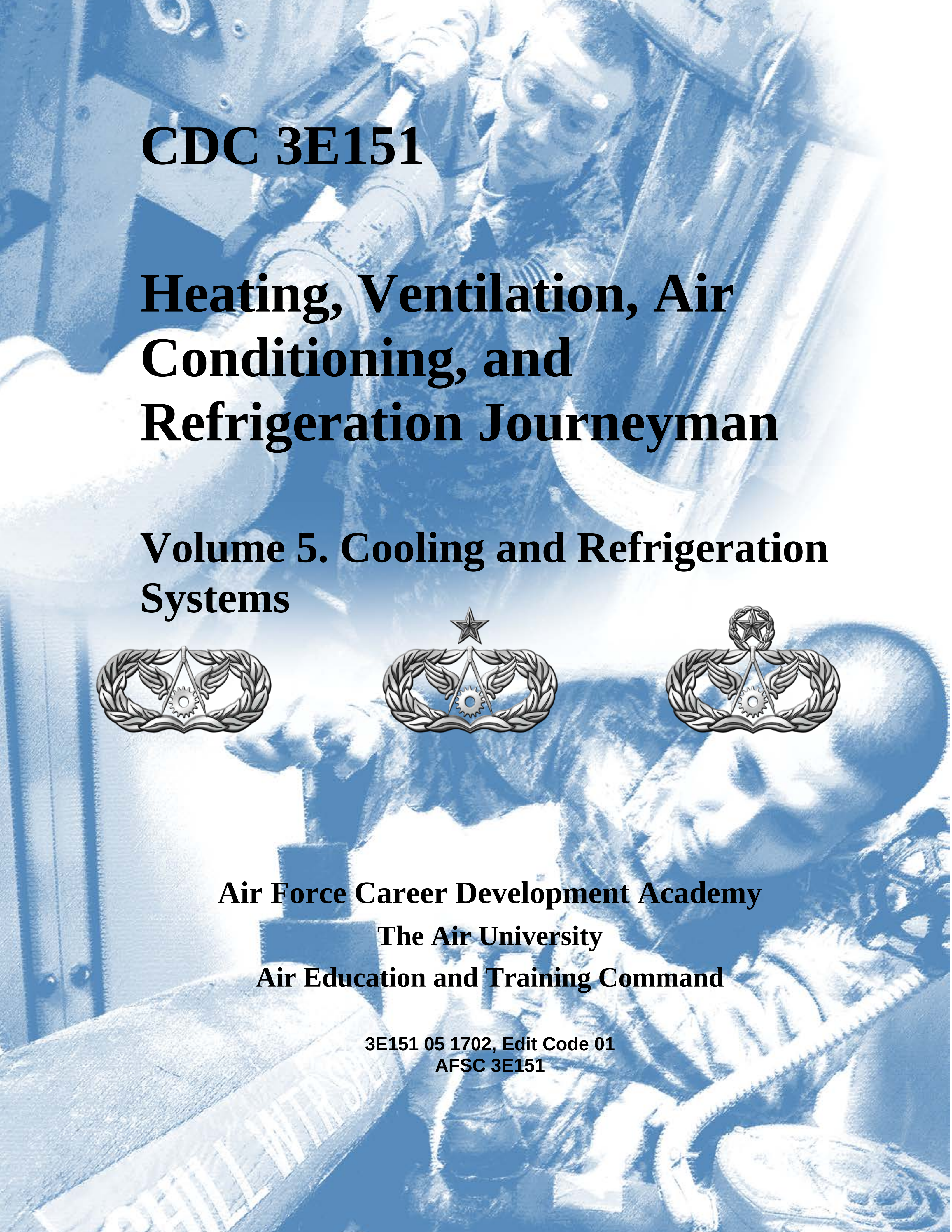

CDC 3E151

Heating, Ventilation, Air Conditioning, and Refrigeration Journeyman

Volume 5. Cooling and Refrigeration Systems

Air Force Career Development Academy

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THIS FIFTH VOLUME of CDC 3E151 *Heating, Ventilation, Air Conditioning, and Refrigeration Journeyman*, introduces you to Cooling and Refrigeration Systems.

Unit one discusses refrigeration and cooling system essentials such as the refrigeration cycle, refrigeration compressors, refrigeration condensers, refrigeration metering devices, and refrigeration evaporators.

Unit two covers refrigerants and oil types, basic controls and accessories and capacity control.

Unit three covers refrigeration and cooling systems that include direct expansion system types, direct expansion operatioan and maintenance and indirect expansion cooling systems.

Unit four jumps into applied refrigeration and cooling. In this unit the pressure enthalpy chart, pressure temperature charts, superheating, subcooling, charging, recovery and pumping down systems are covered.

Unit five covers refrigeration and cooling equipment as it applies to Air Force contingency equipment. The Tricon fridge/freezer and the FDECU heat pump are covered here.

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NOTE:

In this volume, the subject matter is divided into self-contained units. A unit menu begins each unit, identifying the lesson headings and numbers. After reading the unit menu page and unit introduction, study the section, answer the self-test questions, and compare your answers with those given at the end of the unit. Then complete the unit review exercises.

Unit 1. Refrigeration and Cooling System Essentials, Part 1

IN THIS UNIT, we begin with a look at the basic refrigeration cycle and the four major components that make up all mechanical refrigeration and air-conditioning (A/C) systems. In the next unit we continue our exploration of refrigeration and cooling system essentials and turn our attention to the refrigerants and oils that make modern-day refrigeration and A/C possible. Basic controls and accessories you will encounter as you service and maintain HVAC/R systems are covered next. Unit 2 concludes with a discussion about capacity control in refrigeration and A/C systems.

801. Refrigeration cycle

One of the basic laws of science states that removing heat will make an object colder; thus, the job of a refrigeration or A/C machine is to remove heat from a place where it is not wanted and transfer this heat to a place where it is less objectionable. Pumping a refrigerant through a completely closed system comprising a compressor, condenser, metering device, and evaporator makes this possible. All mechanical refrigeration systems including low-temperature freezers, domestic refrigerators, and small- and large-tonnage A/Cs use these four basic components.

The previously mentioned basic refrigeration cycle and its four major components are the cornerstone of the mechanical refrigeration cycle. Without a thorough understanding of each component's purpose and operation, you will not succeed in the HVAC/R career field. In this lesson, we will discuss the basic composition of substances and refrigeration physics. This will provide the scientific foundation of the refrigeration cycle for you and prepare you for the next lesson.

Basic composition of substances

Nearly all substances can exist as a solid, a liquid, or a vapor. This depends on their temperature and the pressure to which they are exposed. Heat energy—measured in British thermal units (Btus)—changes the temperature and can change the state of the substances. Heat energy is absorbed even though no temperature change takes place when a solid changes to a liquid or when a liquid changes to a vapor. When the vapor changes back to a liquid and when the liquid changes to a solid, it rejects the same amount of heat or Btu.

Water in the form of ice is a usable form of refrigeration. At a constant temperature of 32 °F, it will absorb heat as it melts. If you place water in an open pan on a stove and apply heat, the temperature of the water will rise to the boiling point (212 °F at sea level). Regardless of the amount of heat you apply, you cannot raise the water temperature above 212 °F. This happens because the water will completely vaporize into steam. You can raise the temperature above 212 °F by enclosing this steam in a container and then applying more heat. The boiling or evaporating process was absorbing heat.

When steam condenses back into water, it gives off exactly the same amount of heat that it absorbed while it was evaporating. (The steam radiator is a common usage of this source of heat.) Freezing water into ice uses a refrigeration process that causes the freezing action to extract the same amount of heat that is absorbed in melting.

The heat transfer relationship of substances is the backbone of refrigeration and air conditioning. Heat transfer *is* what we do.

Refrigeration physics

You must understand some important physics terms before you can understand the basic refrigeration cycle. Many of these terms overlap into other aspects of the HVAC/R career field and although having been used in other volumes, a refresher here is essential.

Sensible heat

Sensible heat is the heat involved in a change of the temperature of a substance. Sensible heat changes do not involve a change in the state of a substance—only the change of the substance's temperature. For example, when raising the temperature of water from 32 °F to 212 °F, an increase in sensible heat content is taking place. If the temperature of air changes from 70 to 80 °F, it has a sensible heat change of 10 °F.

A thermometer normally measures sensible heat. In refrigeration and air conditioning, you normally measure sensible heat changes with a multimeter and probe, a digital-infrared thermometer, or a normal dial-type thermometer. There are superheat thermometers that come with a thermometer that measures sensible heat of a refrigeration or air conditioning system. This will be discussed shortly.

Latent heat

When a substance changes state without a change in temperature, the change involves addition or removal of latent heat. Referring to the latent heat of boiling or the latent heat of vaporization as boiling is acceptable since boiling is merely a rapid evaporating process. The opposite of vaporization is the latent heat of condensation where refrigerant changes from a vapor to a liquid.

When one pound of water boils at atmospheric pressure, it absorbs 970 Btus at a constant temperature of 212 °F. Extracting 970 Btus from a pound of steam (vapor) will cause it to condense and return to a pound of water. Measuring latent heat changes in Btu only happens when *no* temperature change has taken place in this process.

Because of the large amount of latent heat involved in evaporation and condensation, heat transfer can be very efficient during the process. The same changes of state affecting water apply to any liquid, although at different temperatures and pressures. Keep in mind, however, that different substances, such as refrigerants, boil, condense, and freeze at different temperatures. Therefore, the amount of latent heat required to change those substances from one state to the other varies with the chemical properties of the substance.

> **NOTE:** The absorption of heat by changing a liquid refrigerant to a vapor refrigerant and the discharge of that heat by condensing the vapor refrigerant back to a liquid is a keystone of the mechanical refrigeration process.

Saturation point

In refrigeration, we deal with a change of state of refrigerants. Refrigerants change from a vapor to a liquid in one part of the system and back to a vapor in another part of the system. The saturation point in a refrigeration system is a point where both vapor and liquid refrigerant exist at the same time.

A saturated liquid or vapor is one at its boiling point. For water at sea level, the saturation point is 212 °F. At higher pressures, the saturation point increases; with a decrease in pressure, the saturation point decreases. Different substances have different saturation or boiling points. The temperature at which liquids evaporate (boil), or condense, varies with the pressure and chemical properties of the substance.

Superheat

After a liquid has changed to a vapor, any further heat added to the vapor to raise its temperature—so long as the pressure remains constant—is called *superheat*. Since a rise in temperature results, this is sensible heat. We use the term, superheated *vapor*, to describe a gas whose temperature is above its boiling or saturation point. For example, the air around us is composed of superheated vapor.

In a refrigeration system, the refrigerant is normally in a superheated condition as it moves from the saturation point at the end of the evaporator, through the compressor, to the saturation point inside the condenser.

Desuperheat

Removing heat from a superheated vapor to lower its temperature is *desuperheating*. When the temperature changes and can be measured in degrees, it is sensible heat. If enough desuperheating occurs, the vapor begins to condense.

Subcool

Subcooling is when any liquid has a temperature lower than the saturation point corresponding to its pressure. Water at any temperature less than its boiling temperature (212 °F at sea level) is subcooled.

Refrigerant inside a system subcools after complete condensation has occurred and, depending on the type of metering device, continues to subcool up to and partially through the metering device.

Effect of pressure on refrigerants

The temperature at which a liquid boils is dependent on the pressure exerted on it. The vapor pressure of the liquid—which is the pressure exerted by the tiny molecules seeking to escape the liquid and become vapor—increases with an increase in temperature until at the point where the vapor pressure equals the external pressure, boiling occurs.

Water at sea level boils at 212 °F; but at 5,000 feet elevation, boils at 203 °F. This is due to the decreased atmospheric pressure. If some means (a compressor, for example) is used to vary the pressure on the surface of the water in a closed container, the boiling point could be changed at will. At 100 pounds per square inch gauge (psig), the boiling point is 338 °F.

While water is a type of refrigerant, it is not as good a refrigerant as the ones used in most refrigeration and A/C equipment. The reason is that water requires a lot of energy to make it reach its saturation point. Refrigerants used in common mechanical refrigeration systems do not require as much heat energy to reach their saturation points. The primary reason is that, although water has good heat transfer properties, these properties are not as good as the common refrigerants used in the mechanical refrigeration system. Water and refrigerants do have some things in common though. All liquids react to pressure increases and decreases in the same way.

- An *increase* in pressure increases the boiling point.
- Conversely, a *decrease* in pressure decreases the boiling point.

These similar properties are the reason a commonly known substance such as water is used as an example to explain the effects of pressure on refrigerants.

One of the functions of a refrigeration system is to dispose of the heat absorbed during the cooling process. In a refrigeration system, the heat is disposed of in the condenser. To achieve this, the pressure of the gas is raised so that the saturation point or condensing temperature is above the temperature of the available cooling medium (air or water). The temperature must be above the cooling medium of the condenser for any heat transfer to take place because heat energy travels from warmer objects to cooler objects.

For example, if the temperature of the gas in the condenser is 45 °F and the ambient air is 100 °F, the condenser would actually absorb heat from the ambient air and not *reject* heat like it should be doing. But if the temperature of the gas in the condenser is 150 °F and the ambient air is 80 °F, heat would transfer from the 150 °F condenser to the 80 °F ambient air.

When the low-pressure/low-temperature gas, with its low saturation point, draws into the cylinder of a compressor, the discharge stroke of the compressor piston reduces the volume of gas and discharges the vapor. As a high-pressure/high-temperature gas, it readily condenses because of its high saturation point.

If a fluid is to flow from one point to another, there must be a difference in pressure between the two points to cause the flow. With no pressure difference, no flow occurs. Fluids may be either liquids or gases, and the flow of each is important in refrigeration. Several factors govern the flow of fluid through pipes or tubing:

- The pressure exerted on the fluid.
- The effect of gravity due to the vertical rise or fall of the pipe.
- Restrictions in the pipe resisting flow.
- The resistance of the fluid itself.

We can use a water faucet as an example. Opening the faucet increases the flow, even though the pressure in the water main is constant and the outlet of the faucet has no restriction. Obviously, the restriction of the valve is affecting the rate of flow.

As fluid flows through tubing, the contact of the fluid and the walls of the tube create friction and, therefore, resistance to flow. Sharp bends in the tubing, valves, and fittings and other obstructions also create resistance to flow. Because of this, the basic design of the piping system determines the pressure required to obtain the required rate of flow.

In a closed system in which fluid flows through tubing, you can determine the pressure difference between two given points by the velocity, viscosity, and the density of fluid that is flowing. If the flow is increased, the pressure difference increases. This happens because the increased velocity of the fluid creates more friction. This pressure difference is termed *pressure loss* or *pressure drop*.

Since control of evaporating and condensing pressures is critical in mechanical refrigeration work, pressure drop through connecting lines can greatly affect the performance of the system. Avoid large pressure drops.

Heat flow

The second law of thermodynamics states that heat always travels from a warm object to a colder one. The rate of heat travel is in direct proportion to the temperature difference between the two bodies.

For example, let's say we have two steel balls that are side by side in a perfectly insulated box. One ball weighs one pound and has a temperature of 400 °F; the other ball weighs 1,000 pounds and has a temperature of 390 °F. The heat content of the larger ball (measured in Btus) is many times greater than the smaller one; however, because of the temperature difference, heat travels from the small ball to the large one until the temperatures equalize.

Heat can travel (flow) in any of three ways:

- Radiation.
- Conduction.
- Convection.

Methods of Heat Travel (Flow)	
Type	**Description**
Radiation	Radiation is the transfer of heat by waves similar to light waves or radio waves. For example, the sun's energy transfers to the earth by radiation. You need only step from the shade into direct sunlight to feel the effect of the heat waves. Radiation to the refrigerated space or product from the outside environment, particularly the sun, may be a major factor in the refrigeration load.
Conduction	Conduction is the flow of heat through a substance. Actual physical contact is required for heat transfer to take place between two bodies by this means. Conduction is a highly efficient means of heat transfer as anyone who has touched a piece

Methods of Heat Travel (Flow)	
Type	**Description**
	of hot metal can testify.
Convection	Convection is the flow of heat by means of a fluid medium. This can be either gas or liquid; however, air or water is the common medium used in HVAC/R. For example, a furnace heats the air and then discharges it into a room.

In a typical refrigeration application, heat normally travels by a combination of processes, and the ability of a piece of equipment to transfer heat is the overall rate of heat transfer. While heat transfer cannot take place without a temperature difference, different materials vary in their ability to conduct heat. Metal is a very good heat conductor, while fiberglass has so much resistance to heat flow that it is a good insulator.

Heat transfer from a fluid through a tube wall or through metal fins greatly affects the action of the fluid in contact with the metal surface. Generally the greater the velocity of flow and the more turbulent the velocity of flow, the greater the rate of heat transfer. Rapid boiling of an evaporating liquid also increases the rate of heat transfer. As the velocity and turbulence of the liquid flow decreases to a certain point, it tends to allow an insulating film to form on the metal surface, which resists heat flow and reduces the rate of heat transfer.

Importance of heat transfer

Heat transfer ***is*** our job! For air conditioning, in the summer we remove hot air to make spaces cooler. In the winter we push heat into spaces to make them warm. For refrigeration, we are transferring the heat in the fridge or freezer to another place. These are all examples of heat transfer. You absolutely must understand heat transfer to be a successful HVAC/R technician. It is a key, if not, *the* key concept in this career field.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

801. Refrigeration cycle

1. What type of heat changes the state of a substance without changing its temperature?

2. What is the sensible heat change of air if the temperature rises from 70 °F to 80 °F?

3. What type of heat is removed if a substance changes state *without a change in temperature*?

4. What must you remember about the boiling, condensing, and freezing characteristics of different substances?

5. What is the keystone of the mechanical refrigeration process?

6. Where is the *saturation point* in a refrigeration system?

7. How does an increase in pressure affect the saturation point?

8. What affects the temperature at which liquids evaporate or condense?

9. What term is used to describe a gas whose temperature is *above its boiling point*?

10. What term is used to describe removing heat from a superheated vapor?

11. What term is used to describe a liquid that has a temperature lower than the saturation point?

12. When does subcooling occur inside a refrigeration system?

13. What affects the temperature at which a liquid boils?

14. Why are refrigerants used instead of water in regards to saturation points?

15. In terms of heat transfer properties, why are refrigerants used instead of water?

16. What must occur to the pressure of the refrigerant gas for the heat it absorbed during the cooling process to be dissipated?

17. Why should large pressure drops be avoided in a refrigeration system?

18. Heat always flows in what direction?

802. The sides and components of the refrigeration cycle

Knowledge of the sides and components of the refrigeration cycle is absolutely necessary to work on refrigeration and A/C systems. If you lack this knowledge you will struggle any time you work on equipment. You do not want to be working on the high side of the system while you think you are working on the low side of the system. This is not only embarrassing but its inefficient.

This lesson begins with defining and describing the two sides of the refrigeration cycle, the high and low side. The lesson concludes with a brief description of the components. Study these concepts carefully and understand they are crucial to your development as an HVAC/R technician.

The sides of the refrigeration cycle

Two different pressures exist in the compression refrigeration cycle. The evaporating or low pressure is in the low side of the system. In contrast, the condensing or high pressure is in the high side of the system. Look at the first table below for the various names each side of the system has. Then, look at the second table to see where various components are located in the system.

Alternate Names for Sides of the Refrigeration System	
Low side	**High side**
Suction side	Discharge side
Low pressure	High pressure

Locations of Basic Components of the Refrigeration System	
Low side	**High side**
Suction line	Liquid line
Evaporator	Condenser

Since there is a low- and high-pressure side to each system, there is also a low- and high-temperature side of the system. This means there is low-temperature refrigerant in the system as well as a high-temperature refrigerant in the system.

The two dividing points separate temperature/pressure areas. The low-side pressure begins at the metering device where the refrigerant flow is controlled. The high-side pressure begins at the compressor where the refrigerant vapor is compressed.

With these thoughts in mind, let’s take more a detailed look at what is happening inside the compression system. For our discussion, refer to figure 1–1. We begin with the events taking place in the low side of the system. Then we will look at the processes occurring in the high side of the system.

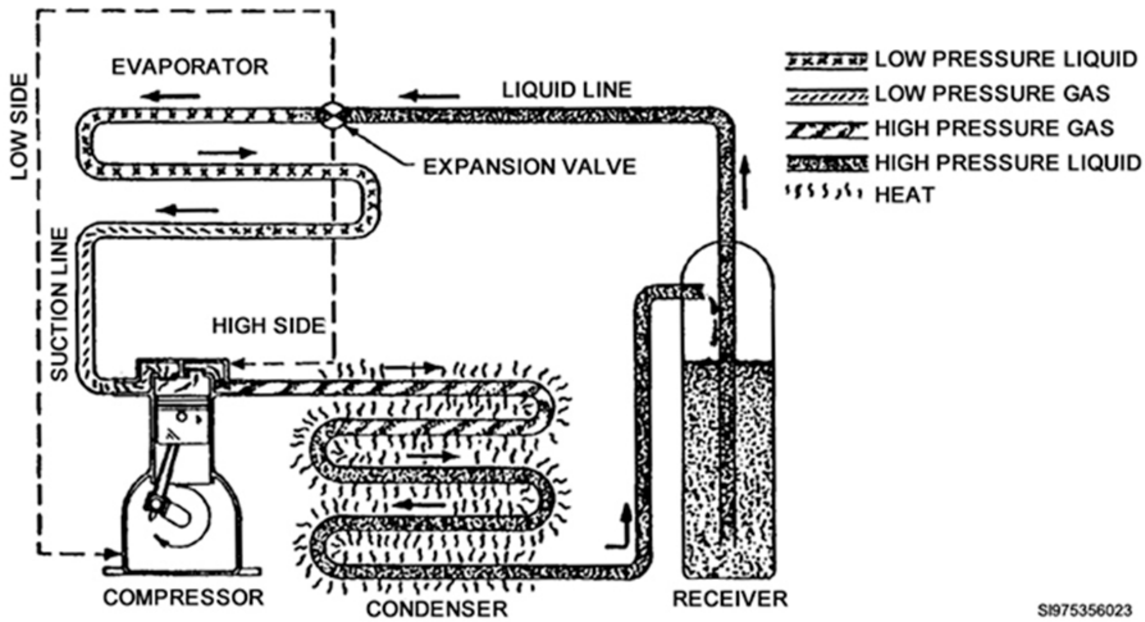


Figure 1–1. Complete refrigeration system.

Low side

As we said, the low side begins at the metering device. Depending on the application, various types of metering devices may be used. In this case, we are using an expansion valve to control the supply of liquid refrigerant to the evaporator. An orifice inside the valve reduces the pressure of the refrigerant to the evaporating or low-side pressure. The reduction of pressure on the liquid refrigerant causes it to boil or vaporize until the refrigerant is at the saturation point corresponding to its pressure. As the low-temperature refrigerant passes through the evaporator coil, heat flows from the air or water (whichever is being used), through the walls of the evaporator tubing, and into the refrigerant. This heat transfer causes the boiling action to continue until the refrigerant completely vaporizes.

Actually the expansion valve regulates the flow through the evaporator as necessary to maintain a preset temperature difference or superheat between the evaporating refrigerant and the vapor leaving the evaporator. As the temperature of the gas leaving the evaporator varies, the expansion valve, power element bulb (not pictured) senses its temperature and acts to modulate the feed of liquid refrigerant as required.

The refrigerant vapor leaving the evaporator travels through the suction line to the compressor inlet. From this point, the high side of the system begins.

High side

The compressor takes the low-pressure and/or low-temperature vapor from the evaporator and suction line and compresses it. This action increases the pressure and temperature and, consequently, increases the saturation point. The hot, high-pressure gas forces out of the compressor discharge valve and into the discharge line where it routes to the condenser. On the way to the condenser inlet, the superheated discharge vapor begins to desuperheat.

The high-pressure gas cools by some external means as it passes through the condenser. This external means must be cooler than the refrigerant for heat transfer to take place. On an air-cooled system, a fan and fin-type condenser surface is normally used. On water-cooled systems, a refrigerant-to-water heat exchanger is usually used. When desuperheating is complete inside the condenser, the process of condensation begins. As the temperature of the refrigerant vapor reaches the saturation point—

corresponding to the high pressure and temperature in the condenser—the vapor condenses into a liquid. Subcooling is when the temperature of the liquid is further reduced. All three processes—desuperheating, condensing, and subcooling—take place inside the condenser. Desuperheating begins at the compressor discharge and finishes inside the condenser. Subcooling starts inside the condenser and finishes just before the high-temperature and/or high-pressure liquid enters the metering device.

After the condenser, the liquid travels through the liquid line and to the expansion valve. Do *not* confuse liquid line with the low side. The liquid line is on the HIGH SIDE after the condenser.

NOTE: After condensing, the high-pressure liquid refrigerant may go to a receiver. Not all systems require a receiver.

From the receiver, the liquid refrigerant flows through the liquid line, filter-drier, and to the metering device separating the high-pressure side of the system from the low-pressure side.

By now, you should begin to have a working knowledge of the processes occurring during the compression refrigeration cycle. To increase your working knowledge, we'll take a more in-depth look at the operation of each of the major components of a typical system.

Component operation

In order to operate properly, every mechanical refrigeration system (regardless of size) must have four major components:

- Compressor.
- Condenser.
- Metering device.
- Evaporator.

If just one of the above components is missing, the refrigeration process cannot take place. Keep in mind that each component may have many different sizes, styles, and operating characteristics. We will discuss these in detail later in the unit. For now, we will present information that will increase your understanding of what takes place in each of these components. Study this information carefully, because it is essential that you have a thorough understanding of the actions taking place in each component. If you fail to gain this thorough understanding, it is doubtful you will ever be successful in the HVAC/R career field.

Compressor

The compressor has two functions in the mechanical refrigeration cycle.

- First, it removes the refrigerant vapor from the evaporator and reduces the pressure in the evaporator.
- Second, the compressor raises the pressure of the refrigerant vapor to a level high enough so that the saturation temperature is higher than the temperature of the cooling medium available for condensing the refrigerant vapor. This is necessary for heat to travel from the refrigerant to the cooling medium.

A reminder of the second law of thermodynamics may be necessary here.

NOTE: Heat only flows from warmer objects to a cooler objects.

Without increasing temperature, the system could not work. The temperature increases through compression, which consequently also increases the pressure. The compressors used in this process compress refrigerants in vapor form only. In most cases, if liquid refrigerants get inside the compression mechanism, some damage will result. The damage varies, however, and it could be as severe as total compressor failure. So *do not* introduce liquids into the compression stroke of the compressor.

> **NOTE:** Some compressors are capable of withstanding some liquid but in good practice, try not to let liquid refrigerant enter the compressor.

Condenser

The condenser is a heat exchanger giving off the heat absorbed by the refrigerant during the evaporating and compression process to the condensing medium. As mentioned previously, the heat given off by the condenser is always greater than the heat absorbed during the evaporating process. This happens because of the heat of compression. As heat from the high-temperature and/or high-pressure vapor cools, its temperature falls to the saturation point and the vapor condenses to a liquid.

Metering device

Metering devices are at the inlet of the evaporator. They provide the pressure drop, which (in turn) causes the temperature difference between the evaporator and the product or conditioned space. This allows the refrigerant to absorb heat from the product or conditioned space and vaporize. This vaporization produces the cooling effect. In essence, metering devices limit or meter the amount of refrigerant that enters the evaporator.

The system design temperature dictates what evaporator temperature is necessary to meet the heat load requirements. We normally rate metering devices in tons of refrigeration. The actual capacity of a metering device during operation depends on the pressure difference between the high and low side. Largely, the design temperature also dictates the amount of pressure drop in the evaporator. Because of this, metering devices come in all different sizes and pressure-drop capabilities. Regardless of the design, metering devices control refrigerant flow by one of four methods:

- They allow only a fixed volume of refrigerant to flow.
- They control the level of liquid refrigerant in the evaporator.
- They control the low-side pressure of the system.
- They control the flow according to the temperature of the superheated refrigerant leaving the evaporator.

Evaporator

The evaporator is that part of the low-pressure side of the refrigeration system in which the liquid refrigerant boils or evaporates. As the evaporator absorbs the heat from an object or conditioned space, it changes the state of the refrigerant from a liquid to a vapor. Since it is a heat absorption device, the evaporator is where the system accomplishes the actual purpose—refrigeration.

As you saw earlier, the metering device decreases the pressure of the liquid refrigerant as it enters the evaporator. This lower pressure allows the liquid refrigerant to boil as heat is absorbed from the air or liquid that surrounds the evaporator. The heat being absorbed comes from the product cooled or the conditioned space. This cools the air or liquid and, in turn, the liquid refrigerant changes to a vapor. The vapor then draws through the evaporator outlet into the suction line and flows back to the compressor. The process continues as long as the compressor continues to operate.

> **NOTE:** For our purposes, conditioned space refers to a refrigerator, freezer, computer room, dining facility, and so forth.

As you can see, we are slowly but steadily building the foundation of your refrigeration system knowledge. We have had several discussions of the operation of the basic refrigeration cycle and the basic purpose of each of the four major components. Earlier we said that each component may have many different sizes, styles, and operating characteristics and we would have in-depth discussions of each component. We begin our next lesson with a discussion about the characteristics of compressors.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

802. The sides and components of the refrigeration cycle

1. Where does the *low-side pressure* begin in the refrigeration cycle?

2. What senses the temperature of the gas leaving the evaporator?

3. What type of gas forces out of the compressor discharge valve?

4. In order for heat transfer to take place, what temperature should the external means of removing heat be in relation to high-pressure gas in the condenser?

5. What happens to refrigerant vapor as it is *cooled to its saturation point* in the condenser?

6. What is the first effect the compressor has on the refrigerant that enters it?

7. What would result if the compressor did *not* increase the temperature of the refrigerant?

8. Why is the heat given off by the condenser always greater than the heat absorbed during the evaporating process?

9. What largely dictates the amount of pressure drop in the evaporator?

10. What happens to the refrigerant as it absorbs heat from an object or conditioned space?

803. Characteristics of refrigeration compressors

Both the high and low sides of the refrigeration system meet here; thus, the compressor is considered the "heart" of the system. All compressors serve the same purpose. They circulate the refrigerant through the system and compress the refrigerant vapor to a higher pressure. This raises the saturation temperature so that the cooling medium can remove the heat that was absorbed in the evaporator. In other words, the compressor raises the pressure and temperature of the refrigerant vapor so that it can condense. In this lesson, we cover five of the most common types of compressors used in refrigeration systems:

- Reciprocating compressors.
- Rotary compressors.
- Centrifugal compressors.
- Scroll compressors.
- Screw compressors.

Reciprocating compressors

Figure 1–2 shows a reciprocating compressor. A reciprocating compressor consists of many components (fig. 1–3). Here we discuss these components to give you a better understanding of how this type of compressor operates. Being more aware of how each part operates can assist you in troubleshooting.

Figure 1–2. Reciprocating compressor. (Courtesy Cengage Learning.)

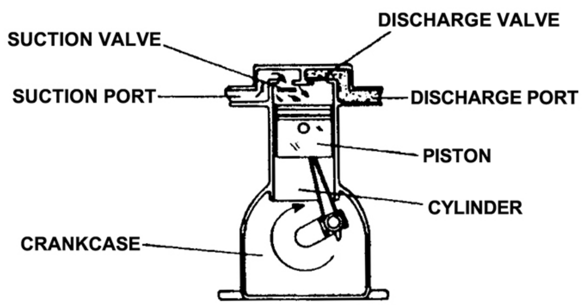


Figure 1–3. Reciprocating compressor components.

Several important components are involved with reciprocating compressors:

- Valves.
- Valve plates.
- Compressor bodies.
- Pistons.
- Crankshafts.
- Connecting rods.
- Compressor heads.

Valves

These valves determine the direction of flow of the gas in the compressor. These valves—the intake and exhaust valves—are also called the suction and discharge valves, respectively. These valves are usually thin disks of hard steel that seat against shoulders in the valve plate. Many of the valves used for the intake and exhaust are the ring or flapper type.

Pressure in the cylinder closes the intake valve and raises the exhaust valve on compression. See figure 1–4 for an example of the exhaust valve open. On the intake stroke, pressure in the suction line opens the intake valve, while backpressure from the high side closes the exhaust valve (fig. 1–5). The clearance between the piston and valve plate is about 0.10 inch to 0.20 inches. This is called the clearance space. Beyond this point, the valve gets noisy.

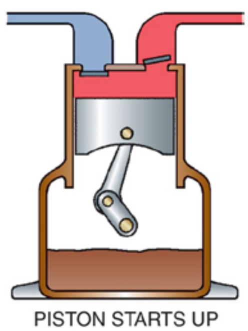


Figure 1–4. Intake valve closed and exhaust valve open. (Courtesy Cengage Learning.)

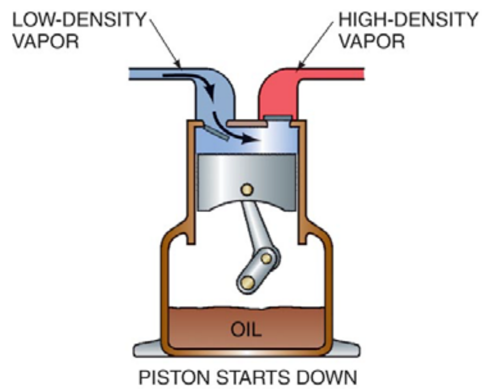


Figure 1–5. Intake valve open and exhaust valve closed. (Courtesy Cengage Learning.)

Valve plates

A valve plate holds the suction and discharge valves. A valve plate is between the head of the compressor and the top of the cylinder. It commonly made of cast iron or hardened steel.

Compressor bodies

The bodies of commercial compressors are made of close-grained cast iron in one- or two-piece construction. The two-piece construction has the crankcase and cylinders cast separately and then bolted together with a gasket between them. This facilitates removing and replacing of bad or damaged cylinders.

The one-piece compressor is a cast in one block with a base plate under the crankcase.

Compressor bodies can be of the open, semi-hermetic, or hermetic type.

Open-type compressor

The open-type compressor has the crankshaft protruding from the compressor body. This requires the crankshaft to go through the body of the compressor. The compressor body contains refrigerant gas and oil that must not leak between the body and the shaft. Air and moisture cannot go into the crankcase. A shaft seal is used to prevent this leakage. The shaft seal must be able to withstand the wide array of pressures (high and low) it is exposed to from the compressor.

In the belt-drive assembly the shaft is turned by a pulley, belt, and electric motor. In this arrangement the compressor shaft and motor shaft are parallel. Pulleys are placed on the shafts and the belt “connects” them. As the motor turns, it drives the compressor via the belt(s) and pulleys.

In the direct-drive assembly the motor shaft and compressor shaft are placed end to end. They are connected by a coupling. As the motor turns, it drives the compressor via the coupling.

Unbalanced loading of the compressor caused by belt tension or a misaligned drive will increase the rate of the wear on the shaft seal. The shaft seal is a common point of failure in these systems.

Hermetic-type compressor

Hermetically sealed compressors are like the open-type compressors, except that the compressor and the motor are together in an airtight housing. There are two types of enclosed systems: the hermetic compressor and the semi-hermetic compressor. The *hermetic compressor* has a welded case that makes it almost impossible for you to repair. Very rarely, if ever, will you open a hermetic compressor and work on it. A faulty hermetically sealed compressor is usually replaced. An important characteristic of most hermetically sealed compressors is that most of them rely on suction gas to keep them cool.

Semi-hermetic type compressor

The semi-hermetic compressor has a bolted case that comes apart for repair (fig. 1–6). One big advantage of the hermetic compressor over the open compressor is that it does *not* require a shaft seal to prevent the entrance of air and the leakage of refrigerant. Gaskets are in between the two parts that are connected by bolts.

Smaller semi-hermetic compressors use a splash lubrication method while larger ones use pressure lubrication. If the splash type method is used, the compressor should usually only rotate in one direction for it to receive proper lubrication. These compressors are often cooled by air and have fins on the shell that increase their surface area to allow more heat transfer from the compressor to the ambient air.

Figure 1–6. Semi-hermetic compressor. (Courtesy Cengage Learning.)

Pistons

The piston is the part that actually compresses the refrigerant gas. As the piston moves downward, the volume increases and the vacuum that is created pulls in refrigerant. As the piston moves up, the volume decreases, the pressure increases, and refrigerant is forced into the discharge line. In large compressors, the pistons are equipped with piston rings of the compression or oil type. Smaller compressors use only oil grooves.

Crankshafts

The crankshaft is the component that a changes the circular motion of the rods into the back and forth motion of the pistons. Crankshafts are usually made of cast-iron or soft steel and are carefully balanced. Some compressors have eccentric crankshafts, which allow for better balancing and less vibration at high speeds.

Connecting rods

The connecting rod is the connection between the piston and the crankshaft. They are made of iron, brass, or aluminum.

Compressor head

This component holds the top of the cylinder and its assembly together. It provides a place for discharge gas until it moves into the discharge line. The suction chamber can be in the head and will be separated internally from the discharge gas.

Rotary compressors

The rotary compressor compresses the gas by a squeezing action; this reduces the gas in volume and increases it in pressure. Rotary compressors are in small domestic units like window units, packaged terminal air conditioners, and small heat pumps up to 5 tons. The discharge line has a check valve to prevent gas from leaking back when the compressor stops. A check valve should also be placed in the oil lines. There are two types of rotary compressors:

- Stationary blade.
- Rotary blade.

Stationary blade

A typical stationary-blade rotary compressor (fig. 1–7) consists of a housing, blade, cylinder, and a shaft with an eccentric rotor. The shaft has an eccentric on which the rotor is mounted. A stationary blade is set into the cylinder, so it maintains contact with the rotor. The blade is held in place against the rotor by a spring. As the shaft turns, it traps a gas charge at the intake and sweeps it around to the discharge. The suction and discharge ports are on opposite sides of the blade. Figure 1–8 is an example of this type of compressor operation.

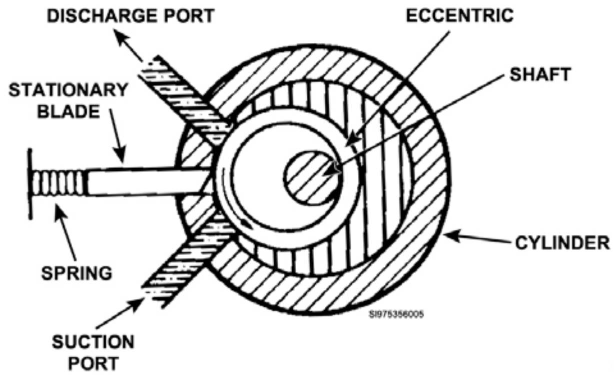


Figure 1–7. Stationary-blade rotary compressor components.

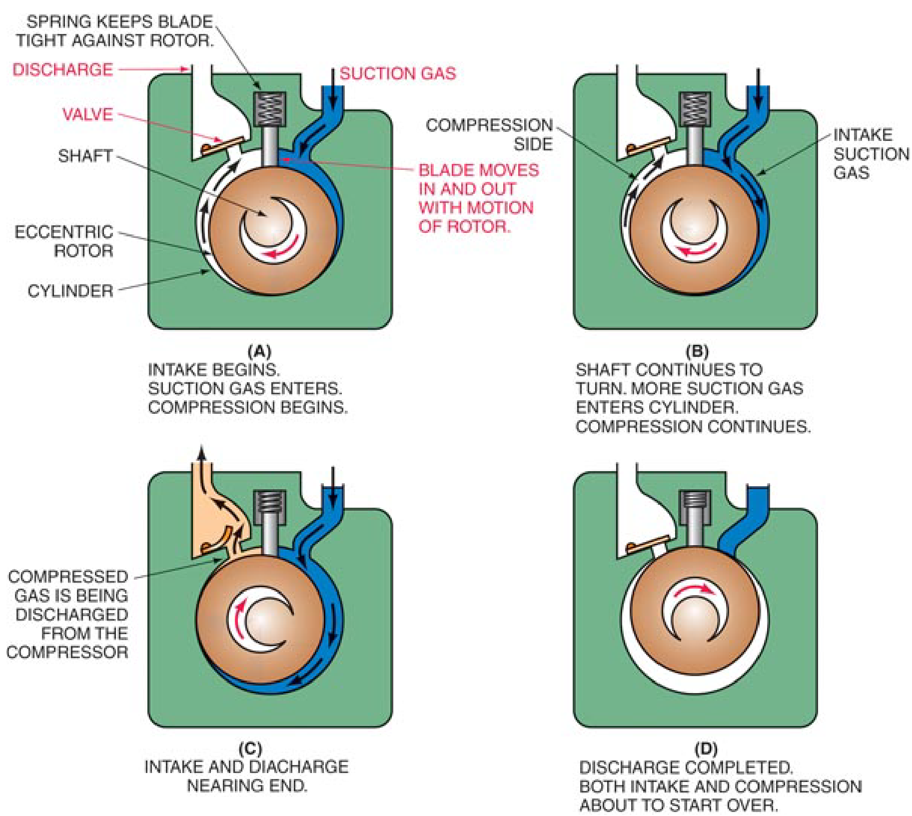


Figure 1–8. Stationary-blade rotary compressor operation.
(Courtesy Cengage Learning.)

Rotary blade

A typical rotary-blade cylinder (fig. 1–9) consists of a cylinder and a rotor containing a number of blades. The center of the rotor is eccentric with the center of the cylinder. In some designs, the blades are spring-loaded to hold them against the cylinder, while others depend on centrifugal force. As the shaft turns, the space between the shaft and the wall becomes smaller, compressing the charge of gas. Figure 1–10 is an example of rotary-blade compressor operation. The discharge port is set in the case where the shaft almost rubs against the case. The compressed charge of gas forces out the discharge at this point.

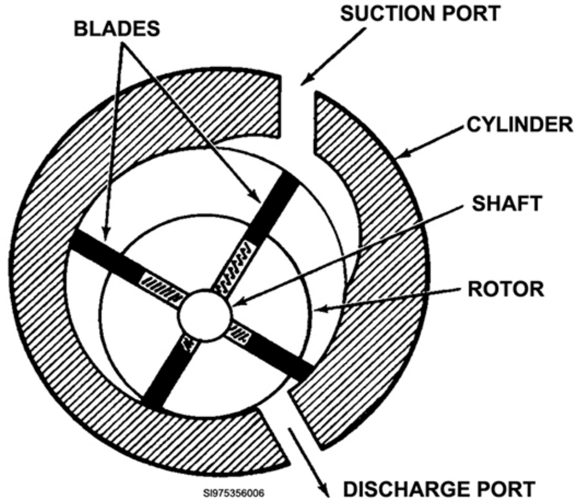


Figure 1–9. Rotary-blade compressor.

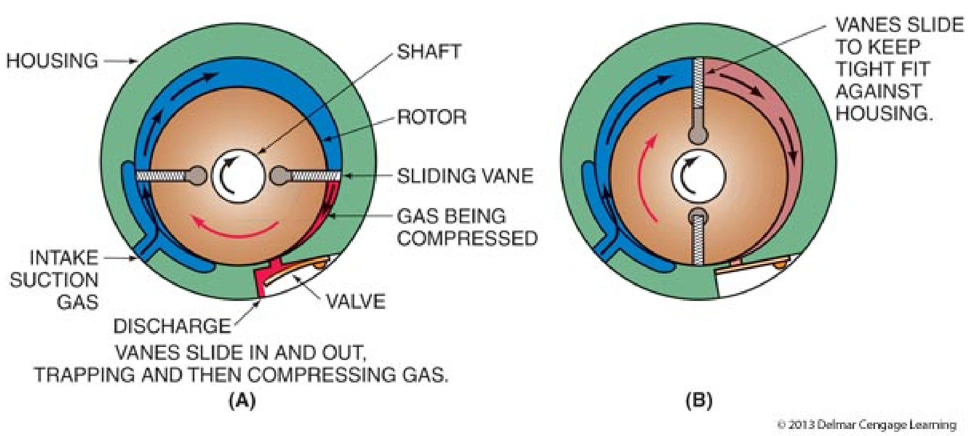


Figure 1–10. Rotary-blade compressor operation.
(Courtesy Cengage Learning.)

Centrifugal compressors

As its name implies, the centrifugal compressor unit compresses the gas by centrifugal force. It is used with refrigerants that have a relatively large gas volume, but small pressure differentials. An example of a chiller that uses a centrifugal compressor is show in figure 1–11.

Figure 1–11. Centrifugal compressor.

Manufacturers normally construct centrifugal compressors with a series of impellers mounted on a steel shaft and enclosed in a cast-iron casing. These wheels are constructed with two discs (a hub and a cover), with many blades (vanes) mounted radially between them. They are made of cast-iron or steel.

The refrigerant is drawn into the center and its flung outward by impellers (fig. 1–12). This “flinging” action compresses the refrigerant. The “flinging” action is called *centrifugal force*. These compressors operate at high speeds.

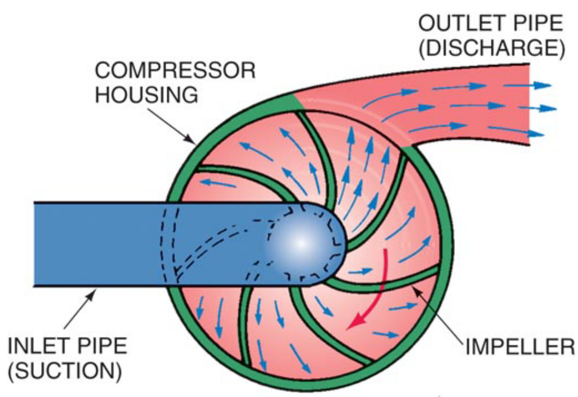


Figure 1–12. Centrifugal compressor impeller.
(Courtesy Cengage Learning.)

Many centrifugal compressors you will see are multi-stage. For example, a two-stage centrifugal has two impellers. The first impeller pulls in suction gas, increases its pressure and temperature, and discharges into the inlet of the second impeller. The second impeller further increases the pressure and temperature of the gas and sends it to the condenser.

Magnetic centrifugal compressors

Some centrifugal compressors have magnetic bearings that levitate a rotor shaft when the compressor is energized. In this type of compressor, the shaft does not make contact with the bearings. This results in less friction and heat. This design can be referred to as "oil free" or "frictionless."

The bearings have bearing sensors the provide information about the rotor's orbit back to a digital bearing control system. This type of compressor is controlled by "on board" electronic controls.

A pulse width modulating power is supplied to the motor. Also used is a variable-frequency drive (VFD) that allows for higher efficiencies and soft start capabilities. Soft start is when the compressor is slowly revved up to prevent large in-rush currents during the system's start-up phase. The VFD also allows the compressor motor speed to be reduced during low load conditions. For example, as the condensing temperature begins to fall the compressor motor, via the VFD, will decrease its speed. Some systems can reduce capacity to as low as 20% of the designed maximum output.

Scroll compressors

Scroll compressors are now known for their quiet and efficient operation. The unique involute spiral shape provides the compression concept of this compressor. Look at figure 1–13, steps 1 through 5, to see the full process. The spiral shapes are "scrolls." There are two scrolls that are mated together to form a spiral concentric shape. One scroll remains stationary and is fixed to the housing. The other scroll revolves around the center of the fixed scroll. This movement is called "orbiting." Figure 1–14 is a cutaway view of a scroll compressor. When the two scroll members mate together, they form crescent-shaped gas pockets.

1 GAS ENTERS AN OUTER OPENING AS ONE SCROLL ORBITS THE OTHER.

2 THE OPEN PASSAGE IS SEALED AS GAS IS DRAWN INTO THE COMPRESSION CHAMBER.

3 AS ONE SCROLL CONTINUES ORBITING, THE GAS IS COMPRESSED INTO AN INCREASINGLY SMALLER "POCKET."

4 GAS IS CONTINUALLY COMPRESSED TO THE CENTER OF THE SCROLLS, WHERE IT IS DISCHARGED THROUGH PRECISELY MACHINED PORTS AND RETURNED TO THE SYSTEM.

5 DURING ACTUAL OPERATION, ALL PASSAGES ARE IN VARIOUS STAGES OF COMPRESSION AT ALL TIMES, RESULTING IN NEAR-CONTINUOUS INTAKE AND DISCHARGE.

Figure 1–13. Scroll compressor compression.
(Courtesy Cengage Learning.)

Figure 1–14. Scroll compressor cutaway.
(Courtesy Cengage Learning.)

During compressor operation, refrigerant vapor draws into the outer crescent-shaped pocket. As movement continues, the vapor is pushed toward the center of the scroll and is compressed. To achieve final compression, the refrigerant vapor has to reach the center of the scroll. The refrigerant vapor moves out of the center through the discharge side of the compressor which is on the non-moving scroll. The discharge pressure on the top scroll helps seal off the upper and lower edge tips of the two scrolls (fig. 1–15). During a single orbit, several pockets of vapor compress at the same time. This is because the suction process and the discharge process are continuous. The suction process is the outer portion of the scroll members, and the discharge process is the inner portion. This results in a very smooth operation and provides continuous compression. There is a check valve in the discharge to prevent hot refrigerant from flowing back to the low side. There is zero refrigerant gas carryover at discharge and this provides the scroll with an advantage over the reciprocating type compressor. Figure 1–16 is an example of a digital scroll compressor.

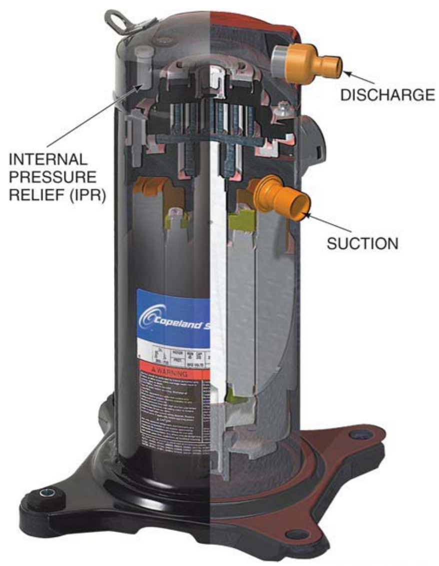


Figure 1–15. Scroll compressor inlet and outlet. (Courtesy Cengage Learning.)

Figure 1–16. Scroll compressor. (Courtesy Cengage Learning.)

Another advantage of the scroll is that its design allows it to intake some liquid refrigerant. A gurgling noise or temporary stoppage of the compressor may be a sign that liquid is entering the compressor.

There are no reed valves with the scroll compressor. Reed valves create an inefficiency with reciprocating compressors that does not exist with scroll compressors.

This type of compressor is commonly seen in residential air conditioning and heat pump systems.

Screw compressors

Screw compressors use a mated pair of special helical rotors that mesh. One is male and the other is female. Figure 1–17 shows the compression cycle as completed. The male rotor has four lobes, and the female has six interlobe spaces. The male often drives the female rotor, but in some cases, they may be gear driven. These compressors may be externally driven, or they may be semi-hermetic. A void creates when the male member starts to unmesh from the interlobe space of the female rotor. Refrigerant vapors draws into this void. The vapors compress as the rotation continues, and they move through the rotors. Oil injects into the rotors to help provide a seal in the compression process. The oil also helps cool the compressor. The compressed vapor discharges at the opposite end of the compressor. The rotors provide for continuous compression while the compressor is operating.

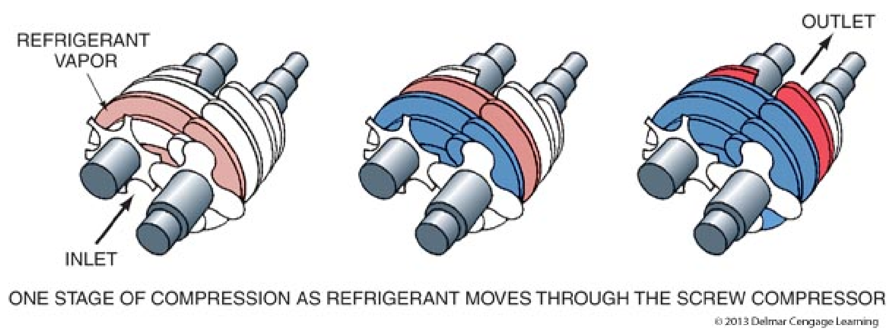


Figure 1–17. Screw compressor compression.
(**Courtesy Cengage Learning.)**

These compressors are used in large applications ranging from 20 to 300 tons.

General compressor components

There are some compressor components that are general in nature to compressors. They include compressor motor terminals, internal overload protection, and service valves.

Compressor motor electrical terminals

The compressor needs a place that supplies power to the internal compressor motor without allowing refrigerant to leak and escape to the atmosphere. There are electrical terminals located on the compressor that provide a space for electricity to enter. These terminals can be fused glass or sealed with an O-ring. Leaks can occur at these terminals if they are exposed to excessive heat.

Be careful when placing meter leads on these compressor terminals. This is usually the weakest section of the compressor and a blowout could occur from the pressure built up inside the compressor shell. The terminals could become weak if the electrical connection is not tight. A result of a loose electrical connection is an increase in heat. If the terminals overheat, they become weak.

Internal motor protection

These overloads protect the compressor motor from overheating. Just like the name states, these devices are internal. They are embedded in or near the motor windings. These devices can either open the line or control circuit during an overheating condition.

If a compressor is three phase, the internal overloads will open all three phases at the same time to prevent single phasing (fig. 1–18).

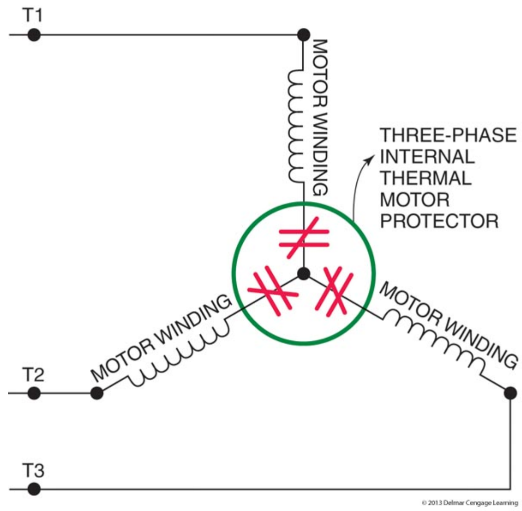


Figure 1–18. Internal overloads.
(Courtesy Cengage Learning.)

Technician's Note: Do not condemn a compressor just because you read open windings! The compressor could have just opened up due to a temporary overheating condition; it does not necessarily mean the compressor is doomed. Give the compressor time to cool or cover the electrical components with plastic and run water over the compressor shell. Once the compressor has cooled, recheck the windings, if they are still open then you know the compressor is bad. BUT if the windings are closed as they should be, you must discover the cause of the compressor's overheating condition that occurred.

Some systems use an internal thermistor to protect the compressor. These thermistor sensors will vary their resistance and send a signal to a solid-state motor protection control. This solid-state device will shut off the power at a predetermined resistance that is read by the thermistor. The control shuts off the compressor by cutting power to the motor contactor coil or the magnetic line starter coil.

Service valves

Some compressors have service valves that allow gauges to be attached and refrigerant and oil to be added. Also, closing the inlet and outlet service valves will isolate a compressor. If you cannot find a service valve on or near a compressor, do not panic because many smaller hermetic compressors do not have service valves. These systems require you to tap into the refrigerant lines using a special tapping valve.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

803. Characteristics of refrigeration compressors

1. What purpose do all compressors serve?

2. Why does the compressor raise the saturation temperature of the refrigerant?

3. Which valves determine the direction of flow of gas in the compressor?

4. How does the intake valve close and the exhaust valve open during compression?

5. What facilitates removing and replacing bad or damaged cylinders?

6. How is air and moisture prevented from entering the crankcase?

7. What do you usually do with a faulty hermetically sealed compressor?

8. Why should the compressor only rotate in one direction when using the splash type method?

9. Where will you find rotary compressors?

10. What is the result of the shaft of the magnetic-centrifugal compressor not making contact with the bearings?

11. What results when the two scroll members mate together?

12. In a scroll compressor how are several pockets of vapor compressed at the same time during a single orbit?

13. What does a check valve in the discharge of a scroll compressor prevent?

14. What is usually the weakest part of the compressor?

15. Where are internal motor overloads located?

16. Why should you not immediately condemn a compressor with open windings?

17. What must be done if the compressor windings close after they cool?

18. Where does an internal thermistor in the compressor send a signal to?

19. How can you access the refrigerant in the system if there are no service valves?

804. Characteristics of refrigeration condensers

The condenser disposes of the heat picked up in the evaporator. The condenser changes the high-pressure and high-temperature gas to a high-pressure, high-temperature liquid. The rate of heat transfer depends on such factors as the surface area, material, and condition of the condenser and the type, the temperature, and the amount of cooling medium.

These three actions take place in a condenser:

1. Desuperheating.
2. Condensing.
3. Subcooling.

Before any condensation can take place, the highly superheated gas must have the superheat removed from it. Desuperheating doesn't always start in the same location. Generally, the process occurs in the discharge line and in the first few coils of the condenser. Removing the superheat places the gas at its saturation temperature. At this point, the gas gives up its latent heat and returns to a liquid. This is the *condensing process.* After the gas has condensed to a liquid, its temperature is still above that of the cooling medium. Remember, the cooling medium will probably be air or water. In the last coils of the condenser, the liquid gives up its sensible heat to the cooling medium. This is *subcooling*.

A condenser that has been in operation for an hour or so will have the top coils much warmer than the middle coils, which, in turn, are warmer than the lower coils.

Two important factors come into play during condenser operation. These factors could negatively affect the operation of the condition and therefore the operation of the entire system. They are:

- Condensing temperature.
- Non-condensable gases.

Condensing temperature

The condensing temperature is a temperature at which the refrigerant gas is condensing from a vapor to a liquid. Do not confuse this with the temperature of the cooling medium, since the condensing temperature must always be higher in order for heat transfer to take place.

To condense the refrigerant vapor in the condenser, heat must flow from the condenser at the same rate at which the refrigerant gas entering the condenser introduces heat. The only way the capacity of the condenser increases under a given set of conditions is by an increase in the temperature difference between the condenser and the ambient temperatures.

Since a reciprocating compressor is a positive displacement machine, the pressure in the condenser will continue to increase until the temperature difference between the cooling medium and the refrigerant condensing temperature is sufficiently great to transfer the necessary amount of heat. With a large condenser, this temperature difference may be very small. With a small condenser or in the event air or water flow to the condenser has been blocked, the necessary temperature difference may be very large. This can result in dangerously high pressures; thus, it is essential that the condenser has proper air or water flow, is clean, and is operating properly any time a refrigeration unit is in operation.

The capacity of the condenser, the temperature of the cooling medium, and the heat content of the refrigerant gas discharged from the compressor determines the condensing temperature, and therefore the condensing pressure, determined by the volume, density, and temperature of the gas discharged.

Experts normally select a condenser for a system by sizing it to handle the compressor load at a desired temperature difference between the condensing temperature and the expected temperature of the cooling medium. Most air-cooled condensers operate on temperature differences (commonly called TD) of 35 to 40 °F at design conditions; sometimes higher and lower TDs are used on specialized applications. When computing the operating temperature:

- Use 35 °F as the condensing factor on *natural convection* condensers.
- Use 30 °F as the condensing factor on *forced convection* condensers.

The design condensing temperature on water-cooled units is normally determined by the temperature of the water supply and the water flow rate available, and may vary from 90 to 120 °F. When computing the condensing temperature, use 25 °F. To determine the condensing temperature of the system, add the sum of the cooling medium temperature and the condensing factor.

For example, let’s say we have a forced convection air-cooled condenser operating at an outside ambient temperature of 90 °F. In this case, the condensing temperature would be (90 + 30 =) 120 °F condensing temperature. For a water-cooled condenser operating at the same condenser water inlet temperature, the resulting condensing temperature would be (90 + 25 =) 115 °F. The same formula is used for natural convection condensers.

Since the condenser capacity must be greater than the evaporator capacity because of the heat of compression and motor efficiency loss; the condenser manufacturer may rate condensers in terms of evaporator capacity or may recommend a factor to allow for the heat of compression in selecting the proper condenser size.

Let’s break down condensing temperature one more time to ensure you understand the concept. The *condensing temperature* is the temperature at which the refrigerant begins to condense. So if the ambient air is 80 °F and you have a condensing factor of the 30 degrees, the refrigerant inside the condenser begins to turn into a liquid at 110 °F. Notice the *condensing temperature is higher than the ambient air.*

Non-condensable gases

Air is primarily composed of nitrogen and oxygen which remain in gaseous form at all temperatures and pressures encountered in commercial refrigeration and A/C systems.

> **NOTE:** Although you can liquefy these gases under extremely high pressures and extremely low temperatures, you should refer to them as “non-condensable” in a refrigeration system.

Scientists have discovered that one of the basic laws of nature is the fact that in a combination of gases, each gas exerts its own pressure independently of others, and the total pressure existing in a system is the total of all the gaseous pressures present. A second basic characteristic of a gas is that if the space in which it is enclosed remains constant so that it cannot expand, its pressure will vary directly with the temperature. Therefore if you seal air in a system with refrigerant, the nitrogen and oxygen each add their pressure to the system pressure, and this increases as the temperature rises.

Since air is a *non-condensable*, it usually traps in the top of the condenser and the receiver. During operation, the compressor discharge pressure is a combination of the refrigerant condensing pressure plus the pressure exerted by the nitrogen and oxygen. The amount of pressure above normal condensing pressure that may result depends on the amount of trapped air. Any time a system is running with abnormally high head pressure, you should consider air in the system as a possible cause.

Now that we have looked at the three actions that take place in the condenser and the effects of condensing temperature and non-condensable gases on condenser operation, let's look at the three basic types of condensers you will encounter on the job:

- Air-cooled.
- Water-cooled.
- Evaporative.

> **NOTE:** Keep in mind that the type of condenser you use in a refrigeration system depends on the cooling load of the unit and weather factors of the locality.

Air-cooled condensers

Air-cooled condensers are normally constructed of steel, aluminum, or copper tubing and made with or without fans. They use ambient air as the cooling medium. Figure 1–19 and Figure 1–20 show how air passes over the condenser. Figure 1–21 is another example of an air-cooled condenser.

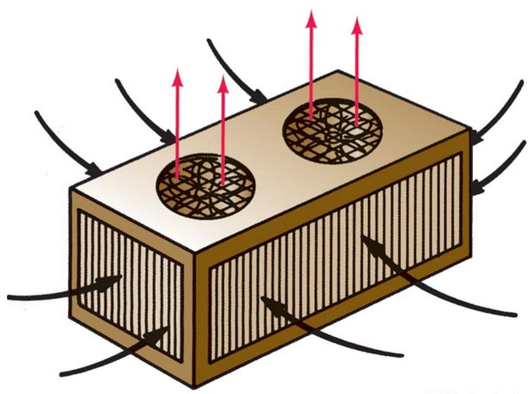


Figure 1–19. Air-cooled condenser air flow.
(Courtesy Cengage Learning.)

Figure 1–20. Air-cooled condenser air flow on a chiller.

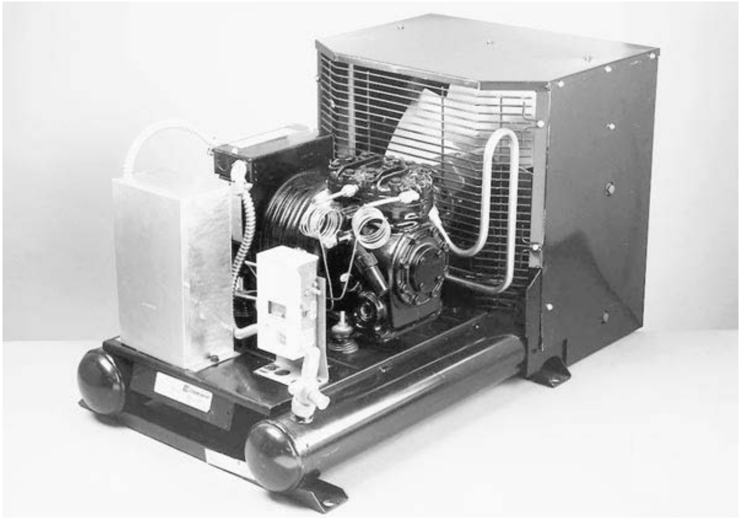


Figure 1–21. Horizontal air-cooled condenser on a chiller.
(Courtesy Cengage Learning.)

Although there are a few disadvantages in using air-cooled condensers, the maintenance is much less than that required for other types of condensers.

Among the disadvantages of using air-cooled condensers are the greater operating cost and the reduced unit efficiency due to higher head pressures. In addition, the power needed to drive the condenser fans is sometimes quite excessive. Not only is this a disadvantage, but the condenser fan noise may also become objectionable. All air-cooled condensers must also have adequate ventilation for the best possible results.

You can ensure adequate ventilation for the compressor during installation or during troubleshooting. For installation purposes, refer to the manufacturer’s installation manual before installing the unit. After the install is complete, you can identify and correct an incorrect condenser install.

Let’s talk about how condenser placement can affect efficiency. Assume a manufacturer tells the technician to allow 4 feet of space around each side of the condensing unit; however, it was installed with only ½ foot of space on three of the four sides. This will not allow enough airflow across the condensing to reject the heat that was picked up in the condition space. The result is high head pressures and the unit probably shutting down due to the high-pressure switch opening. Also, with only ½ of a foot clearance, a technician would not be able to access the equipment for maintenance or troubleshooting.

Air-cooled condensers can use either of two convection processes:

- Natural convection.
- Forced convection.

Natural draft condenser

Most domestic refrigerators use the natural circulation of air. Their condensers consist of tubing mounted on the back of the refrigerator. By allowing a space between the box and the condenser, airflow is similar to that of a chimney, and no fan is necessary.

Domestic refrigerators commonly use natural draft condensers that consist of a serpentine tube that is brazed or soldered fins, wires, or plates. These fins and tubes are usually made of steel or copper. Notice how often the word “usually” is used in throughout these CDCs. There are very few definites in this career field.

NOTE: Static means that air circulation across the condenser surface is by natural convection, which means warm air tends to rise. As we expose the air to the warm condenser surface, it becomes heated, thus the air rises, and cooler air takes its place.

Forced draft condenser

Forced convection condensers have a motor-driven fan that forces air across a fin-and-tube condenser. We find this type of condenser on many domestic and commercial refrigeration and A/C units. There are two basic types of fans used, the propeller and centrifugal types. Figures 1–19, 1–20 and 1–21 were all examples of forced draft air-cooled condensers.

Forced draft condenser airflow patterns

Air may flow horizontally through, vertical from the bottom and out of the top, or draw air in through the sides and discharge it out of the top.

High-efficiency condensers

High-efficiency condensers condense the refrigerant at a temperature closer to the ambient air. For example, a normal forced-air condenser condenses the refrigerant at 30 degrees above the refrigerant temperature. If the refrigerant was 100 °F it would condense at 130 °F. A high-efficiency condenser could condense the same refrigerant at around 115 °F. This reduction in temperature results in a reduction in head pressure. The lower head pressure allows for higher system efficiency. Figure 1–22 shows the operating conditions of a high efficiency condenser.

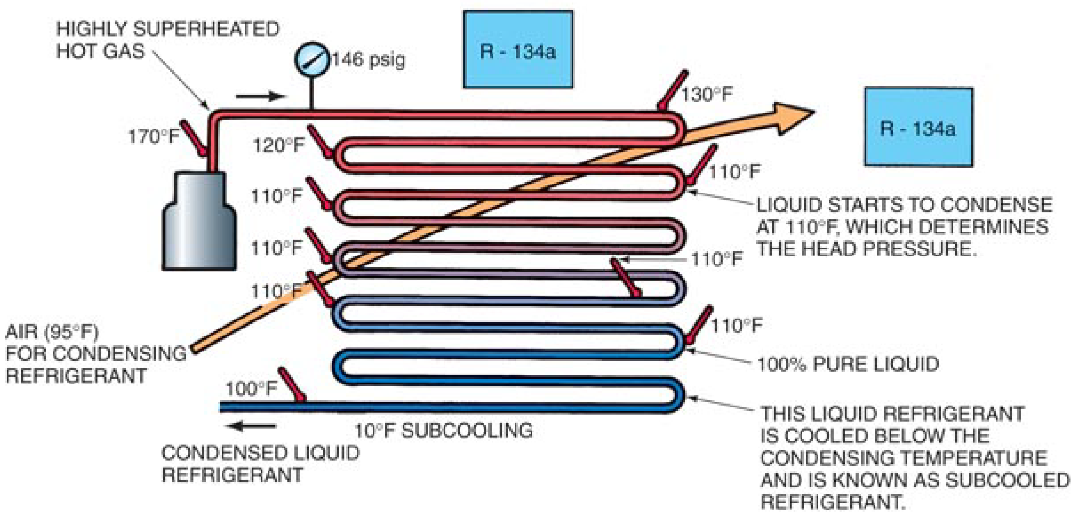


Figure 1–22. High efficiency air-cooled condenser operation.
(Courtesy Cengage Learning.)

Water-cooled condensers

These condensers use water as the cooling medium. Regulating the amount of water through the condenser controls the capacity. The following table lists certain advantages and disadvantages in using water-cooled condensers.

Advantages and Disadvantages of Water-Cooled Condensers	
Advantages	**Disadvantages**
• They have a higher heat transfer. • They have a lower head pressure. • There is an increased condensing unit capacity.	• The higher cost in using water. • Cooling tower maintenance. • The higher cost of installation.

Water-cooled condensers are classified into three general groups:

- Shell-and-coil.
- Double-tube (tube within a tube).
- Shell-and-tube.

Shell-and-coil

A typical shell-and-coil condenser (fig. 1–23) consists of a welded shell containing a finned water coil. So, as the name implies, there is actually a coil in the shell. The coil is usually copper while the shell is usually steel. The refrigerant flow is between the shell and the coil. The water is inside the coil. The water must be reasonably clean and free from minerals. Chemicals are circulated in the water to clean the coil.

The shell serves as a receiver so a separate receiver is not needed.

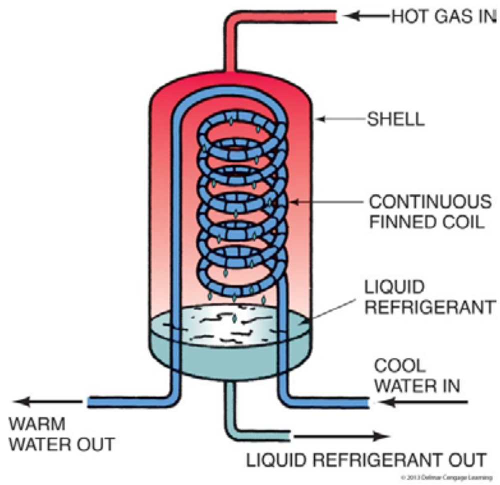


Figure 1–23. Shell-and-coil water-cooled condenser.
(Courtesy Cengage Learning.)

Double-tube

We sometimes refer to this kind of condenser as the "tube-within-a-tube" or "co-axial" (fig. 1–24). The water flows through the inner tube and the refrigerant flows in the outer tube. The water flows in the opposite direction of the refrigerant flow in the outer tube. This counter flow action gives high efficiency. Also a small amount of heat is rejected because of the ambient air that surrounds the outer tube. The water used must be clean and free of minerals, as the internal cleaning of the condenser must be by chemicals circulated in the water.

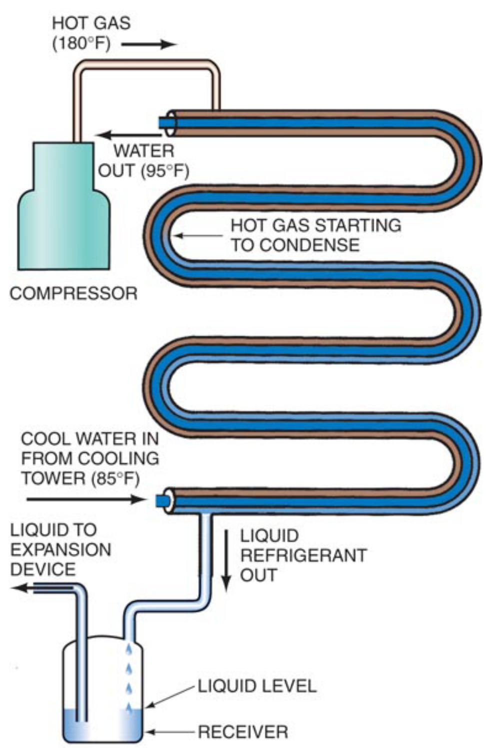


Figure 1–24. Tube-within-a-tube water-cooled condenser.
(Courtesy Cengage Learning.)

Tube-within-a-tube condensers are usually small in capacity and require a receiver.

Shell-and-tube

The shell-and-tube condenser (fig. 1–25) is made of a steel shell with tube sheets at each end. Copper tubing runs from one of these sheets to the other. Iron heads, or end caps (not identified, but see water inlet and outlet, to the right), bolt on each end of the condenser. These are often referred to as water boxes. Water flows into one of these heads and out of the other. The refrigerant is between the sheet and the copper tubing. From a maintenance standpoint, the shell-and-tube is very convenient. We say this because you can remove the heads and clean the tubes out mechanically with a revolving brush.

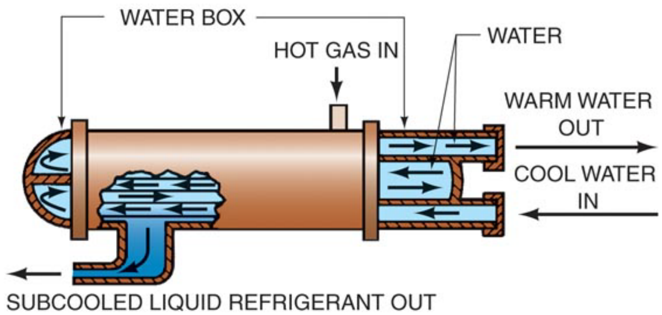


Figure 1–25. Shell-and-tube water-cooled condenser. (Courtesy Cengage Learning.)

The warm water from the condenser travels to a cooling tower or the water is wasted down the drain. In figure 1–26, the water is sent to the cooling tower. In figure 1–27, the green lines on the left are the inlet and outlet of the condenser. In the Air Force, you will more than likely see a cooling tower used than have the water go down a drain.

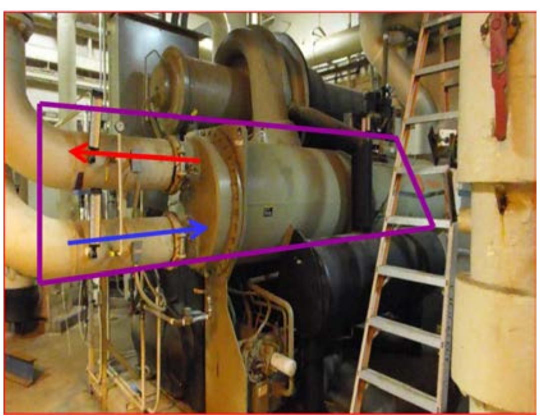


Figure 1–26. Shell-and-tube water-cooled condenser inlet and outlet.

Figure 1–27. Shell-and-tube water-cooled condenser inlet and outlet front view.

Mineral deposits

Minerals will deposit inside a water tube due to the heat from the discharge gas. These minerals develop deposits and scale that reduce the heat transfer capabilities of the condenser. A reduction in heat transfer abilities results in higher operating costs and decreased efficiency.

Because the heat transfer is negatively affected by mineral deposits, the refrigeration system will develop higher head pressure. The heat from the refrigerant is not efficiently rejected to the water because of the deposits or scale buildup.

Cooling towers

We have covered water-cooled condensers but have not really mentioned how the condensers finish the job of rejecting heat. In simple terms, the cooling tower receives water that contains heat picked up by the A/C system. The tower rejects the heat from the water and returns the water to the water-cooled condenser to pick up more heat. Figure 1–28 is an example of a cooling tower. Figure 1–29 will help you understand the relationship between the cooling tower and the condenser.

Figure 1–28. Cooling tower.

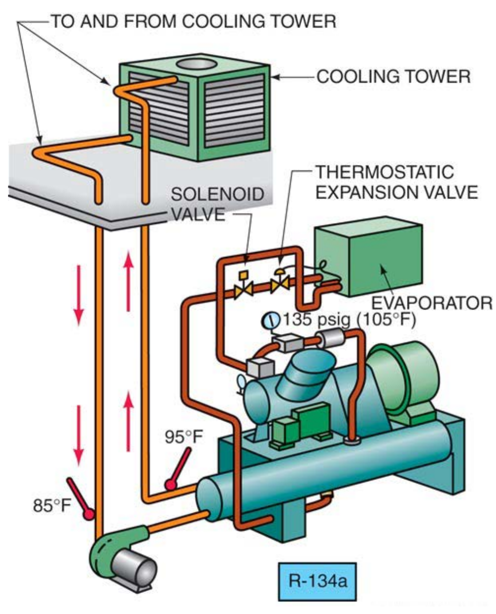


Figure 1–29. Condenser and cooling tower relationship. (**Courtesy Cengage Learning.)**

The cooling tower rejects the heat mentioned in the previous paragraph by passing outside air over the water. Some of the water converts to a gas as it gives up latent heat and is carried away to the atmosphere, taking heat with it.

The ambient air has a relationship with how fast the water evaporates. The more humid the outside air is the slower the evaporation will be. The drier (less humid) it is outside, the faster evaporation takes place. Cooling towers can usually cool the water returning to the condenser within about 7 °F of the ambient wet-bulb temperature. This number is important when you are determining cooling tower efficiency while in the field.

There are three types of cooling towers: natural draft, forced (or induced) draft and evaporative condensers.

Natural-draft

This type of tower relies on natural, prevailing winds. There is no fan to move the air mechanically. Water is sprayed from the top of the tower and falls over fill material until some of it eventually reaches the bottom. Figure 1–30 shows a natural draft cooling tower and its operation. Some of the water will evaporate off which increases the cooling effect. Since some of the water evaporates a float and make-up water assembly is connected to the system to refill it when water amounts drop.

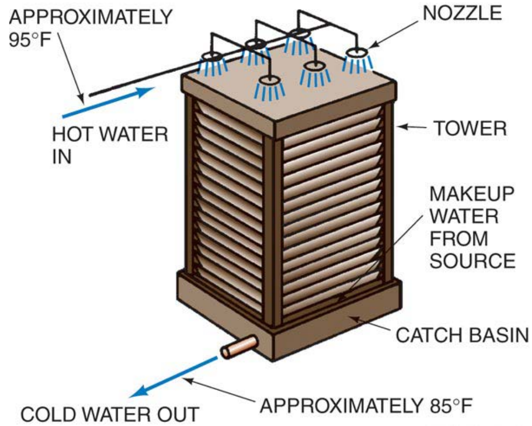


Figure 1–30. Natural draft cooling tower. (Courtesy Cengage Learning.)

Forced-draft (or induced-draft)

Forced or induced-draft cooling towers use a fan to move air over the water's surface. A forced-draft tower has the air pushed across the water while the induced-draft tower has the water pulled across the water. Water from the condenser is pumped to a basin at the top of the tower. From the basin, water falls through holes and then travels over a honeycombed fill material. Figure 1–31 shows a forced draft cooling tower's operation. The fill material increases the surface area of the water which increases the amount of heat transfer (fig. 1–32). Figure 1–33 illustrates how the water trickles down the tower's fill material. As the water travels over this material, it gives up heat to the air that is being pushed or pulled over its surface. Some of the water evaporates in this process, just like the natural-draft tower. Since some water evaporates, the tower uses an assembly similar to that in the natural-draft tower to ensure proper water levels are maintained.

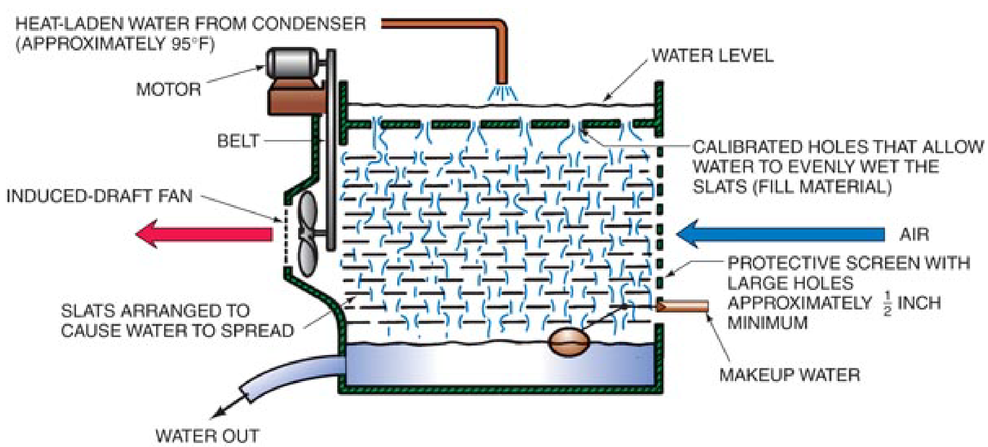


Figure 1–31. Forced draft cooling tower. (Courtesy Cengage Learning.)

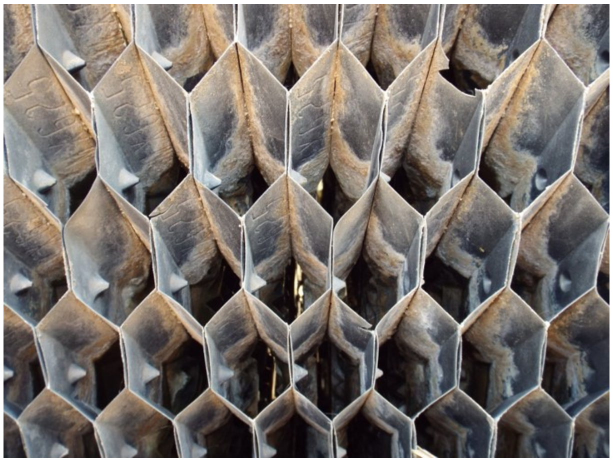


Figure 1–32. Fill material to increase surface area.

Figure 1–33. Fill material water trickling.

Technician's Note: The condenser in natural- and forced-draft cooling tower systems is located remotely. This means it is probably in a mechanical room in the facility. It also means that the water from the condenser is pumped to the cooling tower via pipes. In short, the cooling tower and water-cooled condenser work hand-in-hand to reject heat picked up by the evaporator.

Evaporative condenser

In the evaporative condenser, the condenser coil is actually located in the tower. In this condenser, (fig. 1–34) water is sprayed directly over the condenser to cool it. The heat from the coils causes the evaporated water to carry away the heat of condensation. The remaining water drops to a sump (bottom) located under the condenser, where a pump (lower right) recirculates the water. A fan (top) draws air over the condenser coils to increase the cooling capacity. This type of condenser is very efficient where the temperature varies from very hot to very cold over the course of a year. Like the other cooling towers, the evaporative condenser needs a make-up water supply.

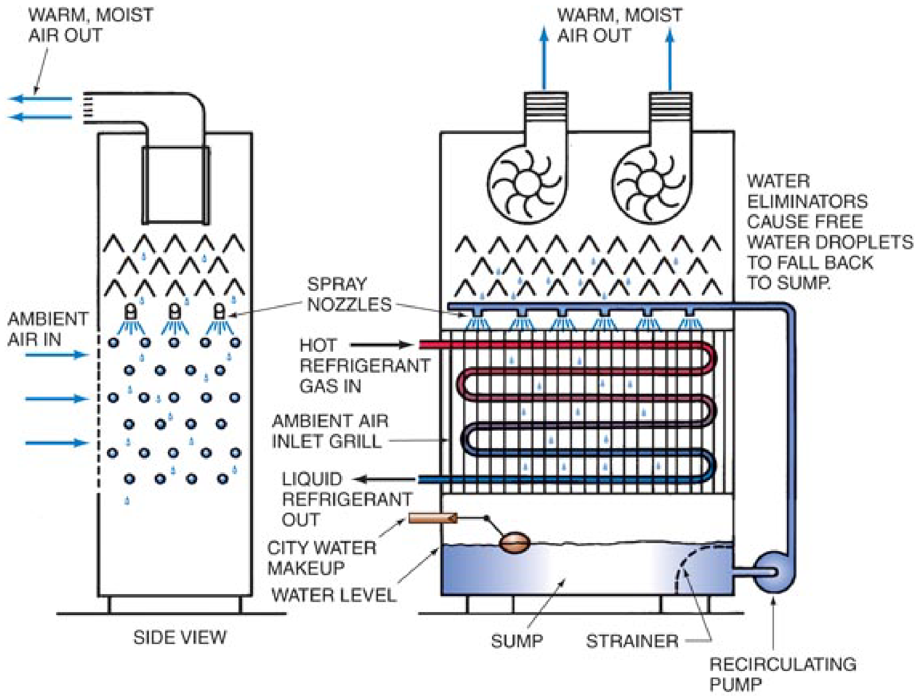


Figure 1–34. Evaporative condenser.
(Courtesy Cengage Learning.)

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

804. Characteristics of refrigeration condensers

1. What does the condenser do to the heat picked up in the evaporator?

2. What affects the rate of heat transfer in a condenser?

3. What happens to the saturated refrigerant's gas as it gives up its latent heat?

4. Where in the condenser does the liquid refrigerant give up its sensible heat?

5. Why must the condensing temperature be higher than the cooling medium?

6. What makes up a system's total pressure?

7. What relationship does pressure have with temperature if the space which it is enclosed remains constant?

8. What possible cause should be considered if a system is running with abnormally high head pressure?

9. What do air-cooled condensers use as a cooling medium?

10. What happens to air as it is exposed to the warm condenser surface on a natural convection condenser?

11. What moves air across the condenser in a forced convection condenser?

12. Compared to a normal efficiency condenser, what temperature does a high-efficiency condenser condense at?

13. How is the condenser cooled in on an evaporative condenser?

14. When mineral deposits affect heat transfer, what result does it have on operating costs and efficiency?

15. What effect does the dryness of air have on cooling tower water evaporation rate?

16. Where is the condenser coil located in an evaporative condenser?

17. In an evaporative condenser, what is water sprayed onto?

18. In an evaporative condenser, what causes the heat of condensation to be carried off?

805. Characteristics of refrigeration metering devices

Metering devices are another point in the refrigeration system where the high and low sides meet. Do you remember the other point? It is the compressor. Earlier we looked at the thermostatic-type metering device. Actually, the engineers designed all metering devices to accomplish the same thing—control refrigerant flow and induce a pressure drop. The pressure drop lowers the saturation temperature of the refrigerant. The lower the saturation temperature, the lower the space temperature can become because of the nature of heat transfer. Remember heat always flows from a warmer to a cooler source. It does this because it is the nature of things to equalize. In this lesson, we will concentrate on the following metering devices:

- Fixed metering orifice.
- Capillary tube.
- Thermostatic expansion valve (TEV).
- Automatic expansion valves.
- Electronic expansion valves.
- Low-side float.
- High-side float.

Metering orifice

The metering orifice restricts refrigerant flow and allows only a designed amount of refrigerant to pass. The refrigerant charge is critical in this system. Split A/C systems or heat pumps often use metering orifices. You will not usually find metering orifices on commercial, medium, or low-temperature refrigeration applications.

The operation of the metering orifice is as follows. When the refrigerant flows in the direction of the evaporator, it forces it through the very small orifice. This action causes a pressure drop.

When reversing the refrigerant flow, such as on a heat pump system, the orifice slips back and permits the refrigerant to flow unrestricted in the other direction. You may see two metering devices installed on a metering orifice. One device will meter refrigerant flow in cooling and allows full-free flow during heating. The other metering device meters flow during heating and allows full-free flow during cooling.

> **NOTE:** There are several types of these devices on the market, and they all work the same, except for the type that uses a short capillary tube of an inch or so in length as the orifice. When we reverse the cycle this type of orifice device does *not* bypass the refrigerant. These types of metering devices are subject to restrictions caused by carbon or other particles that can get through the filters and strainers.

Capillary tube

The capillary tube (fig. 1–35) is located between the condenser and the evaporator. It is mainly used on practically all small applications such as domestic refrigerators and freezers. In addition, you will use it on some central A/C systems.

The capillary tube consists of a length of small-diameter, seamless copper tubing. The diameter and length depend upon the refrigerant, system capacity, and application. The operation of the capillary tube is relatively simple. When you force a liquid through a pipe or small tube, there is always a resistance to flow. You can reduce the flow by decreasing the diameter or increasing the length.

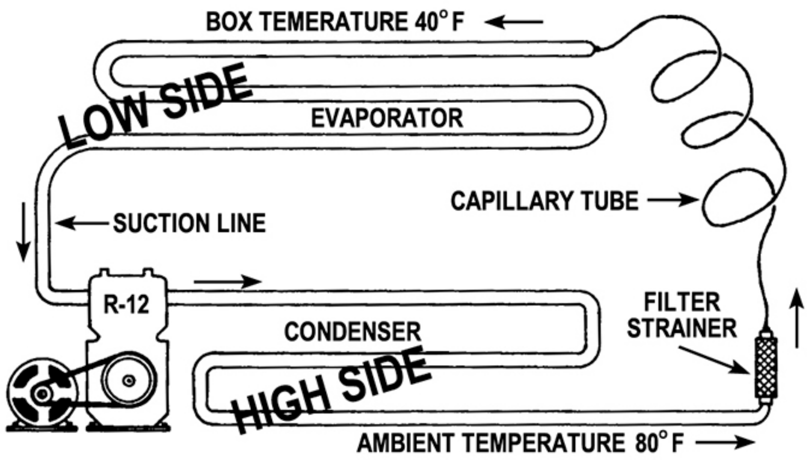


Figure 1–35. System showing capillary tube.

Figure 1–36 is an example of how length affects pressure. Figure 1–37 shows different size bore diameters. Because of these known factors, the capillary tube for a given system is designed to create enough resistance so that the pressure drop allows the liquid refrigerant to begin to vaporize. This occurs near the inlet of the evaporator, where its temperature cools to the evaporator temperature and pressure. Figure 1–38 shows the normal operating conditions of a capillary tube device with a medium temperature application.

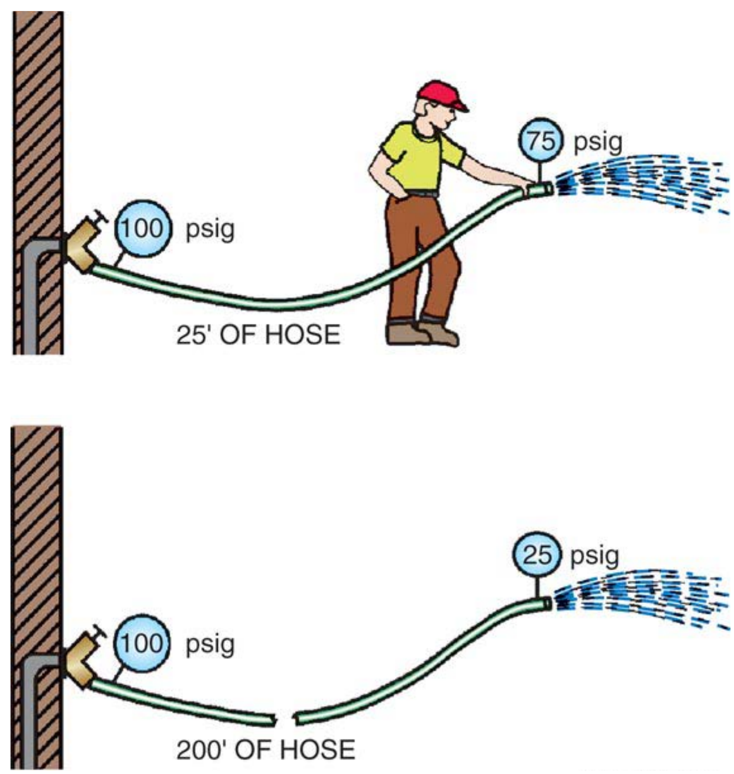


Figure 1–36. Length effects pressure.
(Courtesy Cengage Learning.)

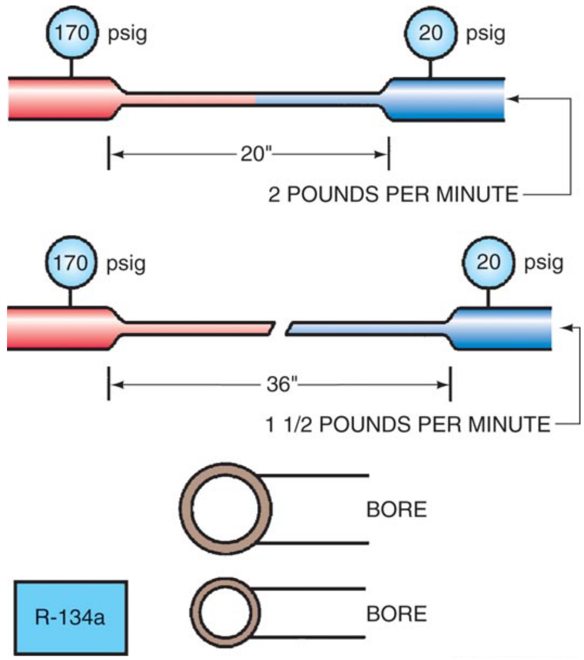


Figure 1–37. Fill material to increase surface area.
(Courtesy Cengage Learning.)

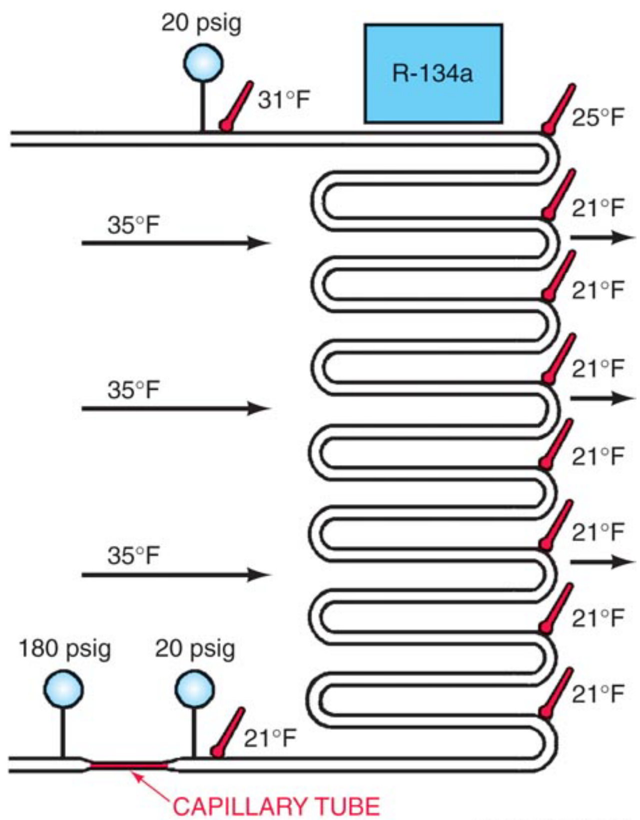


Figure 1–38. Normal capillary operation.
(Courtesy Cengage Learning.)

The capillary tube equalizes system pressure during the off cycle thus minimizing the starting load on the compressor. Under the low load condition, fewer starting devices and less current are required for the compressor motor.

With the capillary tube, the system refrigerant charge is critical. In fact, you can only place a limited amount of refrigerant in the system. If you put too much refrigerant in the system, the evaporator pressure rises above normal and the suction line to the compressor frosts. The evaporator will starve if you do not put in enough refrigerant. In addition to critical charge, the tube is also easily clogged or bent. To prevent clogging, you should install a filter strainer (lower right in fig. 1–35 and fig. 1–39) at the inlet of the capillary tube to prevent dirt and foreign matter from clogging the tube.

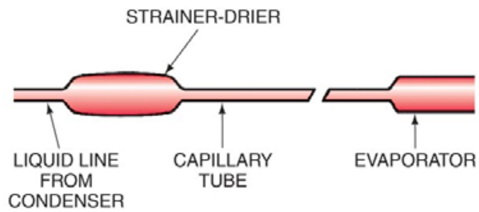


Figure 1–39. Filter strainer or strainer drier.
(Courtesy Cengage Learning.)

A broken or plugged capillary tube requires replacing with one that is identical to the original's length and inside diameter (ID). When exact replacements are not available, you may install an adjustable capillary tube in the system.

Thermostatic expansion valves

The purpose of thermostatic expansion valves (TEV or TXV) is to regulate the flow of refrigerant entering the evaporator and maintain a fully active evaporator regardless of the heat load and pressure changes. It does this by maintaining the proper amount of superheat.

> **NOTE:** Remember superheat is heat added to a gas or vapor above its saturation temperature.

The valve consists of the following parts (fig. 1–40):

- Thermostatic element.
- Push rods.
- Valve body.
- Seat.
- Pin carrier.
- Superheat spring and spring guide.
- Adjusting stem.
- Cap.

The thermal bulb, which can be called a power element, contains a charge of refrigerant. Pressure development by the charge transmits through the capillary to the diaphragm.

We began earlier by saying that the TEV maintains a fully active evaporator, regardless of the heat load and pressure charges. In actuality this is not quite true; instead, it uses a small portion of the evaporator for superheating the vapor. This happens because the change in superheat controls the valve. In the thermostatic valve, $P_1 = P_2 + P_3$ means that the evaporator pressure plus superheat spring pressure is equal to bulb pressure when the valve is in balance.

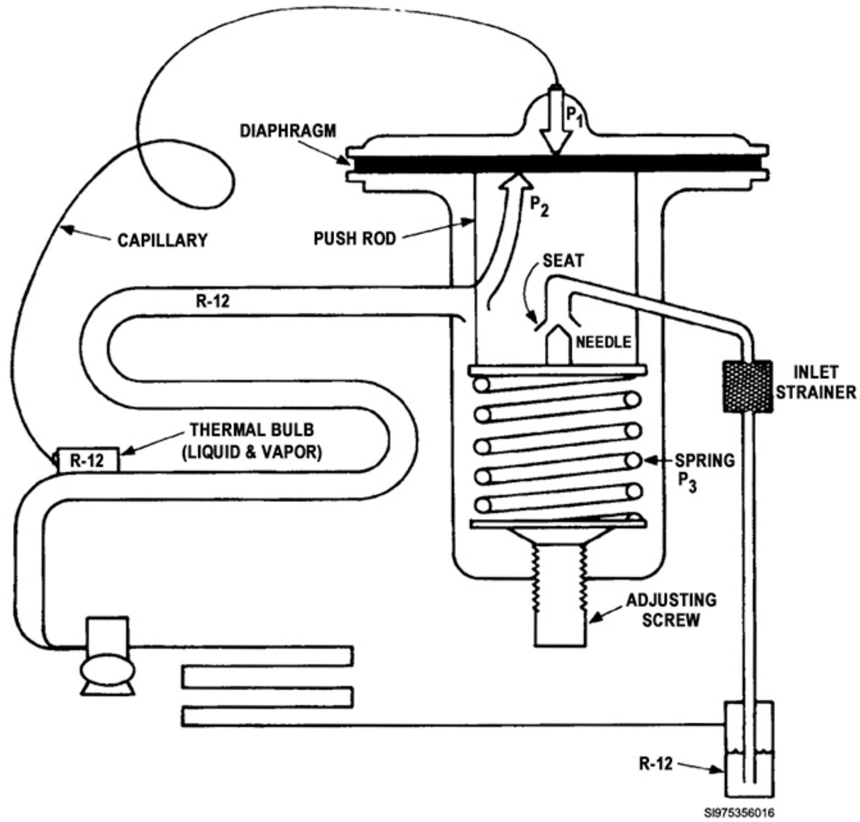


Figure 1–40. TEV.

Now look at figure 1–41. Both the system and the valve contain Refrigerant 12 (R–12). Point *V* (lower middle, left) is the point of complete vaporization. The temperature of the liquid and vapor from *V* to *A* (upper middle, right) is the same. The *location* of point *V* is not too important, but the *temperature* at point *V* is very important. You can determine the temperature at point *V* by converting suction pressure to temperature. Figure 1–42 is an example. The suction pressure is 21 pounds per square inch (psi), and the temperature from *A* to *V* is 20 °F. Now let's find the amount of superheat. To do this, attach the bulb of a superheat thermometer at point *C* (middle, left, fig. 1–42). The temperature at this point is 30 °F. Now, convert the suction pressure to temperature using the temperature-pressure (T-P) chart shown in the figure. As you can see, it is 21 psi = 20 °F. This is the temperature at point *V*. Now subtract the temperature at point *V* from the temperature at point *C:* 30 °F – 20 °F = 10 °F superheat.

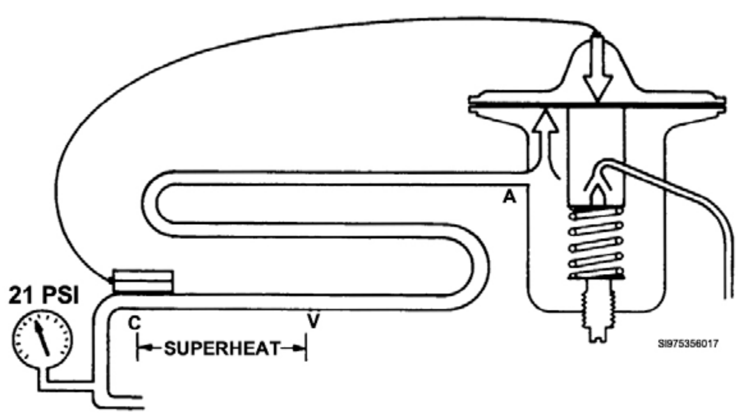


Figure 1–41. Locating point *V*.

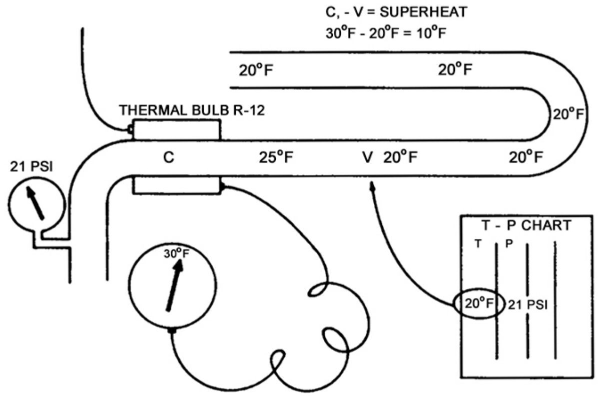


Figure 1–42. Figuring superheat.

Now take a look at figure 1–43 to see the valve in equilibrium, opening and closing.

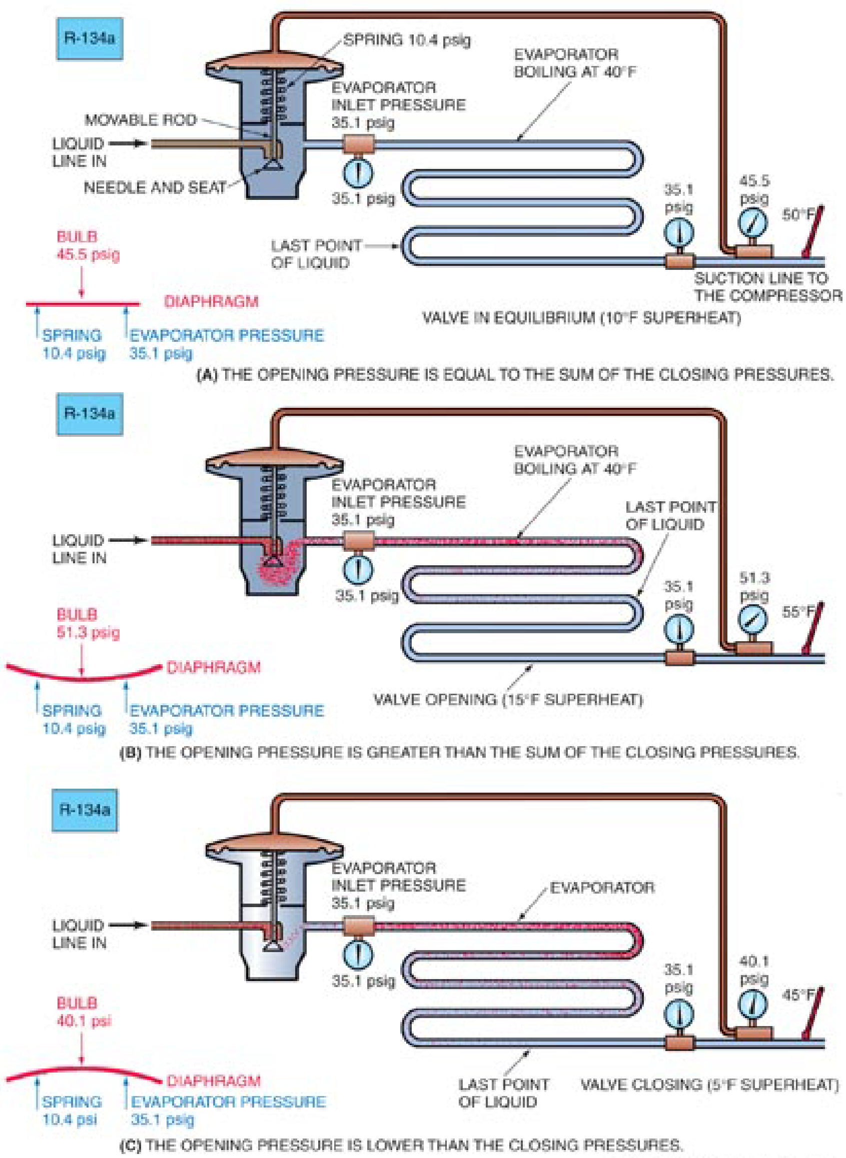


Figure 1–43. TXV operation.
(Courtesy Cengage Learning.)

Mounting of sensing bulb

Installation of the thermal bulb is critical to the proper operation of the TEV. The thermal bulb needs to be clamped to a horizontal part of the suction line near the evaporator outlet. Ensure the suction line is thoroughly cleaned before you clamp the remote bulb in place. Figure 1–44 illustrates the proper positioning of the thermal bulb on large and small lines. Refer to figure 1–44 and be sure to follow these instructions.

- On suction lines under ⅞ inch outside diameter (OD), install the remote bulb on top of the line.
- On lines that are ⅞ inch up to 2⅛ inches OD, install the bulb at the 4 or 8 o'clock position.
- On lines 2⅛ inches and larger, place the bulb in a well in the suction line.

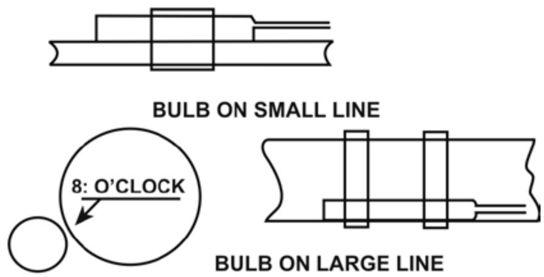


Figure 1–44. Location of thermal bulb.

Never install the thermal bulb where the suction line is trapped. If you do, any collection of liquid refrigerant at the bulb's location will cause irregular operation of the expansion valve. Large fluctuations in pressure and superheat of the suction gas usually result from trapped liquid at the bulb's location.

If installed, *always locate the bulb on the evaporator side of a heat exchanger*. You must insulate both the bulb and the suction line from the surrounding ambient temperature when the remote bulb is outside the refrigerated space. The insulation must extend at least 1 foot or more on both sides of the bulb. When the thermal bulb is inside the refrigerated space, the temperature difference between the evaporator and the open space is not usually large enough to adversely affect expansion valve operation.

Hunting

Hunting of the expansion valve is the alternate overfeeding and starving of the evaporator. You can recognize hunting by extreme cycle changes in both the superheat and the suction pressure. The TEV is hunting when it opens too much and allows an excess refrigerant through and then closes too much and doesn't allow enough refrigerant through. These changes decrease evaporator efficiency.

Thermal bulb charges

TEVs may require a different type of refrigerant charge in the thermal bulb for each temperature range. The type of charge in the bulb depends on the application. We classify charges into four main groups:

- Gas-charged.
- Gas-Cross-charged.
- Liquid-charged.
- Liquid-cross charged.

Gas-charged valve

For this type of valve, the bulb contains the same type of refrigerant used in the system. The amount of refrigerant is limited so that, at a predetermined temperature, all refrigerant in the bulb has vaporized. So, as the temperature of the bulb increases the liquid inside it will eventually vaporize. Once all of the liquid is vaporized, the pressure will reach a maximum point at which the pressure it exerts will no longer increase. This pressure is referred to as the *maximum operating pressure* (MOP) and is labeled on the power head of the valve. Anytime the evaporator pressure becomes greater than the MOP, the valve closes and remains closed until the evaporator pressure reduces below the MOP. Once the pressure of the evaporator drops below the MOP, the TEV will begin to open.

Gas-Cross-charged valves

Gas-Cross-charged valves use a different refrigerant in the power element than used in the system. This type of valve is used in special applications. It creates a high initial superheat, which tends to prevent flood back and motor overload during initial pull-down. At high evaporator temperatures, the cross-charged valve maintains a very high superheat. As the evaporator temperature lowers, the superheat gradually returns to normal. When the compressor stops, the valve closes quickly to keep from flooding the evaporator.

Liquid-charged valves

A liquid-charged valve contains the same refrigerant as the system. This type of valve operates on the principle of expansion or contraction of a liquid as it changes temperature. The advantage of this type is that the valve controls refrigerant flow even if the valve body is colder than the thermal bulb. These elements are designed for temperatures ranging from -20 °F to 40 °F. This design can cause evaporator flooding when the system is pulling down from ambient temperatures. One main disadvantage is that during the initial pull-down (when the compressor starts), the evaporator temperature is immediately reduced. During the off cycle, the bulb may warm up enough to open the valve. This floods the evaporator and causes flood back on start-up.

Liquid-cross charged

This type uses a bulb that has a different liquid refrigerant than the refrigerant the system uses. The bulb could contain more than one type of refrigerant. There will always be some liquid refrigerant in the bulb, regardless of the temperature of the evaporator. The bulb will control the valve if the valve body temperature falls below the temperature of the bulb.

These bulbs are designed for temperatures between –40 °F to 40 °F. The valve will close quickly when the compressor stops.

Automatic expansion valves

Automatic expansion valves (AEV or AXV) are operated by the pressure from the low side of the system. There are no sensing bulbs with this type of expansion valve. The compressor motor is controlled by a separate device. The AEV reduces high-side pressure to a constant output. This will maintain a constant pressure in the evaporator. You will commonly find AEVs on small commercial systems.

When evaporator pressure drops, the AEV increases the amount of refrigerant flow. As refrigerant enters the low-pressure side it begins to boil and absorb heat. When evaporator pressure rises, the AEV decreases the amount of refrigerant flow. For instance, when the compressor stops, the evaporator pressure will increase and the AEV will close. AEVs are adjustable. When adjusting the AEV you are adjusting the spring tension of the valve.

The AEVs capacity should match the capacity of the evaporator. If the valve is under-capacity it will starve the evaporator. A starved evaporator means there is not enough refrigerant for the evaporator operate correctly, hence, the evaporator is considered *starved.* An over-capacity valve allows too much refrigerant into the evaporator.

Construction

The AEVs liquid inlet can have a soldered connection, standard flange, flared connection, or pipe thread. There is usually a screen installed in the liquid inlet. The direction of flow is usually stamped on the side of the valve. The valve capacity is often stamped on the cap that covers the adjusting knob. These AEVs could be of the bellows or diaphragm type.

Bleeder or bypass

AEVs will not balance the high and low sides during the off-cycle unless there is a bypass or bleeder installed. AEVs close the refrigerant orifice during the off-cycle which results in the high and low side pressures not equalizing. If a bypass is installed, refrigerant will leak past the valve when it is closed. This bypass allows the system to operate using a low-torque motor but also requires an accumulator on the evaporator outlet. If an accumulator is not installed, liquid refrigerant could reach the compressor and cause slugging.

Electronic expansion valves

This valve uses an electric operator and does not use the power head of the TXV or the spring in the AEV. We will talk about the electronic expansion valve (EEV) that uses what is called a *stepper motor* and *Pulse Width-Modulating (PWM) solenoid* EEVs.

Stepper motor EEVs

The stepper motor operates a pin or piston that operates the valve. The motor operates the valve through a shaft or gear train. The motor receives a signal from a controller and rotates a precise, small amount. A lead screw is used to convert the motor’s rotation into a motion that opens and closes the valve port. The lead screw is simply a rod with threads on it that rotates with the motor.

The stepper motor modulates the valve’s position under a wide range of load conditions. To clarify, the motor is an electrical component that is controlled by an electronic controller. The EEV serves the same purpose as the TEV; it keeps superheat to a predetermined setting.

The electronic controller’s inputs come from the low side’s temperature and pressure. The pressure reading is obtained using a transducer that is connected to the suction line. A transducer, in this case, is a device that converts pressure to an electrical signal used by the controller. The temperature sensor is mounted on the suction line near the evaporator outlet. The sensor varies its resistance based on its temperature. The controller receives a signal from both of these devices.

The user or manufacturer determines the superheat. The controller maintains the superheat using algorithms. The algorithm determines the specific position of the valve pin or piston and allows the required amount of refrigerant flow. Even though the superheat may be adjusted, the algorithms cannot. They are designed and programmed by the manufacturer.

Other inputs that can be supplied to the controller are pump-down signals and additional temperature sensors.

A transformer usually supplies 24 AC volts to the controller. The controller will convert the voltage to DC. The voltage can be stepped down to the working voltage of the controller and its components via the circuit board. The stepper motor can maintain its position while the power is off.

PWM Solenoid EEVs

This is another type of metering device. This EEV uses a solenoid valve to vary the amount of refrigerant. The solenoid valve receives what is called a pulse width-modulating signal. The signal quickly opens and closes the solenoid valve which results in a varying amount of flow. This valve can also be called a PXV.

Solenoid valves are not commonly used to modulate flow because they are designed to either be open or closed. The modulating signal will open and close the valve for a specific period which varies the flow. For example, if the valve is held open for 10 minutes it will allow more flow through the valve than if it were open for 10 seconds.

Floats used to control refrigerant flow

Floats do not use temperature and pressure to modulate flow, they use the quantity of refrigerant to meter refrigerant. A liquid receiver in the evaporator or the condenser is required for floats. Also, a valve and linkage are used.

Low-side float

Low-side floats control the amount of refrigerant flowing into the evaporator. It maintains a constant level of refrigerant in the evaporator. It is important to note that it maintains *liquid* refrigerant in the evaporator. It adjusts flow into the evaporator based on the level of refrigerant in the evaporator. Systems that use low-side floats are called flooded systems. Figure 1–45 is an example of a low-side float.

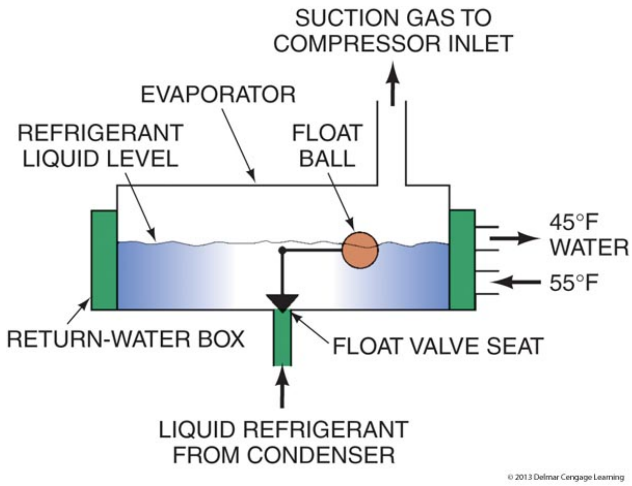


Figure 1–45. Low-side float.
(Courtesy Cengage Learning.)

High-side float

These floats control the amount of refrigerant in the evaporator based on the amount of refrigerant in the high-side receiver. These floats are commonly made of copper or steel. These systems are also called flooded systems. Figure 1–46 is an example of a high-side float.

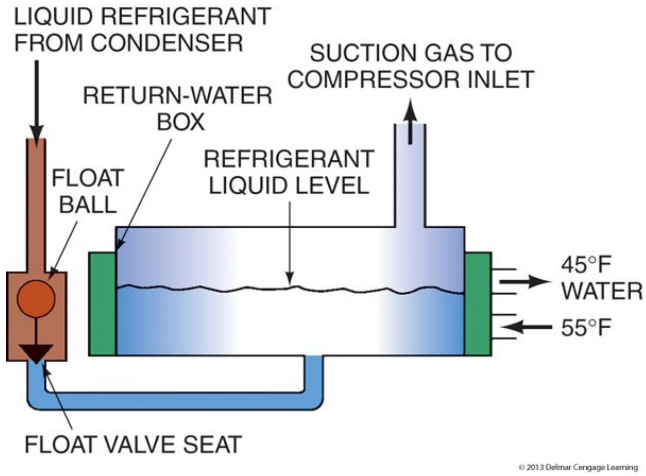


Figure 1–46. High-side float.
(Courtesy Cengage Learning.)

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

805. Characteristics of refrigeration metering devices

1. How can the flow of refrigerant be further reduced through a capillary tube?

2. How does the designed pressure drop of a capillary tube affect liquid refrigerant?

3. What effect does low-load conditions have on starting devices and the compressor motor?

4. What could result if too much refrigerant is placed in a critically charged capillary tube?

5. What is required if a capillary tube is broken?

6. How does the pressure development of the refrigerant charge in the bulb reach the diaphragm?

7. What is the bulb and suction line insulated from?

8. What is expansion valve hunting?

9. What type of refrigerant is used in the bulb of a gas-charged valve?

10. Where is the maximum operating pressure labeled?

11. What happens to the TEV once the pressure of the evaporator drops below the MOP?

12. When would a gas-cross charged valve be used?

13. What pressure operates the AEV?

14. Where will you commonly find AEVs?

15. When adjusting the AEV, what is actually being adjusted?

16. How will an over-capacity valve affect the refrigerant in the evaporator?

17. Why does the high and low side *not equalize* when an AEV is being used?

18. How does the stepper motor operate the valve?

19. What are the two main inputs for the EEV's electronic controller?

20. What does the EEV's controller use to maintain superheat?

21. What does the PXV use to modulate refrigerant flow?

806. Characteristics of refrigeration evaporators

By now, you should know that the evaporator is the place in the system where the absorption of heat takes place. Remember that refrigeration consists of removing heat from a place where it's objectionable and transferring it to a place where it's less objectionable. The purpose of the evaporator in any system is to absorb the heat from the conditioned space. The conditioned space can be an office, dorm room, chow hall, or warehouse.

Evaporator functions

Do not get confused and think that the evaporator's sole purpose is to absorb heat to make the medium cooler. Air-cooling evaporators dehumidify and cool the air. Figure 1–47 is an example of how moisture is pulled out of the air by the evaporator. Also, in heat pumps, evaporators can be used to perform the job of the condenser.

In this lesson, we explore these five major subject areas:

- Direct-expansion (DX) evaporators.
- Indirect-expansion evaporators.
- Temperature ranges of evaporators.
- Evaporator construction features and specifications.
- Evaporator efficiency.

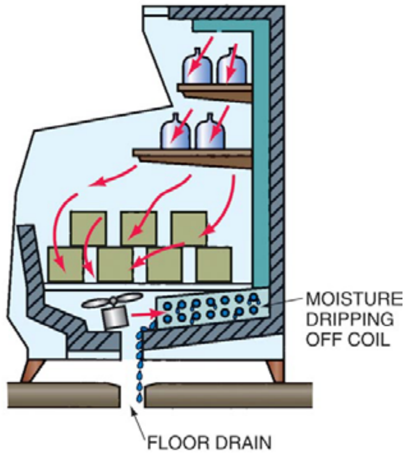


Figure 1–47. Humidity removal.
(Courtesy Cengage Learning.)

DX evaporators

There are distinctive principles of operation that differentiate the DX type of evaporator from the indirect type. DX evaporators use a primary refrigerant to absorb the heat from the conditioned space. Essentially, the refrigerant in a DX evaporator coil makes direct contact with the heat from the conditioned space (fig. 1–48). In the figure, room air is 75 °F and is cooled to 55 °F as the air contacts the coil. There are many different construction features and applications for the DX evaporator. We discuss two types as general examples in the table below.

- Dry evaporators.
- Flooded evaporators.

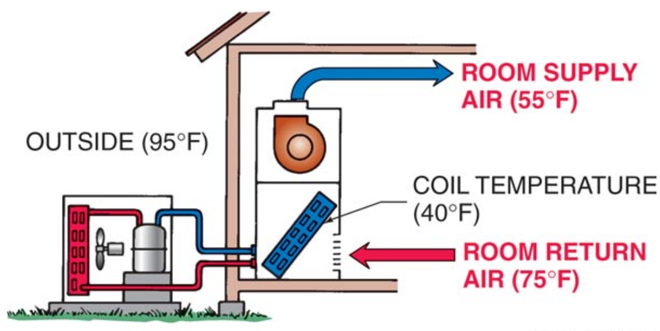


Figure 1–48. Air directly passing over coil and becoming cool.
(Courtesy Cengage Learning.)

DX Evaporators	
Type	**Description**
Dry	Dry-type DX evaporators are those in which the refrigerant is fed directly into the cooling coil through a metering device such as an expansion valve or capillary tube. The refrigerant in the coil absorbs heat from the cooled medium directly through the walls of the coil. The design of the dry-type DX evaporator is to maintain a constant mixture of liquid and vapor refrigerant.
Flooded	Flooded-type DX evaporators are equipped with either a low- or high-side float. In these systems, the float maintains a constant level of liquid refrigerant in the evaporator regardless of load conditions.

Indirect-expansion evaporators

Systems using indirect-expansion evaporators use two "evaporator" coils. One of the coils is usually inside the air handler or refrigerated space. This coil contains a secondary refrigerant. The other coil is usually near or inside the condensing unit and contains the primary refrigerant. The primary refrigerant coil removes heat transferred to the secondary coil. The secondary refrigerant coil absorbs heat by making contact with the air from the conditioned space. Therefore, when a primary coil removes heat from the secondary coil, which directly contacted the conditioned space, we call this type system "indirect expansion."

Many indirect-expansion systems use a finned evaporator coil as the secondary evaporator and a shell-and-tube arrangement as the primary evaporator. Remember the names of these evaporators, but do not concern yourself with why engineers would select these types of evaporators for use. Engineers use many factors to determine which evaporators would be best for the system. Again, at this point, do not concern yourself with these factors.

With these thoughts in mind, let's take a closer look at the processes of an indirect-expansion evaporator. To do this, we will cover these three areas:

- Secondary refrigerant.
- Primary refrigerant.
- Operation of indirect-expansion systems.

Secondary refrigerant

The majority of the systems using indirect expansion have water or a brine solution as the secondary refrigerant. The specific application and temperature ranges dictate which secondary refrigerant the system needs.

- When the temperature in the secondary coil will *not* fall below 32 °F, water is an acceptable refrigerant.
- When the application calls for a temperature *below* 32 °F, it is necessary to use something that will not freeze and possibly damage the equipment.

You can use a brine solution as one example of a secondary refrigerant when temperatures are below 32 °F. A brine solution contains salt or some other chemical that reduces the freezing temperature and, if properly maintained, eliminates the risk of damaging the system due to freeze-up.

Primary refrigerant

The primary refrigerant varies with the system application. In almost all cases, however, it is one of the following types of refrigerant:

- Chlorofluorocarbon (CFC).
- Hydrofluorocarbon (HFC).
- Hydrochlorofluorocarbon (HCFC).

Operation of indirect expansion systems

As an example of the operation of an indirect-expansion system, let's look at a reciprocating-type A/C system. For the purpose of this example, we will use water as the secondary refrigerant and R–22 as the primary refrigerant.

A centrifugal water pump moves the secondary refrigerant through the system. In contrast, the primary refrigerant is moved through the system by the compressor. The secondary side of the system uses fan coil units, which are finned evaporators and have a fan to move room air over the coil. The primary coil is a shell-and-tube evaporator with water passing through the tubes and R–22 on the outside of the tubes.

The air moving across the secondary coil is warmer than the coil so it gives up some of the heat and becomes cooler. The heat transferred into the water, or secondary refrigerant, now flows back to the primary evaporator and gives up this heat to the R–22 in the shell-and-tube evaporator.

Recall that in the DX evaporator systems there is one refrigerant passing through one coil; this type evaporator made direct contact with the conditioned space. Indirect systems, “indirectly” remove the heat from the conditioned space.

Temperature ranges of evaporators

Remember, evaporators are used in both refrigeration and cooling applications. This means evaporators have a wide span of temperature ranges. Evaporators are used in fridges; freezers; and residential, commercial, and industrial cooling applications. Be aware of the evaporator you are working on and the desired effect needed from it.

Evaporator construction features and specifications

Evaporators use a variety of construction features. Normally the application of the evaporator dictates the type of evaporator needed. For instance we would not use a fin-and-tube–type evaporator with forced convection in a chest-type domestic freezer. The reason for this limitation is the lack of space available for installing this equipment. Likewise, we would not use a plate-type evaporator in an A/C application. In the following paragraphs we cover five of the most commonly used evaporator construction features:

- Bare-tube or plate evaporators.
- Finned evaporators.
- Forced-convection evaporators.
- Shell-and-coil.
- Shell-and-tube.

Bare-tube or plate evaporators

We normally use these evaporators where the box temperature is below 32 °F and in liquid cooling applications. Usually small domestic-type refrigerators or freezers use these types of evaporators. Figure 1–49 illustrates a bare-tube evaporator.

Manufacturers usually make plate evaporators by stamping out two plates to form tubes and welding the plates together. Another method of making a plate evaporator is to form a coil, cover it with plates, and weld the plates together. In these applications, the evaporator serves as shelves and the cooled product is placed directly on them. This arrangement allows for a fast heat transfer from the product to the evaporator.

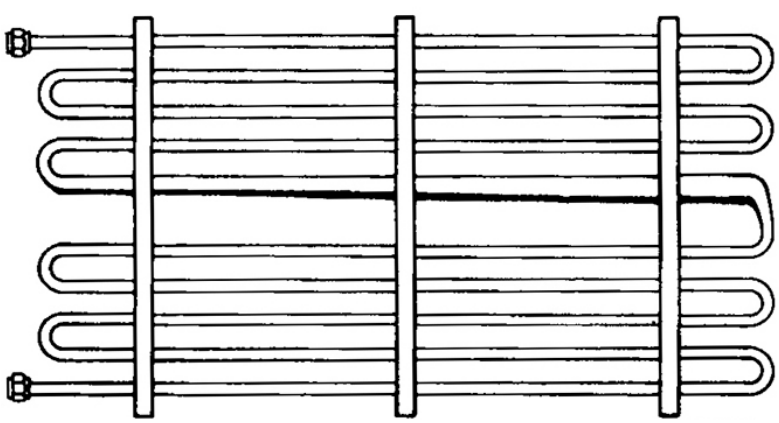


Figure 1–49. Bare-tube evaporator.

Finned evaporators

A finned evaporator is made of bare tubes covered with metal fins. These fins add surface area, which aids in heat transfer. Many applications use such evaporators.

It is important to recall the operating conditions mentioned earlier. When the evaporator temperature stays below 32 °F, ice will remain on the evaporator coil. Consequently the ice may block airflow, which in turn will reduce heat transfer. For this reason, finned evaporators are designed for different types of systems and may or may not require the addition of a defrost system.

Smaller evaporators, like the ones used on window air conditioners, usually have a large number of fins per inch. The higher the number of fins per inch, the higher the rate of heat transfer. Of course there are advantages and disadvantages. The higher the number of fins per inch, the more energy efficient the unit is. A disadvantage to having a high number of fins per inch is the increased possibility for dirt accumulation. When dirt accumulates on the fins or coil surface, it acts as an insulator and reduces heat transfer. Keeping the filters clean reduces the possibility of this occurring.

Evaporators used in low-temperature applications such as a display case used for ice cream have a fin-per-inch rating that is wider than an air-conditioning system. This evaporator must remain well below 32 °F. Ice formation is a major concern when evaporators consistently operate below 32 °F. Defrost systems periodically remove the ice based on local operating conditions. Locations with low relative humidity, or where the coil is not exposed to a high-humidity condition, do not require as many defrosts per day. Humidity, operating temperature, application, fin spacing, and general experience dictate the number of defrosts per day on large evaporators operating below 32 °F.

Forced-convection evaporators

We consider any type of evaporator with a mechanical means of moving the air as a forced unit. Such a unit normally consists of a finned coil with a fan to move the air through the coil. Forced-convection evaporators are very efficient. Many different applications use forced-convection evaporators. Some examples are:

- Window units.
- Split residential air handlers.
- Package heat pumps.
- Indirect-expansion fan coil units.
- Commercial DX air handlers.

Shell-and-coil

The shell-and-coil cooler uses the DX method. You may use it to cool any type liquid. This evaporator consists of a continuous single or double spiral coil, with the refrigerant inlet and outlet located at the top. The refrigerant is inside the coil, while the liquid to be cooled is between the coil and the outside shell.

Shell-and-tube

The shell-and-tube cooler is opposite the shell-and-coil cooler. It consists of a cylindrical shell in with a number of tubes inside. The tubes run lengthwise and are connected by tube sheets at both ends that form an inlet and discharge header. We usually use this cooler to cool water or brine, and you can operate it under dry or flooded-expansion conditions. When the flooded expansion is used, the liquid to be cooled (or secondary refrigerant) flows through the tubes and the refrigerant surrounds the tubes. Usually these are reversed when the dry expansion is used.

Evaporative specifications

Evaporators have product data that includes items such as evaporator dimensions, coil configurations, capacities, and performance data. You should review this data to become more knowledgeable about the coils you are working with. When it comes to replacing evaporators you will need to work with the manufacturer or parts dealer for your shop and the parts NCO in your shop to acquire the proper coil. For installations, the coil and condensing unit should be paired up. We do not cover the procedures for replacing and installing coils in this CDC since they are not a career field requirement. As you progress in upgrade training you should be trained on these tasks.

Evaporator efficiency

As a major component in the refrigeration cycle, evaporator efficiency is critical to the efficiency of the system. It is important for you to know conditions that negatively affect evaporator efficiency. We'll discuss the following conditions:

- Blockage of flow.
- Capillary tubes with evaporators.
- TXV's with evaporators.

Blockage of flow

There are three main causes of blocked airflow over the evaporator. Each one of these conditions results in a reduction in heat transfer which results in reduced evaporator efficiency.

Blockage of Flow Causes	
Cause	**Description**
Dirty evaporator	Dust and dirt can accumulate on the evaporator surface. This dust or dirt acts as an insulator between the air and the refrigerant evaporator thus reducing evaporator effectiveness.
Ice	Ice on the evaporator acts as insulation the same way that dust does. Excessive ice builds-up to due to a low refrigerant charge, faulty defrost, or blocked airflow. You could remove the ice from a coil and start the system again. However, the system could soon ice up because you didn't fix the cause of the ice formation.
Air filter	Air filters are a common cause of reduced evaporator effectiveness. A dirty air filter prevents the required amount of air from passing over the coil and absorbing heat. This results in low evaporator pressures/temperatures and can cause ice to form on the evaporator coil.

Capillary tubes with evaporators

Different metering devices react differently when evaporator efficiency is reduced. With a capillary tube, lower suction pressure and lower evaporator temperatures result when evaporator efficiency is reduced. Less heat is absorbed and the conditioned space temperature will rise. The reduction of heat absorbed results in little or no superheat.

TXV's with evaporators

Like the capillary tube, reduced evaporator efficiency will create a lower suction pressure and evaporator temperature when a TXV is used. The TXV though, will maintain the proper superheat. The lack of heat absorbed will result in lower head pressures and condenser temperatures. Subcooling will be normal if the refrigerant charge is correct.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

806. Characteristics of refrigeration evaporators

1. What is the purpose of the evaporator in any system?

2. What do DX evaporators use to absorb heat from the conditioned space?

3. What feeds refrigerant into the evaporator on a dry type evaporator?

4. What effect do fins have on an evaporator?

5. What effect does ice buildup on an evaporator have on heat transfer?

6. What effect does increasing the fins per inch of an evaporator have on heat transfer?

7. What is a disadvantage to having a high number of fins per inch?

8. What are five applications of forced-convection evaporators?

9. How are the inlet and discharge headers of a shell-and-tube evaporator formed?

10. What effect does a dirty air filter have on airflow over the evaporator coil?

11. What effect does a dirty evaporator coil have on evaporator pressures/temperatures?

Answers to Self-Test Questions

801

1. Sensible heat.
2. 10 °F.
3. Latent heat.
4. Different substances have different boiling, condensing, and freezing temperatures.
5. The absorption of heat by changing a liquid refrigerant to a vapor refrigerant and the discharge of that heat by condensing the vapor refrigerant back to a liquid.
6. At a point where both vapor and liquid refrigerant exist at the same time.
7. It increases the saturation point.
8. The pressure and chemical properties of the substance.
9. Superheat.
10. Desuperheating.
11. Subcooled liquid.
12. After complete condensation has occurred and, depending on the type of metering device, continues to subcool up to and partially through the metering device.
13. The pressure exerted on it.
14. Refrigerants used in common mechanical refrigeration systems do not require as much heat energy to reach their saturation point.
15. Refrigerants have better heat transfer properties.
16. Raise the pressure of the gas so that the saturation point or condensing temperature is above the temperature of the available cooling medium (air or water).
17. Pressure drop through connecting lines can greatly affect the performance of the system.
18. Heat always travels from a warm object to a colder one.

802

1. At the metering device.
2. The power element bulb.
3. Hot, high pressure gas.
4. It must be cooler than the high-pressure gas.
5. It condenses into a liquid.
6. It removes the refrigerant vapor from the evaporator and reduces the pressure in the evaporator.
7. The system would not work.
8. Because of the heat of compression.
9. The design temperature.
10. It changes state of the refrigerant from a liquid to a vapor.

803

1. They circulate the refrigerant through the system and compress the refrigerant vapor to a higher pressure.
2. So that the cooling medium can remove the heat that was absorbed in the evaporator.
3. Intake and exhaust valves; also called the suction and discharge valves.
4. Pressure in the cylinder.
5. The two-piece construction has the crankcase and cylinders cast separately and then bolted together with a gasket between them.
6. Shaft seal.
7. Replace it.
8. To ensure it receives proper lubrication.

9. Small domestic units like window units, packaged terminal air conditioners, and small heat pumps up to 5 tons.
10. Less friction and heat.
11. They form crescent-shaped gas pockets.
12. Suction process and the discharge process are continuous.
13. Hot refrigerant from flowing back to the low side.
14. Compressor terminals.
15. Embedded in or near the windings.
16. They could have opened up due to a temporary overheating condition. They could close back up.
17. Discover the cause of the compressor's overheating condition.
18. Solid state motor protection.
19. These systems require you to tap into the refrigerant lines using a special tapping valve.

804

1. It disposes of it.
2. The surface area, material, and condition of the condenser and the type, the temperature, and the amount of cooling medium.
3. It returns to a liquid.
4. In the last coils of the condenser.
5. For heat transfer to take place.
6. The total pressure of all the gaseous pressures present.
7. Pressure will vary directly with temperature.
8. Air in the system.
9. Ambient air.
10. It becomes heated and rises.
11. A motor driven fan.
12. Closer to ambient air.
13. Water is sprayed directly over it.
14. Higher operating costs and reduced efficiency.
15. Evaporation rate increases.
16. In the tower.
17. The condenser coil.
18. Heat in the coils.

805

1. By decreasing the diameter or increasing the length.
2. It will vaporize it.
3. Fewer starting devices and less current are required for the compressor motor.
4. Evaporator pressure rises to above normal and the suction line to the compressor frosts.
5. Replacement with one that is identical with the original in its length and ID.
6. Through a capillary.
7. From the surrounding ambient temperature when the remote bulb is outside the refrigerated space.
8. The alternate overfeeding and starving of the evaporator.
9. The same type of refrigerant used in the system.
10. On the power head of the valve.
11. It will begin to open.
12. In special applications.
13. The low side of the system.

14. On small commercial systems.
15. The spring tension.
16. It allows too much refrigerant into the evaporator.
17. Because the AEV closes the refrigerant orifice.
18. Through a shaft or gear train.
19. The low side's temperature and pressure.
20. Algorithms.
21. A solenoid valve.

806

1. Absorb heat from the cooled medium.
2. Refrigerant.
3. Metering device such as an expansion valve or capillary tube.
4. Add surface area which aids in heat transfer.
5. It reduces heat transfer.
6. It increases it.
7. Increased possibility for dirt accumulation.
8. Window units, split residential air handlers, package heat pumps, indirect-expansion fan coil units, and commercial DX air handlers.
9. The tubes run lengthwise and are connected by tube sheets at both ends.
10. It prevents the required amount from passing over the coil.
11. Low evaporator pressures/temperatures and can cause ice to form.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

1. (801) How much *sensible heat* is added if the temperature of air increases from 70 to 80 °F?
   a. 5 °F.
   b. 10 °F.
   c. 15 °F.
   d. 70 °F.

2. (801) What occurs during the *latent heat of condensation*?
   a. Refrigerant gas solidifies.
   b. Vapor turns to a liquid.
   c. Liquid turns to a vapor.
   d. Liquid turns to a gas.

3. (801) What determines the pressure required to achieve a specific flow rate?
   a. Pump design.
   b. Ambient temperatures.
   c. Pressure enthalpy charts.
   d. Design of the piping system.

4. (802) What three processes take place in the *condenser*?
   a. Superheating, boiling, and subcooling.
   b. Desuperheating, boiling, and subcooling.
   c. Superheating, condensing, and subcooling.
   d. Desuperheating, condensing, and subcooling.

5. (802) The heat being absorbed in the evaporator comes from the
   a. product being cooled or the conditioned space.
   b. compressor discharge.
   c. condenser.
   d. receiver.

6. (803) What happens to the *exhaust valve of a compressor* during the *intake stroke*?
   a. Backpressure from the low side opens it.
   b. Backpressure from the high side opens it.
   c. Backpressure from the high side closes it.
   d. Frontpressure from the high side closes it.

7. (803) What effect do *fins* on the shell of a compressor have?
   a. Decrease surface area and allow more heat transfer with return air.
   b. Increase surface area and allow more heat transfer with supply air.
   c. Increase surface area and allow more heat transfer with ambient air.
   d. Decrease surface area and allow more heat transfer with ambient air.

8. (803) What does a *check valve in the discharge line* prevent with a rotary compressor?
   a. Liquid accumulation.
   b. Gas leaking back to the condenser.
   c. Liquid condensing in the compressor.
   d. Gas from leaking back to compressor.

9. (803) Why must you be careful when placing meter leads on compressor terminals?
   a. Compressor terminals also act as refrigerant access ports.
   b. Expansion device could open rapidly and cause a blowout.
   c. This is the weakest section of the compressor and a blowout could occur.
   d. This is the strongest section of the compressor but damage could still occur.

10. (803) What is the result of a loose electrical connection at the *compressor terminal*?
    a. Increased heat.
    b. Decreased heat.
    c. Better conductivity.
    d. Decreased resistance.

11. (803) Where are *internal motor protection devices* embedded?
    a. In the discharge line.
    b. On the compressor shell.
    c. In the hot suction gas line.
    d. In or near the motor windings.

12. (804) Desuperheating generally takes place in the
    a. liquid line and first few coils of the condenser.
    b. suction line and first few coils of the evaporator.
    c. discharge line and last few coils of the condenser.
    d. discharge line and first few coils of the condenser.

13. (804) Non-condensables inside a refrigeration system are in what form?
    a. Gas.
    b. Solid.
    c. Liquid.
    d. Non-condensables do not exist in a system.

14. (804) In a refrigeration system air gets trapped at the
    a. top of the condenser and receiver.
    b. bottom of the condenser and receiver.
    c. top of the condenser and accumulator.
    d. bottom of the evaporator and receiver.

15. (804) What effect does *counter flow* have in a *double-tube condenser*?
    a. Creates fluid flow issues.
    b. Gives condenser a *lower* efficiency.
    c. Gives condenser a *higher* efficiency.
    d. Counter flow decreases flow because of counter-resistance.

16. (805) What is the relationship between a capillary tube metering device and refrigerant charge?
    a. The charge is less critical.
    b. Using a capillary device makes the charge critical.
    c. Capillary tube will *not* meter refrigerant if the charge is too high.
    d. Capillary tube maintains constant superheat so the charge is *not* as important.

17. (805) A filter strainer should be installed at the inlet of the capillary tube to
    a. prevent dirt and foreign matter from clogging the tube.
    b. create 40% flash gas for the evaporator.
    c. create the designed pressure drop.
    d. pre-flash the liquid refrigerant.

18. (805) In figure 1–41 where is the *point of complete vaporization*?
    a. V.
    b. A.
    c. C.
    d. At the sensing bulb.

19. (805) When the evaporator pressure rises after the compressor stops the automatic expansion valve (AXV)?
    a. opens.
    b. closes.
    c. opens 60%.
    d. trips out the compressor control.

20. (805) What happens when a stepper motor expansion device receives a signal from the controller?
    a. It shuts the system down.
    b. Rotates a precise, small amount.
    c. It creates a 50% flash gas condition.
    d. Rotates inaccurately and in a large amount.

21. (805) An electronic expansion valve stepper motor's electronic controller receives a *pressure reading* from a
    a. transducer in the *liquid* line.
    b. transducer in the *suction* line.
    c. thermistor placed on the liquid line.
    d. thermistor placed on the compressor discharge.

22. (805) How does a pulse width modulating electronic expansion valve (EEV) vary refrigerant flow?
    a. A signal quickly opens and slowly closes the solenoid valve.
    b. A signal slowly opens and quickly closes the check valve.
    c. A signal quickly opens and closes the solenoid valve.
    d. A signal slowly opens and closes the check valve.

23. (806) In an *indirect expansion system* the coil containing the secondary refrigerant is
    a. in an air handler.
    b. in the primary control loop.
    c. inside offices to reject heat.
    d. located outside to reject heat.

24. (806) Dirt on an evaporator coil acts like
    a. another fin.
    b. a conductor.
    c. an insulator.
    d. increased surface area.

25. (806) In a system using a capillary tube how does very little heat being absorbed affect superheat?
    a. There will be negative superheat.
    b. There will be too much superheat.
    c. There will be little or no superheat.
    d. Superheat is kept constant by the capillary tube.

Please read the unit menu for unit 2 and continue ➔

Unit 2. Refrigeration and Cooling System Essentials, Part 2

IN THIS UNIT, we continue our discussion of refrigeration and cooling system essentials from Unit 1. Here, in section 2–1, we turn our attention to the refrigerants and oils that make modern-day refrigeration and air-conditioning (A/C) possible. The lessons in section 2–2 focus on the basic controls and accessories you will encounter as you service and maintain HVAC/R systems. The unit concludes with section 2–3 lessons discussing capacity control in refrigeration and A/C systems.

2–1. Refrigerants and Oils

By now, you should know that the refrigerant is the vital fluid of any refrigeration system. You should also know that the refrigerant is the substance that absorbs the heat from the place where it is not wanted and transfers this heat to a place where it can be ejected. In this section, we will explore the refrigerant knowledge you must have to do your job safely and competently.

In addition to refrigerants, you must also know the requirements for the oils used in refrigeration and A/C systems. We have included a lesson on them to provide you with this knowledge.

807. Types of refrigerants

Mechanical refrigeration requires a process that can not only transfer large quantities of heat economically and efficiently but can also be repeated continuously. The logical solution is the use of a liquid refrigerant and the processes of evaporation and condensation.

There is no single, perfect refrigerant suitable for universal use. The choice of a refrigerant depends on many properties including:

- Ability to absorb heat.
- Toxicity.
- Flammability.
- Density.
- Viscosity.
- Availability.

Equipment manufacturers consider these factors when designing their equipment. All refrigerating equipment manufacturers attach a nomenclature and/or data plate to their units. This plate specifies the type and amount of “refrigerant charge” the system takes.

In the last few years, the types of refrigerants that can be used in systems have changed dramatically and older refrigerants that were previously the industry standard have been banned. In addition, the industry has introduced newer refrigerants that come with several new requirements.

In this lesson, we will explore the following topics as they relate to certain refrigerants:

- Ozone Depletion Potential (ODP).
- Global Warming Potential (GWP).
- Chlorofluorocarbon (CFC) refrigerants.
- Hydrochloroflurocarbon (HCFC) refrigerants.
- Hydrofluorocarbon (HFC) refrigerants.
- Substitute refrigerants.
- Special refrigerants.
- Refrigerant properties.
- Refrigerant and oil relationships.
- Refrigerant pressure and temperature relationship.
- Refrigerant temperature glide.
- Refrigerant safety.
- Refrigerant cylinders.

Ozone Depletion Potential

The ODP is a number assigned to each refrigerant to represent the amount of ozone depletion it causes. R–11 is used as the baseline for ODP and has an ODP of 1. The higher the ODP, the greater there is a risk for ozone layer depletion.

Global Warming Potential

You should know by now that some refrigerants contribute to global warming. In addition to an ODP, each refrigerant is assigned a global warming potential number or GWP. It is based on the ratio of the refrigerant's warming effect compared to the warming effect of carbon dioxide. The higher the GWP, the greater the risk of global warming.

CFC refrigerants

We know chlorofluorocarbon refrigerants as CFCs. These refrigerants are doomed because they contain large amounts of chlorine. The chlorine destroys the ozone layer of the atmosphere causing harmful effects to the earth and those that live on the planet. The increase in global warming as well as the increase in skin cancer is supposed to be an effect of CFC use. Ozone filters the ultraviolet (UV) rays and protects our skin. Destroy the ozone and we lose this protection. You still need to learn about these refrigerants because there are still units with CFCs that you will service.

Four refrigerants fall into the CFC class:

- R–11.
- R–12.
- R–113.
- Azeotropic refrigerants.

They are described in the table below.

CFC Refrigerants	
Type	**Description**
R–11	We consider this refrigerant a stable, nontoxic, nonflammable, synthetic chemical product. It is widely used in large centrifugal compressors, with as much as 35 pounds supplied for each 1,000 cubic feet (cu. ft.) of air-conditioned space.
R–12	R–12 was one of the most popular refrigerants. It is a nontoxic, noncorrosive, nonirritating, nonflammable, colorless, and almost odorless product. It was used in reciprocating, rotary, and large centrifugal compressors.
R–113	This refrigerant has the advantage of remaining a liquid at room temperatures. It is primarily found in refrigeration and A/C systems using centrifugal compressors.

CFC Refrigerants		
Type	**Description**	
Azeotropic refrigerant blends	The following refrigerants are a mixture of refrigerants that react as one—an “azeotropic mixture.” • R–500. • R–502. • R–503. These refrigerants are sometimes called azeotropic refrigerants. Most azeotropic blends contain a phased-out refrigerant so you will see less and less of their use with time.	
	R–500	This refrigerant is a mixture of 26.2 percent R–152a and 73.9 percent R–12. It is used for both industrial and commercial applications. If we apply it to the same motor for the same purpose, R–500 refrigerant has approximately 20 percent greater refrigerating capacity than R–12. Since this mixture contains phased out refrigerants you may not see it in use very often.
	R–502	This refrigerant is also a mixture; it is composed of 48.8 percent R–22 and 51.2 percent R–115. Since this mixture contains phased out refrigerants you may not see it in use very often.
	R–503	R–503 is a liquid mixture composed of 40.1 percent R–23 and 59.9 percent R–13. R–503 is nonflammable, noncorrosive, and only slightly toxic. This refrigerant is suitable for use in cascade systems, which require very low temperatures. All low-temperature refrigerants require almost complete dryness, as any moisture may form ice within the system at the refrigerant control equipment; thus, one slight disadvantage of R–503 (more than for other low-temperature refrigerants) is that it holds more moisture. Since this mixture contains phased out refrigerants you may not see it in use very often.

Hydrochlorofluorocarbon

HCFC refrigerants are also on the banned list because they contain chlorine. However, they contain so little chlorine that there is not the same worry that CFCs cause. The future of these refrigerants is limited because the Environmental Protection Agency (EPA) requires their complete phase-out by 2030. The two refrigerants in the HCFC classification are R–22 and R–123.

HFC Refrigerants	
Type	**Description**
R–22	Refrigerant 22 is a manufactured substance. It is a nontoxic, noncorrosive, nonflammable, and nonirritating stable refrigerant. R–22 is for those refrigeration units that need low evaporating temperatures. In addition, we successfully use it in A/C and refrigeration units.
R–123	R–123 is a leading candidate in the next generation of refrigerants likely to replace refrigerants containing CFCs. We use R–123 in centrifugal chillers. Because of the low vapor density of R–123, heat transfer vessels are larger than those using R–22. It is much more toxic than other refrigerants.

Hydrofluorocarbons

Since HFCs contain no chlorine, there is no need to worry about ozone depletion. This is important because they require different handling methods that you must learn and keep current with. To be successful, you need to stay on top of all new developments in the refrigerant industry. There is no doubt that change is constant in HVAC/R.

It is important for you to pay attention to the new refrigerants coming on the market. Some are okay during a range of certain pressures. Others may operate outside of the safe range and could present dangerous situations. Other new refrigerants will need special oil. Still others will present new superheat and sub cooling calculation methods.

We will briefly discuss these two types of HFCs: R–134a and Zeotropic blends.

R–134a

This refrigerant has an ozone depletion potential of zero. It has great promise as a CFC substitute for a wide range of A/C and refrigeration systems. This includes residential and commercial applications.

Zeotropic blends

Zeotropic blends are blends of different refrigerants in which each refrigerant acts differently to the conditions within the system. Therefore, in a blend containing three refrigerants, each refrigerant boils and condenses at a different temperature. Because each refrigerant changes its state at different temperatures, causing them to separate—a process called fractionation.

Fractionation causes the refrigerant to have different temperatures at any given pressure. These blends of refrigerants require a temperature glide for calculating superheat and sub cooling methods. *Temperature glide* is a temperature range where the blend evaporates and condenses. This is because these mixtures do not react as a pure compound (a substance formed by a union of two or more elements in definite proportions by weight). In a compound, only one molecule is present. In contrast, blends are a mixture. A *mixture* is a substance consisting of two or more substances mixed together (not in fixed proportions and not with chemical bonding) while still maintaining their separate chemical properties (existences). In a mixture, more than one molecule is present; this is where the difference lies. Therefore, when new refrigerants come out, you will have to use new charts to determine the proper temperature glide. Normally the amount of glide is between 0.3 °F and 10 °F.

HFC zeotropic blend R–410A has a temperature glide of about .5 °F.

There are two other characteristics of Zeotropic blends that you need to know: bubble point and dew point.

Zeotropic Blend Characteristics

Type	Description
Bubble point	This is the temperature at which the first component of the blend begins to boil. It is called the bubble point because when a saturated liquid is heated it starts to form bubbles.
Dew point	This is the temperature at which the last component of the Zeotropic blend is completely vaporized. It is called dew point because when a saturated vapor starts to cool it form dewdrops.

Substitute refrigerants

If tasked to replace a refrigerant type, take the time to determine how well the alternative refrigerant works and whether it may pose any problems for the equipment or liability for you.

Special refrigerants

Here we will look at two types of special refrigerants: R–718 (water) and R–717 (ammonia).

Special Refrigerants	
Type	**Description**
R–718 (water)	R–718 is distilled water that operates in a vacuum. This refrigerant is definitely environmentally safe.
R–717 (ammonia)	Ammonia is an excellent refrigerant as long as safety precautions are used. It is toxic and only experienced technicians should work with it. Ammonia is colorless (under ordinary conditions), considered flammable, and has a very pronounced odor. Ammonia, when mixed with a certain percentage of oxygen, becomes explosive. R–717 is not considered poisonous; however, if inhaled, it has a violent effect on the human body which requires labeling ammonia as “toxic.”

Refrigerant properties

Refrigerants should possess certain desirable properties. They are as follows:

- Refrigerants should be safe; that is, they should be nontoxic, nonflammable, and nonexplosive.
- Refrigerants should be noncorrosive. The reason for this is because we often use common metals in the machine parts exposed to refrigerants.
- All refrigerants should be easily detectable due to the possibility of leaks.
- Refrigerants should have stability. This means the refrigerants must remain chemically unchanged while constantly going from a low temperature to a high temperature and back to a low temperature. In addition, the refrigerants must not set up a chemical reaction with the lubricants used in the systems. Moreover, the refrigerants exposed to air or moisture within the system must not chemically deteriorate.
- Refrigerants should have a high latent heat of vaporization per pound.
- Refrigerants should have a minimum difference between vaporizing and condensing pressure.
- Refrigerants should require a minimum of displacement for a given refrigeration effect.

NOTE: It is desirable to keep refrigerant pressures within the refrigeration cycle as close to atmospheric pressure as possible. The reason for this is because any great differences in pressures tend to cause leaks, overwork the compressor, and lower the overall efficiency of the system.

Refrigerant and oil relationships

The oils used in refrigeration systems have been designed to mix with and travel along with most refrigerants in the liquid state. This means that refrigeration oils are soluble in liquid refrigerant and, at normal room temperatures, they mix completely. In compressors, the oil and refrigerant mix continuously. As the oil circulates throughout the system, it may be exposed to both very high and very low temperatures. Because of the critical nature of lubrication under these conditions and the damage that can be done to the system (by wax or other impurities in the oil), only highly refined oils specifically prepared for refrigeration usage can be used.

Since oil must pass through the compressor cylinders to provide lubrication, a small amount of oil is always circulating with the refrigerant. Oil and refrigerant gas do not readily mix; further, the oil can properly circulate through the system only if gas velocities are high enough to sweep the oil along its path. If velocities are not sufficiently high, oil tends to lie on the bottom of the refrigeration tubing, decreasing heat transfer and possibly causing a shortage of oil in the compressor. As evaporating temperatures lower, this problem becomes more critical since the viscosity of the oil increases with a decrease in temperature. For these reasons, proper design of piping is essential for satisfactory oil return.

One of the basic characteristics of a refrigerant and oil mixture in a sealed system is the fact that refrigerant is attracted by oil and will vaporize and migrate through the system to the compressor crankcase even though no pressure difference exists to cause the movement. On reaching the crankcase, the refrigerant condenses into liquid, this migration continues until the oil is saturated with liquid refrigerant.

Excess refrigerant in the compressor crankcase can result in violent foaming and boiling action, driving all of the oil from the crankcase and causing lubrication problems. Therefore, you must make provisions to prevent the accumulation of excess liquid refrigerant in the compressor.

Do not consider refrigerant oils in themselves as contaminated unless they contain acids or they have mixed with other oils. Most recycle devices remove refrigerant from the oil by boiling it out while the compressor pumps it into the refillable storage tank.

You must process oils that contain acids separately.

Refrigerant pressure and temperature relationship

Understanding the pressure and temperature relationship of refrigerants can be an invaluable tool for understanding the operation of an A/C or refrigeration system. Refrigerant manufacturers develop pressure-temperature (P/T) charts for each of their refrigerants (fig. 2–1). You will find these charts in several places. For example, your manifold gauge assembly has a P/T feature (fig. 2–2). In addition, wallet-sized cards are available. Whether you choose to use the P/T chart attached to your manifold gauge or carry one in your wallet, toolbox, or on the service call truck, you need to understand how to use this chart.

TEMPERATURE	REFRIGERANT						TEMPERATURE	REFRIGERANT						TEMPERATURE	REFRIGERANT					
°F	12	22	134a	502	404A	410A	°F	12	22	134a	502	404A	410A	°F	12	22	134a	502	404A	410A
−60	19.0	12.0		7.2	6.6	0.3	12	15.8	34.7	13.2	43.2	46.2	65.3	42	38.8	71.4	37.0	83.8	89.7	122.9
−55	17.3	9.2		3.8	3.1	2.6	13	16.4	35.7	13.8	44.3	47.4	66.8	43	39.8	73.0	38.0	85.4	91.5	125.2
−50	15.4	6.2		0.2	0.8	5.0	14	17.1	36.7	14.4	45.4	48.6	68.4	44	40.7	74.5	39.0	87.0	93.3	127.6
−45	13.3	2.7		1.9	2.5	7.8	15	17.7	37.7	15.1	46.5	49.8	70.0	45	41.7	76.0	40.1	88.7	95.1	130.0
−40	11.0	0.5	14.7	4.1	4.8	9.8	16	18.4	38.7	15.7	47.7	51.0	71.6	46	42.6	77.6	41.1	90.4	97.0	132.4
−35	8.4	2.6	12.4	6.5	7.4	14.2	17	19.0	39.8	16.4	48.8	52.3	73.2	47	43.6	79.2	42.2	92.1	98.8	134.9
−30	5.5	4.9	9.7	9.2	10.2	17.9	18	19.7	40.8	17.1	50.0	53.5	75.0	48	44.6	80.8	43.3	93.9	100.7	136.4
−25	2.3	7.4	6.8	12.1	13.3	21.9	19	20.4	41.9	17.7	51.2	54.8	76.7	49	45.7	82.4	44.4	95.6	102.6	139.9
−20	0.6	10.1	3.6	15.3	16.7	26.4	20	21.0	43.0	18.4	52.4	56.1	78.4	50	46.7	84.0	45.5	97.4	104.5	142.5
−18	1.3	11.3	2.2	16.7	18.2	28.2	21	21.7	44.1	19.2	53.7	57.4	80.1	55	52.0	92.6	51.3	106.6	114.6	156.0
−16	2.0	12.5	0.7	18.1	19.6	30.2	22	22.4	45.3	19.9	54.9	58.8	81.9	60	57.7	101.6	57.3	116.4	125.2	170.0
−14	2.8	13.8	0.3	19.5	21.1	32.2	23	23.2	46.4	20.6	56.2	60.1	83.7	65	63.8	111.2	64.1	126.7	136.5	185.0
−12	3.6	15.1	1.2	21.0	22.7	34.3	24	23.9	47.6	21.4	57.5	61.5	85.5	70	70.2	121.4	71.2	137.6	148.5	200.8
−10	4.5	16.5	2.0	22.6	24.3	36.4	25	24.6	48.8	22.0	58.8	62.9	87.3	75	77.0	132.2	78.7	149.1	161.1	217.6
−8	5.4	17.9	2.8	24.2	26.0	38.7	26	25.4	49.9	22.9	60.1	64.3	90.2	80	84.2	143.6	86.8	161.2	174.5	235.4
−6	6.3	19.3	3.7	25.8	27.8	40.9	27	26.1	51.2	23.7	61.5	65.8	91.1	85	91.8	155.7	95.3	174.0	188.6	254.2
−4	7.2	20.8	4.6	27.5	30.0	42.3	28	26.9	52.4	24.5	62.8	67.2	93.0	90	99.8	168.4	104.4	187.4	203.5	274.1
−2	8.2	22.4	5.5	29.3	31.4	45.8	29	27.7	53.6	25.3	64.2	68.7	95.0	95	108.2	181.8	114.0	201.4	219.2	295.0
0	9.2	24.0	6.5	31.1	33.3	48.3	30	28.4	54.9	26.1	65.6	70.2	97.0	100	117.2	195.9	124.2	216.2	235.7	317.1
1	9.7	24.8	7.0	32.0	34.3	49.6	31	29.2	56.2	26.9	67.0	71.7	99.0	105	126.6	210.8	135.0	231.7	253.1	340.3
2	10.2	25.6	7.5	32.9	35.3	50.9	32	30.1	57.5	27.8	68.4	73.2	101.0	110	136.4	226.4	146.4	247.9	271.4	364.8
3	10.7	26.4	8.0	33.9	36.4	52.3	33	30.9	58.8	28.7	69.9	74.8	103.1	115	146.8	242.7	158.5	264.9	290.6	390.5
4	11.2	27.3	8.6	34.9	37.4	53.6	34	31.7	60.1	29.5	71.3	76.4	105.1	120	157.6	259.9	171.2	282.7	310.7	417.4
5	11.8	28.2	9.1	35.8	38.4	55.0	35	32.6	61.5	30.4	72.8	78.0	107.3	125	169.1	277.9	184.6	301.4	331.8	445.8
6	12.3	29.1	9.7	36.8	39.5	56.4	36	33.4	62.8	31.3	74.3	79.6	108.4	130	181.0	296.8	198.7	320.8	354.0	475.4
7	12.9	30.0	10.2	37.9	40.6	57.8	37	34.3	64.2	32.2	75.8	81.2	111.6	135	193.5	316.6	213.5	341.2	377.1	506.5
8	13.5	30.9	10.8	38.9	41.7	59.3	38	35.2	65.6	33.2	77.4	82.9	113.8	140	206.6	337.2	229.1	362.6	401.4	539.1
9	14.0	31.8	11.4	39.9	42.8	60.7	39	36.1	67.1	34.1	79.0	84.6	116.0	145	220.3	358.9	245.5	385.9	426.8	573.2
10	14.6	32.8	11.9	41.0	43.9	62.2	40	37.0	68.5	35.1	80.5	86.3	118.3	150	234.6	381.5	262.7	408.4	453.3	608.9
11	15.2	33.7	12.5	42.1	45.0	63.7	41	37.9	70.0	36.0	82.1	88.0	120.5	155	249.5	405.1	280.7	432.9	479.8	616.2

VACUUM (in. Hg) – RED FIGURES
GAUGE PRESSURE (psig) – BOLD FIGURES

Figure 2–1. Pressure temperature chart.
(Courtesy Cengage Learning.)

Figure 2–2. Gauge with pressure temperature feature.

> **NOTE:** We have provided you with these methods of determining proper low- and high-side pressures only as general guidelines to establish normal operating conditions. Many manufacturers offer very specific and detailed procedures for determining proper operating pressures.

Refrigerant safety

In most areas, refrigerant safety is no different from what you are already aware of and certainly already practicing. For example, you need personal protective equipment such as safety glasses (goggles), safety shoes, and, when required, a back support, when working with refrigerants.

Safety items are issued to you, like most military and government employees, and you are responsible for them. In some cases, certain work areas have special equipment located in the individual mechanical rooms that meet the special safety requirements of that mechanical room. Both the EPA and the Air Force expect you to use proper safety equipment and to follow proper safety procedures.

> **NOTE:** Be aware that you can be prosecuted for not following established safety regulations.

The following are 14 of the general safety guidelines for the A/C and refrigeration career field. *You must adhere to these guidelines no matter the type refrigerant you are working with.*

1. Never apply an open flame or live steam to a refrigerant cylinder or vessel.
2. Do not cut, solder, or weld any refrigerant line or system when there is refrigerant in the unit.
3. Do not use oxygen or air to pressurize or purge a refrigeration system.
4. Always be sure you well ventilate the area before starting to work on the system. Most refrigerants are heavier than air and may replace the oxygen, resulting in the service technician losing consciousness.
5. When using nitrogen, always use a regulator and relief valves, and *never exceed system design pressures.*
6. Do not try to repair or adjust pressure safety devices that are factory set and certified.
7. Always follow safety directives when working with chemicals or special equipment.

8. Before operating a compressor, be sure you have adjusted *all valves—especially the discharge service valve*—to the proper position. If left closed, the compressor could blow up or damage the compressor valves, rods, or pistons.
9. Good work habits are the key to safe work.
10. Avoid spilling liquid refrigerant onto the skin; the low-pressure refrigerants are deceptive.
11. Never siphon refrigerant by mouth. As stated before, low-pressure refrigerants are not as violent as the high-pressure refrigerants. Because of this, they are deceptive.
12. Refrigerants are very heavy and the cylinders can be difficult to move. Use the proper equipment, such as a hand truck, when moving the cylinders that weigh over 35 pounds.
13. When working with refrigerant cylinders and recovery equipment, make sure that you have secured the equipment so that it will not roll away, tip over, or fall. You could release refrigerant to the atmosphere and worse yet, the equipment could fall on or roll over you.
14. Lastly, remember all the safety lectures that you have attended and the articles that you have read and follow them.

In addition to these general guidelines, you must also be aware of two other important safety subjects:

- American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) safety classifications.
- Solvent and chemical safety.

We generally consider refrigerants safe to work around, but there are safety rules that we must follow. All refrigerants are heavier than air. If we use them in large quantities and in a closed space, such as a mechanical room, oxygen can be forced out of the room or above your head, and asphyxia can/or will follow. Because of this, you must always ventilate an area suspected to be full of refrigerant before entering it. Breathing or inhaling refrigerant vapors or mist in high concentrations can cause all kinds of problems, such as heart irregularities, unconsciousness, and even death.

NOTE: Always remember that *refrigerant vapor is much heavier than air.*

Technician Reference: For further information on refrigerant standards and safety, refer to ASHRAE Standard 15 and ASHRAE Standard 34.

Solvent and chemical safety

Never trust your memory about what special precautions are required when you are working with any refrigerant, solvent, or chemical. Instead, *always review the material safety data sheets (MSDS) supplied by the manufacturers.* When you are handling liquid refrigerant, do not forget to protect yourself by wearing the proper protective clothing and gloves.

Refrigerant cylinders

By now, you know that there are numerous different types of refrigerants used in A/C and refrigeration systems. Each of these different types of refrigerants requires its own cylinder. We'll cover three important areas concerning refrigerant cylinders:

- Cylinder color codes.
- Cylinder types.
- Handling refrigerant cylinders.

Cylinder color codes

All cylinders used for the storage or transportation of refrigerants are coded according to a universal coloring system. This color-coding permits easy identification of the refrigerant in the cylinder. Colors for different refrigerants can appear very similar so read the label of each cylinder to ensure you grab the correct type of refrigerant. For example, in the table below R–11 and R–404A are both labeled orange. The following table lists color-coding for some of the more common refrigerants. If you need more information about each type of refrigerant, call or visit the manufacturer's website.

Refrigerant Number and Cylinder Color Code	
R–11	Orange
R–12	White
R–22	Light Green
R–113	Dark Purple
R–114	Dark Blue
R-123	Light Blue-gray
R–134a	Light Blue
R-404A	Orange
R-410A	Rose
R–500	Yellow
R-502	Light Purple
R–503	Blue-green
R–717	Silver

Technician's Note: Most refrigerants have color names that most people aren't familiar with. For example, R–502 is light purple which can also be called lavender. Some people may not know the difference between "normal" purple and lavender so be sure you check the cylinder to verify the refrigerant you are using. Another example is R–402B which is light brown but goes by the color *sand.*

Cylinder types

Refrigerant cylinders are made of steel or aluminum and are regulated by the Department of Transportation (DOT). DOT mandates that cylinders containing corrosive refrigerants be inspected and recertified every 5 years while cylinders with non-corrosive refrigerants are inspected and certified every 10 years.

There are three types of refrigerant cylinders:

- Storage.
- Recovery.
- Disposable (throwaway).

Storage cylinders

The least expensive way to buy refrigerants is in 100-pound and 150-pound storage cylinders. Storage cylinders are large and are fitted with a valve and usually a protective cap. The cylinders are located at the shop or supply housing.

You must *never use these cylinders to recover or recycle refrigerants*; instead, they are to be used for shipping and storage of new or virgin refrigerants.

Recovery cylinder

Service technicians use refillable service cylinders, which are the only cylinders they use for recovery, recycling, reclaiming, and shipping of used refrigerants.

You can refill recovery cylinders from a storage cylinder located in the shop or from most refrigeration supply houses. These cylinders are fitted with service valves and used to charge either liquid or vapor into a system.

Suppliers must color-code recovery or recycle cylinders as specified by the EPA. This specification requires yellow tops and gray bodies. Suppliers are also required to hydrostatically test and certify as safe with a date stamp every 5 years if the cylinder is pressurized above 300 psig and every 10 years if pressurized under 300 psig. When refilling a refillable cylinder, *never fill the cylinder beyond its recommended capacity*. This limitation exists because cylinder pressure may rise in heated areas and could cause an explosion or could cause the safety plug to release the charge.

When transferring refrigerant to a pressurized refillable cylinder, there are devices that stop the filling process automatically. If one of these devices is not available, then you must use a scale and control the weight manually.

Never under any circumstance use heat, such as an open flame or live steam, *to speed up the transfer process* of refrigerant from one vessel to another. Doing so could cause an explosion and serious injury to people.

Disposable (throwaway) cylinders

Disposable cylinders are in wide use because of their convenience. Many of the most popular refrigerants are available in these cylinders. They generally come in 1- to 50-pound sizes. Some cylinders will only contain ounces of refrigerant. Disposable cylinders are *only used to charge a system* with either liquid or vapor.

It is against the law to reuse these cylinders for any other purpose than to supply new or virgin refrigerant. Never use them for recovery, recycling, storage, or for conversion to other uses such as air tanks.

Once the refrigerant has been used or extracted, the cylinder must be disposed of by rendering it useless. To do this, reduce the cylinder pressure to 0 psi; break off the valve stem, drill holes into the cylinder, or cut the cylinder in half.

Handling refrigerant cylinders

Because damage to refrigerant cylinders or their valves can create dangerous conditions, you must always handle refrigerant cylinders with care. Be especially careful to protect the valve assemblies from damage. The following are 11 safety rules to keep in mind when you are working with refrigerant cylinders.

1. Make sure the cylinders are rust free.
2. Never mix refrigerants. Use the color-coded cylinder prescribed for the refrigerant.
3. Never place an electric resistance heater in direct contact with any refrigerant container.
4. Avoid heating a cylinder above 125 °F to prevent dangerous pressure buildup.
5. Never drop, hammer, or otherwise abuse refrigerant containers.
6. Never overcharge a refrigerant container. The weight of the refrigerant used should *never exceed the weight marked on the container*.
7. Always replace the cylinder valve cap and hood cap when a cylinder is not in use or is empty.
8. Store refrigerant containers where they are out of direct sunlight and separated according to the type of gas they hold.
9. Fusible plugs on cylinders larger than 4.5 inches in diameter and 12 inches in length protect the cylinders in case of overheating.
10. Secure cylinders not mounted in a stand in an upright position with a chain or band so they will not tip over. Fasten the chain or band securely to a wall or column.

11. Be sure that hoses and tubes used to transfer refrigerants are free from moisture and contaminants. Use refrigerant-charged hoses where possible.

808. Purpose and requirements for refrigerant oils

Refrigeration and A/C systems have numerous moving parts that can create friction, which can be destructive to the metal surfaces. In addition, this friction can result in an increase in the temperature of the moving parts involved. Because proper lubrication will reduce the possible damage caused by friction, it is an important part of any system.

As we stated earlier, the refrigerant oil mixes with the refrigerant and circulates through the system along with the refrigerant flow. Because oil is mixed with the refrigerant, it must have certain properties. For example, it must be harmless to the refrigerants and equipment. It must also be able to withstand low and extreme temperatures. This comes from the fact that the oil is cooled to low temperatures at the metering device and raised to high temperatures at the compressor.

In this lesson, we will cover seven important subject areas that deal with refrigerant oils:

- Purpose.
- Properties.
- Oil types and applications.
- Standards for handling refrigerant oils.
- Lubrication methods.
- Maintaining proper oil level.
- Oil servicing.

Purpose of oils

Earlier we stated that A/C and refrigeration systems have moving parts that can create friction and heat. As you would expect, lubricating oils will prevent this friction and heat and thus minimize wear. Refrigeration grade oils also have special characteristics that enable them to work efficiently under various load and temperature conditions.

The compressor or unit manufacturer usually establishes specifications and oil type based on extensive laboratory and performance tests. Oil refiners then meet or exceed the manufacturer’s specifications. Then they supply their oil in clean, dry, clearly identified and sealed container.

As a journeyman, you must do two things when choosing refrigeration oil:

- Select only oil types recommended by the unit or compressor manufacturer.
- Order only the quantity of oil necessary for current needs. This will prevent leftover oil from becoming contaminated by air and moisture.

Oil properties

Oil used in a refrigeration system must have several favorable properties if it is going to work efficiently in the system with the refrigerant. In your position, you do not get to select these refrigerant oil properties during their production. However, a better understanding of the oils makes you a smarter and more thorough technician. The following table lists and explains the properties you need to know.

Oil Properties	
Property	**Explanation**
Low wax content	Separation of wax from the refrigerant oil mixture may plug refrigerant control orifices. This occurs when low temperatures exist.

Oil Properties	
Property	**Explanation**
Good thermal stability	The refrigerant oil should not form hard carbon deposits at hot spots in the high heat areas such as compressor (valves).
Good chemical stability	There should be little or no chemical reaction with the refrigerant or materials found in the system.
Low pour point	The refrigerant oil must have the ability to remain in a fluid state at the lowest temperature in the system.
Low viscosity	The refrigerant oil must have the ability to maintain good oiling properties at high temperatures and good fluidity at low temperatures; that is, it must provide a good lubricating film at all times.
High flash point	Lubricants come into contact with high temperature components such as compressor windings. This characteristic requires the oil to have a high flash point so it will not ignite.

Oil types and applications

Two groups of oils used in A/C and refrigeration systems are mineral oils and synthetic oils. We'll take a look at each type in the following paragraphs.

Mineral oils

Refrigeration appliances that use CFC and HCFC refrigerants are lubricated using mineral oils. Most new azeotropic mixtures and HFC refrigerants use polyol ester lubricants.

Synthetic oils

The two synthetic oils used with refrigerants are polyol ester (POE) and alkylbenzene (AB). There are many different reasons to use these oils. One is the newer refrigerants used in our systems. Some of the new oils work well with the older refrigerants; however, some will not. Because of this, it is always a good idea to get the technical data for a new product you are about to use. In the table below we will look at the specifics of these synthetic oils you may encounter on the job: POE (ester-based), AB-based, and polyalkylene glycol (PAG).

Synthetic Oils	
Type	**Description**
POE	Most refrigeration applications that use R–134a, R–407C and R–410a use ester-type oils.
AB-based	Common refrigerants that use AB-based oils are HCFCs R–22 and R–123.
PAG	These are used in automobiles. The only reason they are mentioned here is so you are aware they exist. Make sure that you don't accidentally order some.

Standards for handling refrigerant oils

The handling of refrigerant oils is an EPA concern. For this reason, you must handle refrigerant oils according to EPA standards. In the past, refrigeration and A/C mechanics would simply dump oil down a convenient drain or in a field somewhere. Today these practices are strictly forbidden. As you would expect, there are procedures in place governing the proper handling and disposal of oil. Learn and follow these procedures.

Methods of lubrication

Some larger hermetic compressors use an oil pump that is not visible from the outside. Because of this, you should familiarize yourself with the different manufacturers' lubrication methods.

Essentially there are two basic methods used to lubricate the moving parts in compressors: splash and pressure lubrication.

Compressor Lubrication Methods	
Type	**Description**
Splash	In the splash system, the crankcase is filled with the correct oil up to the bottom of the main bearings or to the middle of the crankshaft main bearings. At each crankshaft revolution, the crank throw, or the eccentric, dips into the oil and splashes it around the inside of the compressor. Oil is thrown onto cylinder walls and piston pin bushings and into small openings where it can drain into the main bearings. Some compressor connecting rods have little scoops or dips attached to the lower ends. This scoops up small amounts of oil and slings it around to other parts. To make sure that the compressor is properly lubricated, the rotation of the compressor is critical. This is an excellent system for small compressors; however, clearances between the moving parts must be less than in pressure systems. Noisy bearings occur more often at small clearances than in the pressure system, because there is no oil under pressure to cushion the bearing surface.
Pressure lubrication	The force-feed, or pressure system, uses a small oil pump to force oil to the main bearings, lower connecting rod bearings, and piston pins. The crankshaft and connecting rod must have oil passages drilled in them. With the pump method, the compressor runs more quietly even though it has greater bearing clearances. The oil pump is usually mounted on one end of the crankshaft. The oil pump delivers oil, under pressure, to all bearing surfaces.

Proper oil level

Most compressors are factory shipped with a normal charge of the correct-type refrigeration grade oil in them. Because of this, they rarely require additional oil; however, you must be certain the proper oil level is maintained in the compressor when it is installed and running. There are two ways to check for proper oil level:

- Oil sight glass.
- Oil level plug.

Oil sight glass

Most open semi-hermetic and large full-hermetic compressors have an oil sight glass located in their crankcase or shell. This enables you to see the oil level.

> **NOTE:** When two compressors are connected in parallel, the oil sight glass is usually located in the oil equalizer line.

Normally the compressor oil level is one-half way up the sight glass. However it may vary slightly. When the compressor is running, the oil level may surge up and down due to the sloshing of the oil caused by moving parts. When the compressor is idle, the oil level may be higher due to the absorption of refrigerant by the oil; a crankcase heater helps to prevent this condition and should always be used when available.

When you restart an idle compressor, the oil level may initially fall below normal in the sight glass; however, it should return to near normal in less than 1 minute.

Excessive foaming or a cloudy appearance may indicate a flood back condition, which could be harmful to the compressor and result in overloading the compressor motor. You should always observe the level of oil in the sight glass, whether the compressor is running or idle.

To determine the proper oil level, follow these instructions.

Determining Proper Oil Level via Oil Sight Glass	
Step	**Action**
1	Check to see that an oil level exists.
2	Start the system and fully load to ensure against the possibility of oil being trapped in the system. Allow the system to run fully loaded about 20 minutes.
3	Stop the compressor and allow it to set idle about 5 minutes.
4	Observe the level in the oil sight glass: • If the level is low, either a permanent trap or leak exists. Determine which is correct, and add oil to the compressor. • Too high a level may cause high power consumption and/or possible compressor damage. Remove oil to obtain a one-half sight glass level; however, be sure the extra oil is not absorbed in the refrigerant.

NOTE: Beware of false oil levels caused by the capillary attraction of oil to glass.

Oil level plug

Some compressors contain an oil level plug or valve that will help you determine the compressor oil level. The plug consists of a small hole at the exact normal oil level. A small threaded plug or valve seals the drilled hole.

To determine oil level with an oil level plug, follow these instructions.

Determining Oil Level with an Oil Level Plug	
Step	**Action**
1	Run the compressor fully loaded about 20 minutes.
2	Pump down the system and allow it to set idle about 5 minutes.
3	Disconnect all electrical power and isolate the compressor from the system by closing the discharge shut-off valve.
4	Slowly remove the oil level plug (if a valve is used, open the valve).
5	Check the oil level by observation and/or a probe wire. The correct level should be at opening level.

Oil servicing

Some small full-hermetic compressors have no method of determining oil level. Since these compressors are always installed in factory-designed, assembled, and piped systems, there is rarely any problem with the oil level, except in the case of a leak. If you can reasonably calculate the amount of oil lost, you should add this amount to the compressor. If you cannot calculate the amount of oil lost, you must remove the compressor and drain all remaining oil from the suction line stub. Add a measured normal oil charge by the suction stub or by cutting the oil process tube and resealing.

Excessive and/or too little oil

Having the correct amount of oil in a system is very important. A lack of oil shortens the life of the compressor. It increases friction and heat and causes noise in the compressor. An overcharge causes the compressor to pump excessive amounts of oil, reduce its refrigerant pumping capacity, and subjects the compressor valves to severe strain. Some systems have controls that will stop the unit if the oil pressure drops too low.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

807. Type of refrigerants

1. What two things will the data plate tell you about the refrigerant in the system?

2. Why are we not worried about HFCs and ozone depletion?

3. What is temperature glide?

4. Why is oil always circulating with refrigerant?

5. What is the relationship between refrigerant gas velocities and oil circulation in the system?

6. Why does oil lying on the bottom of tubing become more critical as evaporator temperatures lower?

7. When are refrigerant oils considered contaminated?

808. Purpose and requirements for refrigerant oils

1. What effect does friction have on metal surfaces?

2. What effect does friction have on the temperature of the moving parts involved?

3. What effect does lubricating oil have on friction and equipment wear?

4. Why should you only order the quantity of oil necessary for your current needs?

5. What are two lubrication methods used in compressors?

6. Where is the oil sight glass placed when *two compressors are connected in parallel*?

7. Why might the oil level be higher when the compressor is idle?

8. What may happen to the oil in the sight glass after you restart an idle compressor?

9. What does excessive foaming of the oil indicate?

10. When would a small hermetic compressor have a problem with the oil level?

11. What effect does lack of oil have on compressor life?

12. What effect does an overcharge of refrigerant have on the compressor?

2–2. Basic Controls and Accessories

In our first section, we explored the many processes taking place in the mechanical refrigeration cycle. In the previous lessons, you learned about the refrigerants and oils used in A/C and refrigeration systems. In this section, you will see how A/C and refrigeration systems are automatically controlled. We will discuss the types, classification, and modes of HVAC/R control systems. It is important that you study this material carefully. After all, a big part of your job is calibrating these systems.

Equally important is your ability to understand, service, and maintain the various installed accessories on A/C systems. Although these accessories are durable and dependable components, there are times when they present problems. That is when the material we present will pay you dividends.

809. Types of refrigeration and air-conditioning controls

How does the refrigeration unit actually know when to cycle on and cycle off? The answer is some type of control circuit. A control circuit can be simple and use only one thermostat. In other cases, the circuit may be complex. If this is so, there may be several types of controls in the circuit. The amount and type will vary, depending on the system. Some controls are for system operation, others are for safety, and some are for efficiency.

Terms associated with controls

There are many terms associated with controls. The most important—cut-in, cutout, and temperature difference (TD) or differential—are defined in the following table.

Control Terms	
Term	**Definition**
Cut-in	Cut-in refers to the temperature or pressure that a control will allow a system to operate or cycle on.
Cutout	Cutout refers to the temperature or pressure that a control will allow a system to stop or cycle off.
TD or differential	The temperature difference, or differential, is the difference between cut-in and cutout.

Temperature devices

As the name implies, these types of controls react by sensing temperature. In the following paragraphs we discuss the sensing bulb, bimetal, and thermistor devices.

Sensing bulb

With some types of controls, there is a sensing bulb. This sensing bulb has a charge inside that expands when heated and contracts when cooled. When there is a temperature increase, expansion takes place. When there is a temperature decrease, contraction takes place. The expansion and contraction operate a device that will open or close a set of contacts. The unit cycles on when the contacts close and the unit cycles off when the contacts open.

> **NOTE:** To prevent short cycling, these controls contain a built-in differential. Some are preset from the factory while others are adjustable.

Bimetal

Other controls use a bimetal strip or coil. Bimetal means that two different metals are bonded together. Different metals have different expansion rates. When bonded together, they will bend as they react to temperature. Because of this bending action, a bimetal device becomes a good device to open or close contacts as it blends while responding to temperature.

Some thermostats have a mercury bulb mounted on a bimetal coil with two wires inside. As the temperature increases or decreases, the bimetal coil responds causing the mercury inside to complete the connection or break the connection, depending on which way the bimetal coil bends.

Thermistor

A thermistor is a solid-state (semiconductor) device that varies its resistance as temperature changes. In short, a *thermistor controls voltage according to temperature*. At certain temperatures, voltage flows. At other temperatures, voltage cannot flow because the resistance is too high. This happens because of the nature of a semiconductor; that is, temperature affects resistance, which varies the voltage, which controls current. The result is whether-or-not a device works.

Thermistors work on either the positive temperature coefficient or negative temperature coefficient concept. Positive temperature coefficient thermistors, or PTCs, are thermistors that have a direct relationship between resistance and temperature. This means as temperature goes up, resistance goes up and as temperature goes down, resistance goes down. Negative temperature coefficient (NTC) thermistors are opposite, temperature and resistance are inversely related: as temperature goes up, resistance goes down and as temperature goes down, resistance goes up.

NTC Thermistor	
Temperature goes up ↑	Temperature goes down ↓
Resistance goes down ↓	Resistance goes up ↑

PTC Thermistor	
Temperature goes up ↑	Temperature goes down ↓
Resistance goes up ↑	Resistance goes down ↓

Pressure controls

These control types use system pressure. The pressure inside the system operates a motivating device that is also inside the control. The pressure-activated action of the switch will cycle a system either on or off. Of course, there has to be some method for connecting the control to the refrigeration system. Usually this is accomplished by tubing with a flare or soldered connection. Whether or not the system operates depends on the type of installed control and its settings. To give you an idea of how pressure controls work, we will look at five examples:

- Low-pressure control.
- Low-side pressure limiter.
- High-pressure control.
- Oil-pressure safety control.
- Pressure transducer.
- Air pressure control.

Low-pressure motor control or low-pressure safety switch

This control is a low-pressure motor control (LPMC) or low-pressure safety switch (LPSS) because it is installed on the low side of the system and measures compressor suction pressure and controls the compressor’s operation. Recall that the low side of the system is from the outlet of the expansion valve, through the evaporator, suction line, any accessories, to the inlet of the compressor. The LPMC usually connects either to the suction line or at the low-pressure side of the compressor. If connected at the compressor, it may be at the compressor body or the suction service valve.

The name of this device describes its operation. It is a *control* that monitors *low pressure* to operate a *motor*, therefore it is a *low pressure motor control*. In this case, the *motor* is the compressor motor.

This control will cut-in on a rise in pressure and cut-out on a drop in pressure. This control can be set up many different ways. For now, the important thing to realize is that this control is installed in the low side in a system. When the cut-in pressure is reached (and the rest of the circuit is okay), the switch closes, the circuit is completed, and the refrigeration unit will operate. When it reaches cutout pressure, the switch opens, the circuit is broken, and the refrigeration unit will stop. The unit will not come back on until the pressure rises to the cut-in pressure.

The way to set this control varies depending on the brand. The best advice is always to follow the instructions that come with the control. The top view in figure 2–3 illustrates an actual cut-in and cutout pressure example. The bottom view illustrates an example with a cut-in with a differential.

In addition to controlling temperature, you can use the LPMC to prevent operation at too low a pressure. The hermetic compressor relies on the suction pressure and temperature to keep it cool. If the pressure of the vapor becomes too low the compressor could overheat and eventually burnout. If a low-pressure condition exists, the LPMC shuts the motor off before any damage occurs.

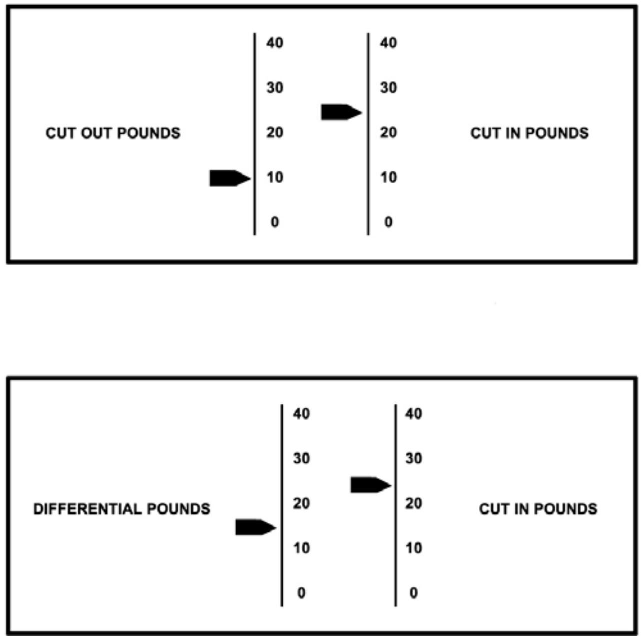


Figure 2–3. Example of pressure control settings.

The LPMC is also used for pump-down. Pump-down allows a unit to pull the refrigerant out of the evaporator and put it into a receiver. This happens because a thermostat controls a solenoid valve installed in the liquid line. When the space temperature is satisfied, the contacts in the thermostat open allowing the solenoid valve to close. This prevents refrigerant from reaching the evaporator. As it pulls the refrigerant out of the evaporator, the pressure drops to the cutout of the LPMC and the compressor stops. This is how the compressor is able to pump the system down.

Low-side pressure limiter

This control prevents the low side pressure from rising to high. When high pressures exceed the setting of the pressure limiter the control opens the electrical circuit to the compressor.

High-pressure motor control or high-pressure safety switch

High head pressure is a harmful condition that can exist in our systems. It could cause oil and refrigerant breakdown. The high-pressure motor control (HPMC), or high-pressure safety switch (HPSS), shuts down the system before this high pressure condition is reached. Much like the LPMC, the name of this device describes its function. It is a control that monitors *high pressure* to *control* the compressor *motor, high pressure motor control.*

You mount the HPMC or HPSS on the high side of the compressor, *before the condenser*. As the name implies, the high-pressure motor control is a safety control that is set to open its contacts when the pressure on the high side increases to the point that damage could result if you allow the system to continue to operate. The compressor stops when the pressure on the high side reaches the cutout.

The HPMC does not allow the unit to come on until the pressure drops to the cut-in pressure. Some high-pressure motor controls automatically reset and the compressor operates when it reaches the cut-in pressure. Others have a manual reset and the reset button has to be pushed to reset the control. This usually will not work if the pressure is too high. It is also good to physically go out to reset the control. In this way, you can monitor the system to find out what caused the control to activate. Now you can fix the system. When setting these controls, be very careful and follow the manufacturer’s directions.

The following table lists some potential conditions the HPMC (HPSS) would trip. The sub-bullets give a few examples of what causes these conditions.

Potential Conditions Causing HPMC (HPSS) To Trip	
Condition	**Cause**
Low air flow across air-cooled condenser	• Dirty condenser coil. • Bad fan motor. • Fan relay not closing preventing fan from running.
Low water flow through a water cooled condenser.	• Dirty/scaled tubes. • Restriction of water.
Increased refrigeration load.	• Excessive load in the space. • Ambient air temperatures exceed design temperatures.

Oil-pressure motor control or oil-pressure safety switch

As the name indicates, the oil-pressure motor control (OPMC) or oil-pressure safety switch (OPSS) is a safety control that protects the system when oil pressure falls too low. It operates on either a differential pressure or an oil level. You connect it to the suction side of the compressor and to the oil pump. This sets up a pressure differential. As long as the pressures are okay, the system will operate. Oil pressure must be higher than suction pressure to ensure oil gets back to the compressor. If the oil pressure falls, the suction pressure will overcome the oil pressure. The difference between the oil pump pressure and the low-side pressure is called the *net oil pressure:*

Oil pump pressure – Low-Side Pressure = Net Oil Pressure

When the control reaches the predetermined net oil pressure for a certain amount of time, a set of contacts opens. These contacts are in the control circuit. The refrigeration unit cycles off when the contacts open.

The oil-pressure safety control has a built-in time delay for system startup. This time delay allows both the suction pressure and the oil pressure to stabilize. In addition to a time delay, this control has a manual reset. When an oil-pressure safety switch operates, you need to check out the system thoroughly to find the cause. In this way, you can repair the system before there is damage to the compressor.

Another type of OPMC is electronic. The electronic control shuts the system down when a low oil pressure exists and some have the ability to light an LED that indicates an Alarm condition.

Common causes of oil-pressure controls tripping are:

- Incorrect oil level.
- Wrong size tubing.
- Low refrigerant charge.
- Refrigerant migrating and causing oil to collect away from compressor.
- Oil-pressure control is set too low.
- Unbalanced system.
- Electrical problems such as a faulty OPMC.

You are more likely to see OPMCs on larger compressors with sizes of about 5 horsepower (hp) and up.

Pressure transducers

These devices measure pressure and convert that measurement into an electronic signal. This signal is then analyzed by a circuit board that creates an output based on input. This device usually consists of three wires: two for voltage input and one for voltage output (usually DC).

Air pressure controls

These controls use large diaphragm to sense low pressures. A switch, called a micro switch, stops and starts a control circuit based off of the air pressure sensed. These controls can be used on heat pumps to sense pressure drops across the outdoor coil. An excessive pressure could result from excess ice buildup. They are also used to prove airflow by blower before electric heat or the main gas valve is energized.

810. Thermostats

Thermostats are a common type of HVAC/R control. They can be found in homes, offices, fridges, freezers, and so forth. Since they are used with so many different systems there are many different types of thermostats. While we can't cover every thermostat, we can sure give you a strong knowledge base to work with!

In this lesson, line and low-voltage thermostats are covered first. Next, thermostat locations and some thermostat parts are discussed. The lesson concludes with a discussion about thermostats' operation and capabilities. You will learn that electronic thermostat have many capabilities.

Line-voltage thermostats

This type of thermostat uses 120 VAC or 240 VAC and can control currents as high as 22 amps. Since line voltage is used, a line voltage thermostat does *not* require a transformer to step-down voltage to control voltage. Many line voltage thermostats are used to control electric resistance heaters.

It is important that you are aware of the type of thermostat you are working on. It would not be good for your troubleshooting if you are expecting 24 VAC on a line voltage thermostat that has 120 VAC.

Low-voltage thermostats

Low-voltage thermostats are very common. They thermostats are typically 24 VAC. This thermostat requires a transformer to step-down the line voltage to low voltage. Low-voltage thermostats use their voltage to operate solenoids, relays, and contactors. The relays and contactors receive low voltage from the thermostat and become energized to control line voltages that travel to loads such as fans and compressors.

Low-voltage thermostats usually use 18 American Wire Gauge (AWG) for lengths up to 50 feet. It is critical that the proper wire is used for thermostats. Ensure you don't just install any available wiring that you have. Ensure you take the time and find 18 AWG. Figure 2–4 is an example of thermostat wire.

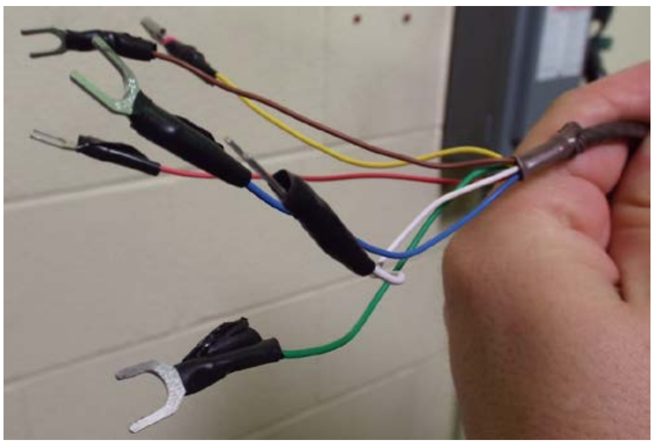


Figure 2–4. Thermostat wire.

Technician's Note: After a 50 foot run of thermostat wire, the wire size needs to change. Usually it requires 16 AWG, but check with the manufacturer to be sure.

Check thermostat voltage ratings if you are having trouble with a thermostat or if you are installing one. If you connect 120 VAC or 240 VAC to a low-voltage thermostat you will damage it.

Location and parts

Location is extremely important for the proper operation of thermostats. If the thermostat is located in the wrong location it will not sense the proper temperatures. In addition to location there are two important parts of the thermostat that are important: the subbase and wall plate.

<table>
<tr><th colspan="2">Thermostat Location and Parts</th></tr>
<tr><th>Topic</th><th>Description</th></tr>
<tr><td>Location</td><td>The thermostat should be placed in an average temperature location. Usually this location is an inner wall and about 5 feet off the ground.
Ensure the thermostat is not susceptible to drafts or hot and cold air directly from the duct.
Also, the thermostat should not be placed behind a door or in a corner. These are called dead spots.
Finally, make sure the thermostat is not located on an outside wall.
Thermostats must be mounted to a firm surface and not be subject to vibration. Using the subbase and wall plate allow for this type of installation.
You may run into situations where a building occupant places a coffee pot, fridge, or other heat source near the thermostat. This gives the thermostat a false heat reading. The facility manager needs to have the heat loads moved away from the thermostat.</td></tr>
<tr><td>Subbase</td><td>Consist of wiring terminals and is the part that the thermostat attaches too.
The subbase can also hold batteries or switches.</td></tr>
<tr><td>Wall plate</td><td>The wall plate attaches to the wall or an electrical outlet box.</td></tr>
</table>

Thermostat operation and capabilities

Thermostats send and receive signals from many components in our refrigeration and A/C systems. They receive control voltage to operate the system safely and efficiently. Here we cover combinations and multistage thermostats.

Combination thermostats

There are various types of thermostats; some are heating-only, while some are cooling-only. Here we focus only on the combination thermostat which incorporates both cooling and heating. These thermostats can help control humidity or notify the user when the filter needs changing. First we will review the terminal designations of common thermostat in the following table. While these designations are not industry standard, they are common.

Common Thermostat Terminal Designations			
Code	**Type**	**Code**	**Type**
R	Power	W2	Heat relay (stage 2)
Y	Compressor	CR	Cooling relay
Y2	Compressor contactor	O/B	Heat pump changeover valve
C	24 V common connection	Aux/E	Auxiliary heat
W	Heat relay (stage 1)	Rc	Cooling power
G	Fan relay	Rh	Heating power

Multistage thermostats

When you think of multiple-stage thermostats you should think of varying capacity. These thermostats can vary heating or cooling capacity of a system. These thermostats are usually low-voltage.

Multistage Thermostats	
Used For	**Description**
Gas furnaces	Multistage thermostats can control modulating gas valves, cycle on and off heating coils, or speed up and slow down indoor blower motors. More precise control of these devices saves energy, extends system life, and maintains average temperatures in the conditioned space.
Cooling	For cooling, the multistage thermostat controls the blower speed and compressor capacity.
Large residential or commercial systems	A multistage thermostat can control contacts for multiple condensing units, furnaces, and blowers.

Electronic

Electronic thermostats use electronics such as transistors, solid-state devices, and microprocessors to control and monitor multiple aspects of a system. The thermostat communicates with various sensors that are throughout the system and determines outputs based on these inputs. Electronic controls greatly increase efficiency and precision control of our HVAC/R systems.

Most electronic thermostats are controlled by either batteries or 24 VAC (batteries are often used as a backup power source). These thermostats provide automatic changeover between heating and cooling (some can be wired for heat-only or cooling-only).

Electronic thermostats offer programming features that allow heating and cooling to be programmed for different times of the day or week. Others use outside temperature to adjust temperatures and operating cycles.

Being able to program thermostats saves energy. Electric companies sometimes charge higher prices for "peak" times or hours during the day when consumption is the highest. In the summer time, a thermostat is programmed to keep a slightly higher temperature during these peak hours. This results in reduced costs during these hours. In the winter time, thermostats are programmed to keep a slightly lower temperature during peak hours. Take note that we are not allowing the conditioned space to get uncomfortably hot or cold, we are simply using less energy. Now imagine the cost savings for an entire Air Force base!

Another programming characteristic is not using unnecessary energy during hours a building is unoccupied. Why does a building need to be 68 °F at night in the summertime when no one is in the building? It doesn't! The temperature can be allowed to reach a higher number such as 74 °F. This temperature is not the standard as required temperatures vary by location and other factors such as humidity.

> **Technician's Note:** Ensure buildings are truly unoccupied if the temperature is allowed to rise or fall to a different temperature. If a few workers stay behind they could be left with unacceptable and uncomfortable working conditions.

Electronic Thermostat Types	
Type	**Description**
Zone	Zone controls allow certain areas to receive cooling and heating at different capacities. Some zone controls operate dampers that allow more, less, or no airflow into the different zones of a building. This prevents 100 percent cooled air constantly being dumped and wasted

Electronic Thermostat Types	
Type	**Description**
	into a room that is always unoccupied. This unoccupied room may only need cooled air at certain points throughout the day to maintain a temperature.
Wireless	Some thermostats are wireless. They can use remote sensors and provide the same programming features of wired thermostats. Also like wired thermostats, wireless thermostats can control heating, cooling, valves, or dampers. Wireless thermostats can connect to smartphones, laptops, personal computers or tablets. This allows the occupant to control the system even when not in the building as long as internect access is available.

811. Types of refrigeration and air-conditioning accessories

Earlier you learned that four major components make up a basic mechanical compression refrigeration system—the compressor, condenser, metering device, and evaporator. In addition to these major components, many systems are also equipped with other components that perform certain specialized functions. We group these components under the heading of accessories. In this lesson, we will discuss these nine accessories:

- Receivers.
- Mufflers.
- Oil separators.
- Accumulators.
- Sight glasses.
- Moisture indicators.
- Filter driers.
- Heat exchangers.
- Crankcase heater.

Receivers

A receiver (fig. 2–5) is a storage tank whose purpose is to hold the refrigerant in the system. It is located between the outlet of the condenser and the liquid line and has fine copper mesh in the outlet to prevent debris from entering the liquid line.

Figure 2–5. Receiver.

Most are equipped with service valves. These service valves are sometimes made similar to the suction and discharge service valves. These valves allow liquid refrigerant to be charged to the system. The *outlet service valve* is often referred to as the King valve. If you front seat the King valve, refrigerant cannot leave the receiver to the liquid line. If the system is running and the King valve is front seated, the system pumps down into the receiver. Normal operation requires the King valve to be in the backseated position; this allows refrigerant to travel out of the receiver to the liquid line. In the backseated position, the service port is closed off from the system.

A receiver is large enough to hold the complete refrigerant charge. This allows you to pump the system down and work on the low side without removing the refrigerant charge from the system. It also allows the system to hold liquid refrigerant during defrost or when some evaporators are not being used.

Receivers are sized 15 percent larger than the system's total liquid volume. Liquid receiver capacities vary according to the type of refrigerants. Liquid receiver sizes are measured by diameter, length, and inlet and outlet size.

The receiver uses manual or automatic control devices to feed the evaporator at approximately the same rate at which it receives the liquid from the condenser, thus maintaining a required temperature.

The receiver is usually cylindrical in shape and is one of two types—vertical or horizontal. The inlet to these receivers is normally at the top and the outlet is on the bottom. If the outlet is at the top, a dip tube (fig. 2–6) extends to the bottom of the receiver to maintain a liquid seal at the outlet. This keeps vapor from entering the liquid line.

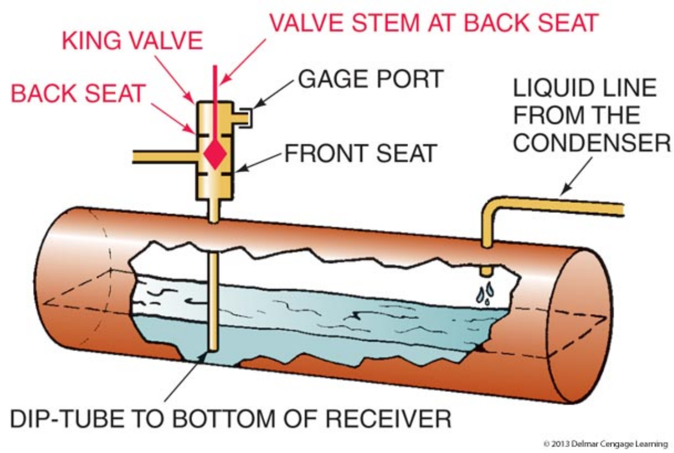


Figure 2–6. Dip tube for receiver.
(Courtesy Cengage Learning.)

Capillary systems do *not* have receivers and store the refrigerant in the evaporator during the OFF cycle.

A large system that uses a shell-and-tube water-cooled condenser does not need a separate receiver; instead, it uses the bottom one-third of the condenser as a receiver. We refer to this application as a "*condenser-receiver*." You must take care to prevent overcharging the shell-and-tube water-cooled condenser system. If liquid refrigerant covers any of the water coils, the head pressure increases, thus reducing the compressor efficiency.

Mufflers

We incorporate mufflers in A/C and refrigeration systems to prevent excessive noise. On domestic refrigerating systems, we build them into the refrigerant circuits to "break up" the pressure pulses, which cause noise. Mufflers can be located in the suction and discharge lines of systems equipped with hermetic compressors. On commercial-type systems, especially air-conditioning, these mufflers are installed near the condensing unit. To ensure efficient oil movement, mufflers are usually installed in a vertical position; however, some manufacturers have some designed for horizontal installation. The muffler is also installed vertically to trap any refrigerant during OFF cycles.

Mufflers are equipped with a dip tube that uses the velocity of the vapor from the suction line to create a lower pressure in the dip tube. The dip tube reaches the bottom of the muffler, and the lower pressure removes oil from the muffler and puts it in the outlet refrigerant line.

Oil separators

Earlier you learned that refrigeration oils are entrained in the refrigerant and are in flow throughout the system. The compressor is lubricated with oil and a small amount of this oil pumps along with the refrigerant vapor. Because of this operating configuration, there is a chance that too much oil may leave the compressor. If too much oil leaves the compressor it could be damaged. Also, an excess of oil in the other three main components of the refrigeration system decreases their efficiency. To prevent this from happening, an oil separator is installed in the compressor discharge line to return oil back to the compressor crankcase.

Figure 2–7 is a cutaway view of a typical oil separator. As you can see, the separator consists of an enclosed steel cylinder with a float and a needle valve (both, middle bottom) inside. It also has a gas line from the compressor (top middle), a gas line to the condenser (upper right), and an oil return line to the compressor crankcase (upper left).

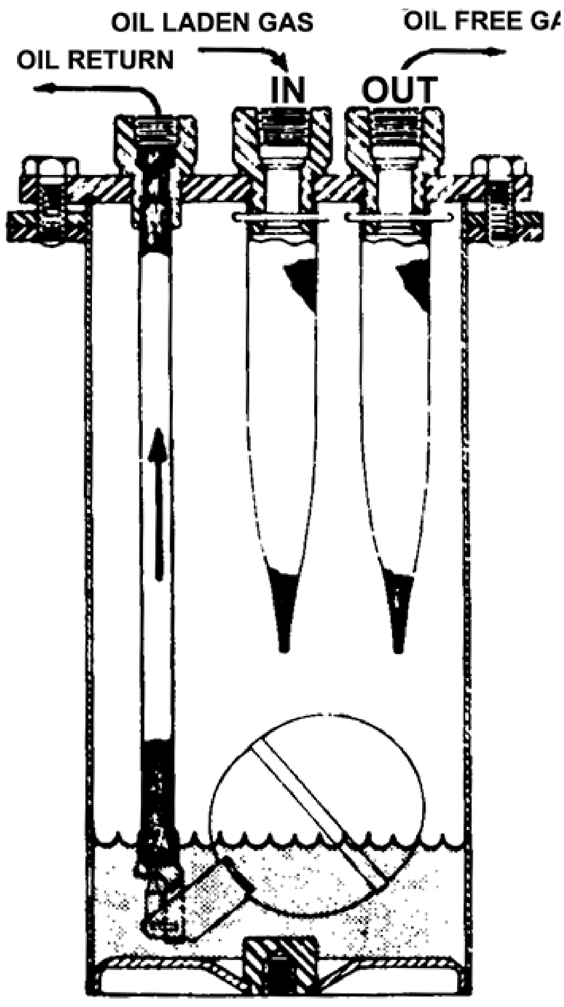


Figure 2–7. Oil separator.

As the hot compressed vapor and oil come from the compressor, they go into the separator (fig. 2–8). As this mixture arrives, the vapor slows down, and the oil falls to the bottom of the separator. The hot vapor is now free of oil deposits and travels to the condenser. As the oil accumulates, its level activates a float assembly which opens the needle valve. The high-side pressure forces the oil to return to the low side of the compressor crankcase. The oil separator is insulated to prevent the refrigerant vapor from condensing in the separator and returning to the compressor as a liquid with the oil.

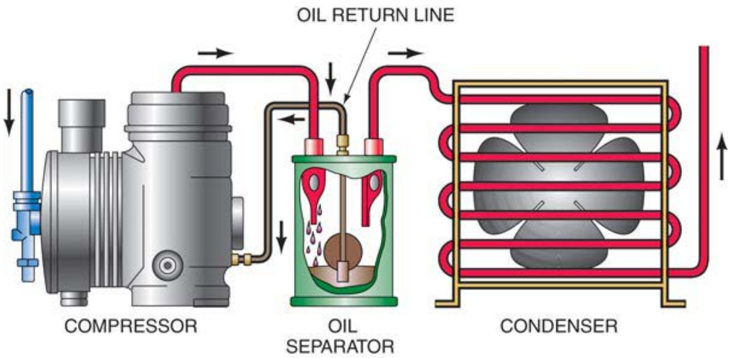


**Figure 2–8. Oil separator after compressor.
(Courtesy Cengage Learning.)**

Most expansion systems operating at temperatures above 0 °F do not need an oil separator, but water coolers, low-temperature systems, and complex multiple installations operate much more efficiently with an oil separator.

Accumulators

The compressor in a mechanical refrigeration system is *not* designed to pump liquids. In fact, if we allowed liquid refrigerant to reach the compressor, it would cause damage due to slugging and diluted oil in the crankcase causes foaming and bearing washout. To protect against this, a suction accumulator is used.

Relationship between accumulator and refrigeration/cooling system

There are many reasons liquid refrigerant could floodback and reach the compressor. The following table shows several of these causes.

Causes for Liquid Refrigerant Floodback Reaching Compressor	
Cause	**Description**
Low load	A lack of heat to absorb from the conditioned space could prevent the refrigerant in the evaporator from boiling. If the refrigerant does *not* boil it remains a liquid. (The end of a cycle could produce low-load conditions.)
Evaporator fan not operating	If the fan is not operating, then not enough heat is being absorbed by the evaporator. This causes the refrigerant to remain a liquid.
Dirty evaporator coil	A dirty coil doesn’t allow enough heat to transfer from the warm conditioned space to the cooler evaporator coil. As a result the refrigerant does not boil and remains a liquid.
Wrong TXV setting	If the TXV is set wrong then it could flood the evaporator with too much refrigerant. There will be too much refrigerant in the evaporator and all of it will *not* vaporize; allowing liquid to remain.
Overcharge	There is too much refrigerant in the evaporator and all of it will not vaporize.
Faulty defrost clock/defrost heater	If the defrost clock or heater does not work then the evaporator remains frozen. This prevents proper heat transfer from the conditioned space air to the refrigerant; as a result all of the refrigerant does not boil and some remains liquid.
Capillary tube overfeeding	This could result from an overcharge condition. Again, too much liquid refrigerant is fed into the evaporator and all of it will not vaporize.

Causes for Liquid Refrigerant Floodback Reaching Compressor	
Cause	**Description**
	This results is liquid being present.
Loose TXV sensing bulb	If the sensing bulb is loose, it could sense higher ambient temperatures than what is in the coil. If this happens, the TXV opens to allow more refrigerant than is really needed. The result, like the previous examples, is that all of the refrigerant does not boil and some liquid remains.
Oversized expansion valve	This condition allows too much refrigerant into the evaporator and the result is the same as the capillary tube overfeeding.
Post hot-gas termination flooding	After hot gas defrost is terminated, the liquid refrigerant in the outdoor (exposed to cold temperatures) coil may not completely vaporize. In this case, liquid refrigerant can remain at the outlet of the evaporator.
Heat pump changeover	As the heat pump changes from heating to cooling it may create a situation where liquid refrigerant enters the compressor.

As you can see, all of the situations above result in liquid still being present at the outlet of the evaporator and suction of the compressor. This is why a suction line accumulator is required; though *sometimes* not on all installations.

Accumulator location and operation

The accumulator is installed in the suction line between the evaporator and the compressor (fig. 2–9). In this location, the accumulator can intercept any liquid refrigerant that may be in the suction line before it can reach the compressor. This is done by having the suction inlet and outlet lines at the top. As refrigerant enters the accumulator, any liquid falls to the bottom of the accumulator. The vapor draws off the top and continues through the suction line to the compressor. The liquid refrigerant collected in the accumulator gradually boils off and rises to the top of the accumulator to reenter the suction line to continue toward the compressor. Heat that is in the refrigerant vapor or an external heat source helps the liquid refrigerant boil off. An oil return is provided so that oil does not trap in the accumulator.

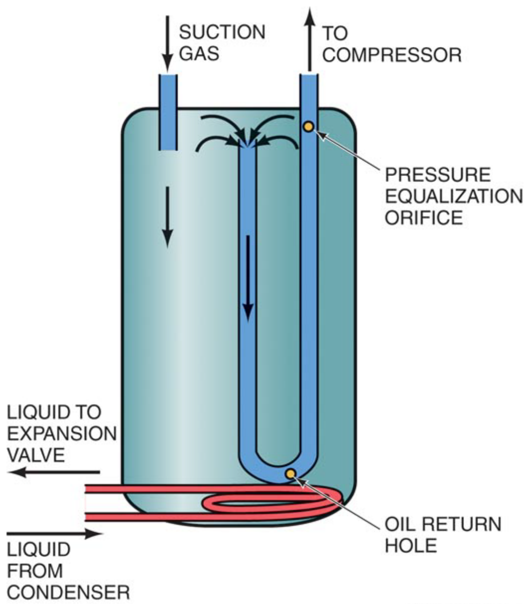


Figure 2–9. Suction line accumulator.
(Courtesy Cengage Learning.)

The compressor may produce higher amps while liquid refrigerant is in the accumulator because the gas it receives is denser.

Severe flooding problems could make the accumulator ineffective; this results in liquid getting back to the compressor and damaging it. The only safe accumulator is the one that can hold 100 percent of the refrigerant charge. Most accumulators are sized at *no less than* 50 percent of the entire system charge.

Refrigerant sight glasses

The sight glass is in the liquid line of a refrigeration system to allow you to visually determine whether the system has enough refrigerant. It is important to use the word *refrigerant* to ensure the person you are talking to doesn't think you are talking about an *oil* sight glass. To work properly, you should install the sight glass as close as possible to the receiver but downstream to avoid any disturbance resulting from valve action. When the system has a low charge, vapor bubbles appear in the sight glass. This tells you that the system may need more refrigerant. It is important to note that bubbles in the sight glass may mean something else is going on in the system besides low charge. It could mean a restricted filter-drier, or the expansion valve may be modulating. Occasionally, when liquid lines are quite long, we install an additional sight glass in the front side of the refrigerant control. This sight glass will show the stream of refrigerant reaching the control. Bubbles at this point indicate the liquid is flashing because of an excessive pressure drop. In this case, you can only eliminate the bubbles by reducing the pressure drop or by further subcooling the liquid refrigerant.

Relationship between refrigerant sight glasses and capillary tubes

Sight glasses are not the best way to determine a system's refrigerant charge. With that being said, sight glasses should not be used *at all* to determine refrigerant charge on a *system with a capillary* because some liquid refrigerant may begin to flash to vapor.

Moisture indicators

In many instances, sight glasses include moisture indicators. Depending on the refrigerant used, the moisture indicator is a particular color. When moisture is present, the indicator changes to a different color. The moisture indicator colors display with one labeled "wet" and the other labeled "dry." As long as you see the dry color in the glass, the system is okay. If you see the wet color in the sight glass, you need to analyze the system to determine the proper corrective action. As a minimum, you should reclaim the refrigerant, change the drier, evacuate the system, and charge the system with new refrigerant.

Some refrigerant sight glass have removable moisture indicators. They should be removed when the refrigerant sight glass is being brazed into the line set so they don't become damaged. If a removable core is not available, you have to be extra careful when brazing so you don't overheat it.

Filter-driers (desiccants)

Manufacturers go to great lengths to eliminate moisture from their equipment during the manufacturing process. There is no doubt that moisture is very harmful to refrigeration systems, and you must guard against it in all fields of operation. Usually moisture in the system causes one or more of these undesirable effects:

- Freezing of the expansion devices.
- Corrosion of metals.
- Chemical damage to the motor insulation.
- Chemical damage to other system components.
- A restricted or plugged filter-drier.

In spite of all efforts, there are times when moisture will enter a system. If moisture does get into a system, you must remove it as soon as possible.

The main sources of moisture are low-side leaks, contaminated oil, contaminated refrigerant, and leakage in a water-cooled condensing unit. At other times, moisture may enter the system when it is open, such as during installation or when you are making repairs. Keep in mind that you must allow only clean and dry refrigerant and oil to circulate in the system.

Debris also causes issues with the system. A filter-drier is used to help catch moisture, dirt, sludge, and debris that may wind up in the system. There are suction line and liquid line filter driers. The name describes exactly what it does, it *filters* and it *dries*—filter-drier.

The filter-drier consists of a brass, copper, or steel cylinder that holds the filters. In addition, its intervening space is filled with a drying agent (desiccant). Some filter-driers have bolted flanges that allow the technician to remove and replace the filter element. These filter-driers can be referred to as *replaceable core filter driers.* If the *core is not removable*, the filter drier is called *permanent*. Common drying agents are silica gel, activated alumina, and synthetic silicates. *Never use a liquid absorber and a solid absorber in the same system.*

Arrows are used on filter-driers to show the direction refrigerant is designed to flow. Ensure the arrow points the direction of flow. Heat pumps can use filter-driers that are bi-directional.

Liquid line filter-drier

You usually install the filter-drier in the liquid line between the receiver and the expansion valve. In this location, it is a *liquid-line drier* and prevents freezing of the expansion device. Also, if the system has a capillary tube, the filter-drier prevents debris from clogging it.

Suction line filter-drier

At times, you will find a filter-drier in the suction line. In this location, it is a *suction-line drier*. Its main purpose is to prevent foreign particles, acids, sludge, and moisture from entering the compressor. A suction line filter-drier needs to be installed if the compressor suffers from a burnout. This helps clean the system out. Suction line filter-driers used to clean a system after a burnout have a high capacity to catch acids. Also, these filter-driers are not left in the system permanently.

When to replace a filter-drier

Filter-driers should be replaced any time a system is opened up regardless of whether they are clogged or not. This includes compressor replacement. Also, they should be replaced if there is any pressure drop across it. There are ports on some filter-driers that allow refrigerant gauges to connect to them. The ports are located at the inlet and outlet of the drier so the technician can check for a pressure drop between the two. Another way to determine a pressure drop is to use temperature. When the pressure drops, so does temperature. You can take a temperature reading on the inlet and outlet sides of the filter-drier; if there is a drop, the filter-drier needs to be replaced. Do *not* use your hands to measure the temperature difference. Your hands are not accurate enough to detect slight temperature changes.

> **Technician's Note:** Remove a filter-drier using tubing cutters. *Do not use a torch or flame.* The heat from a torch could cause moisture to leave the filter-drier and enter the system.

Heat exchangers

You may use a heat exchanger in refrigeration, heating, and many other applications. As its name implies, a heat exchanger is a device for transferring heat. The refrigeration industry uses heat exchangers (known as a liquid coolers) to transfer heat from the warm liquid line into the cool suction line. Figures 2–10 and 2–11 show a typical heat exchanger and its location. The cool suction vapor goes through the inside tube from one direction. The warm liquid refrigerant in the outer tube flows in the opposite direction. The counter flow effect of the warm liquid on the cool vapor increases the heat transfer rate. In addition, the warm liquid in the outside tubes keeps the heat exchanger from sweating.

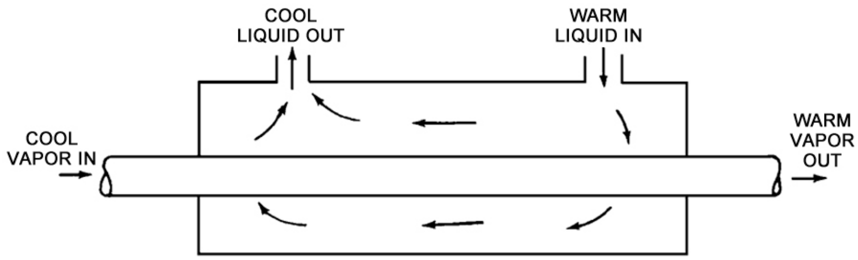


Figure 2–10. Flow-through heat exchanger.

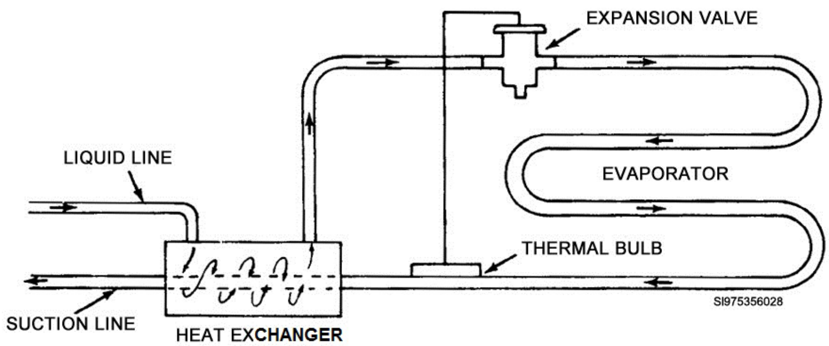


Figure 2–11. Heat exchanger location.

The warm liquid that comes from the receiver must have its temperature reduced in the evaporator before it can be evaporated. This means that the warm liquid carries heat into the evaporator. In passing through the expansion valve, part of the liquid vaporizes and takes up the sensible heat from the liquid, thus reducing its temperature to that of the evaporator.

A heat exchanger provides several beneficial processes (advantages) to the system. Here are five:

- Minimizing flash gas.
- Sweating or frosting of the suction line is minimized or eliminated.
- Flooding of liquid refrigerant to the compressor is minimized or eliminated.
- Liquid enters the expansion valve at a lower temperature.
- Increases compressor efficiency.

The advantage of liquid entering the expansion valve at a lower temperature is very important in low-temperature applications.

The advantage of increased compressor efficiency is very important at air-conditioning temperatures. This happens because the heat exchanger increases the volume of the suction gas enough to offset any advantage gained by reducing the amount of flash gas in the evaporator. Because of this, many manufacturers have eliminated the use of heat exchangers in their A/C systems.

Especially noteworthy is the fact that all compressors must have an oil film on the sides of the cylinder to reduce friction between the cylinder and the piston. If this oil film is full of refrigerant oil evaporates in the cylinder each time the piston goes down. This reduces the amount of vapor the cylinder can remove from the evaporator. Since a heat exchanger increases the temperature of the cylinder wall, the thin oil film can hold very little refrigerant allowing the piston to remove more vapor from the cylinder with each stroke.

Other types of heat exchangers are discussed more in other sections.

Crankcase heater

During OFF cycles, when the compressor becomes colder than the evaporator, refrigerant will migrate to the compressor crankcase and mix with the oil. Figure 2–12 shows an example of refrigerant traveling to the oil. The figure shows that when valve is opened the R–22 migrates to the oil. The refrigerant condenses and could result in liquid slugging of the compressor. Also, it could result in the oil turning to foam and getting pumped out of the compressor. These results damage the compressor. A way to solve this problem is to use a compressor with a crankcase heater.

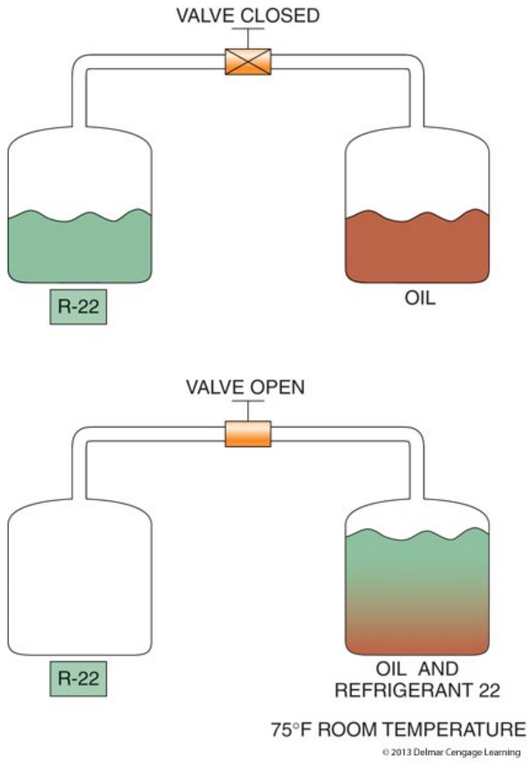


Figure 2–12. Oil migration.
(Courtesy Cengage Learning.)

This heater (fig. 2–13) keeps the compressor body warm enough (about 30 degrees higher than the rest of the system) to keep the refrigerant from migrating to the compressor and mixing with the oil.

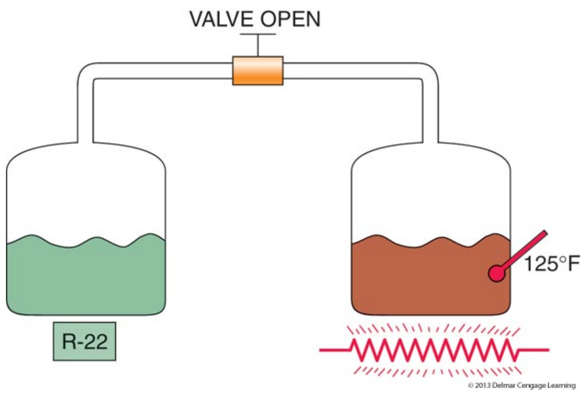


Figure 2–13. Heated oil.
(Courtesy Cengage Learning.)

Depending on the design, crankcase heaters operate during the OFF cycle or they are controlled by temperature. Some temperature-controlled designs use a microprocessor and thermistor to operate the crankcase heater. The factory builds some crankcase heaters into the compressor body; otherwise, an externally mounted heater is used (fig. 2–14).

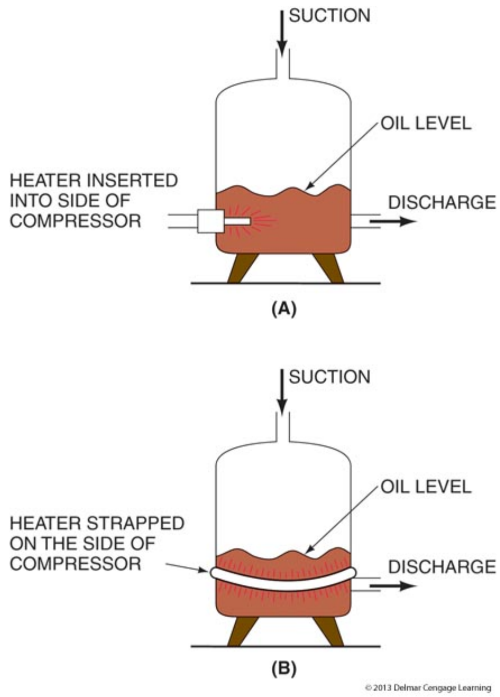


Figure 2–14. Crankcase heater locations. (Courtesy Cengage Learning.)

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

809. Types of refrigeration and air-conditioning controls

1. How does the refrigerant unit know when to cycle on or off?

2. What is the cut-in?

3. Where is a LPMC connected?

4. What is the LPMC used for in addition to controlling temperature?

5. Where does the system put refrigerant during pump-down?

6. When will a high pressure switch shut off the compressor?

7. If it is *not an automatic reset*, what type of reset will a high-pressure safety switch have?

8. What device will protect the system if the oil pressure falls too low?

810. Thermostats

1. What do many line voltage thermostats control?

2. What do relays and contactors do when they receive low voltage from a thermostat?

3. What gauge wire does thermostat wire usually need to change to *after* a 50 foot run?

4. What do thermostats used to control and monitor multiple aspects of the systems?

5. How do programmable thermostats effect energy?

811. Types of refrigeration and air-conditioning accessories

1. What accessory holds the surplus of refrigerant in the system?

2. What side of the system can you perform work on after it is pumped down?

3. What are the two types of receivers?

4. Why does a dip tube extend to the bottom of a receiver that has its outlet at the top?

5. Why does a shell-and-tube water cooler *not* need a separate receiver?

6. What is the result if liquid refrigerant covers any of the water coils in a water-cooled condenser?

7. What do mufflers prevent?

8. Where are mufflers installed?

9. What creates the chance of oil leaving the compressor?

10. What forces oil to return to the low side of the compressor crankcase?

11. What temperature systems do not usually need an oil separator?

12. How does liquid damage compressors?

13. Where in the accumulator is vapor drawn from?

14. How does liquid refrigerant in the accumulator boil off?

15. What can vapor bubbles in the sight glass downstream from the receiver indicate?

16. What are the main sources of moisture in a system?

2–3. Methods of Capacity Control

Ideally, the most efficient construction is to have a compressor that is just large enough to handle the necessary amount of air-conditioning required. If the compressor is too large, temperature control is difficult, energy is wasted, and there is rapid wear of equipment due to the frequent cycling of the compressor. If the compressor is too small, it cannot produce the amount of air-conditioning required. Because of the variable loads encountered, many air-conditioning systems need some form of capacity control. At times, the full system may be needed. At other times, the total capacity of a system is not needed. To meet these varying demands, manufacturers have developed various methods of capacity control. In this section, we cover the most commonly used methods employed with the systems you work with. First we cover the methods of controlling capacities of compressors. Then we look at how you can control the capacity of an air-conditioning condenser.

812. Compressor and metering device capacity control

Compressor capacity control is used to keep the load on the compressor as constant as possible. By keeping the load constant, problems such as an evaporator coil icing up are eliminated or greatly reduced. Capacity control also reduces the number of compressor motor starts and stops. Reducing the number of starts and stops reduces the amount of energy used and saves wear and tear on the compressor. Energy savings come from the fact that a compressor motor actually draws less current when it operates unloaded. Less current draw equals less energy usage.

In this lesson, we discuss the more common types of compressor capacity control methods:

- Thermostats.
- Inverters.
- Multi-compressors.
- Reciprocating capacity control.
- Centrifugal capacity control.
- Scroll capacity control.
- Screw capacity control.

Thermostats

This is the simplest method of capacity control for a system. When the temperature is not at set point, the unit comes on and either heats or cools depending on what is needed. The unit cycles off when the set point is reached. This cycling on and off is fine for residential units; however, this may not be the case for commercial or industrial applications.

Inverter compressors

Constant-speed compressors turn on and run at 100 percent capacity until the indoor temperature is satisfied and then turns completely off. The amount of energy used and the indoor temperature experiences peaks and valleys.

Compressors equipped with inverters can vary the speed of the compressor motor which, in turn, controls its output. Inverters are commonly referred to as *variable frequency drives* or VFDs. Alternating current (AC) is brought into the device where a rectifier converts it to direct current (DC). The switching section, also called the inverter section, converts the DC back into an AC voltage and provides it using pulse-width modulation to produce the desired frequency. The compressor motor, which is an induction motor, varies its speed in proportion with the frequency. This means as the frequency goes up, the induction motor’s speed goes up, and vice versa. Many inverters provide an output voltage that ranges from about 10 percent to 100 percent of the supply voltage.

As the load in the space decreases slightly, the inverter slightly decreases frequency and the motor’s speed is slightly decreased. Let’s say it is 110 °F in Wichita Falls, Texas and half of the doors and windows in the building are opened up. The result is an increase in load. In response, the inverter increases its frequency which, in turn, increases the motor’s speed. The inverter allows for smooth, efficient operation and better space temperature control.

Compressors with inverters are more complex than constant-speed compressors. Therefore, more extensive training is required to work on them. Manufacturers are making more user-friendly designs.

Inverters use electronics and come with software that provides various options. The software allows for a laptop to connect to the VFD and adjust parameters. Some software provides graphs that offer data about compressor operation. Some stores logs of alarms, warnings, and faults.

Some inverters offer codes or light emitting diodes (LED) that notify the technician of the compressor’s operation. For example, a red light that blinks 4 times could mean the compressor module failed.

For added efficiency, inverter compressors can be used with an electronic expansion valve. VFDs, also known as inverters, can be used in every type of compressor.

Variable refrigerant flow configurations and controls

In variable refrigerant flow systems, VRF for short, the amount of *refrigerant* that *flows* is *varied;* hence the name. It accomplishes this by using electronics. The two main control strategies use are proportional and integral, or PI. We discussed these in a previous volume but let's see how they apply to VRF.

Proportional controls react to errors that presently occurring. An error is a difference between a desired condition and the actual condition.

Integral controls react to errors and try to reduce them. They add up all of the values above and below set point and change the output signal. The goal is to reduce errors to a net zero output level.

The VRF with proportional integral (PI) control reacts to the system's saturation conditions. Look at the table below to see what temperatures and pressures are monitored during cooling and heating modes.

Mode	Saturation condition monitored	
Heating	Condenser temperature	Condenser pressure
Cooling	Evaporator temperature	Evaporator pressure

Control strategy for single inverter compressor

Now we will take another look at compressors and how their frequency changes. Let's say an inverter compressor has the ability to change frequency from 60 hertz (Hz) to 200 Hz. The compressor starts at its lowest speed, 60 Hz. As more refrigerant flow is needed the controller moves up in steps. Assume this controller has 15 steps that increases the frequency by 10 Hz for each step. So as the load increases, the steps increase. As the load decreases, the steps decrease. Look at the table below to see how each step correlates to a change in frequency.

Control Strategy Table					
Step	**Frequency (Hz)**	**Step**	**Frequency (Hz)**	**Step**	**Frequency (Hz)**
1	60	6	110	11	160
2	70	7	120	12	170
3	80	8	130	13	180
4	90	9	140	14	190
5	100	10	150	15	200

(**Courtesy of Delmar-Cengage Learning.)**

Control strategy for single inverter and standard compressor

With this design, the single inverter compressor operates in the same as mentioned before. The standard, single-speed compressor comes on when the inverter compressor cannot handle the load itself. Look at the table below. Notice that the standard compressor is OFF until step 16. This means the inverter compressor ramps all the way up to 200 Hz and then the standard compressor is energized so it can help out. At the same time, the inverter compressor drops down to 60 Hz. The inverter compressor ramps up in frequency and speed as needed. As the speed increases, refrigerant flow increases.

Control Strategy Table								
Step	**Inverter Comp Hertz**	**Standard Comp Status**	**Step**	**Inverter Comp Hertz**	**Standard Comp Status**	**Step**	**Inverter Comp Hertz**	**Standard Comp Status**
1	60	OFF	11	160	OFF	21	110	ON
2	70	OFF	12	170	OFF	22	120	ON
3	80	OFF	13	180	OFF	23	130	ON
4	90	OFF	14	190	OFF	24	140	ON
5	100	OFF	**15**	**200**	**OFF**	25	150	ON
6	110	OFF	**16**	**60**	**ON**	26	160	ON
7	120	OFF	17	70	ON	27	170	ON
8	130	OFF	18	80	ON	28	180	ON
9	140	OFF	19	90	ON	29	190	ON
10	150	OFF	20	100	ON	30	200	ON

(Courtesy of Delmar-Cengage Learning.)

Cooling

Let's talk evaporator saturation temperature! As the cooling load goes up, the evaporator saturation temperature and pressure goes up. As the cooling load goes down, the evaporator saturation temperature and pressure go down.

If the cooling load and evaporator saturation temperature and pressure go up then the compressor needs to run faster to perform more work. The PI control module reacts by using both proportional control and integral control. The proportion control reacts to the difference in set point and the actual evaporator conditions. The integral control determines how long the offset has been occurring. If the condition has occurred for a relatively long period of time, the control increases the output signal. The period of time is determined by the design of the control module.

Let's look at an example. Say the evaporator saturation conditions are high and the proportional control increases the output signal to the compressor and the compressor ramps up its speed. The integral decides that the high-saturation conditions have lasted for too long and further increases the output signal. The compressor's speed increases again. You won't "see" these controls working. They work together and all of their "decision making" is done with electronics. Pretty cool, huh?

Heating

In heating mode, the controls and compressors react almost the same way. The only difference is the condenser's saturation conditions are used instead of the evaporator's.

Multi-compressors

This is another method of capacity control. Instead of using one compressor for a given tonnage of air-conditioning, the tonnage is divided between several compressors. These compressors can then be cycled on and off as necessary. For example, there are situations where the total tonnage of a given system is not needed all the time. An illustration of this is shift work. In some cases, the amount of people working in the evening hours is less than during the daytime hours; therefore, less equipment is used. This translates into less tonnage needed, so not as many compressors are needed and can be cycled off. This has a net result of closer temperature and humidity control and saves energy. There is also the advantage of being able to have partial cooling if one of the compressors fails.

Reciprocating compressor capacity control

There are many ways to control capacity of a reciprocating compressor. One of the most common is called unloading cylinders. Another type you may find is the bypass method. Finally, a combination of unloading cylinders and using multiple compressors is used to control capacity.

Cylinder unloaders

Some common cylinder unloaders are the hydraulic (oil), electric, and mechanical types. All of these are used to improve compressor capacity control during light load conditions. This means if there is a light load the compressor doesn’t need to run at 100 percent. These cylinders unloaders decrease the amount of work the compressor is doing.

Unloaders can be classified by systems. One kind of unloader system unloads one-half of the cylinders. Another system uses multiple steps to unload cylinders. In this type, the cylinders are unloaded in increments. These increments depend on the number of cylinders in the compressor.

Internal unloader (opening the intake valve)

These unloaders often use oil pressure and solenoid valves to operate. The solenoid valve closes and stops oil from traveling to the unloader. This makes a spring expand and the holds the intake valves open. When the solenoid valve opens, it allows oil pressure to overcome the spring and the intake valve is no longer held open. The reason the intake valve is held open is so that refrigerant pressure is essentially pumped back to the suction side. The suction side offers very little resistance and very little energy is used. Basically, it stops the compression of the refrigerant and that “unloads” the piston.

External unloaders and hot gas bypass

Electric cylinder head unloading is controlled in response to suction pressure changes. When the suction pressure drops to a predetermined pressure setting on a pressure sensor, a solenoid valve in the bypass line is actuated. When the solenoid valve opens, it allows the discharge from one or more cylinders to flow through the bypass line and back into the suction line. As long as the suction pressure remains below the setting of the pressure sensor, the solenoid valve remains open. When suction pressure rises above the cutout setting of the pressure sensor, the solenoid valve is de-energized and the bypass line is closed, thereby returning the compressor to full operation.

Combination unloaders and multi-compressors

In this configuration, an unloader controls the capacity of a compressor. In addition, other controls are used to cycle other compressors according to load requirements. A special controller can control both applications.

As an example, let’s say you have two compressors. One is equipped with an unloader and the other is expected to run at full capacity. You can wire the controller to control the compressor with the unloader. This allows you to load or unload the compressor with the unloader. If the load continues to increase, the controller activates the compressor that runs fully loaded. In this way, you can match the load up to a given tonnage.

Here is another example. You have two compressors rated at 20 tons each. This is a total tonnage of 40 tons. One compressor has an unloader, and the other runs fully loaded. By using a four-stage controller, you can obtain tonnages of 10, 20, 30, and 40 tons.

Centrifugal compressor capacity control

This capacity control method is used on large centrifugal compressors. These machines move large amounts of refrigerant. If the refrigerant flow were not regulated in some manner, the refrigerating effect would continue no matter what load was on the system. One danger from this situation is that the evaporator tubing bundle would freeze causing it to burst. Of course, this would be expensive to repair. The guide vane system was developed in response to this danger. Guide vanes are often called inlet guide vanes; either term is acceptable and both are used in this lesson.

Guide vanes are designed to control the amount of refrigerant gas going to the compressor. When the load begins to rise, the inlet guide vanes adjust to the load and begin to open. When the load begins to fall, the vanes begin to close. By using the inlet guide vane system, the centrifugal machine can be allowed to run continuously. This is very beneficial because stopping and starting such a big machine is not good in several respects. The amperage is tremendous each time a centrifugal machine starts. By letting it run, money is saved.

The guide vanes are located at the center of the impeller's eye. In addition to modulating capacity the guide vanes match the rotation of the refrigerant to the rotation of the impeller. This reduces compressor drag.

Scroll compressor capacity control

Not all scroll compressors have the ability to modulate during operation. The scroll compressors that can modulate capacity use a bypass port between the outer edge of the compressor and the center of the fixed scroll.

Another method is to use variable frequencies. Variable frequency drives were discussed previously in this section.

Yet another method is moving the fixed and orbiting scroll apart. This creates gaps between the vapor pockets; these gaps allow the pressure differences to equalize.

Screw compressor capacity control

Slide valves are normally used in screw compressors to control capacity. The slide valve blocks the suction gas before it enters the screws. It can modulate the compressor's capacity from 10 percent to 100 percent depending on the manufacturer's designs.

813. Condenser and cooling tower capacity control

Critical control of the capacity of the air-conditioning condensers and cooling towers is necessary for economical and efficient air-conditioning system operation. One design factor is evident in all condensers—to handle the total tonnage of a system. Although this design factor is important to successful system operation, it can cause problems. For example, if the heat load is down or the cooling medium is extra cool, the entire capacity of the condenser is not needed.

If the high-side pressure drops off too much, the pressure drop across the metering device is affected. Some systems are designed to have a specific amount of pressure drop across the metering device. When the pressure entering the metering device is reduced, the pressure and temperature entering the evaporator are reduced and the possibility of coil freeze-up greatly increases.

Reduced pressure can cause another possible malfunction: reducing the velocity of the refrigerant traveling through the system. If the velocity drops low enough, the rate of return of the refrigerant and oil is reduced. The great concern here is the oil. If not enough oil gets back to the compressor, the compressor may very likely become damaged.

In this lesson, we cover these methods of controlling condenser capacity:

- Cycling fans on and off.
- Using variable-speed motors.
- Using modulating dampers.
- Condenser flooding.
- Condenser splitting.
- Floating head pressure.
- Controlling water flow.

Fans

Some air-cooled condensers have only one fan and some have multiple fans. These fans can be automatically cycled to keep head pressure within design limits. On some systems, the fans do not start until the temperature or pressure increases to a given point.

The fans can be started and stopped when the high-side pressure or temperature fluctuates. They usually stop when the temperature or pressure drop(s) below the optimum design conditions. The design conditions vary from place to place.

A pressure-operated control usually senses the discharge gas pressure. Some condensers that use this method of control only start and stop one or two of the condenser fans. Other types of condensers are designed to use both temperature and pressure. This gives better control of the capacity.

> **NOTE:** Never assume that only one type of control is being used on the condenser. This may get you in trouble by extending the amount of time spent troubleshooting the unit.

Some condensers have one “lead” condenser fan(s) and the others are cycled on and off according temperature and pressure. Cycling fans on and off causes head pressure swings. When a fan is cycled off, the head pressure rises because there is now less air moving over the coil. When it turns back on, the head pressure drops because the amount of air over the coil has increased.

Variable-speed condenser motors

In order to prevent temperature/pressure swings caused by cycling fans on and off, some condensers have variable-speed motors. In these cases, special controls change the speed of the fan to meet the demands of the load on the condenser. A unique feature of a variable-speed motor is that it can operate at any speed up to its rated revolutions per minute (rpm). The operation is quite simple. A sensor placed somewhere on the liquid line sends a signal to a controller, which in turn, sends a variable signal to the fan motor. Varying the signal in this manner allows the fan speed to be varied and controls the amount of air being drawn or blown over the condenser surface. This varies the amount of heat transferred from the refrigerant and thereby controls capacity.

The inverter can be linked to the refrigeration system via a head pressure transducer. The inverter could operate based off changes in the outside air temperatures near the condenser air inlet.

Dampers

Dampers are controlled by a device that senses either temperature or pressure. The dampers modulate to the open or closed position based on the temperature or pressure they sense. Controlling the flow of air across the condenser coil controls the capacity of the coil. Limiting the amount of air allowed over the coil reduces the capacity of the condenser coil and increases the high-side pressure.

Condenser flooding

Condenser flooding means the condenser is being flooded with liquid refrigerant. This is necessary to maintain a constant head pressure during cooler or cold days. By flooding the condenser, we ensure the metering device is receiving the constant liquid pressure required for its proper operation. If the metering device is not receiving the proper liquid refrigerant, it could starve the evaporator and cause short cycling due to low suction pressure. Also, a starved evaporator can cause ice formation. All of these conditions result in inefficient cooling.

The evaporator could be starved during start-up if all or most of the refrigerant has migrated to the condenser. Refrigerant would migrate to the condenser if it were located outside and ambient conditions were cooler than the evaporator’s ambient conditions. This could prevent the suction pressure from rising high enough to allow the compressor to start. Even if the compressor starts it may turn right back off because the suction pressure was so close to the cut-out pressure that as soon as the compressor started it pulled the suction pressure to the cut-out point.

We use head pressure control valves to maintain the constant head pressure during mild or cold ambient conditions. These valves are installed at the outlet of the condenser. As the condenser pressure drops at a certain set point, the valve throttles and holds back refrigerant in the condenser. The result is partial flooding of the condenser. This is okay though because we need a certain amount of pressure entering the metering device because the metering device is designed to operate most efficiently within a designed pressure drop.

Open on a rise of inlet pressure

We begin our discussion about head pressure control valves with the open on rise of inlet pressure or ORI valve. As the name states, this valve responds to the *inlet pressure* of the condenser. A fall in condenser inlet pressure results in less pressure on the bottom of the valve disk. This causes it to close more causing refrigerant to back up in the condenser. As condenser pressure builds the valves throttles open some more. The amount the valve opens or closes depends on the valve's setting. The setting can be adjusted using an Allen wrench or, sometimes, a screwdriver.

Open on a rise in differential pressure

ORIs are usually used with open on rise in differential pressure, or ORD valves. ORDs are located between the discharge line and the inlet of the receiver. As the name implies, it reacts to *pressure differences* between these two locations.

When the ORI throttles back refrigerant into the condenser, the receiver still needs proper pressure to supply liquid to the metering device. This is where the ORD steps in. When a predetermined pressure drop is sensed across the ORD, it takes discharge line gas and places into the receiver inlet. The discharge gas increases the receiver's pressure and maintains proper receiver pressure.

Remember, if proper pressure isn't supplied to the metering device from the receiver then the metering device's efficiency is decreased.

Combination ORI/ORDs

There are combination ORI/ORD valves that perform the same functions of each valve that has already been described.

Low-ambient control valve

The low-ambient control valve, or LAC for short, is yet another type of head pressure control that is used to correct for low-ambient conditions. This valve has a refrigerant filled dome at the top. The dome's refrigerant is separate from the system's refrigerant. The dome's refrigerant expands and contracts based on outside ambient conditions (the valve is located outside in the condensing unit). The expansion and contraction of this refrigerant charge moves a diaphragm. The diaphragm then moves a piston in the valve and throttles the valve open or closed. Remember, when the word throttled is used, it means opened or closed in numerous different positions, it doesn't necessarily mean completely opened or completely closed.

As outside ambient conditions fall, the valve restricts flow of refrigerant leaving the condenser. The condenser is now partially flooded and its proper pressure is maintained. In the meantime, the valve also routes discharge gas to the receiver inlet. This happens for the same reasons discussed in the ORD section above.

Relationship between head pressure control valves and receiver size

If head pressure control valves are used, then the receiver must be large enough to hold the normal refrigerant charge and the extra charge required to flood the condenser. Manufacturers provide information so the technician knows how much refrigerant to add to these systems.

As a technician, you need to be aware as to whether a system has head pressure control and if the receiver is oversized. Why? It saves you from unnecessary work. How? If an oversized receiver hasn't been installed and the system is using condenser flooding to maintain proper pressures, then every spring or summer you have to remove refrigerant to prevent high head pressures. Then in the fall or winter, you have to add the refrigerant back so the condenser can be flooded. Do you understand the importance of recognizing proper receiver size?

Condenser splitting

Another method of maintaining head pressure control is to *split* the condenser into separate circuits. One circuit is used during higher ambient conditions and is often called the *summer condenser*. The other condenser circuit is used throughout the year and is often called the *summer-winter condenser*.

In addition to maintaining head pressures, condenser splitting is used to ensure proper amounts of liquid refrigerant is reaching the metering device.

Refrigerant is fed to these two spaces from a three-way solenoid valve. This valves reacts to either outside ambient temperatures or head pressure. When the solenoid is de-energized it allows hot discharge gas to flow to both spaces. When the valve is energized it allows hot discharge gas to flow to the summer-winter condenser **only**.

Valve state	Condenser used
Energized	Summer-Winter
De-energized	Summer-winter and summer

The condensers are arranged in a parallel format. During warmer weather conditions the solenoid valve sends refrigerant to both condensers. This is because the ambient air is warmer and the refrigerant needs more space to sustain proper head pressures and reject heat.

In contrast to warm weather, during lower ambient temperatures the valve closes off flow to the summer condenser. Since the temperature is cooler, the condensers become more efficient; therefore both are not needed. This is the reason refrigerant is not allowed to flow to the summer condenser. A check valve is used at the outlets of both condenser circuits.

When the flow to the summer condenser is stopped there is still refrigerant inside. A bleed line is used with the solenoid valve to allow this refrigerant to escape back into the rest of the system. Another method is to use a pump-out solenoid.

Another method of splitting the condenser is to use a solenoid before the summer condenser. This solenoid is controlled by either a thermostat or low-pressure switch. Condenser splitting can be used with other head pressure controls, such as head pressure control valves, fan cycling, and air louvers.

Floating head pressure

Previously, we have discussed methods to maintain certain head pressures in the system. We used controls and valves to raise the head pressure during low ambient temperatures. The only issue with this is that as the head pressure rises it uses more energy and becomes less efficient. More energy and decreased efficiency means wasted Air Force funds.

Systems are being designed to attain the lowest possible condensing pressures and temperatures. Newer TXVs are being designed to work well with less pressure drops than in the past. They still require pure liquid to function properly but they don’t need as high of pressure drops anymore.

Basically all floating head pressure is allowing the condensing pressure to rise and fall with the ambient temperatures. Head pressure controls can still be used in conjunction with floating head pressure but only in extreme cold situations.

Electric heat during capacity control

Electric heat elements are used in or around liquid receivers to keep them warm. If they were to get colder than the condenser cabinet they would act like a condenser.

Capacity control and water-cooled systems

Capacity for water-cooled systems, such as chillers, is controlled by modulating airflow and/or water flow. Both are covered below.

Airflow

Cooling towers rely on airflow to reject the heat from the water that comes from the condenser. The amount of airflow is varied by cycling fans on and off, variable speed motors, or louvers. See the chart below. Notice that in the middle column airflow is being decreased and as the airflow is decreased so is the capacity. In the column on the far right, airflow is increasing which causes the capacity to increase.

Method of capacity control	Reduces capacity	Increases capacity
Cycling Fans	Fan cycle OFF	Fan cycle ON
Variable speed	Decrease speed	Increase speed
Louvers	Modulate closed	Modulate open

Water flow

The flow of water can be regulated in a water-cooled condenser to keep the head pressure within design limits. The water goes to a cooling tower that has a fan. If the cooling tower is a dry-sump type, then a tank is located inside of a mechanical room. This tank holds all of the water for the tower. The water is released from the condenser at the top of the cooling tower and drains into the tank.

A butterfly damper can be installed in the line going to the cooling tower. This damper can close and allow the water to circulate only in the tank until the water temperature is within design limits. This valve could operate using direct digital controls, or DDC for short.

Water valves can be controlled by temperature or pressure. They move using electricity, motors, bellows, or solenoids.

Some cooling tower systems use a mixing valve that takes cooler return water and mixes it with hot condenser water. This mixing action is used to maintain constant head pressures.

You must be aware of the relationship between cooling tower water and chiller operation. If the return water is too cold the condenser becomes *too* efficient. Yes, you read that correctly, *too* efficient. It becomes too efficient and holds too much refrigerant in the shell; this results in the evaporator becoming starved. In addition, oil could migrate away from the compressor.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

812. Compressor and metering device capacity control

1. What effect does capacity control have on compressor motor starts and stops?

2. What effect does reducing the number of starts and stops have on energy usage and compressor wear?

3. What effect does an *unloaded compressor* have on current draw and energy usage?

4. What are the three common types of cylinder unloaders?

5. What happens to the sound, amperage, and suction pressure when the compressor cylinder unloads?

6. What controls electric cylinder unloading?

7. In a hot-gas bypass control system where does hot gas enter once the solenoid valve opens?

8. What do the inlet guide vanes do in response to an *increase in the load*?

813. Condenser and cooling tower capacity control

1. What are four methods of controlling condenser capacity?

2. When do condenser fans stop while the system is operating?

3. How many condenser fans are usually pressure-controlled for capacity purposes?

4. What is the advantage of sensing both temperature and pressure for condenser fan capacity control?

5. What could result if you assume that only one type of control is being used on the condenser?

6. How does variable speed control condenser capacity?

7. What speeds can a variable speed motor operate at?

8. Where would you look if you are trying to find the sensor that sends a signal to the variable-speed controller?

9. What is the relationship between the amount of air being drawn over the condenser surface and heat transfer?

10. What do dampers use to determine how far they open or close?

11. What is the relationship between the amount of air flowing over the coil and the condenser capacity?

12. What is happening in the condenser during condenser flooding?

13. What could result if the metering device is not receiving the proper amount of liquid refrigerant?

14. What could cause refrigerant to migrate to the condenser?

15. Where are head pressure control valves installed?

16. What pressure does the open on a rise of inlet pressure respond to?

17. Where are ORD valves located?

18. How much refrigerant should be added to a system if a larger receiver is installed?

19. What will need to be done every spring or summer if an oversized receiver wasn't installed on a system using condenser flooding?

20. In a system using condenser splitting, what condenser is used only during higher ambient conditions?

21. In addition to maintaining head pressures, what is condenser splitting used for?

22. What condenser is used if the solenoid valve is energized when condenser splitting is used to control capacity?

23. Why is flow to the summer condenser turned off during lower ambient conditions?

24. What other controls can be used with condenser splitting?

25. What effect does increasing the fan speed have on cooling tower capacity?

26. What controls water valves used with water-cooled condensers?

27. What effect does a condenser operating *too* efficiently have on the evaporator?

Answers to Self-Test Questions

807

1. The type and amount of refrigerant charge in the system.
2. Because they contain no chlorine.
3. A temperature range where the blend evaporates and condenses
4. Because oil must pass through the compressor cylinders to provide lubrication.
5. Oil can properly circulate through the system only if gas velocities are high enough to sweep the oil along its path.
6. This problem becomes more critical since the viscosity of the oil increases with a decrease in temperature.
7. When they contain acids or they have mixed with other oils.

808

1. It can be destructive.
2. It increases the temperature.
3. It prevents friction and heat and minimizes wear.
4. To prevent leftover oil from becoming contaminated by air and moisture.
5. Splash and pump methods.
6. In the oil equalizer line.
7. Due to the absorption of refrigerant by the oil.
8. The oil level may initially fall below normal in the sight glass; however, it should return to near normal in less than 1 minute.
9. A floodback condition which could be harmful to the compressor.
10. In case of a leak.
11. Shortens the life of the compressor.
12. Pumps excessive amounts of oil, reduces its refrigerant pumping capacity, and subjects the compressor valves to severe strain.

809

1. The control circuit.
2. The temperature or pressure that a control will allow a system to operate or cycle on.
3. To the suction line or at the low-pressure side of the compressor.
4. To prevent operation at too low a pressure, thus preventing unit damage or freeze-up, or for pump-down.
5. In the receiver.
6. When the pressure on the high side reaches the cutout.
7. Manual reset.
8. The oil pressure safety switch.

810

1. Electric resistance heater.
2. Become energized to control line voltages that travel to loads such as fans and compressors.
3. AWG.
4. Transistors, solid-state devices, and microprocessors.
5. Saves energy.

811

1. Receiver.
2. Low side.
3. Vertical and horizontal.
4. To maintain a liquid seal at the outlet.
5. It uses the bottom one-third of the condenser as a receiver.
6. The head pressure increases, thus reducing the compressor efficiency.
7. Excessive noise and break up the pressure pulses.
8. Refrigerant circuits; suction and discharge lines; near the condensing unit on commercial units.
9. Small amount of oil pumping with refrigerant vapor.
10. High side pressure.
11. Systems with temperatures above 0 degrees.
12. Slugging and because of diluted oil in the crankcase that causes foaming and bearing washout.
13. The top.
14. From heat in the refrigerant vapor or an external heat source.
15. A low charge.
16. Contaminated oil, contaminated refrigerant, and leakage in a water-cooled condensing unit

812

1. It reduces them.
2. It reduces energy usage and saves wear and tear.
3. Less current is drawn which means less energy usage.
4. Hydraulic (oil), electric, and mechanical types.
5. There is a distinct change in the sound of the compressor. In addition, the amperage drops and the suction pressure rises.
6. Suction pressure changes.
7. The evaporator.
8. Adjust the load and begin to open.

813

1. Any four: cycling fans on and off; using variable-speed motors; using modulating dampers; condenser splitting; controlling water flow.
2. When the temperature or pressure drop(s) below the optimum design conditions.

3. One or two of the condenser fans.
4. Better control of the capacity.
5. Extending the amount of time spent troubleshooting the unit.
6. Special controls change the speed of the fan to meet the demands of the load on the condenser.
7. It can operate at any speed up to its rated revolutions per minute (rpm).
8. A sensor placed somewhere on the liquid line.
9. Changes in the outside air temperatures near the condenser air inlet
10. The temperature or pressure they sense.
11. Controlling the flow of air across the condenser coil controls the capacity of the coil.
12. It is being flooded with liquid refrigerant.
13. It could starve the evaporator and cause short cycling due to low suction pressure.
14. If it was located outside and ambient conditions were cooler than the evaporator's ambient conditions.
15. At the outlet of the condenser.
16. Inlet pressure of the condenser.
17. Between the discharge line and the inlet of the receiver.
18. The amount specified by the manufacturer.
19. You would have to remove refrigerant to prevent high head pressures.
20. Summer condenser.
21. To ensure proper amounts of liquid refrigerant is reaching the metering device.
22. Summer-winter condenser.
23. When the temperature is cooler the condensers become more efficient; therefore both are not needed.
24. Head pressure control valves, fan cycling, and air louvers.
25. Increase in capacity.
26. Temperature or pressure.
27. It holds too much refrigerant in the shell; this results in the evaporator becoming starved.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter.

26. (807) Chlorofluorocarbon refrigerants are "doomed" because they
    a. contain sulfate.
    b. contain chlorine.
    c. contain chloroxide.
    d. are not very efficient.

27. (807) A low flow of refrigerant affects *oil return to the compressor* by causing
    a. the refrigerant to lie on bottom of tubing.
    b. too much refrigerant to return to compressor.
    c. too much oil to return to compressor and flood it.
    d. oil to lie on the bottom of the refrigeration tubing.

28. (808) What effect does friction have on the *temperature of moving parts* in an air conditioning (A/C) system?
    a. Increases temperature.
    b. Decreases temperature.
    c. Maintains constant temperatures.
    d. Oil prevents friction and has *no effect* on temperature.

29. (808) How is oil forced to the main bearings when the *pressure lubrication method* is used?
    a. Splashing.
    b. Crank throw.
    c. Passive force.
    d. A small oil pump.

30. (809) What affects the *resistance* of a *thermistor*?
    a. Weight.
    b. Pressure.
    c. Temperature.
    d. Absolute pressure.

31. (810) Low voltage thermostats *directly operate*
    a. compressors.
    b. electric heaters.
    c. solenoids, relays, and contactors.
    d. compressors and electric heaters.

32. (810) What effect does an *improper location of a thermostat* have on the temperature being sensed?
    a. It senses the wrong *pressure*.
    b. It senses the wrong *temperature*.
    c. Proper control of space temperature.
    d. It senses ambient pressures with more sensitivity.

33. (811) What is the relationship between a liquid receiver and a system's refrigerant charge?
    a. Liquid receivers are too small to hold the complete system's charge.
    b. Liquid receivers are large enough to hold 50% of the system's charge.
    c. Liquid receivers are large enough to hold 75% of the system's charge.
    d. Liquid receivers are large enough to hold the complete system's charge.

34. (811) What effect does a muffler have on a domestic refrigeration system's noise?
    a. Increases the noise level.
    b. It breaks up the pressure pulses.
    c. It creates pressure pulses for quiet operation.
    d. None, mufflers cannot be used on refrigeration systems.

35. (811) Insulating an oil separator prevents the refrigerant
    a. liquid from vaporizing and returning to the condenser as a liquid.
    b. liquid from vaporizing and returning to the compressor as a vapor.
    c. vapor from condensing and returning to the evaporator as a liquid.
    d. vapor from condensing and returning to the compressor as a liquid.

36. (811) Filter-driers are usually installed on the high-side between the
    a. evaporator and compressor.
    b. oil separator and compressor.
    c. expansion valve and evaporator.
    d. receiver and the expansion valve.

37. (812) How do compressors with inverters *vary the output capacity* of the compressor?
    a. By using an inverter.
    b. With cylinder unloaders.
    c. With constant speed devices.
    d. By using light emitting diodes.

38. (812) What allows the technician to adjust variable frequency drive (VFD) parameters via a laptop?
    a. Software.
    b. Stepper motors.
    c. WiFi connection.
    d. Pulse width modulation.

39. (812) Using the control strategy table from page 2–37, what *frequency* is being produced at step 10?
    a. 140 hertz
    b. 150 hertz.
    c. 160 hertz.
    d. 170 hertz.

40. (812) According to the control strategy table on page 2–38, what is the *output* of the *inverter compressor* at step 16?
    a. 20 hertz.
    b. 60 hertz.
    c. 70 hertz.
    d. 80 hertz.

41. (812) What is the *end result of the solenoid valve closing* on a compressor with an *internal unloader*?
    a. Intake valve held open.
    b. Intake valve held closed.
    c. Exhaust valve held open.
    d. Exhaust valve held closed.

42. (812) How is discharge from one or more cylinders allowed to flow through a bypass line and into the suction line on a *compressor with external unloaders and gas bypass*?
    a. Evaporator valve opens.
    b. A solenoid valve opens.
    c. A solenoid valve closes.
    d. Thermostatic expansion valve (TXV) closes.

43. (813) Which of the following is *not* a method of *condenser capacity control*?
    a. Cycling compressor on and off.
    b. Modulating water flow rates.
    c. Cycling fans on and off.
    d. Modulating fan speed.

44. (813) Condenser flooding is necessary on cooler or cold days to
    a. maintain constant superheat.
    b. maintain constant head pressure.
    c. starve the evaporator to increase superheat.
    d. maintain constant evaporator saturation temperatures.

45. (813) What is the *relationship* between condenser flooding and the metering device?
    a. Flooding is required to supply 30% vapor to metering device.
    b. Flooding ensures the metering device is receiving 70 percent vapor.
    c. Flooding ensures the metering device is receiving a constant liquid pressure.
    d. Flooding ensures refrigerant flashes off immediately before metering device.

46. (813) What does the three-way solenoid react to in a system that uses *condenser splitting*?
    a. Suction pressure.
    b. Indoor dry-bulb temperatures.
    c. Indoor wet-bulb temperatures.
    d. Either outside ambient conditions or head pressure.

47. (813) On a condenser splitting capacity control system, a three-way solenoid valve sends refrigerant to both condensers during warmer weather conditions because the refrigerant needs
    a. more space to sustain proper head pressures and absorb heat.
    b. more space to sustain proper head pressures and reject heat.
    c. less space to sustain proper head pressures and absorb heat.
    d. less space to sustain proper head pressures and reject heat.

48. (813) When airflow is used to control condenser capacity what effect does *decreasing fan speed* have?
    a. Reduces capacity.
    b. Increases capacity.
    c. Stops flow in the condenser.
    d. Increases flow in the condenser.

49. (813) What effect does *closing air dampers* have on *condenser capacity*?
    a. Reduces capacity.
    b. Increases capacity.
    c. Increases capacity over 120 percent.
    d. Stops flow in condenser coils.

Please read the unit menu for unit 3 and continue ➔

Unit 3. Refrigeration and Cooling Systems

IN THIS UNIT we focus on refrigeration and cooling systems. As you can see from the contents above the four sections focus on different types, starting with refrigeration systems and concluding with indirect expansion cooling systems. The lessons within each section cover different aspects from characteristics, components, and types, to inspection, test, and maintenance. Let's get this unit started with some good ole cold storage!

3–1. Types of Refrigeration Systems

The lessons in this section cover cold storage and the types of defrosting. When it comes to cold storage you need to know about the different types such as the permanent and portable types. After cold storage, we discuss defrost. When it comes to defrost w cover refrigeration equipment, defrost strategy methods and controls—important aspects that add to your HVAC/R knowledge.

In addition to cold storage and defrosting, multiple component systems are covered. A multiple component system is similar to a traditional fridge, freezer, or cooling systems except it has more than one of a certain component. Systems have either multiple evaporators or compressors. There are a few unique devices that go along with these systems, and they will also be covered in this unit.

814. Characteristics of cold storage devices and refrigeration defrosting

In this lesson, we discuss cold storage and defrosting methods. Cold storage units can keep various products cold or frozen. They can be of the permanent or portable type. In addition to cold storage this lesson includes an extended discussion of defrosting.

Cold storage

There is no doubt that products must be kept at certain temperatures to prevent spoilage. The inside temperatures of these systems vary depending on whether the product is to be kept frozen or cold but above freezing. The cold storage covered equipment in this lesson is the walk-in cooler type. Essentially there are two basic types of cold storage units: permanent and portable.

Permanent

These cold-storage facilities are used to store items for the commissary, dining halls, and so forth. From the outside, the permanent cold-storage plant may look like any other building; however, upon closer observation, you usually find this is not so. You will note there is a receiving dock on one side where trucks back up and off-load their products. From the dock, the products are taken to the appropriate room in the building. The outside rooms of this building are the warmer rooms, while the inside rooms are the coldest. In this configuration, the outside rooms act as a barrier from the outside temperatures. Usually the outside rooms handle fresh produce while the inside rooms are dedicated for frozen-type foods. In addition, there are usually offices for handling and inspection procedures.

> **NOTE:** In the next lesson, we cover some of the refrigeration systems you may find installed at permanent cold-storage plants.

Portable

As the name implies, the portable type of cold storage can be moved. There are two types of portable units: site-assembled, and preassembled.

Portable Cold Storage	
Type	**Description**
Site-assembled	In the site-assembled unit, the walls come from the factory preinsulated and ready to bolt together. The steel may be aluminum or galvanized. They are normally water proof and can be installed outdoors. A packaged refrigeration unit is usually included to provide the necessary refrigeration.
Preassembled	As you would expect, the preassembled unit is already assembled. It can be moved easily with a forklift and loaded on an aircraft for deployment. A package refrigeration-type unit also comes with this type of cold-storage unit.

Condensate drain and pumps

Drains are needed to remove condensation and prevent slipping hazards on the walk-in floor. Sometimes a condensate pump is required when condensate cannot easily flow out of the drain. Also, the hot gas bypass line can be used to heat the condensate to prevent it from freezing. If hot gas isn’t used, electric heaters are.

Doors

The doors of either permanent or portable cold storage units require a gasket to make the box airtight. If the box is not airtight, heat from the outside could enter the unit. The heat entering the unit could cause the refrigeration system to work harder and decrease its life expectancy. Also, the heat from the outdoor air could cause the products inside to spoil.

Doors can be equipped with hot wires called mullion heaters. These heaters prevent sweating and freezing.

Defrosting

Defrost is necessary in freezers. Moisture enters the space and condenses on the evaporator coil. The condensed moisture then freezes on the coil. Ice buildup on the coil reduces the system’s efficiency and could lead to a service call. The defrosting of a coil needs to happen fairly quickly. If defrosting lasts for too long it could cause the temperature in the unit to rise.

Manual defrost strategies can be use but they are time consuming and require the unit to be emptied of its product. Because of this, automatic-defrosting strategies have been developed. We will discuss the manual and automatic strategies and the types of defrost controls and methods.

Control strategies for defrost

We’ll cover six defrost control strategies:

- Manual.
- Simple timed.

- Cumulative run.
- Demand defrost.
- Off-time.
- Adaptive.

You need to be aware of and understand how each type of defrost works. If you don’t understand how they work, it could hinder you while on the job. For example, say you have worked on many refrigeration systems that use simple timed defrost but you arrive at a system with adaptive defrost. If you don’t pay attention to information in this CDC then you will be completely lost.

Defrost Control Strategies	
Type	**Description**
Manual	In manual defrost the systems, the contents of the cabinet must be removed and relocated to another cold storage unit. If products are not removed, they could become spoiled. The system is shut-down and the ice is allowed to melt. The speed of defrost relies on the ambient air temperature and the amount of ice on the evaporator. Many old units use manual defrost but if a system’s automatic defrost is broken you may have to move the product to another unit to defrost the evaporator coil and fix the automatic defrost. This is critical to know! What if you are at the chow hall on a deployment? Don’t you think the food for the base is extremely important to the mission? Yes! The food is very vital to the mission and if the freezer is broken then so are you!
Simple timed	Some systems use a timer to start defrost. A basic timer method consists of the technician or customer setting the amount of time between defrost cycles. For example, the technician sets the interval at 6 hours. This means defrost comes on every 6 hours. Even if the system doesn’t need defrost, every 6 hours defrost is initiated. Also, the duration of defrost is selected by the user (e.g., 10 minutes). This means every 6 hours the unit goes into defrost for 10 minutes. Another name for this type of defrost is *continuous defrost*. During the defrost sequence, the compressor and evaporator fan are *not* running. You don’t want the system to produce a cooling effect while you are trying to warm up the evaporator.
Cumulative run-time	This type of defrost bases the defrost cycle on the amount of time the compressor runs. It uses an intermittent defrost timer. (Intermittent means *not continuous*.) Regarding the defrost timer, this means it is *not* continuously running. It only counts down to the next defrost cycle when the compressor is running. When the compressor is *not* running it doesn’t count down the time until the next cycle. **NOTE:** The defrost timer and compressor are wired in parallel so the both are supplied with power for the same amount of time.
Demand	On-demand defrost systems the defrost controller turns on defrost based on how many times the door has been opened. The reason is that every time the door opens moisture is allowed to enter the space. Therefore, the more times the door is opened the more moisture enters.
Off-time	The off-time defrost method is limited to cabinets that do *not* have freezing temperatures. Ambient temperature is relied on to bring the evaporator-coil temperature up to where the frost melts. The refrigeration system is shut down but the evaporator fan continues circulate return air over the cold coil.
Adaptive	Adaptive defrost determines how long a unit took to defrost and uses that information to determine the interval of the next defrost cycle. This is a “smart” type of defrost. It doesn’t allow excessive frost build-up on the evaporator. The more frost build-up, the longer it takes to defrost and the more

Defrost Control Strategies	
Type	**Description**
	inefficient the system is. This strategy allows some ice build-up but doesn't let it get excessive. The control monitors the amount of time it takes to defrost the coil and compares it the designed "ideal" time. If defrost took longer than the adaptive control design it initiates the next defrost a little sooner. The control continually monitors defrost times and continually adjusts the start times of future defrost.

Defrosting controls

Defrost timers can control and communicate with multiple components. They include hot gas solenoids, fan motors, electric heaters, defrost thermostats, and compressors. Three conditions used with defrost controls—time, temperature and pressure—are described in the table below.

Defrosting Controls	
Type	**Description**
Time-initiated, time terminated (TITI) defrost timer	Defrost begins at a set time and ends at a set time. Only use TITI when the amount of time the system needs to be in defrost remains constant.
Time-initiated, temperature-terminated defrost timer	Defrost begins at a set time and ends at a set cut-out temperature. The term *cut-out* in this application means defrost is turned off, or *cut-out.* A defrost termination switch or thermistor is placed on the evaporator at the last place the ice/frost melts.
Time-initiated, pressure-terminated defrost timer	Defrost begins at a set time and ends at a set cut-out pressure. The pressure is usually detected using a sensing bulb and a pressure switch. The *cut-out* in this application means defrost is turned off when the evaporator pressure corresponds to the temperature at which the ice would have melted.

Defrosting methods

Now that we have covered the types of control strategies, we turn our attention to the methods that are used to actually melt the frost/ice off of the evaporator: hot-gas and hot-wire defrosting.

Hot-gas defrosting

During this type of defrosting, hot gas from the high side of the refrigeration system is circulated through the evaporator. A line is run from the compressor discharge line to the evaporator and is located between the metering device and the evaporator. A solenoid valve is installed in the line. The solenoid is closed during the normal refrigeration cycle and opened during defrost. When the solenoid opens it allows hot gas from the compressor to enter the evaporator (fig. 3–1). The gas melts the ice.

Instead of a simple solenoid valve, a four-way reversing valve can be used. In this method, the entire cycle is reversed so that the evaporator actually becomes the condenser and the condenser becomes the evaporator. A heat pump uses a four-way reversing valve, and we explain its operation later in this unit.

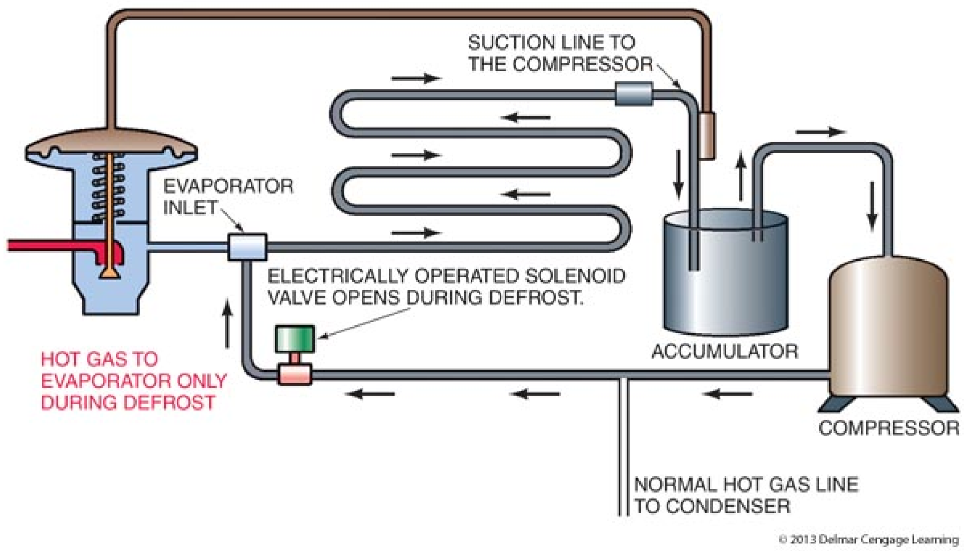


Figure 3–1. Hot gas defrost.
(Courtesy Cengage Learning.)

One disadvantage (among many) of this system is that in cold weather, the compressor may not deliver enough heat for the rapid defrosting. Consequently a number of variations of the simple hot-gas system are needed to overcome its disadvantages. The system should meter the hot gas to the evaporator in such a way as to prevent formation of liquid that could get back to the compressor (a small amount of liquid entering the compressor causes the pistons to hammer). Also, the system can be set up to use a liquid receiver and meter the liquid into the suction line. The system can be set up to add sufficient heat to make sure the refrigerant is a gas when it returns to the compressor.

A disadvantage is that hot gas can defrost the coils so rapidly that the drain lines may require heating to prevent defrost water from freezing in the drains and plugging them.

The hot-gas defrosting system may have a pressure cutout switch to keep the unit from operating at too high a pressure. The contacts in the pressure control open the compressor motor circuit if pressure exceeds its setting, thereby keeping pressure in the system within safe limits.

Hot-wire defrosting

In this method, electrical heating elements or coils are used. The heater wire may be installed in, around, or within the refrigerant passages. A fan shutoff switch is a necessary part of a hot-wire defrost system because the forced air may blow water off the evaporator and away from the drains.

The hot-wire defrost cycle is so short that the drains require heating to prevent freeze-up. Improved electrical heating elements account for the speed because heating is almost instantaneous through the whole evaporator.

A big advantage of the hot-wire method is that it is unaffected by changes in ambient temperature.

Two other defrost methods exist—the water defrost system and the nonfreezing solution defrost system. They are not covered in this CDC; you only need to know they exist.

815. Multiple component refrigeration systems

Up to this point we have discussed refrigeration systems that contain one compressor, one evaporator, one condenser, and a metering device. As you go about your job, you will find that many systems are designed to have multiple components and configurations. In this lesson, you will learn about systems that meet these requirements—multi-evaporator systems and multi-compressor systems.

Multi-evaporator systems

A multiple-evaporator system is one in which several evaporators are operated from one condensing unit. It is cheaper to operate one compressor to control the temperature of two or more evaporators than to operate a compressor for each evaporator. Fundamentally there are only two classifications of multiple-evaporator systems:

- Single-temperature, multiple-evaporator system (all evaporators operate at the same temperature).
- Multiple-temperature, multiple-evaporator system (several evaporators, each having a different temperature).

Single-temperature, multiple-evaporator system

Some multiple-evaporator systems are designed to be operated as a single-temperature system. This means that all evaporators have the same temperature range. In this configuration, the needs of each evaporator can be controlled by a single low-pressure motor control. When all evaporators have been satisfied, the compressor pulls the pressure in the common suction line down to the cutout point of the pressure control. The pressure control contacts then open, stopping the system's operation. As the pressure builds up in the evaporators, it also builds up in the common suction line. The pressure control contacts close and the compressor starts when the pressure in the common suction line reaches the cut-in setting on the pressure control. When the temperature of all the evaporators is again satisfied, the compressor shuts off. This occurs when the common suction line pressure drops to the cutout point set on the pressure control. This is a continuous process. Figure 3–2 illustrates a typical single-temperature, multiple-evaporator system.

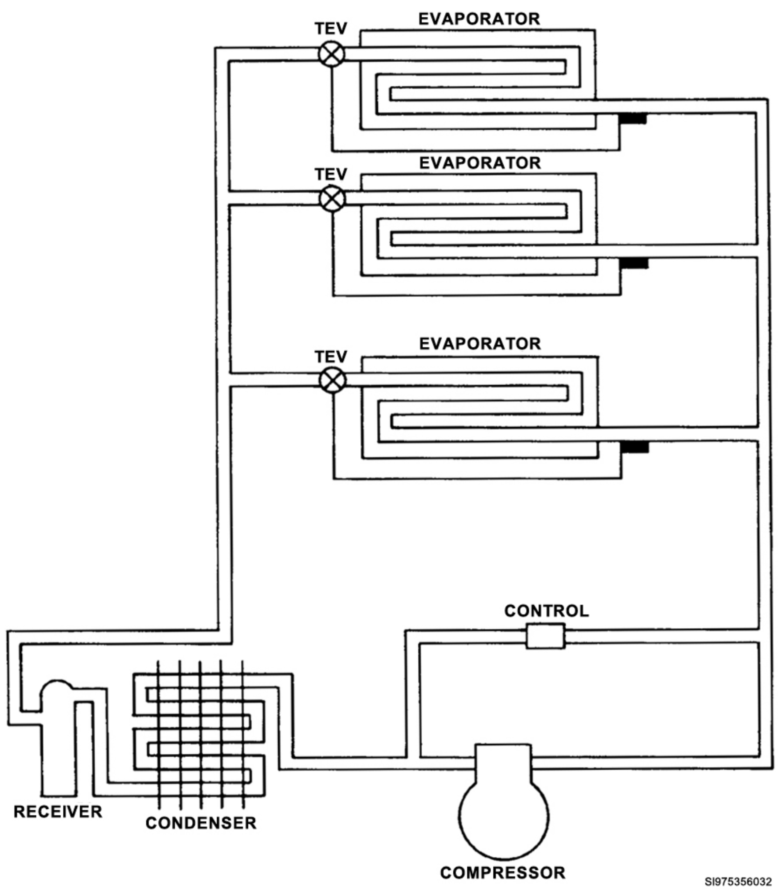


Figure 3–2. Single-temperature, multiple-evaporator system.

Multiple-temperature, multiple-evaporator system

As we mentioned earlier, a multiple-temperature evaporator system has several evaporators operating at different temperatures. When two or more evaporators are operated from the same compressor and the temperature difference is greater than 5 °F, some sort of valve or control for the warmer evaporator is necessary. Solenoid valves are used for this purpose. These valves may be placed in either the liquid line or the suction line.

Figure 3–3 shows a multiple hookup using solenoid valves in the liquid line. As you can see, there is a thermostat in each refrigerated space. You can also see that this thermostat is connected to solenoid valves that are in the liquid lines leading to each evaporator.

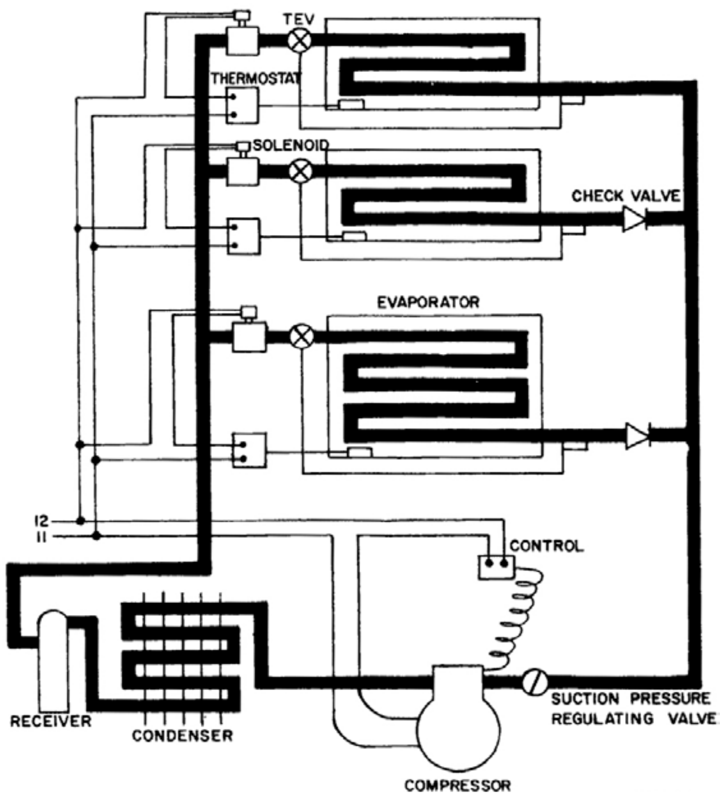


Figure 3–3. Liquid-line solenoid-valve multiple-temperature system.

The operation of the system is as follows. Let's say that all the thermostats are calling for cooling and the compressor is operating. When one thermostat is satisfied, it opens the circuit and the solenoid valve closes the liquid line to the evaporator. When this happens, the compressor pulls the refrigerant from that evaporator and continues to operate on the others. As each thermostat is satisfied, its solenoid valve closes. When all valves are finally closed, the compressor pulls the pressure in the suction line down to the cutout point of the low-pressure control. The compressor then stops.

The thermostat closes the circuit, thus causing the solenoid valve to open when the temperature of any evaporator increases to the cut-in setting. This causes refrigerant to flow into the evaporator and increase the pressure in the suction line. The compressor starts providing refrigerant only to that evaporator calling for cooling when the suction pressure increases to the cut-in point on the pressure control.

As we stated earlier, the solenoid valves may be located in the suction line. If this is the case, there's usually an accumulator installed in the suction line (near the compressor) to make sure that no liquid refrigerant enters the compressor when any solenoid valve first opens. Figure 3–4 shows a system with solenoid valves in the suction line.

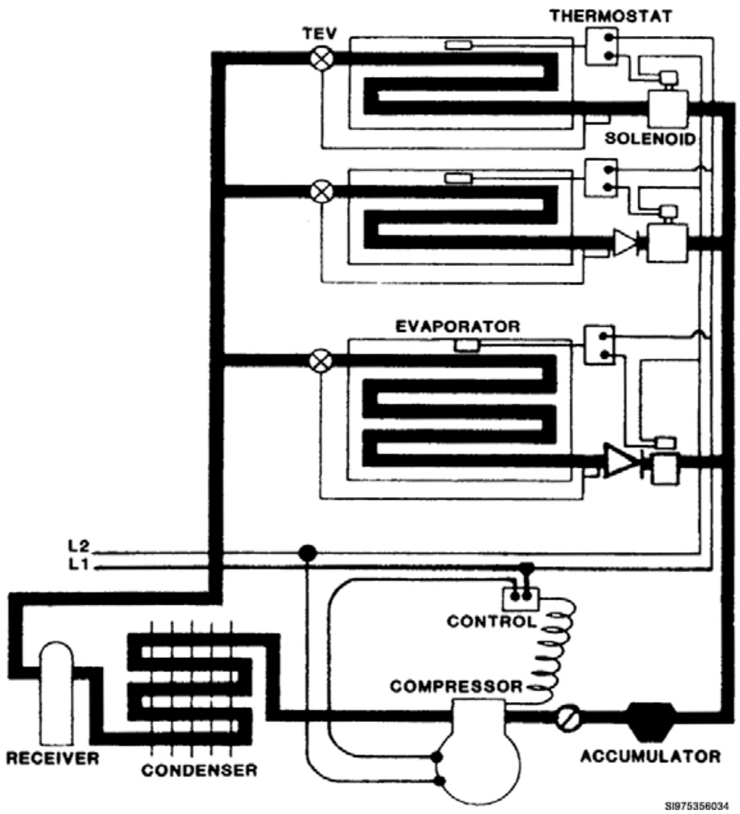


Figure 3–4. Suction-line solenoid-valve multiple-temperature system.

Evaporator pressure regulators

In addition to using thermostats, low-pressure controls, and solenoids to control the temperatures of multiple-temperature, multiple-evaporator systems, a device called an evaporator pressure regulating (EPR) valve may be used. These valves are used in the place of the thermostats and solenoid valves to control the temperature in a multiple-temperature system. To do this, an EPR valve is placed in the suction line of the warmer evaporator. As the name implies, the EPR valve is used to control evaporator pressure. Since it controls evaporator pressure, it also controls the saturation temperature of the evaporator. The valve is designed to keep the evaporator pressure constant and does *not* allow it to go below the predetermined setting of the valve. When two or more evaporators are operated with one compressor, the desired temperature in the warmer evaporator can be maintained by the proper setting of the EPR valve.

There are three types of EPR valves currently in use:

- Snap-action type.
- Metering type.
- Electric type.

Each type is described in the following table.

Evaporator Pressure Regulating Valves	
Type	**Description**
Snap-action	A suction pressure-regulating valve of the snap-action type is *not* designed for throttling refrigerant flow. Instead, this valve is either wide open or closed tightly. As such it can be set to cut in and out at definite predetermined pressures. Snap-action-type EPR valves are used when you want to operate an evaporator on a

Evaporator Pressure Regulating Valves	
Type	**Description**
	defrosting cycle or when a shorter operating time than that provided by the condensing unit is required. The effect of using a snap-action valve on an evaporator in a multiple system is the same as if it were connected to a separate compressor. Most valves of this type have a gauge port where you can attach a gauge to aid in the proper setting and can be used for bypassing to pump the unit down.
Metering	This valves opens up in proportion to the evaporator's pressure. This valve throttles the refrigerant as opposed to the snap action type. The valve can be in any location between fully open and fully closed.
Electric	This type of EPR reacts to the outlet *air* temperature instead of evaporator pressure. A thermistor is placed in the air outlet of the evaporator to sense the air temperature. A control module receives the information from the sensor and operates the valve as required. Again, an input is received by the control from the thermistor and the proper output is sent from the control to the stepper motor. The control module accomplishes this task using electronics and algorithms. As the temperature goes up, the valve opens using a stepper motor. This motor allows the valve to be opened (or closed) in very small increments which provide precision control.

EPR valve multiple-evaporator system

Now that we have discussed the operation of the types of EPR valves, let's look at a system that uses EPR valves (fig. 3–5).

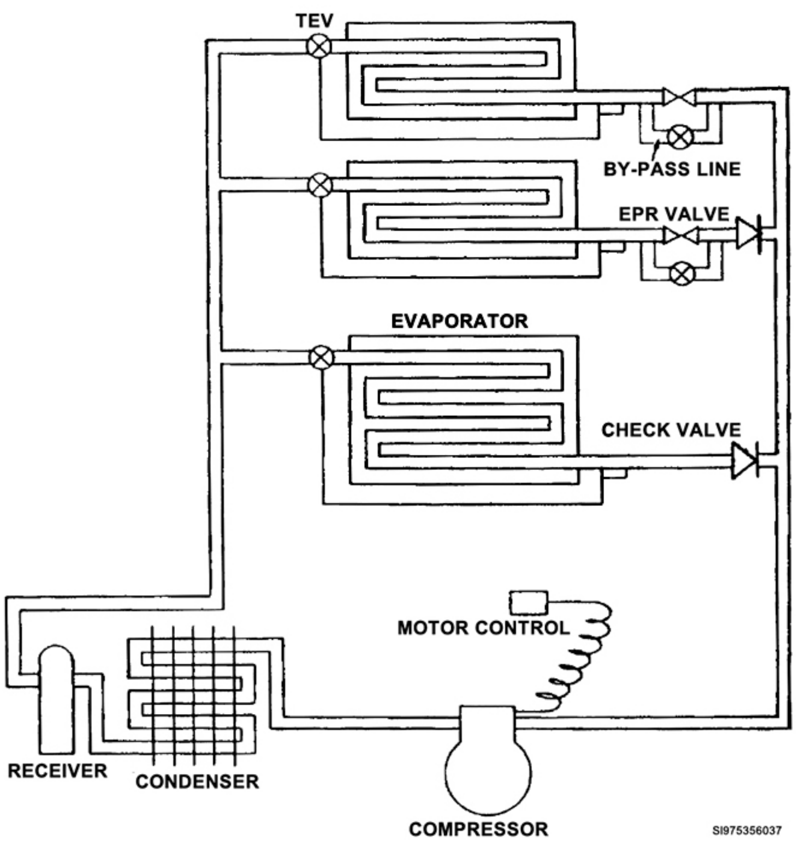


Figure 3–5. EPR valves with multiple evaporators.

Let's say we have determined the cutout temperature of each evaporator and our EPR valves are adjusted. As the compressor operates, the pressure in the evaporator is lowered. When it reaches the cutout temperature point of the evaporator, the EPR valve closes. This stops the flow of refrigerant through the evaporator. As the temperature and pressure rise in the evaporator, they rise in the valve and force the valve off its seat. This holds the evaporator pressure constant because of the gradual movement of the refrigerant. The compressor operates if the gradual flow of refrigerant is sufficient to make the pressure in the common suction line increase to the cut-in point of the motor control. This pulls the pressure down to the cutout point. If there is a rapid evaporator-pressure increase because of the addition of a high-heat load, the valve opens all the way. This directs the evaporator pressure to the common suction line, where it is pulled down to the cutout point of the compressor. The valve closes when the evaporator is cold enough.

Multi-compressor systems

Previously, we looked at multiple-evaporator systems, now we turn our attention to systems that use multiple compressors. There are many reasons why multiple compressors may be used on systems. They are sometimes connected in parallel to obtain greater flexibility. At other times, several small compressors may be used on one evaporator when a large single compressor will not allow a proper balance of operation.

We'll cover four major areas:

- Advantages of multi-compressor systems.
- Disadvantages of multi-compressor systems.
- Multi-compressor connection requirements.
- Control of multiple compressors.

Advantages

The following are three major advantages to be gained by using multiple-compressor units on one evaporator space.

Advantages of Multiple-Compressor Units	
Advantage	**Description**
Partial operation in case of failure of one unit	Some facilities in the Air Force use multiple-compressor systems. These facilities can contain thousands of dollars' worth of perishable commodities. In the event one compressor fails, the other can maintain the temperature low enough to prevent spoilage until the malfunctioning unit can be repaired.
Economy of operation at low loads	Let's say the maximum load of a system is 75 tons and that the system is equipped with three 25-ton units. When there is a large heat load on the system, all three units would be operating. However as the heat load decreases, the load may be 25 tons or less, requiring operation of only one unit with a savings in power cost and equipment usage.
Control of refrigeration effect	Refrigeration effect can be maintained regardless of the heat load. • One 25-ton compressor cools the refrigerated space during low load conditions. • As the heat load increases, the second compressor cycles on. • At maximum load, the third compressor operates.

Disadvantages

There are two major disadvantages of using multiple compressors, described below.

Disadvantages of Multiple-Compressor Units	
Disadvantage	**Description**
Initial cost	The initial cost of two or more small condensing units is more than for one big unit with a capacity that equals the capacity of the smaller ones. In addition, it is cheaper to install one big unit than several smaller ones.
Crankcase and suction pressure	There is a small difference in crankcase pressure. For proper operation, the suction pressure must be the same in each crankcase. If the pressures are not equal, oil collects in the compressor with the lowest pressure. This causes the other compressor to fail due to lack of oil. From this, you can see that the principal difficulty in interconnecting condensing units is in the oil return to the crankcase. The degree of difficulty can be greater or lesser depending on the refrigerant used. In contrast, chlorofluorocarbon (CFC), hydrochlorofluorocarbon (HCFC), hydrofluorocarbon (HFC), and other oil-mixable refrigerants present a real difficulty when condensing units that use them are interconnected. For this reason, multiple installations of condensing units should be avoided and should be made only when it is *not* possible to split up the units so that each evaporator has its own condensing unit.

Multi-compressor connection requirements

Compressors that are to be interconnected should be from the same manufacturer and preferably of the same size. A good installation is one where each condensing unit carries its share of the load and the oil return is such that the proper level is maintained. To get this load balance, the suction and discharge should be interconnected. In addition, oil and gas-equalizer lines *must* be installed between the crankcases. The compressors should be placed close to each other so that the connecting lines are as short as possible.

Balanced refrigerant lines

The refrigerant lines must be balanced to distribute the heat load as equally as possible between the compressors. This involves installing lines of equal lengths and bends between the common junction and the compressors on system suction lines. These lines are the same in regards to number of elbows and lengths of tubing from the junction to the compressors, equalizing internal friction. Another precaution for suction lines is to connect them so that oil returning through the line divides as evenly as possible between the compressors.

The same care should be taken to install discharge lines from the compressor; that is, in the same way to balance the resistance from the compressor to the common junction.

Oil-equalizer line

Earlier we stated that multiple compressors must have oil-equalizer lines. There are two types—crankcase oil-equalizer and gas-equalizer.

The *crankcase oil-equalizer line* may be connected in two ways:

- The preferred method is to connect the lines in a straight line, not allowing oil to collect.
- The other method is to connect the lines below the compressor. This happens because of the location of plugs in the crankcases of some compressors where the equalizer lines may be connected.

In all cases, the oil-equalizer connection should be made at the lowest safe oil level. In addition, condensing units should be placed on their foundations so that the oil level in each is in the same horizontal plane.

The *gas-equalizer connection* is made *above the maximum oil level* and all equalizer lines should be level.

Control of multiple compressors

At times, condensing units may be interconnected for the purpose of capacity control. When this happens, there must be a way to start and stop the compressors according to load demands.

For liquid or air-cooling, there are times when close temperature control is not required. In these cases, two temperature controls may be used—one being set a degree or two higher than the other. A more common method is to use pressure controls on a common suction line. These pressure controls are set in sequence so that the compressors start and stop according to changes in suction pressure. Thermostats and solenoid valves are usually installed when this method is used.

There are times when a number of compressors are connected together, or when an installation consists of a number of single evaporator and condensing unit installations in one refrigerated space. In some designs, all compressors normally start at the same time. As you would expect, this puts a very heavy load on the electric power system. To correct this problem, time delays are often used. In these applications, a timer delays starting the other compressors until after the first one starts. The timer is set so that when the contractor for the first compressor closes there is a delay of 10 or 15 seconds before the timer closes the control circuit of the second compressor and allows it to start.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

814. Characteristics of cold storage devices and refrigeration defrosting

1. What are the two types of cold storage units?

2. Where are the warmer rooms located in a permanent cold storage building?

3. What purpose do exterior rooms serve in cold storage buildings?

4. Why would a hot gas line be placed in the condensate drain?

5. What is required to make cold storage doors airtight?

6. What effect could outdoor heat have on products inside a cold storage device?

7. What can doors be equipped with to prevent sweating?

8. What freezes on evaporator coils in cold storage units?

9. What is the *main disadvantage* of *manual defrost*?

10. What could happen to products if they aren't removed during manual defrost?

11. If a defrost interval is set for every 6 hours, how often would defrost initiate in a *simple time defrost system*?

12. If a defrost duration is set for 10 minutes, how long will defrost run in a *simple timed defrost system*?

13. Why are the defrost timer and compressor wired in parallel in a *cumulative run time defrost* system?

14. Why does *demand defrost* base defrost on the amount of times the door is opened?

15. How does *adaptive defrost* determine the next defrost cycle?

16. What does *adaptive defrost* compare actual defrost time to?

17. How often does *adaptive defrost* monitor defrost times?

18. When does *time-initiated, temperature-terminated* end defrost?

19. When does *time-initiated, pressure-terminated* end defrost?

20. Where does hot gas travel to during *hot gas defrosting*?

21. Why do *hot wire* defrost systems require heating of the drains?

22. What is a big *advantage of hot wire* defrost?

815. Multiple component refrigeration systems

1. How are the needs of each evaporator met in *single-temperature, multiple evaporator* system?

2. What happens when all *single-temperature, multiple evaporators* have been satisfied?

3. What happens when the compressor pulls down pressure in common suction line down to the cutout point?

4. Where can solenoid valves be placed in a *multi-temp, multi-evap* system?

5. What happens when the thermostat for solenoid valve closes in a *multi-temp, multi-evap* system?

6. What does the evaporator pressure regulator control since it controls the evaporator pressure?

7. Where is the thermistor sensor placed when using an electric EPR valve?

8. How does an electric-type EPR valve determine the proper output?

9. What does the control of an electric EPR valve use to accomplish its tasks?

10. What must be installed between the crankcases of a *multi-compressor* system?

11. What are used to correct heavy loads that result from all compressors starting at the same time?

3–2. Direct Expansion Cooling Systems

Now we turn are attention to direct expansion cooling systems. Up to this point we really haven't mentioned the difference between direct and indirect systems. In this section, we discuss direct expansion systems with an emphasis on cooling. Though frigdes and freezers are direct expansion, it is time to turn our focus to cooling or what is usually called air conditioning.

816. Types of residential direct expansion air-conditioning systems

Residential air conditioners come in various configurations. We discuss three types of residential units:

- Packaged units.
- Split systems.
- Heat pumps.

As the name "residential air-conditioning systems" implies, these units are found in residential areas.

Packaged (self-contained) units

As the name implies, packaged units come as a complete package. As such, they have the compressor, metering device, evaporator, condenser, fans, and controls in one unit. Package units don't come with ductwork, gas piping, electric power supply and a complete condensate drain line.

> **NOTE:** Some units may have a condensate drain that needs piping to carry the condensate to a location away from walkways or areas where condensate puddles are troublesome or dangerous. Also, some units may have thermostats built into them and some need a thermostat installed.

Package units are installed in a hole in the wall, the eaves of a structure, on the side of the building or on top of the building.

They can be as small as the window unit that handles one room or large enough to handle a family residence or small office building. Here we cover these package units:

- Window units.
- Packaged terminal air conditioners (PTAC).
- Console air conditioning.
- Central self-contained.
- Roof top units (RTU).

Window units

The window-unit air conditioner is designed for mounting in a window or through a wall. It is also designed for delivery of conditioned air to an enclosed space without the use of ducts. The basic function is to provide comfort by filtering, cooling, dehumidifying, and circulating the room air. It can also provide ventilation by introducing filtered outdoor air into the room or exhausting room air to the outside. These systems are often used on deployments to the desert. If they "go bad," the normal procedure is to replace the entire unit.

Window unit features

Many window units use thermostatic expansion valve (TXV), automatic expansion valve (AXV), or capillary tubes for metering devices. One motor can be used to drive both the condenser fan and evaporator fan. In some units each fan has its own motor.

As the evaporator cools air, moisture in the air condenses on the evaporator and falls into a drip pan. The drip pan is connected to tubing that carries the condensate outside or to a pan in the compressor compartment. The drip pan can become clogged and cause the unit to leak condensate.

Window units have built-in thermostats (T-stat). The sensing bulb for the T-stat is located at the inlet of the evaporator. Some window units have a remote control. The remote control allows the user or technician to control the system without having to walk over to the unit. The control can also program the system for certain times, temperatures, and fan speeds.

Some window units have heating capabilities. It is usually electric heat and it is also controlled by the thermostat. Figure 3–6 is an example of a window unit with electric heat. Other systems bring in fresh air. Finally, some window units are heat pumps (discussed later).

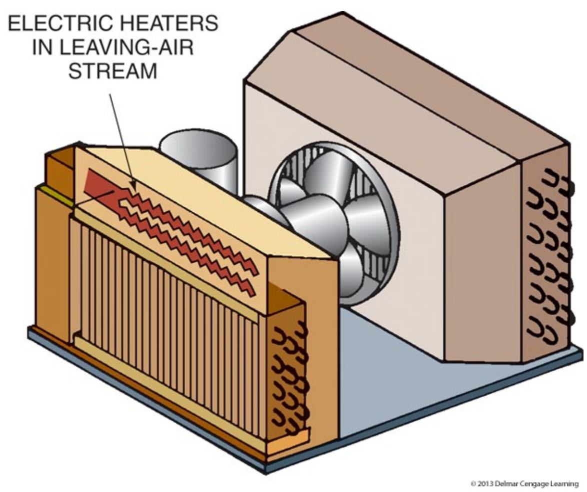


Figure 3–6. Window unit with electric heat.
(Courtesy Cengage Learning.)

Packaged terminal air conditioner

A packaged terminal air conditioner (PTAC) is a self-contained AC unit that is ductless. You find them on the exterior walls of the building they are installed on. They are used in buildings such as dorms, lodging units, and offices. They often provide both heating and cooling capabilities but some are for cooling only. When equipped with heat it uses either electric resistance heaters, heat pumps, both electric and heat pump, or gas fired heaters. Return air enters the PTAC through a lower grille and is discharged at the top of the unit.

PTACs are easily removed from the hole in the wall that they sit in.

> **Technician's Note:** If the PTAC you are working on uses electric heaters, it usually requires 220-volt wiring. Ensure you are aware there could be 24 volts, alternating current (VAC) control voltage, 120 VAC, and 220 VAC all in one PTAC unit.

Console air conditioner

Console air conditioners house an entire AC system in one vertical cabinet. They may have water-cooled or air-cooled condensing units. Air-cooled units require air ducts to carry heated air from the condenser to the outside. Water-cooled units require water to be piped to and from the unit.

Two separate fans and motors are used to move the air. In contrast, the window-mounted air conditioner normally uses only one fan. Fresh air or ventilating air is bypassed from the condenser air just as it leaves the condenser fan. This air conditioner is often applied to small commercial uses. In these applications, it can be used for comfort cooling and may be applied to the control of cooling temperature and humidity for small manufacturing processes.

Central self-contained

Just like the window unit, these units are a complete package. They differ from the window unit in that they have supply and return air ducts that are attached to the building's duct system. The building's ductwork then supplies air-conditioning to individual rooms. The ductwork makes this unit a central unit.

Some central units even have heat, which can be either gas or electric. These type units also have two fans—one for the evaporator and one for the condenser. A thermostat mounted inside the conditioned space is used to control system operation to keep the space at the desired temperature. These units are popular for mobile homes where they can be seen at one side or mounted underneath.

Roof top package units

As the name implies, you will find roof top package units on roofs. Also, as the name implies, these systems are package units. They are shipped factory-assembled and factory-charged. In the industry, a roof top package unit can be called an RTU.

Return air from the building is brought up to the unit. The controls in the unit determine if the return air is exhausted or mixed with outside air. This mixed air then travels over the cooling coil and cool air is produced. The supply air can be either constant or varied.

Roof top unit economizer

The economizer on a RTU uses cool outside air to help cool the conditioned space when outside ambient temperatures are low. The amount of outside air used is determined from either the dry-bulb temperature of the outside air or the enthalpy of the outside air. *Enthalpy is more accurate* because it considers the *total heat content* of the air. Total heat means sensible and latent heat are considered.

The dry-bulb temperature or enthalpy of the inside air is compared to the outside air.

If outside air is used to cool the space, it is called *free cooling* because it costs no money to cool outside air. The outside air intake is modulated by two dampers—one in the return air (RA) stream and the other in the outside air (OA) stream. They are opposed which means as one closes the other opens. So, as the controller determines the air requirements it moves the dampers' position. As more outside air can be used the OA dampers modulate open and the RA dampers modulate close. Notice the use of the word *modulate*. This is important because the dampers don't just *close or open.* They close *a little* or *a lot.* They could potentially open all the way but it is important for you to know they don't open or close 100 percent every time a signal is sent to them.

Split systems

Split system is a term that can be applied to a number of different situations and configurations. When you take a component and make it separate from the previously discussed packaged unit, you have created a split system. Split systems are a popular type of air-conditioning in residential systems. In the residential split system, the evaporator (air handler) is placed inside the home while the condensing unit is placed outside (fig. 3–7). The condensing unit (outside unit) has the compressor, condenser, and fan motor, while the air handler houses the metering device and evaporator. In figure 3–8 you can see that part of the system is outside.

> **NOTE:** Some condensing units may have the metering device at the condensing unit. An example is the heat pump, which we discuss later.

Some computer room units consist of a split system contained in one console. One part of the system protrudes inside the room. This part of the console contains the compressor, evaporator, metering device, evaporator fan, and humidity control. The other part of the console is outside the room and contains the condenser and fan.

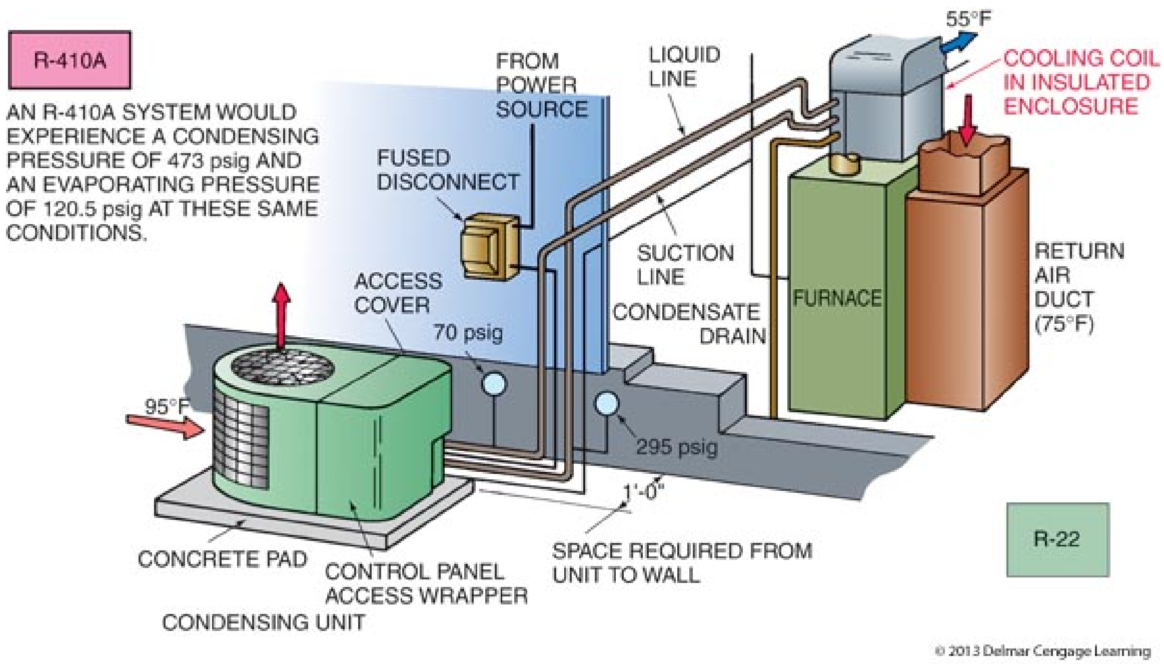


Figure 3–7. Split system.
(Courtesy Cengage Learning.)

Figure 3–8. Outside and inside unit of split system.

817. Heat pumps

A heat pump is a heat-moving mechanism. Just like in a simple air conditioner, heat is absorbed by an evaporator in one location and is released through a condenser in another location. What makes the heat pump unique is that the system can reverse its operation so that the evaporator becomes the condenser and the condenser becomes the evaporator. By using a special reversing valve, we can make the mechanism either heat or cool a conditioned space.

Heat pumps are classified according to their heat sources. There are ground source heat pumps and air source heat pumps. This lesson covers air source heat pumps only. Ground source heat pumps are covered in a future lesson. Heat pumps can be used as split systems or package units.

A heat pump can operate both in winter and in summer; however, to accomplish this requires special design factors:

- The compressor must be capable of operating at low outdoor temperatures.
- The evaporator and condenser coils must be sized and circuited to both evaporate and condense refrigerant.
- The metering device must be able to meter refrigerant properly to each coil.
- The refrigerant must pass through the previously mentioned reversing valve. This valve is usually four-way and is controlled by a solenoid.
- Heat pumps also have to be equipped with an accumulator and a crankcase heater.

Air-source heat pumps

This type of heat pump uses outdoor air as its source of heat to create desired conditioned space temperatures. They are the most efficient in milder climates where the winter temperatures don't drop below freezing very often. Air-source heat pumps fall into two sub-categories: air-to-air and air-to-water heat pumps.

Air-Source Heat Pumps	
Type	**Description**
Air-to-air	Air-to-air heat pumps transfer heat from the air in the conditioned space to outside ambient air. These systems can look similar to a regular split or package system. The outdoor unit contains the outside coil, fan and compressor. The outdoor unit contains the reversing valve also. The indoor unit contains the indoor coil and blower assembly. As a package unit, all components are in one unit that is placed outside the facility. Return and supply air is ducted to the facility. Finally, there are ductless, split system heat pumps.
Air-to-water	These heat pumps also transfer heat between inside and outside air but they use a water system to aid the process. A water coil heat exchanger absorbs heat from the refrigerant while the unit is in heating mode and rejects heat that was absorbed by the refrigerant in the cooling mode.

Heat pump efficiency

Heat pump efficiency is determined by one of four methods:

- Energy Efficiency Rating (EER).
- Seasonal Energy Efficiency Ratio (SEER).
- Heating seasonal performance factor (HSPF).
- Coefficient of performance (COP).

The higher the number, the more efficient the system. Thus, a 14-SEER heat pump is more efficient than a 12-SEER heat pump.

For air-to-air heat pumps in heating mode, efficiency drops as the outdoor air temperature drops. This is because the heat pump is trying to absorb heat from the outdoor air but there is less heat available to absorb as the temperature falls.

With all these thoughts in mind, let's turn our attention to the heat pump's operating principles during these cycles:

- Cooling.
- Heating.

- Defrost.

Cooling cycle

Refer to figure 3–9 as we trace the cooling cycle. In figure 3–9, the evaporator coil is the one on the right. You can tell that by the type of fan—a squirrel-cage type. The coil on the left is the condenser. You can tell by the type of fan—a propeller type. The middle of the drawing shows three parts: a compressor, an accumulator, and the reversing valve (directly above the compressor).

Follow the arrows guiding you through the cycle in figure 3–9 as we cover the refrigerant. Starting at the top of the compressor, follow the arrow up to the reversing valve and over to the condenser. Here the compressed gas cools until it becomes a liquid refrigerant. Now follow the arrows through the metering device and liquid line to the evaporator. As you know, the evaporator picks up heat and the refrigerant is changed to a vapor. Follow the arrow from the suction line to the reversing valve. In the cooling cycle, the refrigerant travels through the reversing valve to the accumulator. At the accumulator, any liquid collects so it does not go to the compressor. Follow the arrow from the accumulator back to the compressor. At the compressor, the refrigerant vapor is compressed and discharged through the discharge line. Again the refrigerant goes to the reversing valve to continue the cycle.

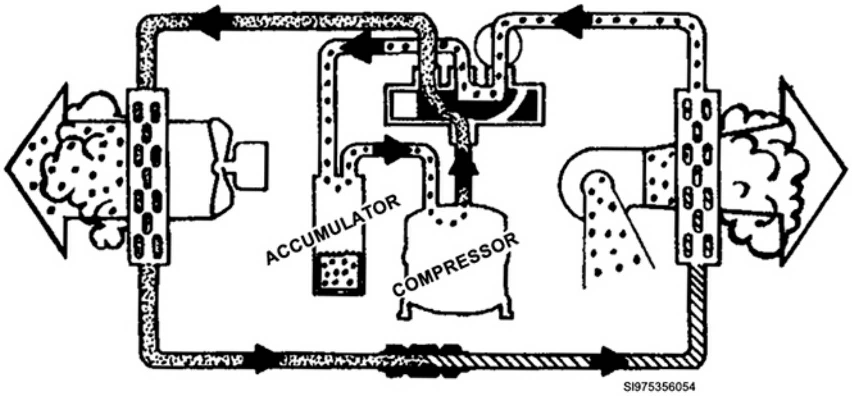


Figure 3–9. Cooling cycle.

Even though we are covering the heat pump, the refrigerant cycle has not changed from what you have learned previously. By now, you are probably starting to understand that the reversing valve is the key to the operation of the heat pump. Before moving on to the heating cycle, make sure you understand the basic cooling cycle.

Heating cycle

Now it is time to get a handle on the heating cycle (fig. 3–10). Begin at the top of the compressor and follow the arrow to the reversing valve. Notice that this time, the refrigerant travels through a reversing valve—the key feature of a heat pump—and goes to the indoor coil. Remember the compressor has just compressed the refrigerant vapor; that is; the vapor has been heated and needs to be cooled. As the evaporator fan circulates air across the coil, the air is heated because it is cooler than the hot refrigerant in the coil. As the coil gives up heat to the room, the refrigerant condenses and travels through the coil and into the liquid line toward the outdoor coil. The refrigerant goes to the outdoor coil and absorbs heat from the outside.

This happens because the refrigerant has a pressure drop as it goes through the metering device. As it travels through the condenser coil, the fan circulates outside air over the coil. Because the coil is colder than the outside air, heat is absorbed. Follow the arrow from the condenser coil to the reversing valve. The refrigerant travels through the valve to the accumulator. Any liquid refrigerant is collected here, preventing it from entering the compressor. The refrigerant leaves the accumulator and goes to the compressor. The compressor compresses the vapor, discharges it back toward the valve, and the cycle starts over again.

Did you understand how the coils traded places? Remember the evaporator became the condenser and the condenser became the evaporator. Interchanging terminology can sometimes cause confusion. For many individuals, an evaporator is always the coil inside and the condenser is always the coil outside. So to prevent confusion, when referring to a heat pump the **evaporator** is called the *inside coil;* the **condenser** is called the *outside coil.*

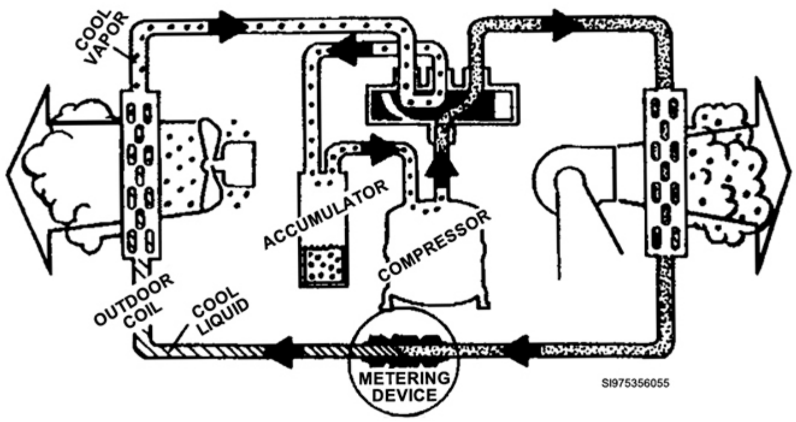


Figure 3–10. Heating cycle.

Defrost cycle

It is quite possible for the outdoor temperature to be below freezing when a heat pump is in the heating cycle. Under these conditions, the moisture removed from the air passing over the outdoor coil can freeze on the surface of the cold coil. Eventually the frost on the coil can build up enough to reduce the amount of air passing over the coil. Of course, this causes the coil to lose its efficiency. If the frost gets on the fins, the coil efficiency is reduced even further. When the coil efficiency is impaired enough to appreciably affect the system capacity, the frost must be removed. This is accomplished by the unit's going into a defrost cycle. Refer to figure 3–11 as we discuss this cycle.

Figure 3–11 shows that by de-energizing the reversing valve, the system returns to the cooling cycle. This will direct the hot discharge gas to the outdoor coil to melt the frost. The outdoor fan shuts off during the defrost cycle. If the fan blows air across the outdoor coil during defrost, more work is made for the compressor. Not only does the compressor have to pump sufficient heat to melt the frost, it also has to pump enough heat to overcome the additional load imposed by the cold air being blown across the coil. Figure 3–12 shows the fan off in the defrost cycle.

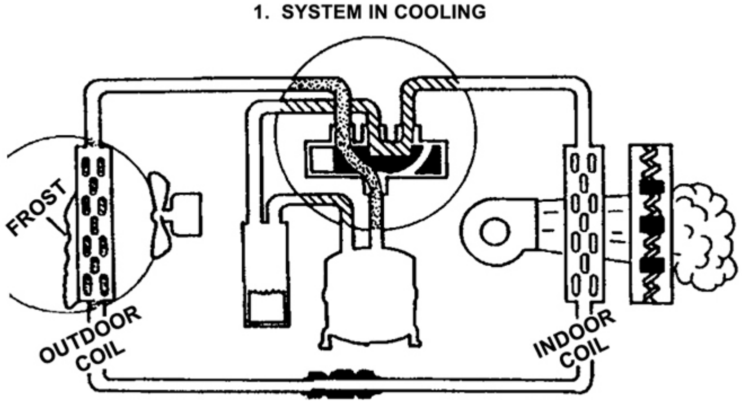


Figure 3–11. Defrost cycle.

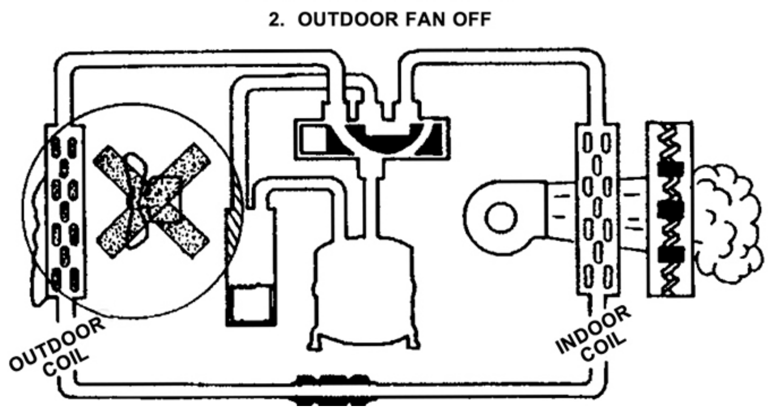


Figure 3–12. Fan off in the defrost cycle.

The heat pump is in the heating cycle when the defrost cycle begins. In the defrost cycle, the heat pump switches to the cooling cycle. This means that cool air would be blown into the conditioned space. This is not desirable during the winter months. To overcome this, electric resistive strip heaters are energized to temper the air into the conditioned space during defrost (fig. 3–13). If the heaters are already on when the defrost cycle is initiated, they remain on as needed.

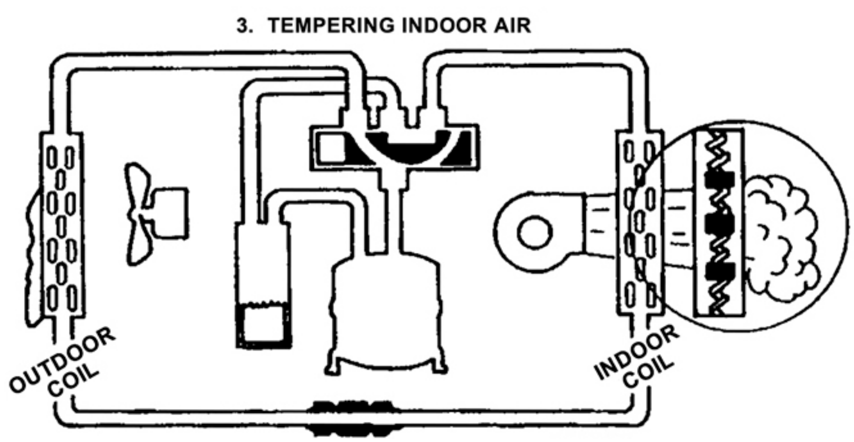


Figure 3–13. Electric strip heaters during defrost cycle.

Figure 3–14 shows the heat pump in the complete defrost cycle. The unit is in cooling, the outdoor fan is off, and the indoor air is tempered by supplemental heat. The electric resistive heat strips give off supplemental heat.

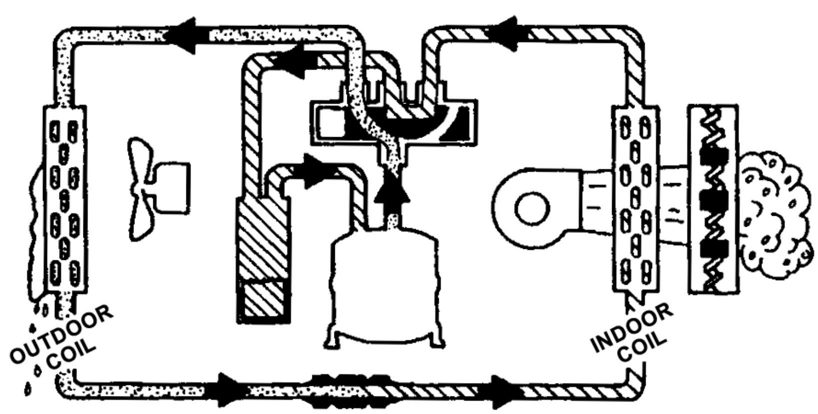


Figure 3–14. Complete defrost cycle.

These resistive heaters also provide additional heat during the winter if the heat pump cannot keep up with the heating demand. A single-stage cooling and two-stage heating thermostat is used to control their operation. When the heat pump is operating and the temperature keeps dropping, the thermostat contacts close and the electric resistive heat strips come on to aid the heat pump in heating the home. As the heat begins to rise, the heater strips cycle off first. The heat pump cycles off when the set point is reached.

Now that you understand the refrigerant flow during cooling and heating cycles of the heat pump, we need to further expand your knowledge by covering some of the operating principles of the important components found on heat pump units:

- Reversing valve.
- Metering device.
- Compressor.
- Accumulator.
- Controls.

Reversing valve

We briefly looked at the flow of refrigerant through the reversing valve when we discussed the cooling and heating cycles. We now take an in-depth look at the operating characteristics of the valve. As you can see in figure 3–15, the reversing valve has four piping connections. Refrigerant flow through two of these connections never changes: the hot gas discharged from the compressor and the suction line back to the compressor. On the side of the valve with three stubs the middle stub is for the suction line. The side with only one stub is the compressor discharge. The remaining two ports connect to the outdoor and the indoor coils, and the direction of flow depends on the cycle.

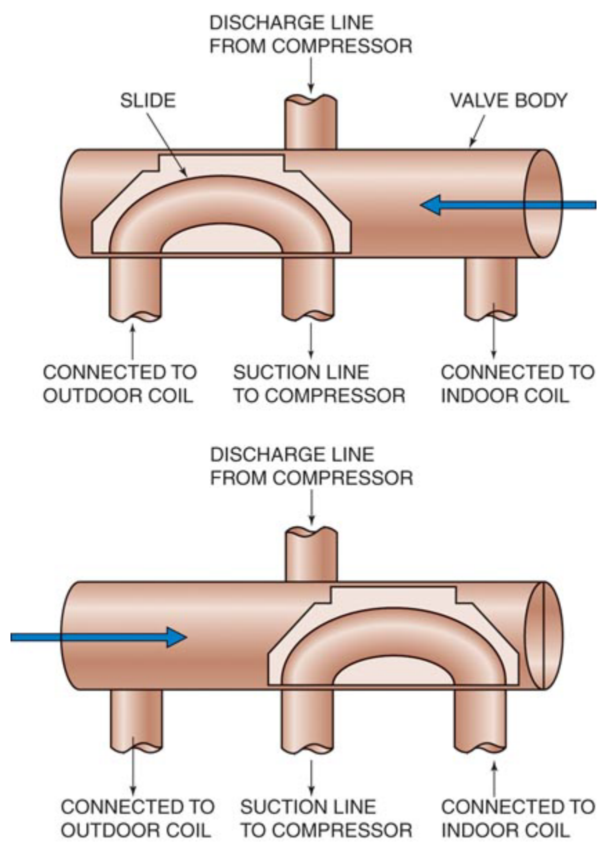


Figure 3–15. Reversing valve slide.
(Courtesy Cengage Learning.)

There is a free-floating slide that directs the refrigerant flow. Refrigerant pressure is used to change the slide position. The direction of flow changes appropriately as the slide changes the refrigerant flow to and from the coils.

The compressor discharge is connected to a single port on the cylinder. There is always discharge-pressure bleeding between the ends of the slide, this is represented by the arrows. There is a small orifice at each end of the slide that allows the discharge gas to bleed behind the slide.

Now look at figure 3–16. Notice the capillary lines at both ends of the cylinder. As you can see, these connect to a pilot solenoid chamber. Also connected to the pilot solenoid chamber is another capillary that connects to the suction line. Here it is the center capillary.

The valve is solenoid controlled. The pilot solenoid pin carrier changes position when the solenoid coil is energized or de-energized.

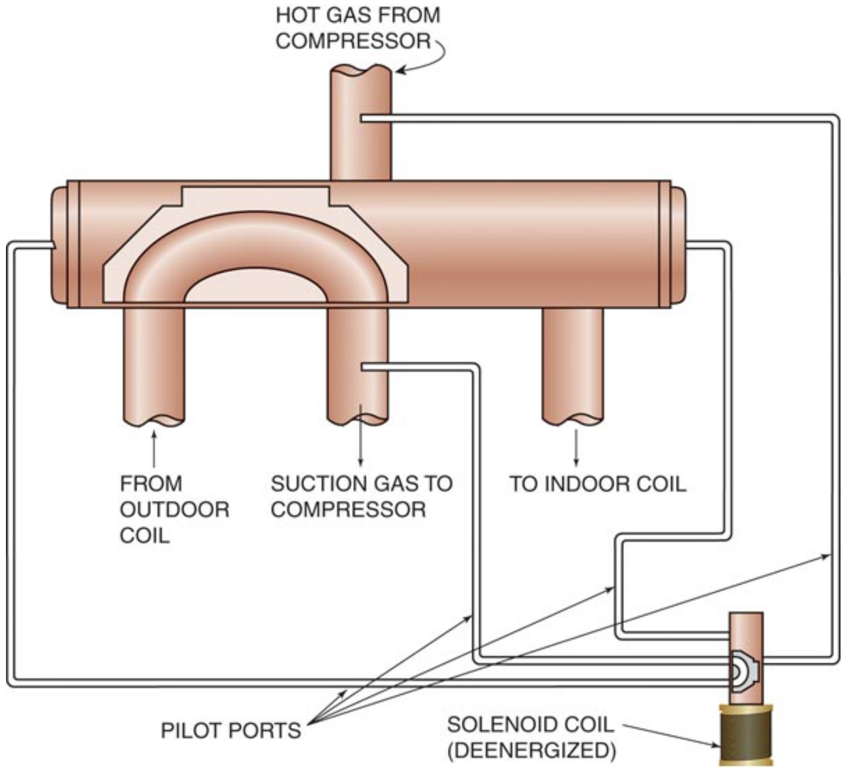


Figure 3–16. Pilot solenoid.
(Courtesy Cengage Learning.)

To give you an understanding of how the valve works in the cooling cycle, we start with figure 3–17. The solenoid is energized and the pilot solenoid pin carrier moves to the left. The compressor discharge gas bleeds behind the left-hand side of the slide. The discharge gas is trapped in the capillary tube, and the pressure builds until it reaches the discharge pressure.

Here you see the pressure is behind the right side of the slide. The pressure equals the compressor suction pressure and passes through the pilot solenoid chamber and through the center capillary to the suction line. Since the pressure behind the right side of the slide is less than the pressure behind the left side, the slide moves to the right. The flow of refrigerant is directed to the outdoor coil from the compressor discharge and the heat pump is operating in the cooling cycle.

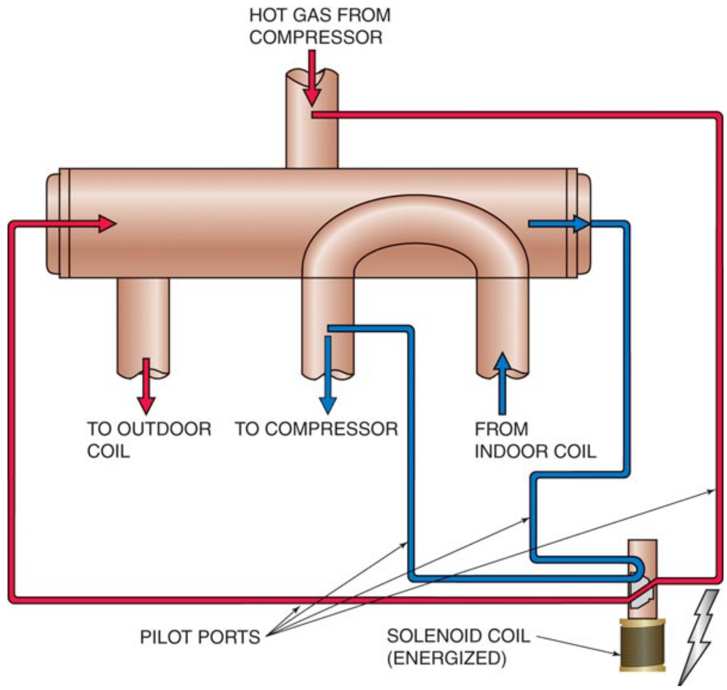


Figure 3–17. Reversing valve in cooling mode.
(Courtesy Cengage Learning.)

In figure 3–18, the pilot solenoid valve is de-energized. The pilot pin carrier moves to the right. Compressor suction pressure now passes through the center capillary and the pilot chamber down to the left side of the slide. The compressor discharge pressure bleeds through the orifice behind the right side of the slide where it is trapped. The pressure behind the left side of the slide is now less than the pressure behind the right side causing the slide to move to the left.

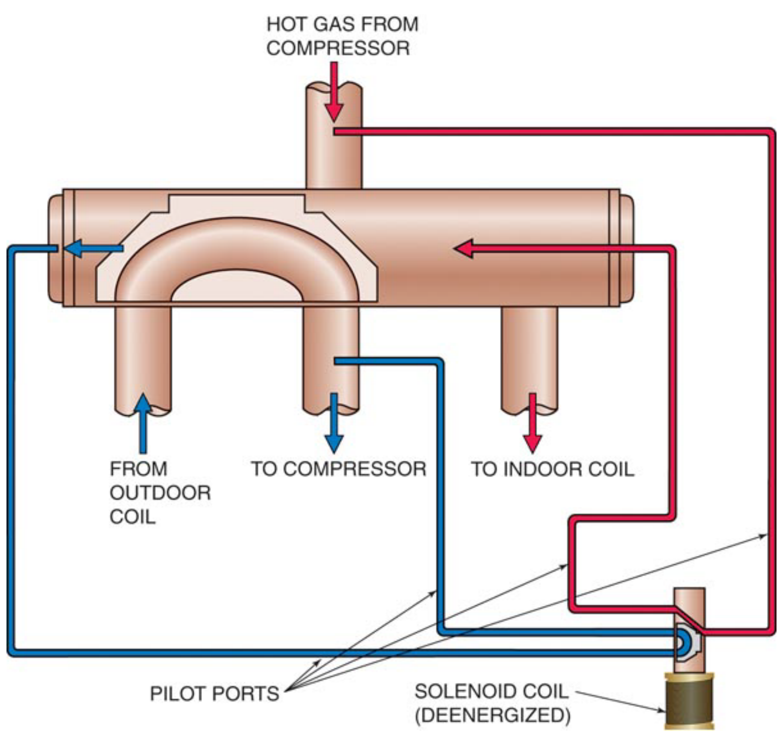


Figure 3–18. Reversing valve heating mode.
(Courtesy Cengage Learning.)

The hot gas is now directed to the indoor coil from the compressor discharge and the unit is now in the heating mode.

Let's take a final look the refrigerant line, state, and direction of flow in summer and winter modes in figures 3–19 and 3–20.

SUMMER OPERATION		
REFRIGERANT LINE	REFRIGERANT STATE	DIRECTION OF FLOW
Larger refrigerant line	Cold gas	Indoors → Outdoors
Smaller refrigerant line	Warm liquid	Outdoors → Indoors

WINTER OPERATION		
REFRIGERANT LINE	REFRIGERANT STATE	DIRECTION OF FLOW
Larger refrigerant line	Hot gas	Outdoors → Indoors
Smaller refrigerant line	Warm liquid	Indoors → Outdoors

Figure 3–19. Summer and winter operation. (Courtesy Cengage Learning.)

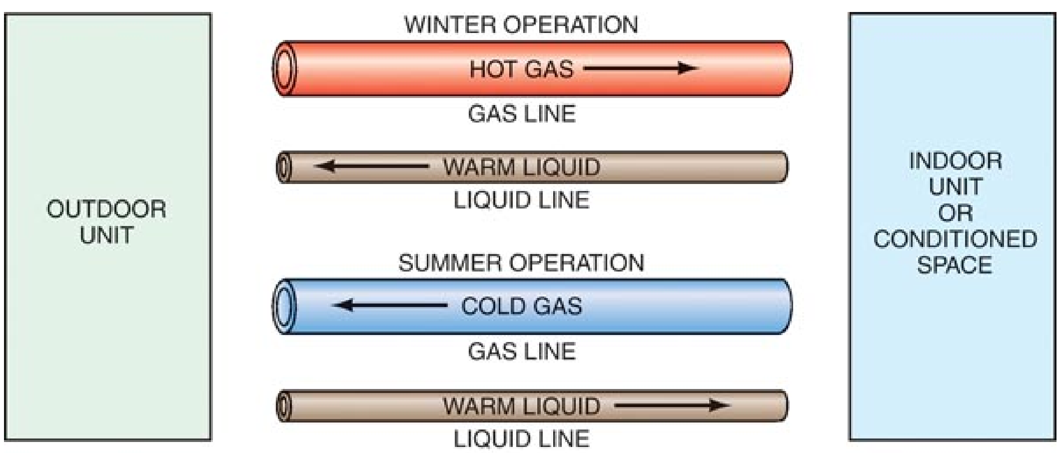


Figure 3–20. Summer and winter flow. (Courtesy Cengage Learning.)

Metering device

Heat pumps can be equipped with one or two metering devices. The most efficient heat pumps use a metering device that varies the flow, like a thermostatic expansion valve (TXV). Fixed orifices, capillary tubes and flow check pistons can also be used with heat pumps.

Thermostatic expansion valves

TXVs are very common in heat pumps. Two TXVs are used with one at the inlet of the outdoor coil and the other at the inlet of the indoor coil. Sometimes, one TXV may be used with another metering devices such as capillary tube. If this is the case, the capillary tube is used in the summer because of relatively constant temperatures and the TXV is used in winter because winter conditions are less constant (fig. 3–21).

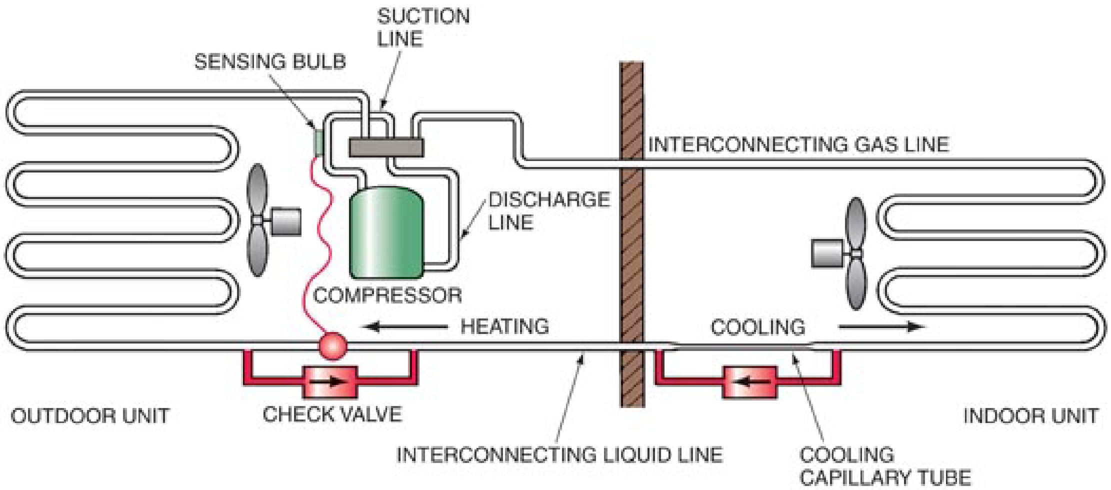


Figure 3–21. TXV for winter, cap tube for summer. (Courtesy Cengage Learning.)

Since standard TXVs allow flow in only one direction, two TXVs are required. One of these TXVs blocks refrigerant flow in each cycle. To allow flow past the TXV a check valve is installed in parallel. Each TXV has a check valve parallel to it. See figures 3–22 and 3–23 for an example.

Not all TXVs allow flow in only one direction. Some TXVs allow biflow, or flow in two directions. These TXVs have internal check valves that serve the same purpose of having two TXVs and two check valves.

Flow check pistons

The flow-check piston allows free flow in one direction and meters flow in the other direction. When the cycles reverse the flow-check piston reverses it function. It allows free flow in the other direction and meters refrigerant the other way (fig. 3–24).

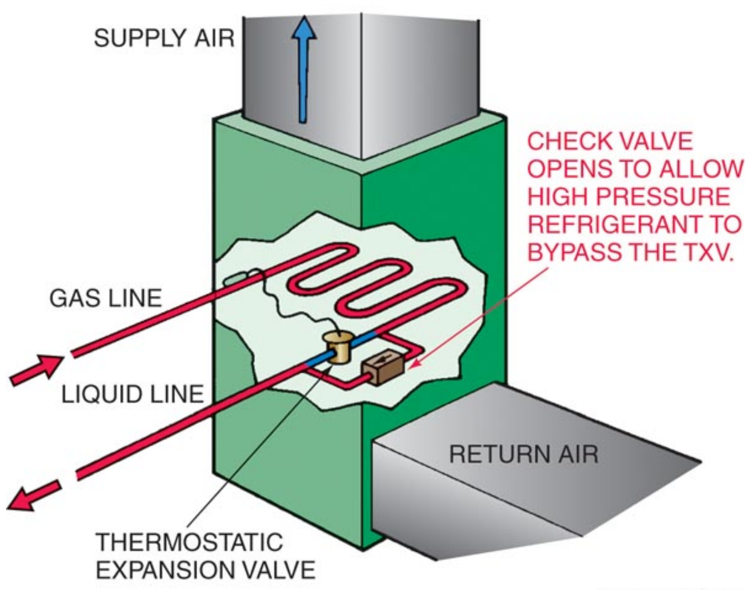


Figure 3–22. Check valve bypassing TXV. (Courtesy Cengage Learning.)

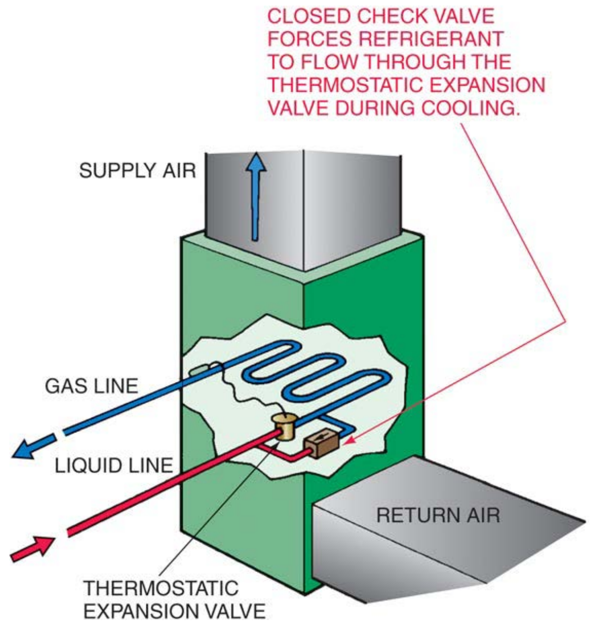


Figure 3–23. Flow through TXV.
(Courtesy Cengage Learning.)

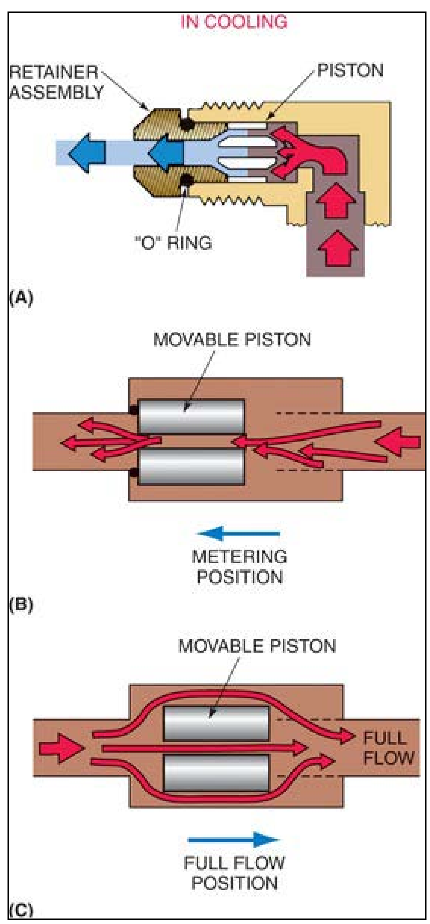


Figure 3–24. Flow check pistons.
(Courtesy Cengage Learning.)

Fixed orifice and capillary tubes

These metering devices are not desired in heat pumps. One size is used for the indoor coil and the other is sized for the outdoor coil. The reason fixed-orifices and capillary tubes are not used very often is because most heat pump systems need a metering device that varies the flow of refrigerant. See figure 3–25 for an example of a system with two capillary tubes.

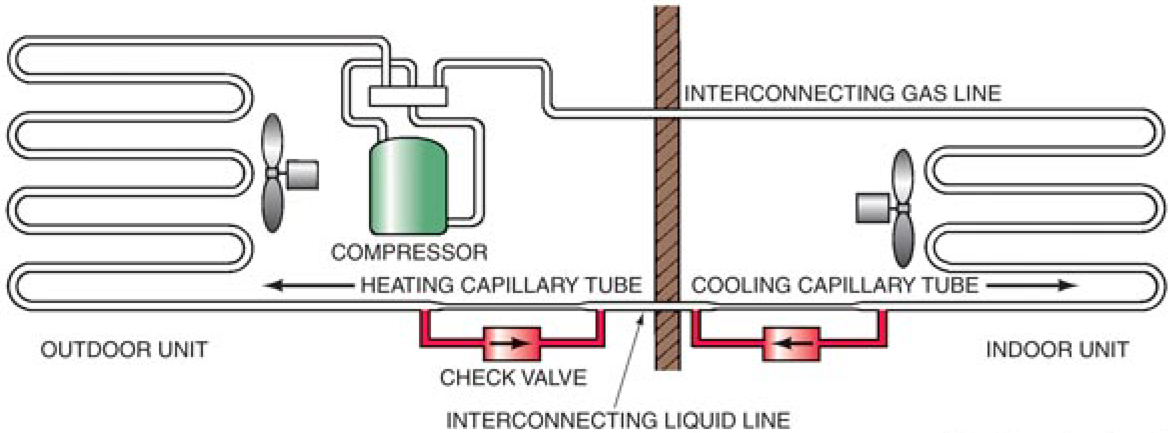


Figure 3–25. Check valves with capillary tube.
(Courtesy Cengage Learning.)

Compressor

Heat pump compressors are similar to normal compressors except they must operate during cooler ambient conditions. Since compressors operate in these lower temperature conditions they must be designed to handle some liquid slugging. This is accomplished by using stronger internal valves and components.

Suction line accumulators are used to help prevent liquid from reaching the compressor. Another component used to help with the potential of liquid in the compressor is the crankcase heater.

Finally, two way filter-driers are used to protect the compressor from contamination.

Accumulator and charge compensator tank

A suction-line accumulator is used with heat pumps because the system requires less refrigerant when operating in heat mode. Not all of the refrigerant is used in heating so it must be stored somewhere. Instead of returning to the compressor as a liquid, it travels to the suction-line accumulator. Accumulators used with heat pumps have smaller orifices than regular systems.

A charge compensator tank serves the same purpose as the accumulator. This tank has the hot gas line running through a canister. The hot gas is not released in the tank, it is just a line that runs through it. A liquid line is connected to the canister and releases liquid into the canister.

In heating mode the gas line is cooler than the liquid line. The refrigerant from the liquid line condenses and is stored in the tank. In cooling mode, the gas line is warmer than the liquid line and boils the refrigerant in the liquid line. The boiled refrigerant circulates in the system.

Controls

Like any of our HVAC/R equipment, heat pumps require controls to operate efficiently. Temperature and defrost controls are used to accomplish proper operation of heat pumps. Thermostats are often used to control the cooling, heating, or auxiliary heat modes, fan on and off, and system on and off.

> **Technician's Note**: Not all thermostats are compatible with heat pumps. As a technician, you must ensure any thermostats that are to be used with a heat pump have heat pump capabilities.

Defrost is usually controlled by a defrost board. Time and temperature usually control defrost operations. A timer is set to intervals of either 30, 60, or 90 minutes. If the timer is set for 30 minutes, every 30 minutes the timer sends a signal to check the temperature of the outside coil and outside air. The temperatures are compared and if the coil temperature drops low enough and the outside air temperature is cold also, defrost is initiated. If the coil temperature stays above set point then nothing happens and the system continues to run normally in heat mode.

Some systems use an air pressure drop across the coil to help control defrost. As the pressure drop increases above a designed set point, the pressure switch senses this increased drop and sends a signal to the board. The board starts defrost. The pressure drop strategy is usually used with the time and temperature strategy.

Yet another defrost control strategy is one that senses the current draw of the outdoor fan. As ice builds up on the outdoor coil, the outdoor fan has to work harder to draw air over the coil. The increase in work for the fan results in higher current draws. The increase in current is sensed by the defrost control and defrost is initiated at a predetermined set point.

Another control strategy for defrost is demand control which we discussed in a previous lesson.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

816. Types of residential direct expansion air-conditioning systems

1. What is included in a package unit?

2. What is required for a *package unit* to run but is *not included* with it?

3. Where are package units installed?

4. What is the usual protocol if a *window unit* goes bad?

5. Where is the *sensing bulb* located in a *window unit*?

6. Where does *return air enter* on a PTAC unit?

7. Where is return air brought from on a PTAC unit?

8. How does a rooftop unit determine the amount of outside air used?

9. What is the outside air enthalpy or dry bulb temperature compared to on a rooftop unit?

10. Where are the outside air modulating dampers located?

817. Heat pumps

1. What makes a heat pump unique?

2. How are heat pumps classified?

3. Where are heat pumps the most efficient?

4. Why does heat pump efficiency drop as the outdoor air temperature drops?

5. What is the *evaporator on a heat pump* called to avoid confusion?

6. What is the state of the outdoor fan during defrost?

7. What is used to overcome cool supply air during defrost?

8. How does the reversing valve direct refrigerant flow?

9. What moves the reversing valve slide?

10. In figure 3–17, why does reversing valve's slide move to the right?

11. Why are two standard TXVs required in a heat pump system?

12. Why must heat pump compressors be designed to handle some liquid slugging?

13. Why does heating mode require a suction line accumulator?

14. What is the result of the defrost control sensor sensing an increased outdoor fan current draw during heat mode?

3–3. Direct Expansion Operation and Maintenance

In this section, we cover the pre-operational inspections, operational tests, and recurring maintenance you perform with direct expansion systems. These tasks are important and are not to be taken lightly. If everyone would take inspections and maintenance seriously and perform them in an efficient manner, the result would be longer life and better equipment performance. In turn, this leads to large savings in energy and fewer standby calls.

818. Preoperation inspection

There are checks you must perform on HVAC/R systems before you put them into operation. In fact, it is not advisable to ever start up an HVAC/R system without first performing a preoperational check.

Before we get into the subjects of our lesson, we again stress the fact that you must look at the electrical and mechanical systems *before*—let's stress that again—*before* you put them into operation.

In this lesson, we cover the preoperational checks for the electrical and mechanical equipment.

Electrical

Before you do any electrical preoperational checks, first make sure that all electrical power is off (use a voltmeter). When you are sure the power is off, properly tag and lock the electrical box (when required). In addition, it is always a good idea to let the building custodian know when you are working on any equipment.

A list of items you should check is given below. Remember this list is not all-inclusive; that is, it does not contain everything that needs to be checked in all cases. In addition, some of the items may not apply to the equipment you are working with. Add those that apply and delete those that do not. As a general rule, the steps to perform are:

- Check the incoming power.
- Check all connections to make sure that they are not loose, corroded, or showing discoloration or other signs of overheating.
- Check all wires for broken or frayed conditions.
- Inspect all contacts (when accessible).
- Make sure that all relays and line starters have the necessary free movement for proper operation.
- Make sure capacitors are not swollen or bleeding.
- Look for hot spots or blackened areas in conduit that may indicate possible shorts in the wiring.
- Make sure switches and electrical safety devices are free from physical damage and missing hardware that may prevent proper operation.
- Check circuit boards for peeling or burnt spots.

In addition, you should check out anything else that you can think of. Be sure to correct anything that is not right before starting the equipment. Keep in mind that you may save yourself and others from serious injury or perhaps worse. At the least, you may save yourself from a late night standby call.

Remember the list gives a general concept of what is required when you are performing an electrical preoperational check. Always use the manufacturer's recommendations when they are available.

Mechanical

Before you do any mechanical preoperational checks, make sure the power is off and properly secured. Again let the building manager know you are working on equipment in the building.

A list of items that you should check during a preoperational check is given below. As before, the list does not contain all the items to be checked, and some items may not apply. Again use what is valid, ignore what is not valid, and add what you need. As a rule, perform these steps:

- Check the cleanliness of the equipment as a whole including all fans, coils, and filters.
- Check all belts for frayed edges, cracking, glazing, and tension adjustment.
- Check for free operation of moving parts such as motors, fans, and dampers.
- Make sure that all bearings move freely and are properly lubricated.
- Check for any signs of refrigerant leaks.
- Check all water-pump shaft seals for excessive leaks or damage.
- Check for any signs of oil leaks.
- Check the coupling and belt alignment.
- Inspect all access panels for loose and/or missing hardware.

Be sure to correct anything that is not right before starting the equipment. Keep in mind that you may be saving yourself a standby call.

As before, the list is by no means complete; instead, it provides a general idea of the requirements for performing a mechanical preoperational check. Remember it is always a good idea to use the manufacturer's recommendations when they are available.

Locating refrigerant leaks

Finding leaks is a task that can be performed during the pre-operational inspection or during the operational test. Since it wouldn't make sense to put this subject into two separate lessons, we will discuss it here.

You should understand that every system you work on has leaks. No system is completely sealed; every system has flaws. The difference is that some systems are "tighter" than others. One system may leak at a rate of 1 ounce every 20 years while another has a large leak and loses its refrigerant charge in less than a minute.

Look and listen for leaks

The first thing you should do is look and listen for leaks. Spots of oil are a good indication of a refrigerant leak. Another leak indicator is a hissing sound. These two indicators could help you find a leak without any tools. Sometimes though, you need a refrigerant leak detector tool to find leaks.

Pressure system to find a leak

If there is refrigerant still in the system you can attempt to find leaks. If all of the refrigerant has escaped you should use an inert gas such as nitrogen. Even though there may be some refrigerant, it may not be enough for you to find the leak with sight and sound, so use a tool. To find a leak with an inert gas take the following steps.

Finding a Leak Using Inert Gas	
Step	**Action**
1	Recover remaining refrigerant from system.
2	Connect inert gas cylinder, pressure regulator, pressure-relief valve, and a hand valve.
3	Allow inert gas (usually nitrogen) to enter system and raise pressure to about 100 to 170 psig.
4	Wait about an hour to see if there is a decrease on the pressure gauge.
5	If no pressure loss is discovered, remove the gas from the system by opening the suction and discharge service valve and set them to the mid-position.
6	Evacuate system by pulling it into a deep vacuum or by using the triple evacuation method. (These methods are discussed later in this CDC.)
7	Charge the system with the proper amount of refrigerant.

Ensure you never over-pressurize the system. There are nameplates on the system components that prescribe the maximum amount of pressure they can withstand. For example, an evaporator may have a design test pressure of 300 psig. Therefore, do not pressurize the system over 300 psig or you could bust the evaporator. The same goes for the condenser.

The procedures above discussed a system with that had no pressure drop but what if there is a pressure drop you notice on the gauge? This means you have a leak. Search for the leak using a soapy bubble solution. The following are places to check for leaks:

- Near bent tubing.
- Near crimped tubing.
- Around all joints.
- Where tubing rubs against a moving part such as a fan.
- Where tubing is in contact with other metal (system vibration could cause the tubing open).

Halide leak detection

This type of detection involves burning a fuel gas near a copper plate. Air is siphoned, or pulled, from locations where you think there may be a leak. Figure 3–26 is an example of this detector.

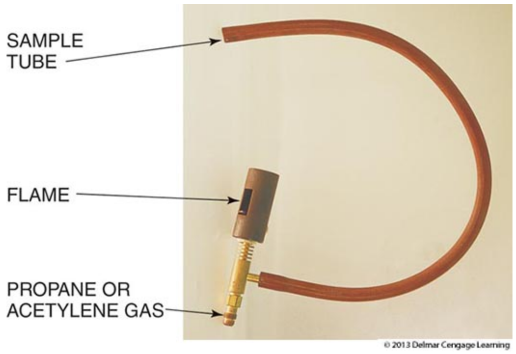


Figure 3–26. Halide leak detection.
(Courtesy Cengage Learning.)

To detect a leak with this method, follow the steps below. Note that the flame is normally blue but changes to green in the presence of a leak; meaning you have found the leak source.

- Connect a tube, sometimes called a sniffer tube, to the base of the burner and allow the other end to hang freely.
- Light the burner which draws air through the tube.

- Move the free end of the tube around the parts of the system. Any refrigerant vapor that is leaking is drawn into the free end of the tube and changes the flame green when it reaches the burner.

Electronic leak detector

This detection method can find very small leaks. Air is drawn through a tube via a pump. The air that is drawn into the detector is analyzed. The detector determines if refrigerant is found and notifies the technician via a light, a sound, or both. The procedures for electronic leak detection are described in the following table.

Electronic Leak Detection Procedure	
Step	**Action**
1	Turn on the detector and let it go through its warm-up phase. Keep away from potential refrigerant leaks during warm-up.
2	Keep the tip of the wand fairly close to the surface that you are checking. The manufacturer may specify the distance for holding the tip.
3	Move the tip at a speed determined by the manufacturer. About 1 to 3 inches per second.
4	Move the tip until the alert sound or lights flash.

Fluorescent leak detector

This method requires a fluorescent dye and a ultraviolet (UV) light. The dye mixes with the oil in the system. When the UV light changes to bright yellow-green, you know you have found the leak. The procedures are:

- Put fluorescent dye inside the system. (Ensure it is compatible with the refrigerant in the system.)
- Turn on the UV light and move it over the fittings and search for the leaks.

Ultrasonic leak detector

Ultrasonic leak detection uses microphones to pick up high-pitched sounds that are caused by the turbulence of refrigerant escaping the system (fig. 3–27). When the sound is detected the ultrasonic leak detector sounds an alarm. This alarm notifies the technician that a leak is present. Sometimes headphones are used to hear the sound alarm. Also, an LED could light when a leak is found.

Figure 3–27. Ultrasonic leak detector.
(Courtesy Cengage Learning.)

Follow the steps below:

- Put on headphones (if used).
- Turn the detector on.
- Move the detector in a zig zag motion around any place suspected of leaks.

You should now be able to find a leak in a refrigeration system. Get with your supervisor and make them demonstrate to you these methods. Then, try them out for yourself!

819. Operational test

In our previous lesson, we covered the requirements for performing preoperational inspections on electrical and mechanical equipment. In this lesson, we turn our attention to the operational test required for refrigeration and cooling equipment.

Okay, let’s say your preoperational inspection shows that everything that is electrical and mechanical appears to be serviceable. If so, you can start the HVAC/R system. When the unit is operating, there are more checks you must perform. First we cover the operation tests in general, then the electrical and mechanical checks. Finally, we cover the use of the pressure temperature chart and the process of adding oil to a system.

Operational test in written format

You are not going to become an expert on performing an operational test in this CDC. This text focuses on general procedures for refrigeration and cooling systems. It is not useful to give you procedures for a specific system that you may never see. Also, there are so many systems that are used in the Air Force it is nearly impossible to create a list of procedures that is all inclusive.

So, why are these procedures in this CDC? Because you need to know the general procedures for performing an operational test. Without this foundation, you may be lost when you try to perform this task in the field.

The best thing you can do is to take this knowledge, grab your supervisor or trainer, and have them take you to various types of systems. Go to split systems, package units, window units, and heat pumps. At these systems, have them show you how to perform an operational test. Have them give you detailed explanations of each step and ensure you use the manufacturer’s manuals. If you do this, you will be on the correct path to becoming a sharp HVAC/R technician.

Electrical

As you would expect, you must follow all safety precautions when you are working around operational equipment. *There are no exceptions!* When you are around operating equipment, you must always be aware of the voltages present as well as all moving parts. In addition, you must follow all safety precautions when you are working with electrical test equipment. If you are not certain how to use any piece of equipment—ASK!

A list of items that you should check during an operational test of the electrical system is given below. As before, the list does not contain all the items to be checked, and some items may not apply. Again use what is valid, ignore what is not valid, and add what you need. As a general rule, perform these steps:

- Ensure proper power.
- Perform an amperage check on the electrical equipment such as motors that drive compressors and fans.
- Be aware of any unusual odors. (Through on-the-job training you will learn the difference between a normal odor and an unusual one.)
- Watch for any unusual operation of electrical devices, for example Chattering contactors.
- Make sure all equipment is operating as required.

- Operate all stages of the HVAC/R system (when feasible).

Check out anything else that you think of. Be sure to correct anything that is not right. Keep in mind that you may be saving yourself a standby call. Again the list is not complete; instead, it provides a general idea of what is required when you are performing an electrical operational check. Remember always use the manufacturer's recommendations when they are available.

Mechanical

As before, you must follow all safety precautions when you are working around operational equipment. Beware of the voltages present as well as the moving parts. Remember do not be afraid to ASK for help if you are not certain how to use a piece of equipment.

The following list of checks is not complete. Some items may not apply. Use what is valid, ignore what is not, and add what you need. Always be prepared to shut down the system quickly if necessary. The actions for a mechanical check include:

- Check all refrigeration system pressures.
- Ensure free movement of all moving parts.
- Listen to the system and make note of any unusual noises.
- Be alert for unusual odors.
- Check for proper airflow.
- Inspect for signs of refrigerant, condensate, and oil leaks.
- Check for proper temperature difference between the return and supply air.
- Make sure all equipment is operating as required.
- Measure and record superheat and subcooling.
- Operate all stages of the HVAC/R system (when feasible).

Check out anything else that you think of. Be sure to correct anything that is not right. Keep in mind that you may be saving yourself a standby call. As before, always use the manufacturer's recommendations when they are available.

Ensure you record all of your findings and file them according to your shop procedures. Every shop needs to have a recorded history of the equipment on base. This assists in troubleshooting because a technician can compare old readings to new ones and try to discover the fault.

> **Technician's Note:** Did you notice some of the similarities between the electrical and mechanical checks? If you did, you noticed that there is some overlapping between the two. You find that the more you perform these checks, you eventually reach the point where you do them simultaneously.

Using the pressure-temperature chart

A pressure-temperature (PT) chart can be referenced any time a technician needs to find out what a particular refrigerant is actually doing inside a closed system. All refrigerants have specific pressures depending on the temperature they are operating at. As an example, R–134a has a pressure of 86.7 psig at 80 °F.

When you are using a PT chart, the system condition must be saturated. A *saturated condition* means that vapor and liquid are present. A saturated condition normally exists in a workable system. In some cases all refrigerant may have escaped from the system due to a leak. If this is true, the saturated condition is gone.

A PT chart aids you in determining if a system has a correct, over, or under charge condition. A PT chart is not a sole tool for charging a system. It is to be used in conjunction with other tools.

Basic chart components

One PT chart format has three parts to it. It has the vapor (system) pressure forcing against the refrigerant, the temperature of the refrigerant, and the type of refrigerant. Figure 3–28 is an example of this format.

TEMPERATURE	REFRIGERANT						TEMPERATURE	REFRIGERANT						TEMPERATURE	REFRIGERANT					
°F	12	22	134a	502	404A	410A	°F	12	22	134a	502	404A	410A	°F	12	22	134a	502	404A	410A
−60	19.0	12.0		7.2	6.6	0.3	12	15.8	34.7	13.2	43.2	46.2	65.3	42	38.8	71.4	37.0	83.8	89.7	122.9
−55	17.3	9.2		3.8	3.1	2.6	13	16.4	35.7	13.8	44.3	47.4	66.8	43	39.8	73.0	38.0	85.4	91.5	125.2
−50	15.4	6.2		0.2	0.8	5.0	14	17.1	36.7	14.4	45.4	48.6	68.4	44	40.7	74.5	39.0	87.0	93.1	127.6
−45	13.3	2.7		1.9	2.5	7.8	15	17.7	37.7	15.1	46.5	49.8	70.0	45	41.7	76.0	40.1	88.7	95.1	130.0
−40	11.0	0.5	14.7	4.1	4.8	9.8	16	18.4	38.7	15.7	47.7	51.0	71.6	46	42.6	77.6	41.1	90.4	97.0	132.4
−35	8.4	2.6	12.4	6.5	7.4	14.2	17	19.0	39.8	16.4	48.8	52.3	73.2	47	43.6	79.2	42.2	92.1	98.8	134.9
−30	5.5	4.9	9.7	9.2	10.2	17.9	18	19.7	40.8	17.1	50.0	53.5	75.0	48	44.6	80.8	43.3	93.9	100.7	136.4
−25	2.3	7.4	6.8	12.1	13.3	21.9	19	20.4	41.9	17.7	51.2	54.8	76.7	49	45.7	82.4	44.4	95.6	102.6	139.9
−20	0.6	10.1	3.6	15.3	16.7	26.4	20	21.0	43.0	18.4	52.4	56.1	78.4	50	46.7	84.0	45.5	97.4	104.5	142.5
−18	1.3	11.3	2.2	16.7	18.2	28.2	21	21.7	44.1	19.2	53.7	57.4	80.1	55	52.0	92.6	51.3	106.6	114.6	156.0
−16	2.0	12.5	0.7	18.1	19.6	30.2	22	22.4	45.3	19.9	54.9	58.8	81.9	60	57.7	101.6	57.3	116.4	125.2	170.0
−14	2.8	13.8	0.3	19.5	21.1	32.2	23	23.2	46.4	20.6	56.2	60.1	83.7	65	63.8	111.2	64.1	126.7	136.5	185.0
−12	3.6	15.1	1.2	21.0	22.7	34.3	24	23.9	47.6	21.4	57.5	61.5	85.5	70	70.2	121.4	71.2	137.6	148.5	200.8
−10	4.5	16.5	2.0	22.6	24.3	36.4	25	24.6	48.8	22.0	58.8	62.9	87.3	75	77.0	132.2	78.7	149.1	161.1	217.6
−8	5.4	17.9	2.8	24.2	26.0	38.7	26	25.4	49.9	22.9	60.1	64.3	90.2	80	84.2	143.6	86.8	161.2	174.5	235.4
−6	6.3	19.3	3.7	25.8	27.8	40.9	27	26.1	51.2	23.7	61.5	65.8	91.1	85	91.8	155.7	95.3	174.0	188.6	254.2
−4	7.2	20.8	4.6	27.5	30.0	42.3	28	26.9	52.4	24.5	62.8	67.2	93.0	90	99.8	168.4	104.4	187.4	203.5	274.1
−2	8.2	22.4	5.5	29.3	31.4	45.8	29	27.7	53.6	25.3	64.2	68.7	95.0	95	108.2	181.8	114.0	201.4	219.2	295.0
0	9.2	24.0	6.5	31.1	33.3	48.3	30	28.4	54.9	26.1	65.6	70.2	97.0	100	117.2	195.9	124.2	216.2	235.7	317.1
1	9.7	24.8	7.0	32.0	34.3	49.6	31	29.2	56.2	26.9	67.0	71.7	99.0	105	126.6	210.8	135.0	231.7	253.1	340.3
2	10.2	25.6	7.5	32.9	35.3	50.9	32	30.1	57.5	27.8	68.4	73.2	101.0	110	136.4	226.4	146.4	247.9	271.4	364.8
3	10.7	26.4	8.0	33.9	36.4	52.3	33	30.9	58.8	28.7	69.9	74.8	103.1	115	146.8	242.7	158.5	264.9	290.6	390.5
4	11.2	27.3	8.6	34.9	37.4	53.6	34	31.7	60.1	29.5	71.3	76.4	105.1	120	157.6	259.9	171.2	282.7	310.7	417.4
5	11.8	28.2	9.1	35.8	38.4	55.0	35	32.6	61.5	30.4	72.8	78.0	107.3	125	169.1	277.9	184.6	301.4	331.8	445.8
6	12.3	29.1	9.7	36.8	39.5	56.4	36	33.4	62.8	31.3	74.3	79.6	108.4	130	181.0	296.8	198.7	320.8	354.0	475.4
7	12.9	30.0	10.2	37.9	40.6	57.8	37	34.3	64.2	32.2	75.8	81.2	111.6	135	193.5	316.6	213.5	341.2	377.1	506.5
8	13.5	30.9	10.8	38.9	41.7	59.3	38	35.2	65.6	33.2	77.4	82.9	113.8	140	206.6	337.2	229.1	362.6	401.4	539.1
9	14.0	31.8	11.4	39.9	42.8	60.7	39	36.1	67.1	34.1	79.0	84.6	116.0	145	220.3	358.9	245.5	385.9	426.8	573.2
10	14.6	32.8	11.9	41.0	43.9	62.2	40	37.0	68.5	35.1	80.5	86.3	118.3	150	234.6	381.5	262.7	408.4	453.3	608.9
11	15.2	33.7	12.5	42.1	45.0	63.7	41	37.9	70.0	36.0	82.1	88.0	120.5	155	249.5	405.1	280.7	432.9	479.8	616.2

VACUUM (in. Hg) – RED FIGURES
GAUGE PRESSURE (psig) – BOLD FIGURES

Figure 3–28. PT chart.
(Courtesy Cengage Learning.)

Another PT chart format used with blends has the type of refrigerant, the refrigerant temperature, and both a liquid (bubble point) and a vapor (dew point) pressure. Two pressures are on the chart due to temperature glide. When using a PT chart with azeotropic refrigerants, remember to account for temperature glide.

Understanding temperature glide, dew point, and bubble point

Temperature glide was discussed in a previous unit. Let's review those concepts here before moving forward.

Fractionation causes the refrigerant to have different temperatures at any given pressure. These refrigerant blends require a temperature glide for calculating superheat and sub cooling methods. *Temperature glide* is a temperature range where the blend evaporates and condenses. This is because these mixtures do not react as a pure compound (a substance formed by a union of two or more elements in definite proportions by weight). In a compound, only one molecule is present. In contrast, blends are a mixture. A *mixture* consists of two or more substances mixed together (not in fixed proportions and not with chemical bonding) while still maintaining their separate chemical properties (existences). In a mixture, more than one molecule is present; this is where the difference lies.

Therefore, when new refrigerants come out, you will have to use new charts to determine the proper temperature glide. Normally the amount of glide is between 0.3 °F and 10 °F.

Bubble point is the temperature at which the first component of the blend begins to boil. It is called the bubble point because when a saturated liquid is heated it starts to form bubbles. The bubble point is the temperature of saturated liquid at the end of the condenser.

Dew point is the temperature at which the last component of the zeotropic blend is completely vaporized. It is called dew point because when a saturated vapor starts to cool it form dewdrops. The dew point is the temperature of saturated vapor at the end of the evaporator.

PT chart applications

Cross reference a PT chart from two known variables. Examples are:

- Type refrigerant + Ambient temperature = Refrigerant pressure.
- Ambient temperature + Refrigerant pressure = Type refrigerant.
- Type refrigerant + Refrigerant pressure = Ambient temperature.

How do you get these temperatures and pressures? Let’s talk!

Look at the first set of variables to determine a recovery tank’s characteristics.

- The type of refrigerant is on the data plate of unit.
- Use a temperature sensing device to get the ambient temperature.
- Connect gauges to the tank and record the pressure reading.
- Use the PT chart and line up the temperature with a pressure.

Look at this example.

The ambient is 75 °F and the refrigerant is R-410a.

The pressure that lines up with this temperature is 217.6 psig.

This is useful to find out if non-condensables are in a recovery refrigerant tank. If the pressure were 250 psig it would be a strong indication there non-condensables are in the tank.

If you are unsure of the type of refrigerant that is in a recovery tank use the second example from above. Let’s take a look:

- Use a temperature sensing device to get the ambient temperature.
- Connect gauges to the tank and record the pressure reading.
- Use the PT chart and line up the temperature with the pressure. Wherever the temperature and pressure intersect, that is refrigerant in the tank.

For this example:

The ambient temperature is 60 °F.

The tank pressure reading is 57.3 psig.

This lines up with R-134a.

The third set of readings is not covered in this CDC.

Assumptions made when taking readings

It is often impossible to take readings at the exact location where they are needed. Therefore, there is a set of assumptions that is made and is accepted.

- The first assumption is that the *manifold gauge reading at the compressor discharge is also the pressure in the system*. This is not completely precise but it is accurate enough for HVAC/R technician purposes.

- Another assumption is that the *pressure read at the suction service valve of the compressor is the same pressure at the outlet of the evaporator*.

Using the chart to find the average coil temperature

Even though we aren't discussing troubleshooting in this CDC, you may need to determine the average coil temperature on a system. In this example, we assume you are gathering *pressure* readings from the manifold gauge assembly. This example is referring to dew point so we are talking about the evaporator coil.

Using the Chart to Find the Average Coil Temperature	
Step	**Action**
1	Gather the manufacturer's data on the refrigerant in the system.
2	Determine the temperature glide of the refrigerant.
3	Determine the dew point pressure from gauges.
4	Find the matching temperature on the PT chart.
5	Subtract half of the temperature glide from the dew point temperature. This number is the average coil temperature.

The same procedure is used to find the average coil temperature of the condenser coil is the same except you find the bubble point pressure instead of the dew point pressure.

Using the chart to detect non-condensables

As you now know, non-condensables are very undesirable in a system. The table below describes the procedures for using the PT chart to detect non-condensables. In this example, the refrigerant is *not* a blend.

Using the PT Chart to Detect Non-condensables	
Step	**Action**
1	Isolate the condenser.
2	Let condenser settle and reach ambient temperature.
3	Read and record the ambient temperature.
4	Use the PT chart to determine the pressure the condenser should have. Record it.
5	Read the condenser pressure with a gauge.
6	Compare the proper pressure with the measured pressure.
7	If the pressures match everything is good. If the measured pressure is higher than pressure indicated on the PT chart, non-condensables may be present.

Let's use an example to further describe this process. The system is R–410a. This example is presented as if a technician is writing down everything he/she did:

- Condenser isolated.
- Allowed condenser to reach ambient temperature.
- Read an ambient temperature of 95 °F. Recorded it on my phone.
- Used PT chart. With R-410a and 95 °F the condenser pressure should be 295 psig. Recorded on phone.

- Read condenser pressure on gauges. It was 325 psig.
- Compared the proper pressure of 295 versus the actual pressure of 325 psig.
- Non-condensables may be present.

Adding oil

There are many methods of adding oil to a compressor. One of the most practical is the open system method described in the following table.

Open System Method of Adding Oil	
Step	**Action**
1	Run the compressor fully loaded. Then, close the suction shut-off valve and reduce the crankcase pressure to 2 psig.
2	Stop the compressor and isolate it from the system by closing the discharge shut-off valve.
3	Slowly remove the oil fill plug. Next add the required amount of oil. Be sure no dirt enters the oil fill hole. **NOTE:** Do not leave the compressor open any longer than necessary.
4	Replace the oil fill plug. Open the shut-off valves and restart the compressor. Run the compressor for a full 20 minutes in the loaded condition. Then recheck the oil level.

In this procedure, we assume that when venting or pumping the compressor crankcase between 1 to 5 psig, a small quantity of refrigerant remains in the oil. If no refrigerant vapor is present in the oil, it is necessary to evacuate the compressor by way of the service ports or sweep the air from the compressor. To sweep the compressor, crack open the discharge shutoff valve, pressurize the crankcase, and vent the air and some refrigerant vapor to the atmosphere by way of the suction shutoff valve service port.

820. Preventative maintenance

In the last two lessons, we discussed the requirements for preoperational and operational checks. In these checks, the equipment was prepared for operation. Now it is time to cover preventative maintenance. Preventative maintenance (or work) consists of operations, recurring maintenance, service work, and other recurring work where the scope and level of effort is already known without requiring a visit to the job site. In addition, preventative maintenance includes all recurring work needed to prevent breakdown of critical facilities, equipment, or utilities.

Motors and compressors

For motors and compressors follow the manufacturer’s instructions. It may require you to take an amp draw. If not, it is a good idea to perform an amp draw and compare your readings to the data plate. Also, look for dirt and dust buildup on the motor. Dirt and dust raise the temperature of the motor and can lead to a motor burnout.

Condenser coils used in DX systems

Ensure there is nothing blocking the condenser’s airflow. Leaves, grass, commissary bags, and so forth, can accumulate against the condenser. This increases the system’s head pressure which, in turn, decreases efficiency and life expectancy.

Clean the coils using a chemical cleaner or just water. The cleaner is applied with a sprayer and draws the dirt out from the inside of the coil. Because dirt decreases efficiency it must be removed. You may not want to use chemical cleaner on a rooftop because it could degrade the integrity of the roof. If this is the case, then just use water for cleaning. Do *not* use hot water or high pressure water. Hot water raises the refrigerant temperature and it could raise it too high. High pressure can bend the fins of the coil. Bent coil fins reduce airflow and reduce the overall efficiency of the system because the proper amount of heat can longer be rejected. Spray water from the direction the air is exiting. This ensures the water is pushing the dirt back in the opposite direction rather than pushing it further into the coil.

Filters, evaporator coils, and condensate drains in a DX system

As long as the filter is changed out according to guidelines, the evaporator coil should need very minimal maintenance. However, you should inspect the coil and clean it as needed. A dirty coil causes the pressure to drop lower than what is needed. Think about it like this, the heat from the conditioned space is not absorbing into the refrigerant, therefore, the refrigerant is not getting warmer. As the system continues to run the refrigerant could get so cold that it will freeze. As moisture hits the dirty coil it freezes on the surface. This is why it is important to change the filter.

Scrape the coil with a soft brush to remove dust, dirt, hair, and so forth, from the surface. Then clean the coil with a chemical spray. Spray the coil and give the spray time to pull the dirt out. If the coil is so impacted with debris that the spray won’t penetrate it then you must pump down or remove the refrigerant from the system. Then unsweat the evaporator and remove it. Use a garden hose or air pressure to force the debris out from the inside of the evaporator.

Condensate drains can be flushed and vacuumed out to remove grime. Condensate can build up in a dirty condensate pan and leak. This creates a service call and could cause damage to the area surrounding the drain pan.

Vents, diffusers and grilles

Ensure there is nothing blocking any vents, diffusers, or grilles. This restricts airflow which, in turn, reduces the system’s efficiency and life expectancy.

Fans and blowers

Clean the blades of all fans and blowers. As they accumulate dirt they lose efficiency. As they lose efficiency they move less air which reduces heat transfer.

Sea coast locations

Outdoor equipment that is used in locations on the coast should be serviced more frequently. This is because airborne ocean salt in these locations is highly corrosive. If an outdoor unit, such as condensing unit, requires maintenance every 6 months, the manufacturer may require you to clean the unit every 2 or 3 months. If you are at a base on the coast, the frequency of this type of maintenance should already be incorporated in your preventive maintenance program. If not, then check the manufacturer’s instructions.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

818. Preoperational inspection

1. When must electrical and mechanical systems be inspected?

2. What electrical power should be checked during a *pre-op* inspection?

3. What are electrical wires checked for?

4. What are capacitors checked for during a pre-op?

5. What are belts checked for during a pre-op?

6. What are moving parts like motors, fans, and dampers checked for during a pre-op?

7. What are access panels inspected for during a pre-op?

8. What is *first way* to inspect for a refrigerant leak?

9. Where is a component’s *maximum pressure* indicated?

819. Operational test

1. What is the best thing you can do with the CDC text about operational test procedures?

2. What should you do if you are not certain how a piece of equipment is used?

3. What task is includes performing an amperage check?

4. When feasible which stages of HVAC/R equipment should be operationally tested?

5. What pressure can be determined if you have the type of refrigerant and the ambient temperature?

820. Preventative maintenance

1. What can preventative maintenance prevent?

2. What should you look for on motors?

3. What effect does coil cleaner have on a condenser coil?

4. Why should you *not* use chemical cleaner on a rooftop?

5. What must be done if the evaporator coil is unaffected by coil cleaner?

6. What results of dirty fans and blowers?

7. What effect does equipment installed in locations along the ocean’s coast have on its service frequency?

3–4. Indirect Expansion Cooling Systems

In previous sections, we looked at air-conditioning units that were designed for direct expansion applications. This section focuses on indirect expansion systems that are often used to supply cooling to large facilities. The type of system used to provide indirect cooling to large buildings is a chiller. On Air Force bases, chillers are used at dorms, large office buildings like finance or headquarters. Chillers are extremely important to an Air Force base. For example, if the chiller goes down for a dorm full of pilots, they will not be able to get their crew rest. This results in them not being able to fly. If you can’t fix the chiller then the mission could stop!

In addition to chillers this section also covers geothermal heat pumps. As this course went to press geothermal heat pumps are becoming increasingly popular. They are expensive to install but are more efficient than air source heat pumps. These heat pumps can reject heat or absorb heat from the ground or water source instead of the air.

Let’s get started with chillers!

821. Chillers

As stated in the introduction, chillers are used to supply cooling to large buidlings. All types of compressor systems can be used on indirect-expansion systems.

- *Direct-expansion* is when the evaporator makes direct contact with the space being cooled.
- *Indirect-expansion* is when the evaporator does *not* make contact with the cooled space.

In addition, there may be one or more compressors depending on the amount of the load and desired results. In addition, the compressors for these systems have some type of capacity control.

In this lesson, we first look at screw, scroll, and reciprocating compressor systems used with chillers. The concept is the same for each type but the operational details of each one vary. We cover only the basic concept here. Your on-the-job training will expose you to different brands and types of chillers.

Cooling

Multi-compressors are used for many chiller applications. This makes it easier to maintain a close temperature tolerance. It also aids in humidity control, as these are the two main factors when applying cooling. The compressors come on one at a time, and if needed, all will operate.

Split evaporator coils are sometimes used. This is good because you actually have two separate systems. Solenoid valves are usually installed in the liquid line. When a temperature level is reached and the compressor is no longer needed, the solenoid valve is de-energized. This closes the liquid line, causing this part of the system to pump down and cycle on the low-pressure motor control.

Dehumidification

Chillers can dehumidify the air by removing moisture if the humidity is too high. Dehumidifying usually depends on a cold coil over which the conditioned air is blown. Moisture in the air is condensed out by coming in contact with the cold surface of the coil.

Microprocessor boards

Compressor systems are usually equipped with a central processing unit that is programmed to react to changes in temperature and humidity and to keep them within established set points. A solid-state microprocessor board (fig. 3–29) is a popular method of controlling the temperature and humidity.

Figure 3–29. Chiller control board.

> **NOTE:** Set points for temperature and humidity are determined by the manufacturer's recommendation for the equipment to be cooled. The room temperature is generally kept at 72 ± 2 °F, and humidity at 50 percent ± 5 percent.

The microprocessor board or central processing unit has buttons that allow setting temperature, humidity, and sensitivity. In addition, there are dip switches that allow for things like setting which compressor comes on first or whether the numeric display shows Fahrenheit or Celsius readings.

Often the microprocessor board comes with a battery backup. If there is an electrical failure, the battery backup usually maintains the programmed values for up to 3 months. If something happens and power is off for longer than the life of the battery or the battery fails, the system defaults to factory-preset values.

Chiller classification

Chillers are classified in various ways. You need to know all of them because some technicians use only one classification method while others may use a combination of them. Chillers are classified by the way they are cooled, the type of compressor used, where it is installed, or the tonnage.

Warnings and cautions

As you work with chillers, ensure you stay focused on any warnings that are in the manufacturer's manual. If you do not heed these warnings you or fellow airmen could sustain injury or death. Common hazards include live electricity, rotating parts, sharp edges, high temperatures, and refrigerants.

Cautions are also given by the manufacturer. These cautions identify situations that can cause injuries that are minor in nature or damage the equipment.

General data

In order to work more efficiently with chillers you need to be aware of the general information provided by the manufacturer. The general data given includes nameplate information, acronyms, component location, sequence of operation of mechanical and controls, pressure-enthalpy charts, lubrication system overview, and operator interfaces.

Nameplate and acronyms

Let's breakdown this data to see how it relates to you and proper chiller operation. First, the nameplate information. Most chiller information gives an explanation of the nameplates in their manuals. Chiller model numbers can be quite long and they contain good information. Dataplates are a good starting point to learn about a chiller. They offer information about the brand, type of chiller, whether it is air or water cooled, voltages, type of refrigerant, type of starter, type of evaporator and type of controls used. A good working knowledge of the data plate information helps your effectiveness around the chiller system. Acronyms are provided for the reader's convenience.

Component location

Many manufacturers provide a diagram that shows where different components are located. This is especially helpful for the inexperienced technician. It helps to easily identify major components such as control panels, service valves, terminal boxes, valves, evaporator, condenser, compressor, suction elbows, flow switches, and so forth.

Sequence of operation

In addition to compressor sequencing, chillers have an electrical and mechanical sequence of operation. You should read the manufacturer's manuals to gain a better understanding of each system's operational sequence. We will not cover an individual chiller's operation because there are many designs and brands and it is difficult to identify a "typical" example much less determine which you might encounter at your base.

However, all modern chillers share a very important concept you must understand—electronics! You must know why, when, how and what the control module is doing. You will not be able to actually see everything that is happening because the board does a lot of work through its circuitry and algorithms. Most chillers have an interactive display screen that you can use to use to observe system conditions. With some chillers you can connect a laptop computer to the chiller's controls and gain a better understanding of what is happening. Ultimately, you should read and study the sequence of operations as part of becoming a successful chiller technician.

Chiller storage

Manufacturers provide information on how they prefer their equipment to be stored. You may think that a chiller can just sit and wait to be installed in the back of your shop without needing any attention. This is *not* the case. For instance, some chillers must be “blocked” so the base doesn’t sag. Openings, such as the water connections, should be plugged to prevent animals, bugs, or debris from getting in. Some manufacturers have storage temperature requirements to prevent the system from being ruined. The condensers on air-cooled condensers should be covered to protect the coils and fins. The chiller’s surrounding could cause damage or corrosion if the coils and fins are not covered. Another way to prevent damage is to store it in a place where there is minimal movement and activity. Finally, periodically inspect the chiller throughout the time it is being stored. There have been a few instances where chillers were left in the back of shop and forgotten about. In some cases when they were needed they were found no longer operable.

Compressor sequencing

Every compressor on chiller doesn’t run at the same time, all the time. If the chiller has multiple compressors they can be started in a variety of sequences. For example, all compressors could be sequenced to start at the same time to minimize the amount of time it takes to pull down the system. Alternately, the compressors could be started in a sequence so that the amount of work performed by each compressor is balanced. Still another method is to designate a specific sequence in which the compressors start. For instance, compressor 1 always starts before compressor 2 or vice versa.

Chilled water piping

You may or may not be involved installing chiller piping. Either way, you need to be familiar with the incoming and outgoing chilled water piping. Figure 3–30 is an example of water flowing into and out of a screw chiller evaporator. Follow lines from dark blue to lighter blue. Figure 3–31 is a manufacturer’s example of water piping and components.

Figure 3–30. Evaporator water flow.

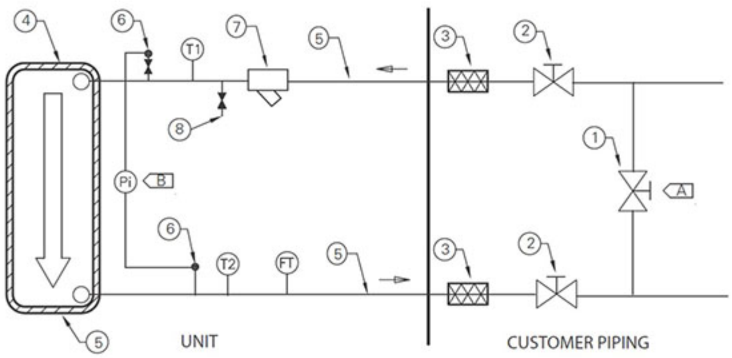


Table 22. Water piping components

Item	Description	Item	Description
1	Bypass Valve	Pi	Gauge
2	Isolation Valves	FT	Water Flow Switch
3	Vibration Eliminators	T1	Evap Water Inlet Temp Sensor
4	Evaporator Heat Exchanger	T2	Evap Water Outlet Temp Sensor
5	Water Heater	A	Isolate unit for initial water loop cleaning
6	Valve for Pressure Point	B	Brazed plate differential pressure gauge and piping not supplied. Must account for water head height difference when calculating brazed plate pressure differential.
7	Strainer		

Figure 3–31. Water piping and components from a Trane chiller.

Freeze protection

There are a few strategies used for freeze protection. If a chiller is going to be exposed to freezing temperatures while it contains water then some form of freeze protection is required. The first strategy is to run the chilled water pumps. As the temperature drops to a predetermined setting, the chiller controller tells the chilled water pump to come on. The circulation of water helps to prevent freezing. This strategy requires power to be supplied to the chiller at all times. This ensures the pump is controlled by the chiller according to temperature.

Another strategy is to use heaters. Heaters can come factory-installed on the evaporator and the water pipes to protect the water from freezing. Also, heat tape can be installed on pipes, pumps, or any component that is exposed to freezing temperatures.

Yet another method is adding a freeze inhibitor or antifreeze to the system. Common freeze inhibitors are ethylene glycol and propylene glycol. Once again, look at the manufacturer’s manuals to find out the type and percentage of antifreeze to add to a chiller system.

The amount of antifreeze placed in the system is very important. You can’t just add as much as you think works. If too much is mixed into the water system the unit’s efficiency and the saturated evaporator temperature is reduced.

The final freeze protection strategy is to completely drain the water out of the circuit. Water cannot freeze if it isn’t present.

Technician’s Note: If supply power to the chiller fails, neither the heaters nor the chilled water pumps will run. To prevent the piping or evaporator from freezing, use the antifreeze or evaporator drainage strategy.

Heat recovery

Some chillers have heat recovery devices. These devices take heat energy from the refrigeration system to produce hot water. If you think about the name, heat recovery, you can realize that *heat* is taken from the refrigeration system and is *recovered* to a water line.

There is an auxiliary heat exchanger in the discharge line between the compressor and the condenser. The compressor discharge gas is cooled as it heats the water.

Chilled water pump control

Chilled water pumps shut off and on depending on a variety of factors. Figure 3–32 is an example of a chilled water pump. For instance, the pump doesn't run only for cooling purposes. As mentioned before, it could also run for freeze protection purposes.

The pump is commanded by the chiller controller. The type of pump control is annotated in the manufacturer's manuals. For instance, some chillers have variable speed pump flow control while other types just have a basic On/Off control.

For freeze protection there is temperature sensor in the chilled water outlet after the evaporator. If a predetermined temperature is met, the signal changes and is sent to the controller. The controller then tells the pump to start.

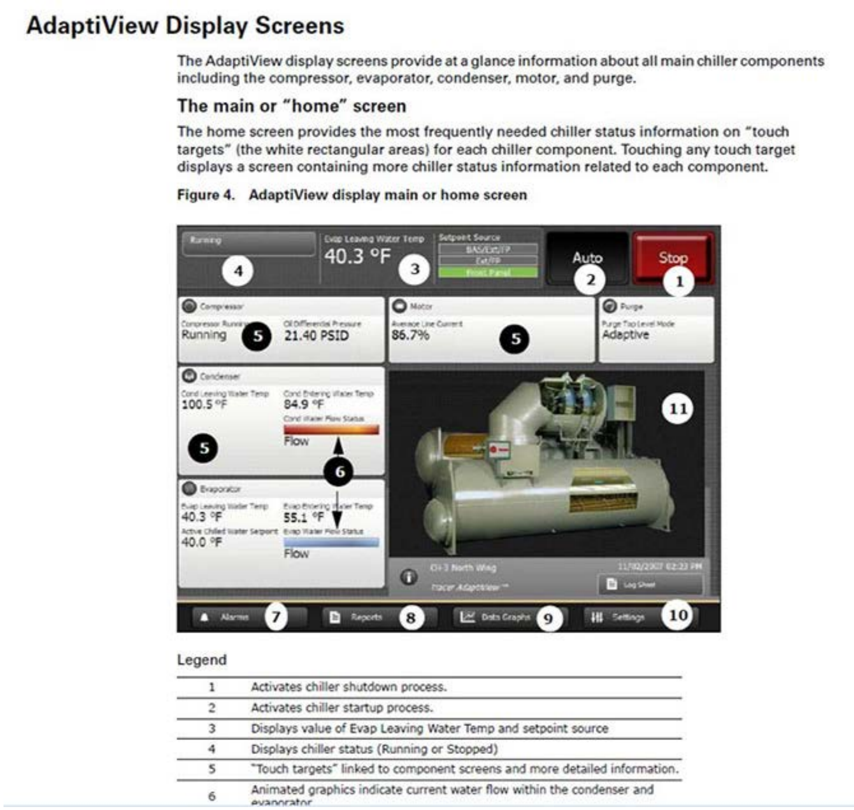
Condenser water pumps are controlled in similar manners.

Figure 3–32. Chilled water pump.

Controls and interface

Basically, an interface is a device that allows the technician to "talk" with a computer. For a chiller, this is the place where you can interact with the system. Also, the interface allows the chiller to communicate with a Building Automated System (BAS).

These interfaces have displays that make information readily available to technician. The display is made to withstand weather and still function properly. Figure 3–33 is an example of an interface display.



AdaptiView Display Screens

The AdaptiView display screens provide at a glance information about all main chiller components including the compressor, evaporator, condenser, motor, and purge.

The main or "home" screen

The home screen provides the most frequently needed chiller status information on "touch targets" (the white rectangular areas) for each chiller component. Touching any touch target displays a screen containing more chiller status information related to each component.

Figure 4. AdaptiView display main or home screen

Legend

1	Activates chiller shutdown process.
2	Activates chiller startup process.
3	Displays value of Evap Leaving Water Temp and setpoint source
4	Displays chiller status (Running or Stopped)
5	"Touch targets" linked to component screens and more detailed information.
6	Animated graphics indicate current water flow within the condenser and evaporator

Figure 3–33. Trane interface screen.

Laptops are used with some chillers to check on chiller status, configuration settings, and diagnostics. The diagnostics that are given can include evaporator, condenser, compressor, set points, motor, purge status, pressures, temperatures, communications, inverters, alarms, phases, and software. Figure 3–34 shows a chiller system's architecture. Diagnostic information is provided about a certain component. An example would be "BAS communication is lost." This tells the technician that chiller lost communication with the Building Automated System. Other diagnostics include information about pump operation, chilled water flow and freezestat operation.

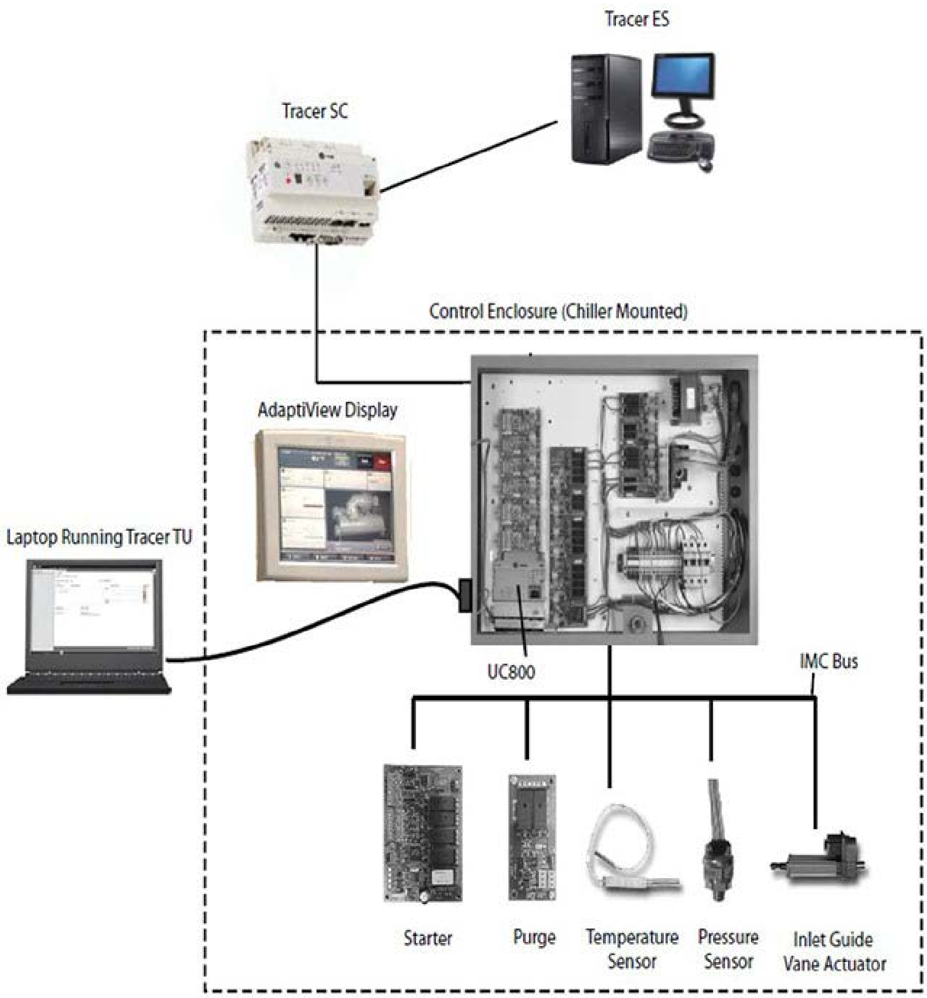


Figure 3–34. Chiller system's architecture.

High pressure chillers

Chillers remove heat from water so the water can absorb heat from the conditioned space. The heat that is removed from the conditioned space is removed from the system. This is very similar to a typical split system except that water is being cooled directly by the refrigeration system instead of air. For high pressure chillers a screw, scroll, reciprocating, or, sometimes a centrifugal compressor is used as the heart of the refrigeration system. Let's discuss how these systems create chilled water.

There are basically two systems on an air-cooled chiller system: the refrigeration and chilled water system. These systems affect each other but never physically exchange any liquid or refrigerant. The refrigeration is the same that you are familiar with: the compressor pumps refrigerant to the condenser, the condenser desuperheats, condenses, and subcools the refrigerant. Refrigerant then travels through the metering device where it experiences a pressure drop and the evaporator boils off the refrigerant and flow goes back to the compressor. The only change in concept for the air-cooled high pressure chiller is the evaporator.

The evaporator has refrigerant inside a shell rather than in a coil. Tubes have water running inside of them and the tubes are located in the shell. Therefore, as approximately 55 °F water runs through the tubes it gives off its heat to the colder evaporator refrigerant. As the water leaves the evaporator its new temperature is about 45 °F. The system has *chilled* the water from 55 to 45 °F. The refrigerant never mixes with the water during normal operation. The heat picked up by the evaporator travels through the rest of the refrigerant cycle as normal. That is how chilled water is made!

The chilled water is moved using pumps which are controlled by the chiller controller. The pumps move the water to air handling units (AHU) which have chilled water coils. Warmer return or mixed air is moved across the chilled water coil. The chilled water picks up heat from the warm air. The water, which is now about 55 °F because it picked up heat, returns to the evaporator to give up its heat to the refrigerant system.

As long as the pumps and compressor are running this process is continuous.

Centrifugal chillers

Many large air-conditioning installations use centrifugal compressors. These large centrifugal units are frequently designed with capacities of 100 to 2,000 tons. The centrifugal system uses the same general refrigeration cycle as you saw on the compression-type system; however, it differs from the earlier-discussed system by several special features. Centrifugal units use a low-pressure refrigerant—most units use R–123 although older units may use R–11 and R–113. These refrigerants possess the large specific volume needed. With these refrigerants, the evaporator operates at below atmospheric pressures.

Both the evaporator and the condenser are of the shell-and-tube type. The compressor portion is usually a two-stage centrifugal type that is driven by a hermetically sealed motor. In addition, the machine is equipped with an economizer unit, designed to reduce the horsepower required per ton of refrigeration.

In the following paragraphs we cover these aspects of centrifugal chillers:

- Centrifugal refrigeration cycle.
- Compressor lubrication system.
- Purge and recovery unit operation.

Centrifugal refrigeration cycle

Refer to figure 3–35 as we go through the centrifugal refrigeration cycle. We begin the cycle at the evaporator.

The chilled water flowing through the evaporator tubes is warmer than the refrigerant in the shell surrounding the tubes; consequently, heat flows from the chilled water to the refrigerant. This heat evaporates the refrigerant at a temperature corresponding to the pressure in the evaporator. The refrigerant vapors are drawn from the evaporator shell into the suction inlet of the compressor. The suction vapors are partially compressed by the first-stage impeller and join the flash gas vapors coming from the economizer at the second-stage impeller inlet. The refrigerant gas discharged by the compressor condenses on the outside of the condenser tubes by giving up heat through the condenser tubes to the cooler condenser water. The condensing temperature corresponds to the operating pressure in the condenser

The liquefied refrigerant drains from the condenser shell down through an inside conduit into the condenser float chamber. The rising refrigerant level in this chamber opens the float valve and allows the liquid to pass into the economizer chamber. The pressure in the economizer chamber is about halfway between the condensing and evaporating pressures; consequently, enough of the warm liquid refrigerant evaporates to cool the remainder to the lower temperature corresponding to the lower pressure in the economizer chamber. This evaporation takes place by rapid “flashing” into gas as the liquid refrigerant passes through the float valve and the conduit leading into the economizer chamber.

The flashed vapors pass through eliminator baffles and a conduit to the suction side of the second stage of the compressor. The cooled liquid then flows into the economizer float chamber located below the condenser float chamber. The rising level in the economizer float chamber opens the float valve and allows the liquid refrigerant to pass into the bottom of the cooler.

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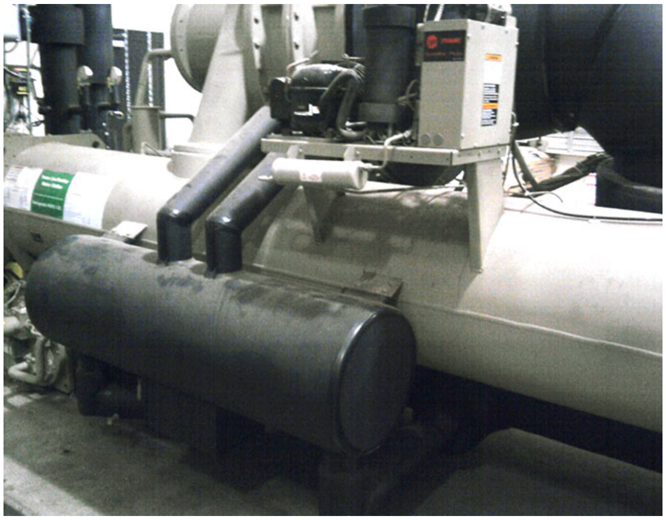


Figure 3–35. Centrifugal machine.

Since the evaporator pressure is lower than the economizer pressure, some of the liquid is evaporated to cool the remainder to the operating temperature of the evaporator. These vapors pass up through the liquid refrigerant to the compressor suction. The remaining liquid serves as a reserve for the refrigerant continually being evaporated by the chilled water. The cycle is now complete.

Now, let’s take another trip through the refrigeration cycle. This time we cover the cycle according to the actions taking place in each of these major components:

- Compressor.
- Condenser.
- Economizer.
- Evaporator (cooler).

Compressor

Again refer to figure 3–35. The compressor takes its suction from the cooler (evaporator). As the refrigerant gas enters the first-stage impeller, it is at cooler conditions. As the gas passes through the impeller, its pressure, temperature, and heat content are increased. The gas leaving the first stage enters the suction of the second-stage impeller. The process of the gas through the second stage is very similar to that through the first stage. As the gas leaves the compressor, its pressure has increased and it is at a superheated condition.

Condenser

From the compressor, the gaseous refrigerant enters the condenser in a superheated condition. As we said earlier, the condenser is a shell-and-tube type similar in construction to the cooler. The primary function of the condenser is to receive the hot refrigerant gas from the compressor and to condense it to a liquid. A secondary function of the condenser is to collect and concentrate noncondensable gases, so that they may be removed by the purge recovery system that we will discuss later.

The top portion of the condenser is baffled. The baffle plate prevents direct impact of refrigerant vapors on the tubing bundle of the centrifugal system. This baffle encloses a portion of the first water pass. The noncondensables rise to the top portion of the condenser because they're lighter than refrigerant vapors and because the top is the coolest portion of the condenser. A perforated baffle or distribution plate is installed along the tube bundle to prevent compressor discharge directly impacting the tubes. The baffle also serves to distribute the gas throughout the length of the condenser. In the condenser, the gaseous refrigerant is first cooled down to a saturated vapor; then it gives up its latent heat of vaporization as it is condensed. The liquid refrigerant drains into the metering device (economizer) as it condenses.

Normally condensing water enters the condenser at 85 °F and leaves at 95 °F. Since the water is cooler than the refrigerant, heat is transferred from the refrigerant vapor to the water. The gaseous refrigerant is first cooled down to a saturated vapor; then it gives up its latent heat of vaporization as it is condensed. The total heat removed from the system equals the heat removed from the chilled water in the cooler and the heat absorbed during compression.

The condenser water pump carries the heat-laden water to the cooling tower. In the tower, the heat is removed from the water reducing its temperature to 85 °F. The water is then ready for recycle to the condenser to pick up more heat.

Economizer

In figure 3–36 you can see the economizer is located in the liquid return from the condenser to the evaporator. In essence, the economizer acts as the expansion device. As we said earlier, using the economizer reduces the horsepower required per ton of refrigeration cycle. This increase in efficiency is made possible by using a multistage compressor and piping the flash gas to the second stage.

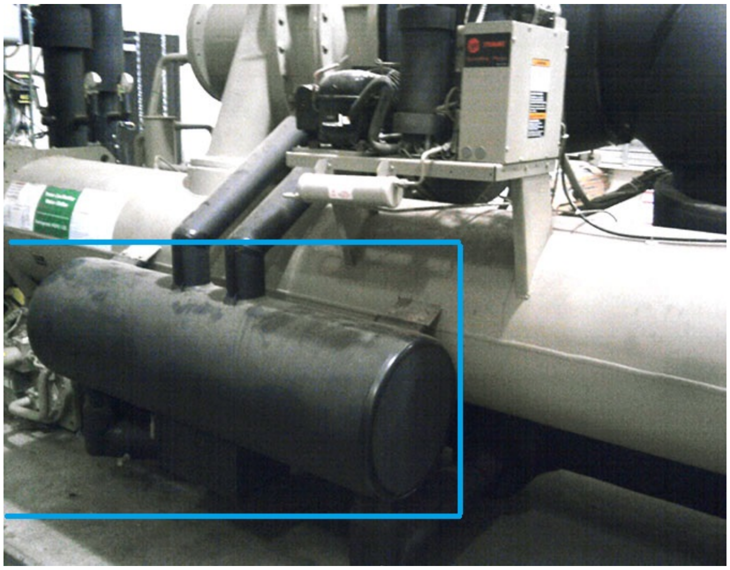


Figure 3–36. Economizer (Black barrel in this graphic).

We gave a brief explanation of the function of the economizer earlier. The economizer is located in the cooler shell at the opposite end from the compressor suction connection and above the tube bundle. On some centrifugal machines the economizer acts as a metering device. The economizer is a chamber with the necessary passages and float valves, connected by an internal conduit passing longitudinally through the cooler gas space to the compressor second-stage inlet. The connection maintains a pressure in the economizer chamber that is intermediate between the cooler and condenser pressures and that carries away the vapors generated in the chamber. Before entering the conduit, the economizer vapors pass through eliminator baffles to extract any free liquid refrigerant and drain it back into the economizer chamber. This prevents liquid refrigerant from entering the compressor at the second stage.

Two floats are located in separate chambers on the front end of the economizer. The top, or *condenser float valve*, keeps the condenser drained of refrigerant and admits the refrigerant from the condenser into the economizer chamber. The bottom, or *economizer float valve*, returns the liquid to the cooler.

Evaporator (cooler)

The cooler is of horizontal shell-and-tube construction with fixed tube sheets. The shell is low-carbon steel plate rolled to shape and welded electrically. Both the cooler and the condenser have corrosion-resistant cast-iron water boxes. They are designed to permit complete inspection without breaking the main pipe joints. Full-size, separate cover plates give access to all tubes for easy cleaning. They are provided with cast-iron division plates to give the required water pass flow.

The tubes in the cooler are copper and have an extended surface. The belled ends are rolled into concentric grooves in the holes of the tube sheets. Tube ends are rolled into the tube sheets, and the expanded charge in the cooler covers only about 50 percent of the tube bundle. However, during operation, the violent boiling of the refrigerant usually covers the tube bundle.

The cooler is equipped with multibend, nonferrous eliminator plates located above the tube bundle, removing the liquid droplets from the vapor stream and prevent carryover of liquid refrigerant particles into the compressor suction. Inspection covers are provided in the ends of the cooler to permit access to the eliminators.

The cooler is provided with a rupture valve with bursting disk. In addition, a pop safety valve is screwed into a flange above the rupture disk. These items are strictly for safety. It is highly improbable that a pressure greater than the bursting pressure can be attained without purposely blocking off the compressor suction opening.

During operation a thermometer indicates the temperature of the refrigerant within the cooler. A sight glass is provided for observing the charging and operating refrigerant levels. A charging valve with connections is located on the side of the cooler for adding or removing refrigerant. The connection is piped to the bottom of the cooler so that complete drainage of refrigerant is possible.

A refrigerant drain to the atmosphere is also located near the charging connection and expansion thermometer. A small chamber is welded to the cooler shell at a point opposite the economizer and above the tube bundle. While the machine is running a continuous supply of liquid from the condenser float chamber is brought to the expansion chamber.

The bulb of the refrigerant thermometer and the refrigerant safety thermostat bulb are inserted into this expansion chamber for measuring refrigerant temperature.

In the indirect-expansion process, the centrifugal system differs from other systems in that it uses a secondary-refrigerant such as a water or brine solution to cool the conditioned space. The heat from the conditioned space is absorbed by the secondary refrigerant. The secondary refrigerant's heat is then absorbed by the primary refrigerant in the evaporator. The heat that has originated in the conditioned space is eventually returned to the outside air by means of the machine's condenser or cooling tower.

As long as the controlled variable does not require a temperature below freezing, the secondary refrigerant may be water. If, however, the temperature of the controlled variable requires a temperature below 32 °F, then a brine mixture of ethylene glycol must be used. The secondary refrigerant is circulated to the cooling coil by means of a circulating pump. This secondary refrigerant, being cooler than the air in the controlled area, absorbs heat as it passes through the cooling coil. The secondary refrigerant is then returned to the evaporator in the centrifugal machine.

The chilled water enters the cooler at about 55 °F. It then makes several passes through the cooler, depending on the configuration, and leaves at a temperature of about 45 °F. The chilled water being warmer than the refrigerant causes heat to transfer from the water; then the refrigerant causes heat to transfer from the water, through the tubes to the refrigerant.

Since the pressure in the cooler remains constant and the refrigerant is at a saturated liquid condition, the heat absorbed causes the refrigerant to boil. The refrigerant gas in the condenser is condensed by giving up its latent heat of vaporization to the condenser water, which passes through the tubes.

The normal refrigerant charge in the cooler covers only about 50 percent of the tube bundle. However, during operation, the violent boiling of the refrigerant usually covers the tube bundle.

Compressor lubricating system

The entire oiling system is housed within the compressor casing and the oil is circulated through cored openings, drilled passages, and fixed copper lines. This eliminates all of the usual external lines and the possibility of their being ruptured, damaged, or leaking. A helical gear pump circulates all of the oil for the lubricating system. The simple positive drive ensures ample oil for pressure lubricating and cooling all journal bearings, thrust bearings, and seal surfaces. The reservoir that houses the oil pump is an integral part of the compressor casing and is accessible through a cover plate on the end of the compressor. Circulating water cooling coils are fitted to a cover plate to maintain proper oil temperature.

Purge and recovery unit operation

The presence of even a small amount of water in a centrifugal refrigeration system must be avoided at all times; otherwise, excessive corrosion of various parts of the system may occur, or worse, the hermetic compressor may ground out. Any appreciable amount of water is caused by a leak from one of the water circuits. Since the pressure within a portion of the centrifugal refrigeration system is less than atmosphere, the possibility exists that air may enter the system. Since air contains water vapor, a small amount of water enters when air enters.

The purge and recovery system is designed to maintain the highest possible refrigerating efficiency in the centrifugal machine. Figure 3–37 is an example of a purge unit. The function of the purge system is to remove air and water vapor from the refrigeration system and to recover refrigerant vapors which are mixed with these gases. The air is purged automatically to the atmosphere. In contrast, the refrigerant is condensed and returned automatically to the cooler as a liquid. Any water that is present is trapped in a compartment of the purge separator unit and can be drained manually.

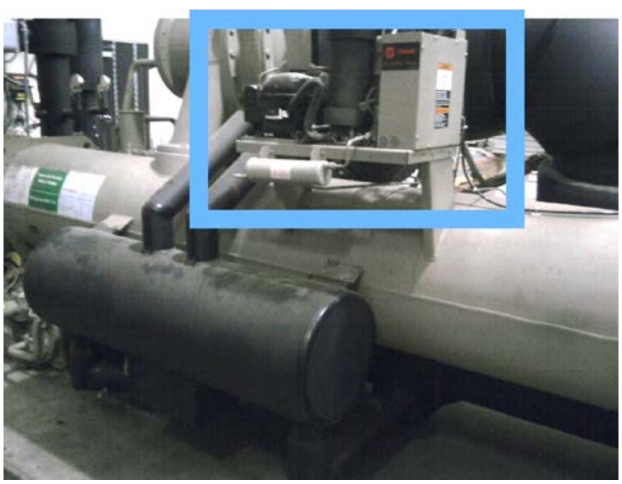


Figure 3–37. Purge unit.

Moisture removal by the purge recovery unit is just as important as air removal. The moisture may enter the machine due to humidity in the air which can leak into the machine, or by a brine or water leak in the cooler or condenser. If there are no water leaks, the amount of water collected by the purge unit will be small (1 ounce per day) under normal operating conditions. If large amounts of water are collected by the purge unit (one-half pint per day), check the machine for leaky tubes. Water can be removed more rapidly when the machine is stopped than when it is operating. If the machine is collecting a large amount of moisture, it is advisable to run the purge unit a short time after the machine has stopped and before you start the machine again. This running of the purge unit before the machine is started again helps to reduce purging time after the machine has been started.

The purge and recovery unit is equipped with a pressure-reducing valve. This valve is adjusted to produce a suction pressure on the purge recovery unit, and does not allow condensation in the suction line. If condensation does occur, the condensate collects in the crankcase of the purging unit compressor. This causes foaming and excessive oil loss. If the pressure-reducing valve is wide open, there is a pressure drop of a few pounds across the valve and the suction pressure cannot be adjusted higher than a few pounds above the machine condensing pressure.

The purge and recovery unit is also equipped with a purge separator chamber. The purpose of the purge separator chamber is to separate the air, refrigerant, and water. This chamber has two sight glasses—the top sight glass indicates the presence of water in the chamber, while the bottom sight glass shows the rise of refrigerant in the chamber. Air and water that pass into the purge separation compartment are separated with air being released to the atmosphere. In contrast, the water is trapped in the upper chamber of the purge separation chamber. The liquid refrigerant passes to the lower chamber. The water is drained from the chamber manually while the liquid refrigerant is passed into the economizer.

The amount of refrigerant loss depends on operational conditions; therefore, these conditions have a determining effect on the amount of refrigerant lost. Purge units can come with an automatic data logging and diagnostic capability that is run by a microprocessor. In this manner, you can determine the time a leak develops and the amount of refrigerant lost, find the cause, and correct the trouble.

822. Geothermal heat pumps

Geothermal, also known as ground source, heat pumps use thermal energy from the earth to heat or cool a conditioned space. These systems are very efficient because they use a renewable energy source—the earth’s heat. Water or refrigerant is circulated through coils and loops in the ground. The heat is exchanged between the refrigerant, water, and the ground.

There are different designs, configurations, and operation of geothermal heat pumps. In this lesson we discuss open- and closed-loop heat pumps and their configuration and flow. Also, system materials and fluids are covered. Water-to-water heat pumps will be covered briefly to show you the different types of geothermal heat pumps available. Geothermal heat pump’s cooling and heating mode are covered to enhance your understanding of these systems. Finally, a few controls are covered.

Geothermal heat pump efficiency

Let’s look at an example of why geothermal heat pumps are more efficient than regular heat pumps. Ground/water temperatures are more consistent than air temperatures. Say the outdoor air temperature is 20 °F and the ground/water temperature is 45 °F and the desired indoor temperature is 68 °F. The difference between the outdoor air and indoor air is 48 °F (68 – 20 = 48). The difference between the ground/water and the desired indoor air is only 25 °F (68 – 45 = 23). The geothermal heat pump using the ground/water heat has less work to do.

Direct-expansion and water source heat pumps

Even though this heat pump is direct expansion we discuss it here because it is ground source related. The outdoor coil for this system is placed in the ground and rejects or absorbs heat with the ground (fig. 3–38). This coil is sometimes called the ground coil because it is *in the ground.* It is made of copper. The disadvantage to ground coils is that leaks are difficult to find because the coil is buried underground. An advantage is that they are more efficient than water source heat pumps because the pipes containing refrigerant are in direct contact with the ground.

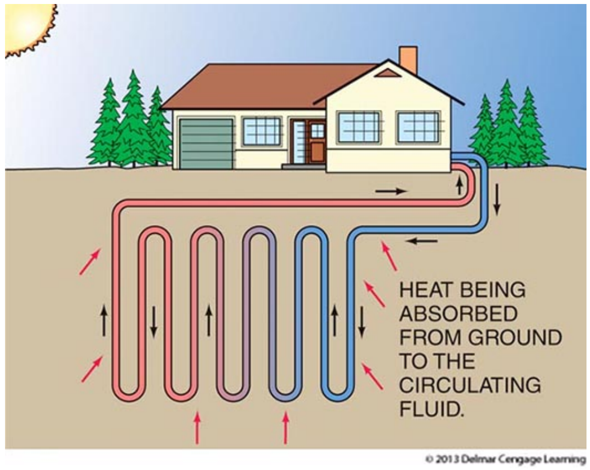


Figure 3–38. Ground source direct expansion heat pump.
(Courtesy Cengage Learning.)

Water source heat pumps circulate water through a secondary water loop. This water loop is under the ground or placed in a body of water. In *cooling mode*, the refrigerant picks up heat from the building and gives it to the water loop where the water takes the heat and rejects it out to the ground or the water it is placed in. In *heating mode*, heat is picked up by the water from the ground. The water then travels to a heat exchanger and transfers the heat to the refrigerant. The refrigerant travels through the refrigeration cycle and rejects the heat into the conditioned space. Figure 3–39 shows how heat is transferred from one place to another.

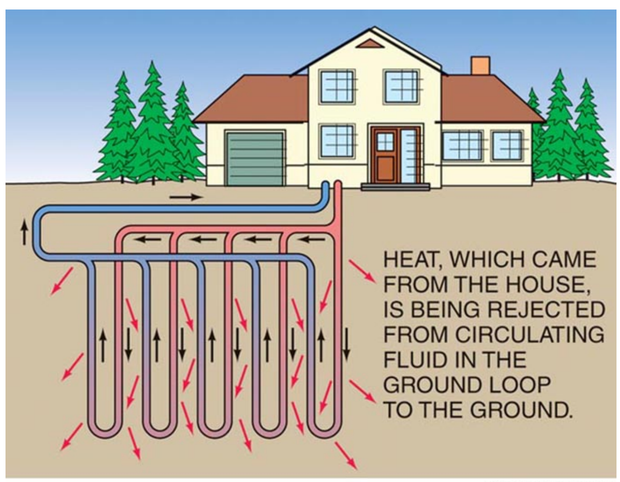


Figure 3–39. Heat transfer, rejection.
(Courtesy Cengage Learning.)

The water side of a refrigerant-to-water heat exchanger can become clogged with mineral deposits that fall out of the water. These deposits decrease the heat transfer capabilities of the heat exchanger.

Open loop

Open loop systems use wells or lakes. It is important to note that the well or lake is both the source of water and the discharge point for the used water. Since this is the case, the well or lake needs to be large and the water needs to be clean. This type of system may not be used if prohibited by local codes. Also, if a large body of water isn't available then the closed loop is used.

Closed loop

This loop is closed off and doesn't discharge the water like the open loop system. The same water circulates in the system unless there is a leak and water needs to be added.

Configuration and flow

Ground loop configurations can be vertical, horizontal, slinky, or placed in a pond or lake. The configuration depends on the amount, shape, and soil of the land. A softer soil is easier to dig into but if you get rocky or hilly land then digging is much more difficult. This increases the costs of installation.

The vertical configuration is used when land is limited. Figure 3–39 is an example of a vertical configuration.

If land is available use the horizontal configuration seen in figures 3–40 through 3–43 shows an example of pipe being put into the ground with a drill.

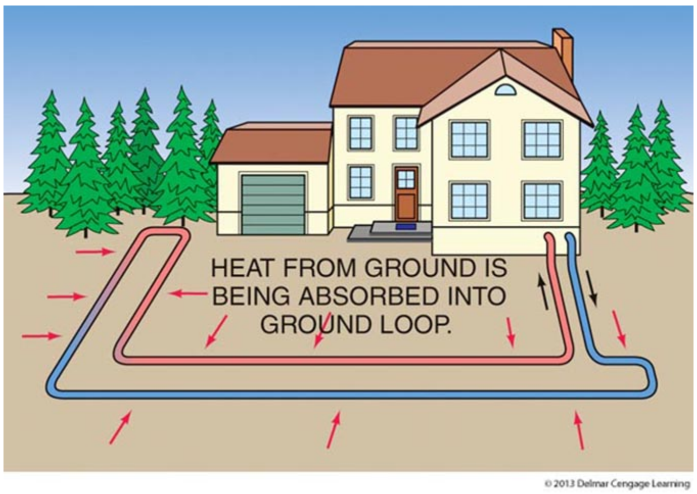


Figure 3–40. Horizontal single layer ground loop. (Courtesy Cengage Learning.)

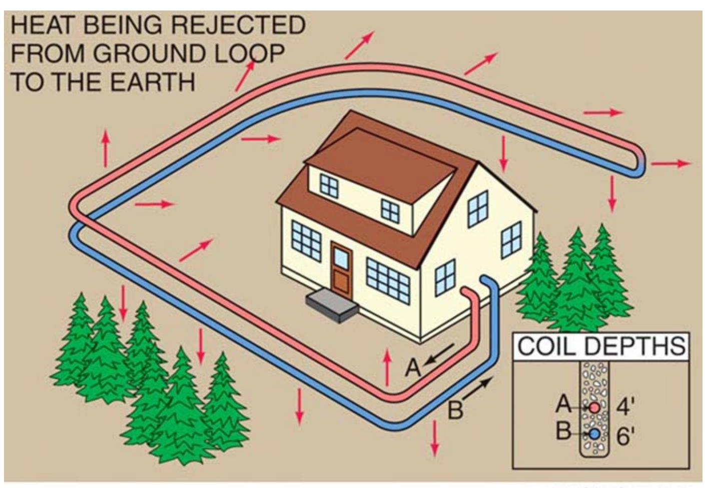


Figure 3–41. Horizontal two layer ground loop. (Courtesy Cengage Learning.)

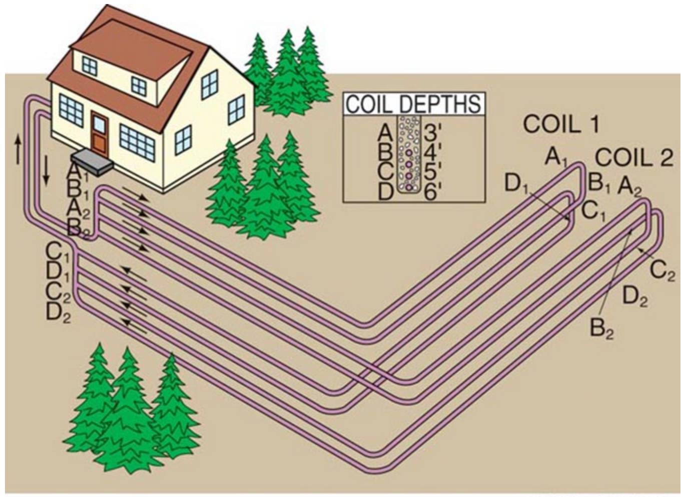


Figure 3–42. Horizontal four pipe ground loop. (Courtesy Cengage Learning.)

Figure 3–43. Diagonal drilling feeing pipe. (Courtesy Earthlinked Technologies.)

The slinky loop (fig. 3–44) is a circular coil that is placed in the ground. Using a loop reduces the amount of ground that needs to be trenched.

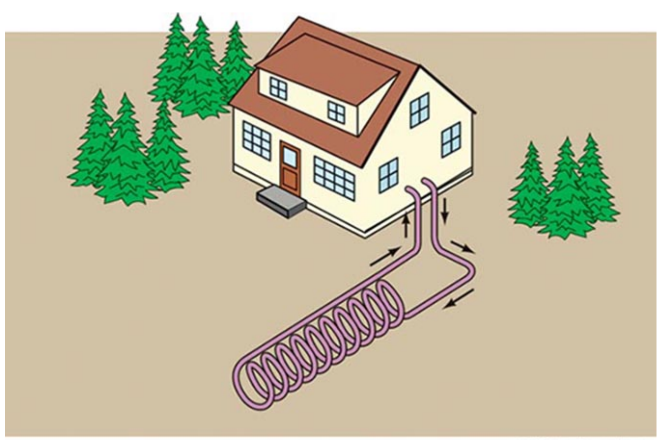


Figure 3–44. Slinky loop. (Courtesy Cengage Learning.)

System materials and fluids

Pipe buried underground is either polyethylene or polybutylene. The fluids flowing through the pipes may require antifreeze. Antifreeze may not be required in warmer climates where freezing ground or water temperatures are unlikely. However, if antifreeze is used it is either salts, glycols, or alcohols. Pipe and antifreeze selection is important. The type of pipe and antifreeze must be compatible; if not corrosion and leaks could develop.

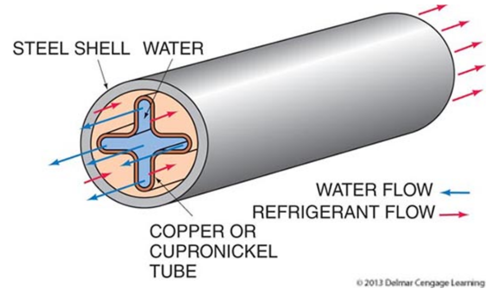


Figure 3–45. Heat exchanger. (Courtesy Cengage Learning.)

Heat exchangers

Water source heat pumps use tube-within-a-tube heat exchangers. Water flows in the inner tube and refrigerant flows in the outer tube. It is important to note that the water and refrigerant never come in contact with each other, they just transfer heat. Figure 3–45 is an example of this heat exchanger.

Each heat exchanger will have a range for the temperature difference between the incoming and outgoing water. The proper temperature difference depends upon the manufacturer and/or the geographical location. If the temperature difference range is 6 to 10 °F then the measurements taken at the inlet and outlet of the exchanger should fall into this range.

For example:

The inlet water is 56 °F.

The outlet water is 48 °F.

Then the difference is 8 °F (56 – 48 = 8).

This is an example of a difference in the range of 6 to 10 °F. Once again, the range varies by manufacturer and location.

Geothermal wells and water sources

Wells offer a source of water for heat pumps. Water is taken from the well by a water pump (or pumps) and transported it to the heat pump. If a water pump fails it causes an increase in the temperature drop of the water in and out of the refrigerant-to-water heat exchanger. This increase in temperature difference is caused by the low (or no) flow rate. Eventually, this condition causes the low pressure control to trip and lock out the unit. Common types of wells are drilled, return, geothermal, and dry. In a *drilled well* the water pump, piping, and electrical components are encased underground (fig. 3–46). This type of well is used with the open loop design (fig. 3–47).

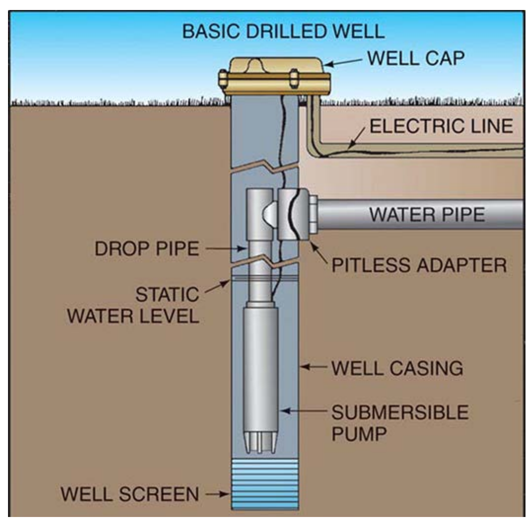


Figure 3–46. Drilled well. (Courtesy Cengage Learning.)

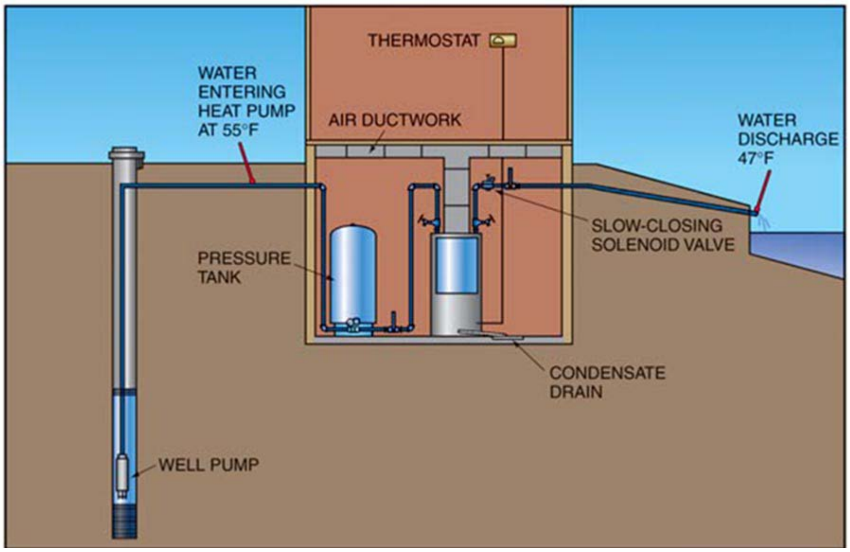


Figure 3–47. Well with open design.
(Courtesy Cengage Learning.)

Many wells used with geothermal heat pumps are grouted wells. *Grouted wells* are used to prevent contamination of the water source and protect the components inside the well casing. The grout is pumped in between the well casing and the earth. Figure 3–48 is an example of a grout pump used to put the grout in the well.

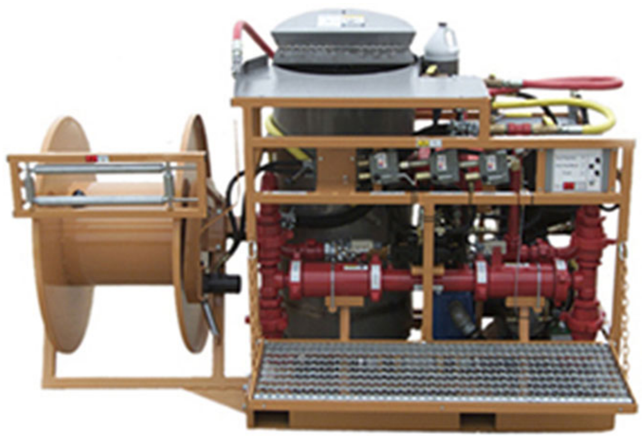


Figure 3–48. Grout pump.
(Courtesy of Geo-Loop Inc. Aurelia, IA 51005.)

The *return well* is another design of geothermal heat pumps. As the name implies, the water is *returned to the ground* after being used by the heat exchanger. The return well heat pump uses two wells: one is the return well and the other is the supply well. These wells must *not* be located too close together. If they are the return water's temperature could negatively affect the supply water temperature. For instance, in cooling mode if the warmer return water reaches the supply water too early it will heat the supply water. We don't want this! This decreases the efficiency of the unit. In the winter, the opposite effect takes place; the return water would cool the supply water too much. With that being said, there are some designs that have the return water piped to the supply water to maintain the proper amount of water volume.

Another type of well is the *geothermal well* which is a closed loop design. Water is drawn from the top of water in the well, used in the heat exchanger, and then discharged back into the bottom of the well. By the time the return water reaches the top of water column in the well it is back to its normal usable temperature.

The last well we discuss is the *dry well* which is an open loop design. This is basically just a large amount of gravel and sand in the ground. The water seeps through the gravel and sand and ends up back at the water source. Figure 3–49 is an example of a dry well.

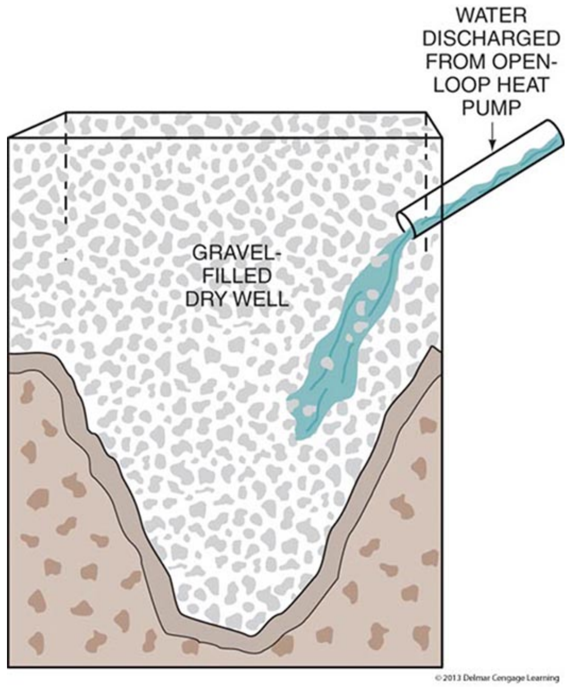


Figure 3–49. Dry well.
(Courtesy Cengage Learning.)

Pressure tanks are used with wells. The tank is pressurized with air and is used for water storage. This tank allows the system to have a steady amount of water pressure.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

821. Chillers

1. What does using multiple compressors in a chiller provide?

2. What can dip switches on a chiller board do?

3. When storing air-cooled chillers what should be done?

4. What must you be familiar with even though you may not be installing a chiller?

5. What happens when temperature drops to a predetermined setting and chilled water pumps are used to prevent freezing?

6. What freeze protection strategy can be used instead of heaters or running chilled water pumps?

7. Why does the strategy of draining the water out of the circuit work well?

8. What commands the chilled water pump to come on?

9. Where can the technician interact or “talk” with the chiller?

10. What does the chiller interface allow the chiller to communicate with besides the technician?

11. What is the *secondary function* of the condenser in a centrifugal chiller?

12. How much of the tubing bundle is covered while refrigerant is boiling in the evaporator shell?

13. What effect does the cooler have on water after it passes through the cooler?

14. When can water be removed more rapidly from a centrifugal chiller?

822. Geothermal heat pumps

1. What is the disadvantage of using ground coils?

2. Where is the water loop for rejecting or absorbing heat located?

3. What effect do deposit have on refrigerant-to-water heat exchangers?

4. Ground loop configurations are dependent upon what?

5. Where are temperature readings taken to determine the heat exchange *temperature difference*?

6. What causes an *increase* in heat exchanger temperature difference?

7. What are *grouted wells* used to prevent?

8. What is a dry well?

Answers to Self-Test Questions

814

1. Permanent and portable.
2. Outer sides.
3. Barrier.
4. To prevent it from freezing.
5. A gasket.
6. It could spoil it.
7. Mullion heaters.
8. Moisture in the box.
9. Time consuming and requires unit to be emptied of product.
10. Spoilage.
11. Every 6 hours.
12. 10 minutes.
13. So both are supplied with power for the same amount of time.
14. Because moisture enters every time the door opens.
15. Looks at how long the last defrost took.
16. Design defrost time.
17. Continually.
18. At a set cut-out temperature.
19. At a set cut-out pressure.
20. The evaporator.
21. Defrost is so quick drains need heated to prevent freezing.
22. It is unaffected by ambient temperature.

815

1. By a single low pressure control.
2. Compressor pulls pressure in common suction line down to the cutout point.

3. Pressure control contacts then open, stopping system operation.
4. In the liquid or suction line.
5. Solenoid opens.
6. Saturation temperature of the evaporator.
7. In the air outlet of the evaporator.
8. The control receives an input from the thermistor.
9. Electronics and algorithms.
10. Gas equalizer lines.
11. Time delays.

816

1. Compressor, metering device, evaporator, condenser, fans and controls in one unit.
2. Ductwork, gas piping, electric power supply, and a complete condensate drain line.
3. In a hole in the wall, the eaves of a structure, or on the side or on top of a building.
4. Replace entire unit.
5. Inlet of the evaporator.
6. Lower grille.
7. From the building.
8. Dry bulb temperature or enthalpy of outside air.
9. Inside air.
10. Return air and outside air stream.

817

1. System can reverse its operation so that the evaporator becomes the condenser and the condenser becomes the evaporator
2. Heat source.
3. Milder climates.
4. Heat pump is trying to absorb heat from the outdoor air and as the temperature falls there is less heat available to absorb
5. Inside coil.
6. Off.
7. Electric resistive heaters.
8. Free-floating slide.
9. Refrigerant pressure.
10. Pressure behind the left side is greater.
11. Because they only allow flow in one direction.
12. They operate in lower temperatures.
13. Because not all of the refrigerant is used in heating mode.
14. Defrost is initiated.

818

1. Before the system is operated.
2. Incoming power.
3. Frayed or broken conditions.
4. Swelling or bleeding.
5. Frayed edges, cracking, glazing, and tension adjustment.
6. Free operation.
7. Loose and/or missing hardware.

8. Look and listen for leaks.
9. Nameplate.

819
1. Grab supervisor or trainer and perform ops tests on various A/C equipment.
2. ASK.
3. Motors that drive compressors and fans.
4. All stages, if feasible.
5. Refrigerant pressure.

820
1. Breakdown of critical facilities, equipment, or utilities.
2. Dirt and dust buildup.
3. Draws the dirt out.
4. Could degrade the integrity of the roof.
5. Pump down or remove refrigerant from the system.
6. Move less air and reduce heat transfer.
7. More frequent service is required.

821
1. Temperature and humidity control.
2. Allow for setting features such as which compressor comes on first or whether the numeric display provides either Fahrenheit or Celsius readings.
3. Cover the protected coils and fins.
4. Entering and leaving chilled water piping.
5. Chiller controller tells the pumps to come on.
6. Antifreeze and draining the evaporator.
7. Water cannot freeze if it isn’t present.
8. Chiller controller.
9. Interface.
10. BAS.
11. Collect and concentrate noncondensable gases so that they may be removed by the purge recovery system.
12. The entire bundle.
13. Chills it to 45 °F, usually.
14. When the chiller is stopped.

822
1. Difficult to find leaks.
2. In ground or in a body of water.
3. Decreases heat transfer capabilities.
4. The amount, shape, and soil of the land.
5. Inlet and outlet of the exchanger.
6. Low or no flow.
7. Contamination of the water source and protect the components inside the well casing.
8. Basically a large amount of gravel and sand in the ground.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter.

50. (814) What happens every 6 hours when a *simple timed defrost system* is set for an interval of 6 hours?
    a. Defrost is terminated.
    b. Defrost heaters are de-energized.
    c. Defrost initiated only when needed.
    d. Defrost is initiated even if it is not needed.

51. (814) Why do the compressor and evaporator fan *not* run during defrost?
    a. The evaporator fan would freeze.
    b. The system should not be producing a cooling effect.
    c. The compressor would increase temperature too much.
    d. Compressor would burst the evaporator because of extra pressure.

52. (814) When does a *time initiated, pressure-terminated defrost timer turn off defrost*?
    a. When discharge pressure corresponds to the temperature the ice would have melted.
    b. When condenser pressure corresponds to the temperature the ice would have melted.
    c. When liquid line pressure corresponds to the temperature the ice would have melted.
    d. When evaporator pressure corresponds to the temperature the ice would have melted.

53. (815) On a *single temperature, multiple evaporator system* the needs of each evaporator are controlled by a
    a. high temperature control.
    b. low pressure motor control.
    c. high pressure motor control.
    d. liquid line, low pressure control.

54. (815) Where are evaporator pressure regulator (EPR) valves placed in a *multiple temperature, multiple evaporator system*?
    a. In the liquid line.
    b. In the discharge line.
    c. In the suction line of the warmer evaporator.
    d. Immediately after the metering device, before the evaporator.

55. (816) What is a result of a clogged window unit’s drip pan?
    a. Condensate leak.
    b. Decreased humidity.
    c. Increased system efficiency.
    d. Evaporator fan shut down and an alarm sounds.

56. (816) What is the relationship between a rooftop unit and its refrigerant charge as it is *shipped to the job site*?
    a. Roof top units need refrigerant added to account for added line sets.
    b. Roof top units come empty and need to be charged.
    c. All roof top units used chilled water to cool.
    d. Roof top units come factory-charged.

57. (816) When *ambient temperatures are low* what does the *economizer* on a roof top unit do with outside air?
    a. It uses it to heat the space.
    b. It shuts off outside air 100%.
    c. It uses only return air to cool the space.
    d. It uses the outside air to cool the space.

58. (816) Using the outside air to cool a space is called "free cooling" because
    a. no mechanical components are operating.
    b. it bypasses the heating and cooling systems.
    c. it costs no money to cool the already cool outside air.
    d. outside is easier to move due to lower static pressures.

59. (817) When a heat pump is in heat mode, heat transfers from the outdoor air to the outdoor coil because the
    a. outdoor coil is warmer than the outdoor air.
    b. outdoor coil is colder than the outdoor air.
    c. indoor coil is colder than the outdoor coil.
    d. indoor coil is colder than the outdoor air.

60. (817) What is used to *control the resistive heaters* used with a heat pump?
    a. Either a single-stage cooling or two-stage heating thermostat.
    b. Thermostatic expansion valve (TXV).
    c. Solenoid valves.
    d. Aquastats.

61. (817) Where do the reversing valve's *capillary lines* at both ends of the cylinder of connect?
    a. Suction line.
    b. Pilot solenoid chamber.
    c. The port going to the compressor.
    d. The port going to the outdoor coil.

62. (817) When does the reversing valve's pilot solenoid pin carrier change position?
    a. This pin does *not* move.
    b. During shutdown mode.
    c. When the compressor is off.
    d. When the solenoid coil is energized or de-energized.

63. (817) When both a thermostatic expansion valve (TXV) and a capillary tube are installed on a heat pump system, the TXV is used in a heat pump's winter operation because
    a. it can fluctuate the subcooling.
    b. it maintains constant subcooling.
    c. winter conditions are less constant.
    d. winter conditions are more constant.

64. (817) How do heat pump compressors handle some liquid slugging?
    a. By using smaller valves.
    b. Through the liquid slug port.
    c. Through the accumulator slugging port.
    d. Using stronger internal valves and components.

65. (817) What is the relationship between the outdoor fan's current draw during defrost and ice buildup on the outdoor coil?
    a. More ice buildup means a higher current draw.
    b. More ice buildup means a lower current draw.
    c. Zero ice buildup means too much amperage.
    d. Small ice buildup means amps are too low.

66. (818) During a pre-operational inspection all electrical connections are checked
    a. for 120 volts.
    b. to ensure they are discolored.
    c. to ensure they have overheated.
    d. for looseness, corrosion, discoloration, or other signs of overheating.

67. (818) What is checked for cleanliness during a pre-operational inspection?
    a. Only mechanical devices.
    b. Only electrical devices.
    c. The unit as a whole.
    d. Only your truck.

68. (818) A spot of oil is a good indication of
    a. a leak.
    b. clean tubing.
    c. a leak free system.
    d. good oil flow through system.

69. (819) During an operational test what step is performed *after* you ensure proper power?
    a. Turn off the breaker.
    b. Turn evaporator fan off.
    c. Turn the compressor off.
    d. Amperage checks on motors.

70. (819) What must be accounted for when using the pressure-temperature chart for an *azeotropic* refrigerant?
    a. Temperature glide.
    b. Only one refrigerant is used.
    c. The same saturation temperatures throughout the system.
    d. The same boiling temperatures throughout the evaporator.

71. (819) An assumption when reading pressure on the suction service valve with gauges is the pressure read at the suction service valve of the compressor is the same pressure at the
    a. outlet of the evaporator.
    b. outlet of the condenser.
    c. inlet of the evaporator.
    d. inlet of the condenser.

72. (819) When trying to detect non-condensables what is the *next* step *after isolating the condenser*?
    a. Read condenser pressure.
    b. Run the system fully loaded.
    c. Let condenser settle and reach ambient temperature.
    d. Compare the proper pressure with the measured pressure.

73. (819) When adding oil to a system what is the *next* step after closing the suction shut-off?
    a. Replace the oil fill plug.
    b. Run the compressor fully loaded.
    c. Stop the compressor and isolate it by closing discharge valve.
    d. Stop the compressor and isolate it by closing the suction valve.

74. (819) What is the *final* step when *adding oil to a system*?
    a. Shut the compressor off.
    b. Slowly remove the oil fill plug.
    c. Remove the oil fill plug slowly.
    d. Replace oil fill plug, run the compressor, and recheck oil.

75. (820) Why should outdoor equipment in locations on the ocean's coast be serviced more frequently?
    a. Because of the sand in contactors.
    b. Because of the sand buildup on the coils.
    c. Ocean salt is airborne and is highly corrosive.
    d. Equipment on the coast has shorter manufacturer specified maintenance intervals.

76. (821) How could an inexperienced technician *best* locate various chiller components?
    a. Troubleshooting flow charts.
    b. Manufacturer's diagrams.
    c. Asking a coworker.
    d. Guesswork.

77. (821) How are chilled water pumps controlled?
    a. Through laptops.
    b. Chiller controller.
    c. Antifreeze sensors.
    d. Cooling tower sensors.

78. (821) On a centrifugal chiller system *before entering the second stage impeller* the vapors from the first-stage impeller mix with flash gas vapors from the
    a. condenser.
    b. evaporator.
    c. economizer.
    d. compressor's third stage.

79. (821) Refrigerant is added on a *centrifugal chiller system* through a charging valve on the side of the
    a. cooling tower.
    b. compressor.
    c. condenser.
    d. cooler.

80. (821) What is the probable cause of large amounts of water collected by a centrifugal chiller's purge unit?
    a. Leaky tubes.
    b. Good heat transfer.
    c. Water in the system is too hot and needs to be purged.
    d. Purge unit malfunction because it is supposed to remove air only.

81. (822) Water in a *closed-loop design geothermal heat pump* that uses a well is discharged
    a. at the top of the well.
    b. at the bottom of the well.
    c. in the middle of the well.
    d. at least 50 feet from the well.

Please read the unit menu for unit 4 and continue ➔

Student Notes

Unit 4. Applied Refrigeration and Cooling

WE START OFF with the pressure-enthalpy (PE) and pressure temperature (P/T) charts. The charts help you determine the processes happening inside the HVAC/R system. Next, we cover superheat and subcooling. These two concepts are absolutely critical to you do your job well. Finally, the unit concludes with a discussion about the procedures of charging, recovering and pumping down HVAC/R systems. Again, this unit deals with the actual application of the A/C aspect of your job. Like any other unit, take this information then grab your trainer or supervisor and have them show you these concepts hands-on!

4–1. Pressure-Enthalpy Chart and Pressure Temperature Charts

The PE chart is a tool that can help you determine what is going on in a refrigeration system. Using the chart, you can make a comparison between what is actually happening and what is supposed to be happening. By making this comparison, you can determine whether the system is working properly.

823. Pressure-enthalpy chart characteristics

At this point you understand that a refrigerant exists in both the liquid and vapor state during the refrigeration cycle. You will recall that the vapor state is often referred to as the “gas state.” In operation, you understand that the refrigerant is evaporated from liquid to vapor and then condensed back to a liquid state. In this lesson, we expand this basic premise by presenting focusing on three major areas:

- Thermodynamic properties of refrigerants.
- Characteristics of the PE chart.
- Plotting the chart.

Thermodynamic properties of refrigerants

Five thermodynamic properties of refrigerants allow you to follow the refrigeration cycle on a refrigerant PE chart. We have discussed some of these properties before but we revisit them again here because they are important for understanding the PE chart. The five refrigerant properties covered in the following table are:

- Temperature.
- Volume.
- Pressure.
- Enthalpy.
- Entropy.

Thermodynamic Properties of Refrigerants	
Property	**Description**
Temperature	If you want to know how hot or cold a substance is, you can use a thermometer to check its temperature. This only tells you the heat intensity; it does not tell you how much heat is in the substance or how much heat the substance can hold. It also does not tell you how much heat must be added or taken away to change the temperature. In refrigeration and A/C work, temperatures are generally measured with thermometers that have either Fahrenheit (F) or Celsius (C) scales. • On the *Fahrenheit* scale, water freezes at 32 °F and boils at 212 °F at sea level. • On the *Celsius* (or centigrade) scale, water freezes at 0 °C and boils at 100 °C at sea level.
Volume	Volume is a measure of the space occupied by a substance. Specific volume is the amount of space a specific weight of the substance occupies. Specific volume is the common way to give the volume for refrigerants, and its units are cubic feet per pound.
Pressure	A gauge can be used to measure this value and would be read in pounds per square inch gauge (psig). On the PE chart, the pressure is *absolute pressure* (pounds per square inch absolute [psia]). To get the absolute pressure, add atmospheric pressure to the gauge pressure. • At sea level, the atmospheric pressure is 14.7 pounds per square inch (psi). • If a gauge reading is 20 psig adding 14.7 psi to it the result is 34.7 psia.
Enthalpy	Enthalpy is the total heat content and is a measure of the amount of heat a vapor or liquid can hold. It also shows how much heat needs to be added or removed to change temperature. Keep in mind that a vapor can have the same heat content at different temperatures; however, other properties such as pressure and volume have to be different. Enthalpy is not measured directly; instead, it is determined by reading the value from a diagram, chart, or table using values that can be measured. Enthalpy readings are given in British thermal units per pound (Btus/lb.).
Entropy	Entropy is a term that is applied to the compression process (in most cases). It is a thermodynamic measure of the amount of energy unavailable to do useful work in a system. More technically, entropy is the ratio of the heat content of a vapor to the absolute temperature of the vapor. The most important thing to remember about entropy is that it stays the same when a vapor is compressed, if outside heat is not added to or removed from the vapor. The compression is *adiabatic* when the *entropy is constant*.

Technician's Note: In order to discuss pressure enthalpy diagrams it is absolutely critical you understand the difference between the terms *temperature* and *heat content*. Temperature IS NOT heat content. Temperature factors into heat content but it does *not* make up the total heat content of refrigerant so **DO NOT** use these terms interchangeably.

Characteristics of the PE chart

There two important points you must remember when you are using a PE chart:

- The chart is *based on one pound of refrigerant*.
- Each refrigerant has its own chart.

Earlier you learned that matter can exist in three states: vapors, liquids and solids. An example of a PE chart is shown in figure 4–1. The PE chart shown is concerned only with liquid and vapor. By using the PE chart, you can see refrigerant vapor and liquid at work. If you put liquid on one side of the chart and vapor on the other, you see that they both are involved together in the change of state. The change of state takes place inside of the curve on the chart. The change is either from a liquid to a vapor or from a vapor to a liquid.

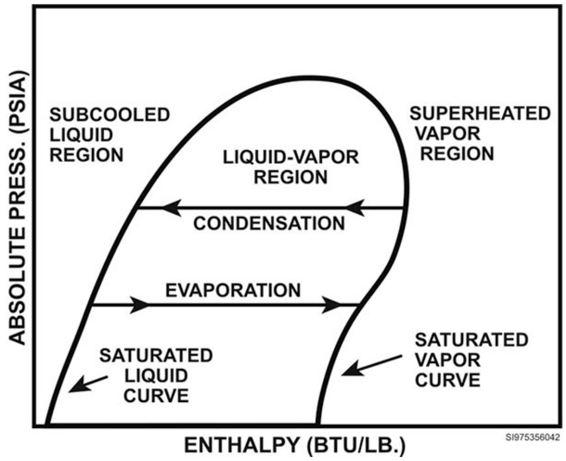


Figure 4–1. Simple PE chart showing regions.

Pressure-Enthalpy Chart Regions	
Region	**Description**
Saturated Refrigerant Curve	The liquid and vapor areas of the PE chart are separated by a line that forms a curve. This curve is the *saturated refrigerant curve* (fig. 4–2). If a plot falls on or in this curve the refrigerant is saturated (see fig. 4–2 shaded interior). There is one point on the curve at the top. This is point has many names: critical point, critical pressure, or critical temperature. *Above this point the refrigerant does not condense*; it remains a vapor. The *saturated liquid curve* is on the left hand side (see fig. 4–2, blue shaded region). Any point on this line is a saturated liquid. The *saturated vapor curve* is on the right hand side (see fig. 4–2 red shaded region). Any point on this line is a saturated vapor.
Subcooled Liquid	The subcooled liquid region is located to the left of the saturated liquid curve. Refrigerant in the subcooled region is completely liquid.
Superheated Vapor	The superheated vapor region is located to the right of the saturated vapor curve. Refrigerant in the superheated region is completely vapor.
Saturated	Refrigerant in the saturated region is a partial liquid, partial vapor combination. Look at the point in figure 4–3, it is a saturated vapor. Follow the line as it travels to the left. The refrigerant passes over what are called quality lines or percentage of quality lines. Each line represents 10 percent. The best way to remember the lines is as vapor lines. This means that the percentage on the line represents the percentage of vapor. For example, if the refrigerant point falls on the 20 percent line it means refrigerant's state is 20 percent vapor. Since it is 20 percent vapor, it must be 80 percent liquid. This is based off of the total refrigerant being 100 percent. Let's look at the math: 100% total – 20% vapor = 80% liquid.

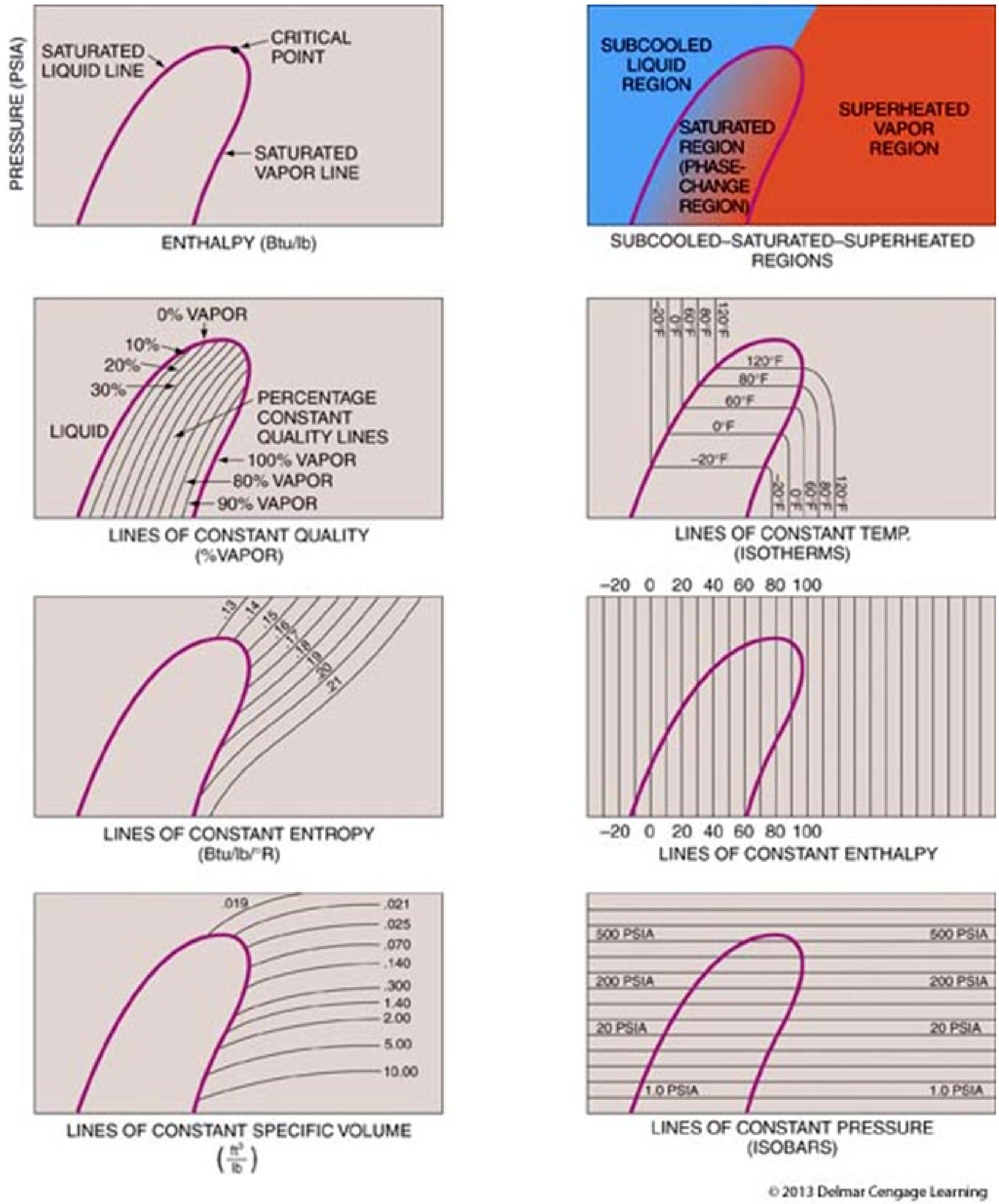


Figure 4–2. Saturated refrigerant.
(Courtesy Cengage Learning.)

The chart

Use figure 4–2 with the following breakdown of the PE chart.

- *Absolute press*ure is located on the left side and cross the chart horizontally.
- *Enthalpy numbers* are on the bottom and extend vertically through the chart.
- *Lines of constant quality* are slightly curved lines on the inside of the saturated curve.

- *Lines of constant temperature* curve up into the saturated region, level out horizontally and then head straight up vertically.
- The numbers for the temperature lines are to the right of the curve about halfway up.
- *Lines of constant entropy* extend from the curve out to the right of the chart.
- Lines of *constant specific volume* extend from the saturation at a different angle than entropy.

The numbers are found as shown in figure 4–2.

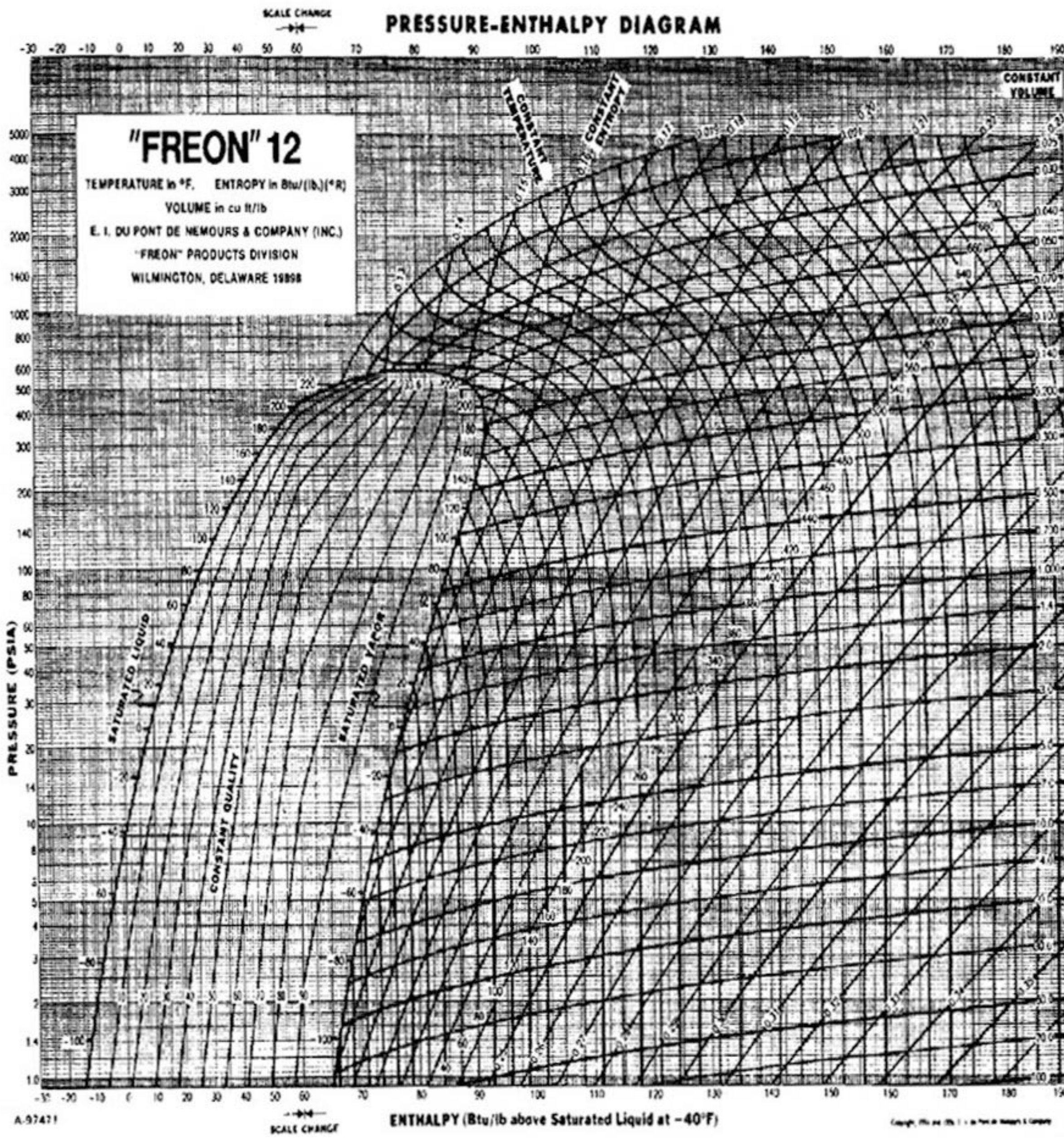


Figure 4–3. Quality lines.

824. Refrigeration process and plotting the pressure-enthalpy chart

The PE chart is basically a graph that shows you what is occurring inside the refrigeration system. In this lesson we cover each step of the cycle in depth. Let’s begin at the entrance to the compressor.

Compression

Refrigerant enters the compressor at point H on figure 4–4. Point H is plotted based off the PRESSURE reading taken at the inlet of the compressor. The compressor pumps the refrigerant which exits at point B. Notice the lines slopes up and to the right. This means the heat content and pressure are rising. By going to the right, the line represents the increase in enthalpy and by going up it represents the pressure rising. The heat added is from the heat of compression. Remember, the compressor decreases the volume and increases the pressure of the refrigerant. The compressor is drawn in parallel to the constant entropy lines. In this case, entropy, represents the compression process.

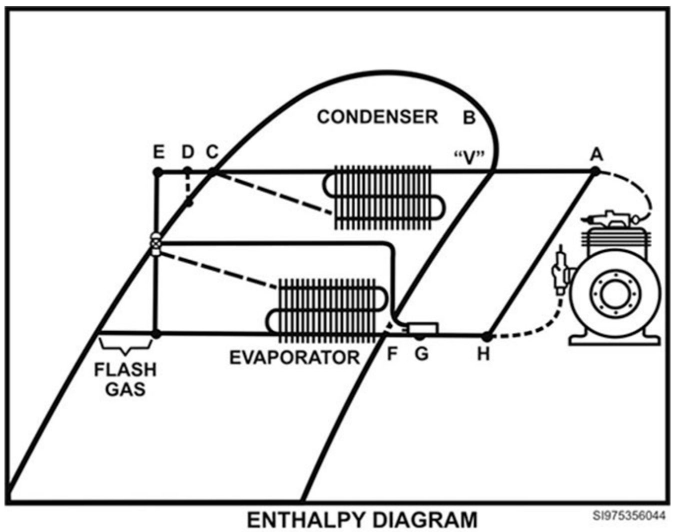


Figure 4–4. Refrigeration cycle.

Heat rejection

The refrigerant leaves the compressor with heat content, measured in Btu/lb. The refrigerant is now in the discharge line. From this point on the total heat absorbed by the evaporator and the heat gained during compression must be rejected. We place a plot point B by measuring the temperature at the compressor's outlet. Because the temperature lines curve be careful when placing this point. For example, if the temperature is 190 °F you may have to "eyeball" it and place it halfway between 180 and 200 °F.

The refrigerant begins to desuperheat as soon as it leaves the compressor but most desuperheating is done inside the condenser. Desuperheating is represented from A to "V." The line stays horizontal so there is no drop in pressure. However, there is a drop in temperature and heat content.

As soon as the refrigerant enters the saturated curve it begins to condense. It begins to change from 100 percent vapor to a liquid. As it travels through the curve it becomes more of a liquid because it is condensing. Remember, we are in the condenser so it makes sense that the refrigerant is condensing. Eventually the refrigerant reaches the other side of the curve and as soon as it passes the curve it is 100 percent liquid. Anything to the left of the curve represents the liquid being subcooled.

Expansion

The subcooled liquid eventually hits the expansion valve. The temperature is measured at the inlet of the expansion valve and plotted as point E. Before we continue from the expansion valve, notice where the refrigerant hits the left side of the saturated refrigerant curve, point C, and then travels to the point it enters the expansion valve, point E: this is the amount of subcooling that takes place inside the system. You can determine the amount of subcooling by using the vertical temperature lines.

So, continuing from point E, the lines go down vertically. This straight vertical drop represents the pressure and temperature drop that occurs inside the expansion device. Notice the line is completely straight, this means that there *no change in the enthalpy of the refrigerant*. The line is drawn to the corresponding temperature measured at the outlet of the expansion device.

This downward vertical line falls back into the saturated refrigerant region. The expansion device flashed liquid refrigerant off and turned a percentage of it into a vapor. For example if the refrigerant is 100 percent liquid at point C but falls onto a line of constant quality—the 30 percent line. This means that the refrigerant is now 30 percent vapor. It also means that 30 percent of the liquid is now flash gas. Now that refrigerant has flashed off, the remaining refrigerant can be used to produce the refrigeration (or cooling) effect.

Heat absorption

The refrigerant travels through the evaporator and picks up heat from the conditioned space. As it picks up heat it turns into a vapor. This is represented by a horizontal line traveling towards the right side of the curve. Notice the quality lines go up towards 100 percent vapor which is the curve. The *horizontal line represents no change in pressure but a change in temperature and enthalpy*. In this case, the temperature and enthalpy are rising because the refrigerant is picking up heat.

After the refrigerant turns to vapor and leaves the evaporator, at point G, it begins to superheat because it is still absorbing heat. Point G is the temperature taken from the evaporator outlet. Superheat is represented by point F until the line reaches the curve and continues up until it reaches, A, the compressor exit. We measure the superheat from G to H with devices. The *total superheat* is F to H.

Plotting the chart

In the last lesson you learned the basic parts of the PE chart. Now we will focus on plotting the chart.

Pressure and temperature readings

For this lesson segment, we use the PE diagram shown in figure 4–4 and the refrigeration diagram in figure 4–4. Using these diagrams, let’s go through a simple refrigeration system and see how it is plotted on the PE chart.

You will take a total of 7 readings. You will plot 9 total plots on the chart but you need to take 7 readings from the actual system to accomplish this task.

You first need to take 2 system pressure readings.Convert the reading from the low-side manifold gauge to psia and plot the evaporation line (Point H). Also, take the reading from the high-side gauge and convert that to psia, you can plot the condensation line (Point A). Now extend these two lines to each side of the chart as we plot them.

The lines intersect the saturated vapor curve forming points of intersect to be used later. The absolute pressure scales or psia (not shown here) should be the same on both sides of the chart.

You can now use a temperature measuring device and measure the temperature at the following places (fig. 4–4).

- Control point of the expansion valve (thermal bulb) (Point G).
- At the inlet and at the outlet of the compressor (Points H and A).
- At the outlet of the condenser (Point D, figure 4-4).
- At the inlet of the expansion valve or metering device (Point E).

Now, plot those temperature readings on the chart:

- Control point of the expansion valve (thermal bulb) (Point G).
- At the inlet and at the outlet of the compressor. (Points A and H).
- At the outlet of the condenser (Point D).

- At the inlet of the expansion valve or metering device (Point E).

After you plot the temperatures fill in the following additional information:

- Evaporator superheat, point F to point G.
- Suction line superheat, point G to point H.
- Heat of compression, point H to point A.
- Desuperheating is from point A to "V."
- Subcooling in the condenser from point C to point D.
- Subcooling in the liquid line from Point C to point D.
- Total subcooling from point C to point E.
- Flash gas from where line E stops when it goes vertically downward.

When plotting the temperatures of the expansion valve control point and the inlet and outlet of the compressor, follow the curved lines from the saturation vapor curve down to the previously plotted suction and discharge pressure lines. The temperatures of the expansion valve control point and the compressor inlet are drawn down to the line representing the evaporator. The compressor outlet temperature is drawn down to the line representing the condenser. The lines are then drawn vertically and extended to the bottom of the chart. The compressor outlet temperature is also extended to the top of the chart.

The condenser outlet and expansion valve inlet temperatures are vertical lines and are drawn accordingly. Plotting these points also shows you how much heat is gained or lost (in both degrees and Btus) in each of these processes.

Pressure enthalpy chart software

If you don't want to mess with the charts then you can use pressure enthalpy software if it is available to your shops. You still have to take the temperature and pressure readings but the information is put into a program and the program outputs the PE chart. Pretty cool, huh?

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

823. Pressure-enthalpy chart characteristics

1. What are the five refrigerant properties used on the PE chart?

2. What substance does temperature tell you about?

3. What is the amount of space a specific weight occupies?

4. What is the common way to give the volume of refrigerants?

5. What is the *absolute pressure* of a gauge reading 21 psig?

6. What is enthalpy?

7. What are enthalpy readings given as?

8. What process is entropy associated with?

9. What is entropy?

10. What is the most important thing to remember about entropy?

11. How much liquid exists if the pressure enthalpy chart plot lands on the 20 percent quality line?

824. Refrigeration process and plotting the pressure-enthalpy chart

1. What does a *horizontal line traveling to the right* of the PE chart represent?

2. What is represented from point "A" to point "V" in figure 4-4?

3. What happens to the refrigerant as soon as it enters the saturated curve?

4. What does the straight vertical drop represent?

5. What does the straight vertical drop mean for *enthalpy*?

6. What does a *horizontal line traveling to the right side* of the curve represent?

7. What does a horizontal line mean for pressure, temperature, and enthalpy?

8. How is the evaporation line plotted?

9. How is the condensation line plotted?

10. According to figure 4–4, what is the point G?

11. According to figure 4–4, what is the point E?

12. According to figure 4–4, what is represented by points A and H?

13. According to figure 4–4, from what two points does superheating take place?

4–2. Superheat and Subcooling

Superheating and subcooling are a commonly confused set of concepts. Many technicians avoid these terms and their application because they don't fully understand them. For this reason, we devote an entire section to these concepts. Spend as much time as you need with this section and ensure you fully understand these concepts.

Not only will this section help you understand the concepts but the true intent is to help you learn how to apply superheat and subcooling. Within this section we will discuss how to measure and adjust both superheat and subcooling. We start with superheat.

825. Superheat

Superheat is any heat added to refrigerant vapor. For our purposes, you *cannot superheat a liquid*. If you add heat to a liquid you are simply heating a liquid. If you *add heat to a vapor* you are *super* heating it. Superheat is found near the end of a coil that is absorbing heat and up to and through the compressor. The heat of compression superheats the vapor.

Superheat is often a term we use when dealing with the evaporator. Liquid refrigerant enters the evaporator and vaporizes as it absorbs heat. Eventually the refrigerant reaches the complete vapor state near the end of the coil. Any heat added after it reaches the full vapor state is considered superheat. The heat is mostly from the conditioned space while some heat is added from the ambient air around the suction line going to the compressor.

What controls superheat?

Superheat is determined by the expansion device. Thermostatic and stepper motor expansion valves control superheat. The capillary tube and fixed bore metering devices do *not* control superheat. TXVs and stepper motors not only control superheat they are also designed to maintain a designated set point.

Superheat is critical for capillary tubes or fixed bore metering devices because these devices do *not* control superheat. They are more susceptible to over- and under-charged conditions.

Why is superheat important?

Superheat is important because it ensures we have the proper amount of refrigerant in the evaporator. Superheat is also important because superheat in and after the evaporator means there is no liquid refrigerant reaching the compressor.

Superheat can also tell you when to charge a system. A TXV or stepper motor valve should be maintaining a constant superheat which means that superheat is not a good measurement of when to charge/remove refrigerant to/from these systems. However, a superheat measurement could tell you when a TXV or stepper expansion valve is malfunctioning.

Systems with a capillary tube or fixed bore metering device *can* use the superheat measurement to determine proper refrigerant charge. A *high superheat* means the evaporator has a refrigerant shortage which could mean the system is low on refrigerant. A *low superheat* means the evaporator has too much refrigerant and the system could be overcharged. This could result in liquid getting back to the compressor.

Notice how we don't say the system ***is*** undercharged or overcharged, we say it ***can*** or ***could*** be. Something else in the system could be causing these conditions but we don't cover them in this section.

How do you know the superheat is too high or too low?

The manufacturer and current conditions! The manufacturer and current conditions! The manufacturer and current conditions! There are various ranges for various types of equipment but when it comes down to it the manufacturer makes the determination of the proper superheat for its systems at certain conditions.

When and how do you measure superheat?

Superheat should be measured for any of these conditions:

- The system appears to not be cooling.
- The expansion device is replaced.
- The compressor is replaced.
- The amount of refrigerant is changed or during an operational test.

Larger evaporators have Schrader valves for taking pressure at the evaporator outlets.

Superheat measurement steps

The following table provides the step-by-step process for measuring superheat.

Measuring Superheat	
Step	**Action**
1	Gather information about the proper airflow across the evaporator and any superheat charts or curves.
2	Allow the system to run long enough for temperatures and pressures to stabilize.
3	Verify proper airflow across the evaporator coil.
4	When using the curve or chart, take the condenser entering dry bulb air temperature, indoor dry or wet bulb return/mixed air temperature.
5	Clean the area of the pipe where temperature readings are going to take place (see step 5). Remove any foreign dirt, objects or liquid. Use a rag and/or emery cloth.
6	Take temperature at the outlet of the evaporator. (Pipe clamps like the one shown in figure 4–5 are good for this measurement.)

Measuring Superheat	
Step	**Action**
	 **Figure 4–5. Pipe clamp.** **(Images Copyright Fieldpiece Industries.)** See notes 1, 2, and 3.
7	Take a pressure reading from the suction line service valve. (Take reading at compressor inlet if measuring total superheat or suction line is less than 15 feet.) (The service port on your manifold gauge assembly is commonly used to obtain this pressure.)
8	Convert the pressure reading from step 7 to temperature using the P/T chart.
9	Subtract the saturation temperature from the suction line temperature.
10	Compare the superheat to the manufacturer’s chart or curve. If a chart or curve was not provided, call the manufacturer to ensure you use the proper superheat to compare your readings against.
11	Determine if a corrective action is necessary. If so, determine what corrective action should be taken.

NOTES:

1. Pipe clamps come in different sizes. Ensure you are using a clamp size that matches the refrigerant pipe size.
2. If the distance from the evaporator outlet to the compressor inlet is short, less than about 15 feet, then the temperature reading can be taken at the compressor inlet.
3. If the distance is more than about 15 between the evaporator outlet and the compressor inlet then there may be too much of a pressure drop and this gives the technician an inaccurate superheat reading.

Explanation of temperature and pressure readings

We take the pressure reading downstream from the temperature reading. What if the temperature reading is 50 °F and the pressure reading converts into 40 °F. Did we *de*superheat? NO! The location of the pressure reading we convert to temperature may be downstream of the temperature reading but it is based off of an assumption.

We assume the temperature converted from the pressure reading is the saturation temperature at saturation vapor point further back in the evaporator. We assume this because this is the most convenient place to measure saturation temperature at the vapor point. We need the temperature at V point because this represents the first place in the evaporator where VAPOR ONLY exists. From here to the evaporator outlet (sometimes the compressor inlet) is the superheat we are concerned with. We can’t measure pressure at V point because the V point is never in the same location because the refrigerant vaporizes at different points in the evaporator during different conditions. Therefore, we could never place a gauge or pipe clamp to take readings at V point because it is always changing. So, the assumption is the gauge reading converted to temperature on the suction line is our V point saturation temperature!

Normal superheat example

Let's use an example to help you determine the step-by-step procedures for performing this task. This entire task does not take very long at all so don't be intimidated by performing it.

1. SSgt Soandso uses his cell phone to gather information about the proper evaporator airflow and the superheat curve for System X that uses R-410A refrigerant.
2. SSgt Soandso turns on a cooling system and allows it to run long enough for temperatures and pressures to stabilize.
3. The SSgt verifies proper airflow across the evaporator coil. He measures the pressure drop and then compares it the manufacturer's data he gathered in step 1. Airflow is correct.
4. He measures condenser entering dry bulb air temperature, indoor dry and wet bulb return/mixed air temperature. Condenser entering temperature is 90 °F and the indoor temperatures are 80 °F DB and 67 °F WB. This means the superheat should be 17 plus or minus 2.5 °F.
5. He then cleans the area of the pipe where readings are going to take place. He discovers the pipe where he is going to measure is dirty and cleans it with a rag and then emery cloth.
6. He then takes the refrigerant temperature at the outlet of the evaporator using a pipe clamp. The temperature is 55 °F.
7. Next, he takes a pressure reading from the compressor inlet (remember, some manufacturers want you to use the compressor inlet) using his manifold gauge assembly. The reading is 118 psig.
8. He then converts the 118 psig reading to a temperature of 40 °F using the P/T chart.
9. Then he subtracts the boiling temperature, 40 °F, from the suction line temperature 55 °F (55 - 40) and arrives at superheat of 15 °F.
10. The superheat of 15 °F falls within the range of the manufacturer has provided, 17 plus or minus 5 °F. The range for this instance is between 14.5 and 19.5 °F superheat.
11. SSgt Soandso determines there is no corrective action needed and decides this is a good unit to use for training a younger Airman about proper superheat.

Abnormal superheat example

In the example above, the superheat was correct so no action was needed but what happens if the superheat reading is incorrect. Check out the next example and see what SSgt Soandso finds.

1. SSgt Soandso uses his cell phone to gather information about the proper evaporator airflow and the superheat curve for System X that uses R-410A refrigerant.
2. SSgt Soandso turns on a cooling system and allows it to run long enough for temperatures and pressures to stabilize.
3. The SSgt verifies proper airflow across the evaporator coil. He measures the pressure drop and then compares it the manufacturer's data he gathered in step 1. He has the proper airflow.
4. He measures condenser entering dry bulb air temperature, indoor dry and wet bulb return/mixed air temperature. Condenser entering temperature is 90 °F and the indoor temperatures are 80 °F DB and 67 °F WB. This means the superheat should be 17 plus or minus 2.5 °F.
5. He then cleans the area of the pipe where readings are going to take place. He discovers the pipe where he is going to measure is dirty and cleans it with a rag and then an emery cloth.
6. He then takes the temperature at the outlet of the evaporator using a pipe clamp. The temperature is 56 °F.
7. Next, he takes a pressure reading from the compressor inlet using his manifold gauge assembly. The reading is 142 psig.
8. He then converts the 142 psig reading to a temperature of 50 °F using the P/T chart.

9. Then he subtracts the boiling temperature, 50 °F from the compressor inlet temperature 56 °F (56 – 50) and arrives at a superheat of 6 °F.
10. The superheat reading does *not* fall within the range of 8 to 12 °F the manufacturer has provided. He has too little superheat.
11. SSgt Soandso determines a corrective action is needed and decides this is a good unit to use for training a younger Airman about *improper* superheat.

Adjusting superheat

From the example above, SSgt Soandso needs to make an adjustment of the superheat. He did not have enough superheat. In the example, the expansion device was not mentioned. This was done on purpose because adjusting the superheat depends on the type of expansion device used.

- If a TXV was used, then the TXV would need to be adjusted *as long as the rest of the system was functioning properly and had the proper charge.*
- If a capillary tube or fixed bore metering device was used, then the amount of refrigerant would need changed *as long as the rest of the system was functioning properly.*

Be careful to remember in these examples that we assume every other part of the system works properly. In reality, there could be numerous issues and knowing the superheat is another measurement used to help you troubleshoot. Once you have determined that the superheat needs adjusting then track the steps in the following paragraphs. This lesson is *not* designed for troubleshooting but to *provide the steps for adjusting superheat.*

Adjusting superheat with a TXV metering device

The steps for adjusting the superheat in a TXV system are given below. These steps involve adjusting the TXV. This usually a last resort move because TXVs are factory set. In fact, many are actually non-adjustable. Do NOT adjust a TXV until you are 100 percent sure that it is the problem.

If you do *not have enough* superheat then follow these steps:

1. Remove stem cap from TXV.
2. Turn the TXV adjustment screw *clockwise*.
3. Read new superheat. Continue to adjust until you reach the desired superheat.
4. Place stem cap back on TXV.

If you have *too much* superheat then follow these steps:

1. Remove stem cap from TXV.
2. Turn the TXV adjustment screw *counter*clockwise.
3. Read new superheat. Continue to adjust until you reach the desired superheat.
4. Place stem cap back on TXV.

Adjusting superheat with a capillary tube or fixed bore metering device

This task involves charging and removing refrigerant from a system. Charging and recovery are covered in a later lesson. For now, just know that refrigerant needs to be added or removed to adjust the superheat with cap tubes and fixed bore metering devices.

If you do *not have enough* superheat, then follow these steps:

1. Remove refrigerant from the system.
2. Read new superheat.
3. Continue to remove until you reach the desired superheat.

If you have *too much* superheat, then follow these steps:

1. Add refrigerant to the system.
2. Read new superheat.

3. Continue to add until you reach the desired superheat.

NOTE: Add or remove refrigerant gradually so that you do not create conditions that result in the opposite effect.

826. Subcooling

Subcooling is the amount of heat that has been removed from refrigerant after it has condensed. Subcooling is measured in degrees. Normally, near the end of the condenser, refrigerant turns into 100 percent liquid. The point, L point, from which the refrigerant turns into a liquid, and up until the inlet of the metering device the liquid is subcooling. A common rule of thumb for subcooling is 10 to 20 °F. Remember that when the refrigerant first turns into a liquid it is at its saturation temperature.

The refrigerant in the coil is turning into a liquid. As it turns, the sensible heat remains the same until the refrigerant turns into 100 percent liquid. From this point forward, the liquid gives up heat and is subcooling.

Let’s use an example of a subcooling with R–410a. Assume that temperature when the refrigerant turns to a liquid is 120 °F and the point just before the metering device is 110 °F. 120 minus 110 equals 10 °F, so there is 10 °F of subcooling.

Why is subcooling important?

Subcooling can determine if a refrigerant charge is acceptable in a thermostatic expansion valve system. Also, it determines if any gas is entering the evaporator. We do not want gas entering the evaporator, it needs to be 100 percent liquid. The more liquid in the evaporator means more heat can be absorbed from the conditioned space.

The subcooling measurement tells you how much refrigerant is in the condenser. There is a balance though, we don’t want all of the subcooling we can get. Much like everything in life, too much of one thing is a bad thing. Subcooling has a design limit. There is the possibility of having too much or too little subcooling.

If subcooling is too low the compressor could overheat due to a lack of refrigerant in the system. If it is too high, the system is overcharged and efficiency drops. Also, with too much refrigerant, you could damage the compressor’s valves.

How do you measure subcooling?

There are numerous ways to find subcooling. Here we look at four methods of measuring subcooling: with gauges and temperature device, with meter accessory, with digital gauges, and wirelessly. The first way we cover is more traditional.

Measure subcooling with gauges and temperature device

The table below provides step-by-step instructions for this subcooling measuring process.

Measuring Subcooling with Gauges and Temperature Device	
Step	**Action**
1	Allow system to run long enough for temperatures and pressures to stabilize.
2	Use high side gauge to measure pressure at the *liquid* line.
3	Convert the pressure in the previous step to temperature using a pressure temperature chart.
4	Clean the area of the pipe where temperature readings are going to take place (see step 5). Remove any foreign dirt, objects or liquid. Use a rag and/or emery cloth.
5	Measure the temperature of the liquid line near the metering device using a pipe clamp.(Other temperature sensing devices can be used.)

Measuring Subcooling with Gauges and Temperature Device	
Step	**Action**
	If the metering device is not near, take the reading approximately 6 inches from the outlet of the condenser.
6	Obtain subcooling by subtracting the temperature reading of the liquid line from the temperature converted from pressure. (Condenser saturation temperature minus liquid line temperature.)
7	Compare the subcooling value versus the manufacturer's specs.

Measuring subcooling with meter accessory

The meter used in this example has an accessory head that attaches to the meter and provides subcooling readings. Follow the steps below.

Measuring Subcooling with Meter Accessory	
Step	**Action**
1	Turn on system and allow it stabilize.
2	Connect the head to the meter.
3	Set meter to proper setting according to the manufacturer's instructions.
4	Attach refrigerant hose to the accessory head and to the liquid line service port.
5	Select subcooling and choose the refrigerant.
6	Connect the pipe clamp to the liquid line as close to the service port as possible.
7	Read the display to obtain the subcooling.

Measuring subcooling with digital gauges

Another way to measure subcooling is to use digital gauges and pipe clamps (see fig. 4–6 for digital gauges). These tools automatically provide you with subcooling data.

Figure 4–6. Digital gauges.
(Images Copyright Fieldpiece Industries.)

Measuring Subcooling with Digital Gauges	
Step	**Action**
1	Turn on system and allow it to stabilize.
2	Connect the high side hose to the liquid line service port.
3	Connect thermocouple as close to the service port as possible.
4	Read the subcooling display on the gauges.

Measuring subcooling wirelessly

There are also subcooling tools that give readings wirelessly. Pretty cool huh? You can use an app on your phone, tablet, or other wireless device to receive the subcooling reading! This information can be emailed to yourself. This allows you to use the readings for training or to keep historical records of the different systems on base. Follow the steps below.

Measuring Subcooling Wirelessly	
Step	**Action**
1	Turn on system and allow it to stabilize.
2	If required, pair your device with the wireless gauges and pipe clamp.
3	Connect the gauge to the liquid line service port.
4	Attach the pipe clamp as close to the liquid line service port as possible.
5	Read the display on your wireless device.

Determining if subcooling is at design specifications

Now that you know the many ways to measure subcooling, you need to know if the subcooling you measured is accurate or not. There are rules of thumb, charts, and curves that enable you to determine if the subcooling you measured is the proper amount.

Rules of thumb for subcooling vary. A common range is 10 to 20 °F of subcooling. Another one is 5 to 15 °F. Some say 10 to 15 °F is the right amount. The proper way to determine subcooling is by following the manufacturer's instructions! What a concept!

Manufacturers provide subcooling curves. Figure 4–7 is one example.

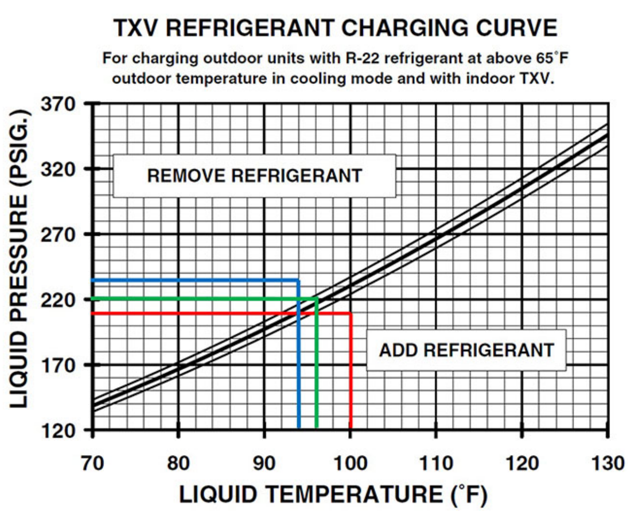


Figure 4–7. Subcooling curves.

In this example the actual subcooling number does not need to be determined but the measurements still need to be taken. The left hand side has the liquid pressure is psig and ranges from 120 to 370 psig. The bottom of the chart features the liquid temperature ranging from 70 to 130 °F. The curve that passes through the middle of the chart represents where the pressure and temperature should meet for a proper charge. There are smaller lines around the curve which give a range that the measurements can meet and still be accurate. If the pressure and temperature meet *above the curve* then refrigerant needs to be removed and if they meet *below the curve* then refrigerant needs to be added. The examples below give you a step-by-step way of determining if a charge is correct. On the chart in figure 4–7, the system has an indoor TXV, R-22, and the outdoor temperature must be above 65 °F.

Let's break down determining the proper amount of charge step-by-step using the table below.

Determine Proper Amount of Charge	
Step	**Action**
1	Assume 220 psig of liquid pressure.
2	Find 220 psig on the left of the chart in figure 4–7.
3	Assume a liquid temperature of 96 °F.
4	Find 96 on the bottom of chart in figure 4–7.
5	Draw a line from 220 psig to the left and stop where it intersects with a vertical line from 96 °F.
6	Determine if charge is correct.

In this example, the charge is correct and no adjustments need to be made.

Adjusting subcooling

Use charts like the one if figure 4–7 to determine if the subcooling needs adjusted. We already used an example of a system that had the proper amount of subcooling. Let's look at a few examples where the system would need adjusting. We'll look at examples with too much refrigerant, not enough refrigerant, and adjustments with not enough or too much subcooling in the system.

Too much refrigerant

The following table provides step-by-step procedures for determining if there is too much refrigerant in the system.

Too Much Refrigerant	
Step	**Action**
1	Assume 234 psig of liquid pressure.
2	Find 234 psig on the left of the chart in figure 4–7.
3	Assume a liquid temperature of 94 °F.
4	Find 94 on the bottom of chart in figure 4–7.
5	Draw a line from 234 psig to the left and stop where it intersects with a vertical line from 94 °F. (Blue lines on the chart in figure 4–7.)
6	Determine if charge is correct.

In this example, there is *too much refrigerant* because the *lines intersect above the charging curve*.

Not enough refrigerant

The process for determining if there is not enough refrigerant is described in the table below.

Not Enough Refrigerant	
Step	**Action**
1	Assume 210 psig of liquid pressure.
2	Find 210 psig on the left of the chart in figure 4–7.
3	Assume a liquid temperature of 100 °F.
4	Find 94 on the bottom of chart in figure 4–7.
5	Draw a line from 210 psig to the left and stop where it intersects with a vertical line from 100 °F. (Red lines on the chart in figure 4–7.)
6	Determine if charge is correct

In this example, there is *not enough refrigerant* because the *line intersects below the charging curve*.

Adjustments

If you do *not have enough* subcooling the system is undercharged, so follow these steps.

1. Gradually remove refrigerant from the system.
2. Let system stabilize.
3. Read new subcooling.
4. Continue to remove refrigerant until you reach the desired subcooling.

If you have *too much* subcooling then the system is overcharged, so follow these steps.

1. Gradually add refrigerant to the system.
2. Let added refrigerant and system to stabilize.
3. Read new subcooling.
4. Continue to add refrigerant until you reach the desired subcooling.

> **NOTE**: Add or remove refrigerant gradually so you do not create conditions that create the opposite effect.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

825. Superheat

1. Why is superheat *not* a good way to determine a system's charge if the system uses a TXV?

2. In a system using a capillary tube, what is the relationship between a high superheat and the amount of charge?

3. What is the *first step* when measuring superheat?

4. What is done with pressure reading obtained in step 7?

5. If superheat is *low*, how is the TXV adjusted?

6. If superheat is *high*, how is the TXV adjusted?

7. What is done *after* adjusting the TXV?

826. Subcooling

1. On a system with a TXV what will subcooling tell you about the system's charge?

2. Where is the *high side* pressure gauge attached to?

3. Where is the temperature measured with a pipe clamp?

4. How is subcooling calculated?

5. How should refrigerant be *removed* from the system when adjusting subcooling?

6. How should refrigerant be *added* to the system when adjusting subcooling?

4–3. Charge, Recovery, and Pump-Down Procedures

Charging, recovery and pumping down a system are critical tasks you must understand when working with the refrigerant side of the system. To *charge a system* is to add refrigerant to it. To *recover* is to remove refrigerant, and *pumping a system down* means to put all the refrigerant in the receiver or the condenser.

This section covers procedures for each of the three tasks. Practice makes perfect though so read this section and get out there with your supervisor and perform this task!

827. Charging procedures

The term charging means to put refrigerant into a refrigerant system. This needs done if the system is empty or low and during a new installation. The proper amount must be added so the system can operate as it is designed. Refrigerant is added by weight, measuring, or using charts.

The charging methods in this lesson should only be applied once you are 110 percent sure the system is low on charge AND there are no leaks to fix. Many technicians see a low pressure on the gauge and assume it means a low refrigerant charge. This is not true. Many other conditions could cause the low side pressure to read low.

Manufacturer's data versus field conditions

The manufacturer provides the exact amount of refrigerant that needs to be added to the system. This is fine for a package unit that doesn't need additional refrigerant lines run but what about a split system? If the refrigerant lines connecting the inside unit to the condenser unit are further than the distance specified by the manufacturer then additional refrigerant needs added on top of the amount stated on the data plate.

Regardless of the methods of charging you learn about, you must always charge by the method stated in the manufacturer's instruction. You may want to charge by weight but the manufacturer may want you to charge by subcooling.

Vapor charging

Vapor charging is effective when the system is empty because the pressure in the system is lower than the pressure in the cylinder. Vapor can be added to both sides of the system because of the pressure difference.

Vapor charging by weight

An accurate way to charge a system is by its weight. This can be easier said than done. If a system has been in operation in can be difficult to determine the actual weight of the refrigerant in the system. Therefore, we in the following table we discuss the procedures of charging by weight with the system empty and evacuated.

Vapor Charging by Weight	
Step	**Action**
1	Determine the proper amount of refrigerant that is required in the system.
2	Connect the manifold gauges and service hoses. Leave the hoses somewhat loose at the service valve.
3	Ensure the service valves are in the mid-position.
4	Purge the service hoses by cracking open the refrigerant cylinder.
5	Tighten the hoses at the service valves.
6	Zero the digital scale.
7	Begin charging with the compressor off. Watch the scale to ensure you don't overcharge.
8	When the refrigerant stops flowing, close the high side valve on the manifold gauge assembly (MGA).
9	Start the compressor.
10	Close the low side valve on the MGA when the scale shows that the proper amount of refrigerant has been added. See note 1.
11	Let the system stabilize. This takes about 10-15 minutes.

Vapor Charging by Weight	
Step	**Action**
12	Verify proper charge by checking superheat, subcooling, compressor amperage and the suction and discharge pressures.
13	If the charge is complete, annotate how much refrigerant was added to the system and use your local procedures for tracking refrigerant usage.

Note 1: Some scales can stop the charging automatically or sound an alarm when the programmed amount of refrigerant has been added. See figure 4–8 for an example of a scale with an alarm.

Figure 4–8. Digital Scale with alarm feature.
(Images Copyright Fieldpiece Industries.)

Vapor "top-off" charging

As we stated earlier it is difficult to determine the weight of the refrigerant that is already in the system. Therefore we have to use other measurements such as superheat or subcooling to verify the proper charge. Measuring and adjusting superheat and subcooling was covered in the previous lesson and is not repeated here.

Vapor charging to both sides of the system is not possible while the compressor is running because the pressure on the high side of the system is higher than the cylinder pressure. If a recovery tank is used, the higher system pressure would push refrigerant back into the cylinder. If a virgin tank is used the system pressure will not flow back into the tank because there is a check valve in the tank that doesn't allow back pressure.

So, while vapor charging a system that is running, charge the refrigerant to the low side. If cold ambient conditions make the tank pressure less than the system pressure then the tank needs to be heated by warm water or heater blankets.

Let's charge a system that had a small leak that was fixed without having to remove the refrigerant from the system. This leak could have been caused by something like a loose and leaking valve core. Follow the steps in the table below to "top-off" a system with refrigerant.

"Top-off" With Refrigerant	
Step	**Action**
1	Determine the proper amount of refrigerant that is required in the system by measuring the superheat or subcooling. • If the metering device is fixed expansion type then measure superheat. • If the metering device is a TXV or stepper motor then use subcooling.
2	Connect the manifold gauges and service hoses.

"Top-off" With Refrigerant	
Step	**Action**
	Leave the hoses somewhat loose at the service valve.
3	Ensure the service valves are in the mid-position.
4	Purge the service hoses by cracking open the refrigerant cylinder.
5	Tighten the hoses at the service valves.
6	Zero the digital scale
7	If winter conditions exist, heat the cylinder with a heater blanket or warm water to keep pressure flowing from the cylinder to the system; not vice versa.
8	Close the high side valve on the manifold gauge assembly (MGA).
9	Start the compressor.
10	Open the refrigerant cylinder valve to add refrigerant.
11	Close the cylinder valve when you think sufficient refrigerant has been added.
12	Let the system stabilize for about 10-15 minutes.
13	Check superheat or subcooling. If superheat is high or subcooling too low then you need to add more refrigerant.
14	Repeat until the proper superheat or subcooling temperatures are where they need to be.
15	If tank is low on refrigerant, warm it using a heater blanket or warm water of no more than 90 degrees. See note 1.

Note 1: The tank and system pressure could equalize as the tank nears being empty. Adding heat keeps the pressure of the tank above that of the system and therefore keeps refrigerant flowing from tank to system; not vice versa.

> **Technician's Note:** When adding large amounts of refrigerant to a system use larger cylinders. Do *not* use a 30 pound cylinder to charge 27 pounds of refrigerant if you can use a 125 pound cylinder.

Liquid charging by weight

Zeotropic refrigerants, like R-410A, should be liquid charged into the system. The liquid usually enters the system in the liquid line. Add *liquid* refrigerant to the King valve of the receiver for quicker charging. Let's charge a completely empty and evacuated system by weight by following the steps in the table below.

Liquid Charging by Weight	
Step	**Action**
1	Connect the MGA's to the refrigerant cylinder and the low side and receiver service valves. Leave the service hoses somewhat loose at the service valves. Install a special metering device between the low-side service hose and the low-side service valve. See Note 1.
2	Purge the service hoses by cracking open the refrigerant cylinder.
3	Tighten the service hoses onto the service valves.
4	Ensure liquid service valve is in the mid-position. The low-side service valve is closed for now.

Liquid Charging by Weight	
Step	**Action**
5	Flip the refrigerant cylinder upside down. This may not need to be done if the cylinder is equipped with a liquid tube that extends to the bottom of the cylinder to draw liquid into the system and not vapor.
6	Open the high side valve on the MGAs.
7	Watch the scale to ensure the system doesn't become overcharged.
8	If flow stops before the proper amount of refrigerant was added, close the high side valve on the MGA and open the low-side service valve to the mid-position.
9	Slightly crack open the low-side valve on the MGA to meter refrigerant into the low side. See Note 2.
10	Start the compressor. Monitor the amperage of the compressor while charging the low side with liquid. If the amperage rises too far above the current rating, stop charging and let the system stabilize.
11	Once you believe the proper amount has been added close the low-side MGA valve.
12	Check superheat or subcooling. If superheat is high or subcooling too low then you need to add more refrigerant.
13	Repeat until the proper superheat or subcooling temperatures are where they need to be.

Note 1: This special metering device prevents liquid from reaching the compressor.

Note 2: Slightly cracking open the valve allows the technician to meter the refrigerant and help prevent liquid from reaching the compressor.

Another method involves front-seating the liquid receiver so no refrigerant leaves it. This creates a low pressure in the liquid line. Once the liquid line pressure drops below the tank pressure, the liquid refrigerant flows into the system. Liquid charging with the system operating should be done for long durations.

Not all receiver valves allow this type of charging. If the valve isolates the liquid line and leaves the gauge port open to the receiver when the valve is front seated, the valve cannot be used with this method. If the liquid line is isolated from the receiver and open to the gauge port when the receiver is front-seated then it can be used with this method.

> **Technician's Note:** Refrigerant cylinders often have arrows on their shell that tell you if the cylinder needs to be flipped or not.

Charging curves and charts

As mentioned in the superheat and subcooling lesson, there are curves and charts that can be used to charge systems. Charts are designed to charge by either superheat or subcooling. Superheating charts are used on fixed orifice, capillary tube, or piston type metering devices. Subcooling charts are used with TEVs. Let's look at the steps for charging with a superheat chart in the following table.

Charging with a Superheat Chart	
Step	**Action**
1	Measure relative humidity. If above 70 percent or below 20 percent use the wet-bulb temperature in the next step.
2	Measure indoor dry bulb return air temperature if conditions in step 1 are not met. If the conditions in step 1 exist, use the return air wet-bulb temperature.

Charging with a Superheat Chart	
Step	**Action**
3	Measure the outdoor dry bulb temperature entering the condensing unit.
4	Using the chart (fig. 4–9), draw a vertical line from the outdoor temperature you measured up the diagonal line of the indoor DB or WB temperature you measured.
5	From the point of intersection, draw a horizontal line to the left of the chart and see what the superheat is supposed to be for these conditions.
6	Measure the *total* superheat of the system and compare to the superheat from step 5.
7	Add refrigerant to the system as needed.

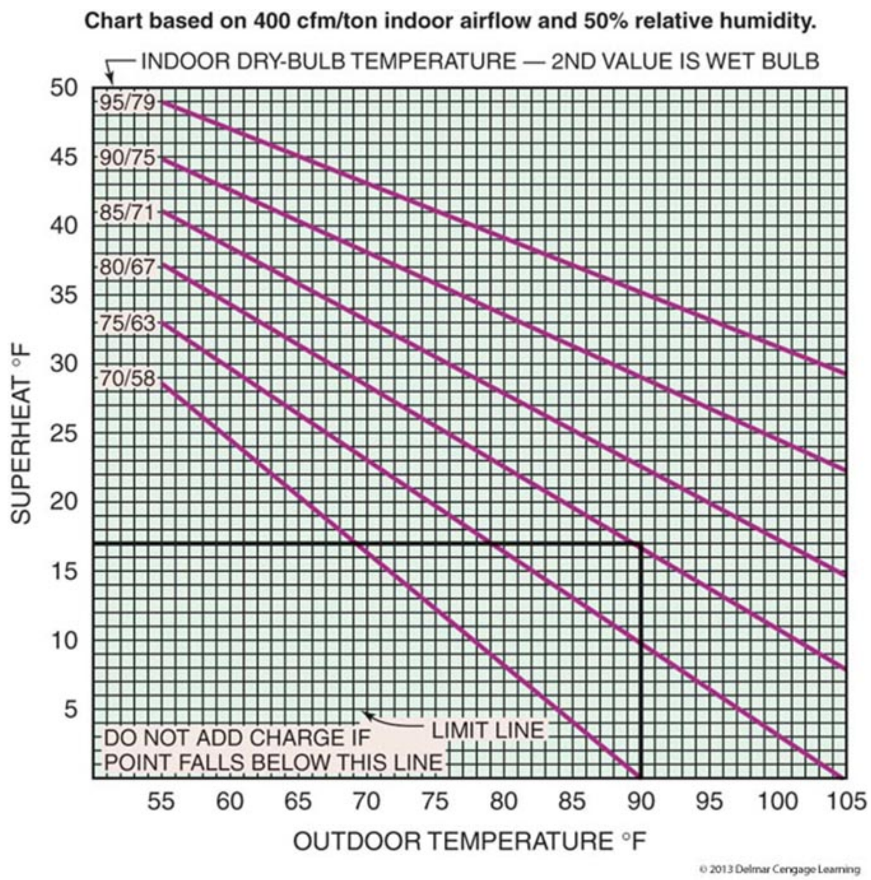


Figure 4–9. Superheat chart.
(Courtesy Cengage Learning.)

The curve is designed to prevent you from overcharging the system and allowing liquid refrigerant to reach the compressor on hotter than usual days. On these hotter days the head pressure of the system is higher than usual. The higher pressure forces more refrigerant through the fixed metering device and decreases the superheat. This could lead to liquid reaching the compressor.

If you look at the chart you can see that as the outdoor air increases and the indoor air stays the same, the superheat drops. Again, if overcharged, the superheat could be nearly eliminated and liquid refrigerant could reach the compressor and damage it.

You may also notice in figure 4-9 that the superheat is 17 °F. If you are used to using the rule of thumb of 8 to 12 °F of superheat then 17 °F seems really high. This is not evaporator superheat though it is the *total* superheat from the V point to the compressor inlet and that is why it is higher.

Subcooling

For subcooling the manufacturer provides either a chart or a designed subcooling rating. Follow the steps below for subcooling charging.

Subcooling Charging	
Step	**Action**
1	Operate the system to allow pressures and temperatures to stabilize.
2	If temperature is below 65 °F cover up the condenser coil to raise the condensing temperature to at least 105 °F. The charging jacket in figure 4–10 can be used to raise the temperature.
3	Measure the high-side pressure at the unit's service valve and convert to *saturation* temperature using the pressure-temperature chart.
4	Measure temperature near the same location you took the pressure reading.
5	Find the manufacturer's required subcooling.
6	Subtract the manufacturer's subcooling from the saturation temperature in step 3. This gives you what the liquid line temperature should be.
7	Compare the measured liquid line temperature to the desired temperature in step 6.
8	If the measured liquid line temperature is higher than the desired liquid line temperature you need to add refrigerant.
9	Add refrigerant gradually until the proper charge is met.

Figure 4–10. Charging jacket.
(Images Copyright Fieldpiece Industries.)

Using refrigerant left in the hose

When done charging there could be refrigerant left in the hoses that we do not want to waste. To use the refrigerant that is left in the hose, follow these easy steps:

- Close the cylinder valve.
- Operate the unit.
- Crack the low-side manifold hand valve.

That is it! Three easy steps and you save the Air Force money and help the environment a little.

Liquid charging chillers

Low pressure chiller are charged through an evaporator charging valve. Do *not* charge liquid into an evacuated chiller or water cooled condenser. The liquid boils and could freeze water in the tubes. Therefore, charge by vapor until the system reaches 36 °F which is above freezing. Now you can introduce liquid into the system without freezing the water in the tubes.

828. Recovery and evacuation procedures

Recovery of a system is simply removing refrigerant from the system. The refrigerant is placed into a recovery cylinder. After the system is recovered, work can be performed on the entire system. There are two types of recovery: passive and active.

- *Passive recovery* uses the pressure inside the A/C system for recovery.
- *Active recovery* uses the compressor of a recovery machine to pull the refrigerant out of the system.

Passive recovery

In passive recovery, the static pressure in the system is used to force refrigerant into an unpressurized recovery device, sometimes a recovery bag. Passive recovery is often used on small appliances with about 5 lbs. or less of refrigerant. The key concept to understand is that during passive recovery **no recovery machine is used.**

Passive recovery using the system's compressor

The following table tells how to use the system's compressor to pump refrigerant from the high side to a recovery device.

Passive Recovery Using the System's Compressor	
Step	**Action**
1	Turn off the system.
2	Attach a hose to the high side of the system.
3	Attach the same hose in step 2 to the recovery device.
4	With the system still off, open the high side valve on the MGA to allow refrigerant to flow from the system to the recovery device.
5	Turn on the compressor.
6	When all refrigerant has been removed close the high side valve and turn off the compressor.

Passive recovery not using the system's compressor

Sometimes you need to perform a passive recovery of refrigerant but the compressor doesn't work. This is okay! The additional steps in the table below help speed up the recovery of the refrigerant, even when the compressor is broken.

Some of these tips include placing the recovery device in an ice or water bath. This reduces the temperature and pressure of the recovery device. The reduction in pressure creates a larger pressure difference between the system and the recovery device which speeds up recovery.

Another helpful tip is to gently tap the compressor to release the refrigerant trapped in the oil. This helps recover as much refrigerant as possible. Follow the steps below to successfully recover a system with a broken compressor.

Passive Recovery	
Step	**Action**
1	Turn off the system.

Passive Recovery	
Step	**Action**
2	Connect both high and low-side hoses to system.
3	Connect center hose to the recovery device.
4	Place recovery device in ice or water bath.
5	Open both high- and low-side valves on the MGA to allow flow from the system to the device.
6	Heat the compressor using crankcase heaters, electric blankets, heat guns, or heat lamps. (*Never use an open flame.*)
7	Tap compressor with soft mallet to release remaining refrigerant. Do *not* bang the compressor and do *not* use a metal hammer.
8	After all possible refrigerant has been removed, close MGA valves and you are done.

Active recovery

Within the realm of active refrigerant recovery there is vapor and liquid recovery. Both of these recovery techniques use a recovery machine that uses a compressor to pull the refrigerant from the system.

Vapor recovery

Again, this type of vapor recovery uses a recovery machine. The machine, in conjunction with the manifold gauge assembly (MGA), allows vapor to be drawn from both sides of the system.

Vapor Recovery	
Step	**Action**
1	Run the system for a few minutes to circulate refrigerant out of the oil.
2	Turn off the system.
3	Find tare weight of recovery cylinder and calculate the maximum weight the cylinder and refrigerant can safely weigh. (If digital scale cannot be zeroed out.) (Steps covered later in this lesson.)
4	If available, use shorter hoses with a larger diameter than the normal diameter hoses.
5	Connect the MGA and recovery machine to the system.
6	Set high- and low-side service valves to the mid-position.
7	Ensure an in-line filter drier is installed between the MGA center port and the recovery machine.
8	Completely open both valves on the MGA.
9	Turn on the recovery machine.
10	Monitor weight of cylinder to ensure you don’t pass the total weight calculated in step 3.
11	Turn off recovery machine when the proper vacuum level has been reached. (Manufacturer of recovery machine determines proper vacuum levels.)
12	Close low-side service valve.
13	Record pressure reading.
14	Let the system sit for 5-10 minutes.
15	Record pressure reading and compare to reading from step 11. If the pressure rises more than 10 psi there are still pockets of refrigerant in the system.

Vapor Recovery	
Step	**Action**
	Place recovery cylinder in an ice bath and heat the compressor and repeat the recovery steps until pressure stabilizes.
16	Close the manifold valves.
17	Turn off the recovery machine.
18	Close the recovery cylinder.

Liquid recovery

Liquid recovery is also an active way of recovering refrigerant. Remember, active recovery **uses a recovery machine.** Passive recovery **does not.** Liquid recovery pulls liquid refrigerant from the high-side of the system. Liquid recovery is faster than vapor recovery. Unfortunately, the charge in the system is vapor and liquid and vapor recovery techniques must be used to recover the full charge. Liquid is used **first** though.

> **Technician's Note:** Do *not* use liquid recovery on heat pumps or systems with 10 lbs. or less of refrigerant. Also, not all refrigerant recovery machines can pump liquid, so be careful.

Liquid Recovery	
Step	**Action**
1	Turn off the system.
2	Find tare weight of recovery cylinder and calculate the maximum weight the cylinder and refrigerant can safely weigh. (Steps covered later in this lesson.)
3	If available, use shorter hoses with a larger diameter than the normal diameter hoses.
4	Connect the MGA and recovery machine to the system.
5	Set high- and low-side service valves to the mid-position.
6	Ensure an in-line filter drier and sight glass is installed between the MGA center port and the recovery machine.
7	Open ONLY the high-side valve on the MGA.
8	Set recovery machines valves for liquid recovery.
9	Turn on the recovery machine.
10	Monitor the sight glass and MGA and recovery machine gauges. Monitor the feel of the filter-drier, hoses, hose connectors between the MGA and recovery machine inlet.
11	When high-side pressure gauge drops and the hose connectors and MGA don't feel as cold as they did before then the recovery machine now pulling vapor.
12	Open the low-side MGA valve.

Once you get to step 12 you have officially transitioned into vapor recovery.

Push-pull liquid recovery

This method involves actually pulling vapor back into the system to push liquid refrigerant out. This method requires a cylinder that has both a liquid and vapor valve.

Push-Pull Liquid Recovery	
Step	**Action**
1	Turn off power.
2	Connect all components in the way shown in figure 4–11.
3	Place high- and low-side service valves in the mid-position.
4	Purge hoses.
5	Open both valves on the cylinder.
6	Set recovery cylinder valves according to manufacturer’s instructions.
7	Turn on the machine.
8	Monitor sight glass in service line. Once you see bubbles this means vapor is starting to flow.
9	Change your set-up for vapor recovery that was discussed previously in this lesson. See figure 4–12.

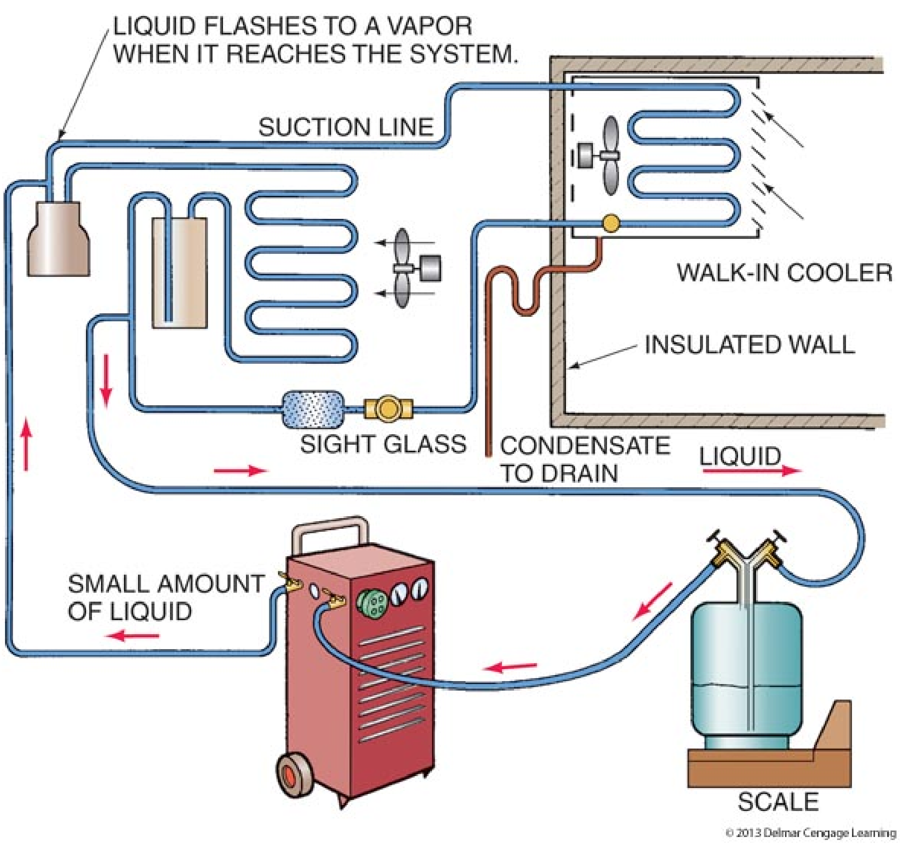


Figure 4–11. Push-pull recovery.
(Courtesy Cengage Learning.)

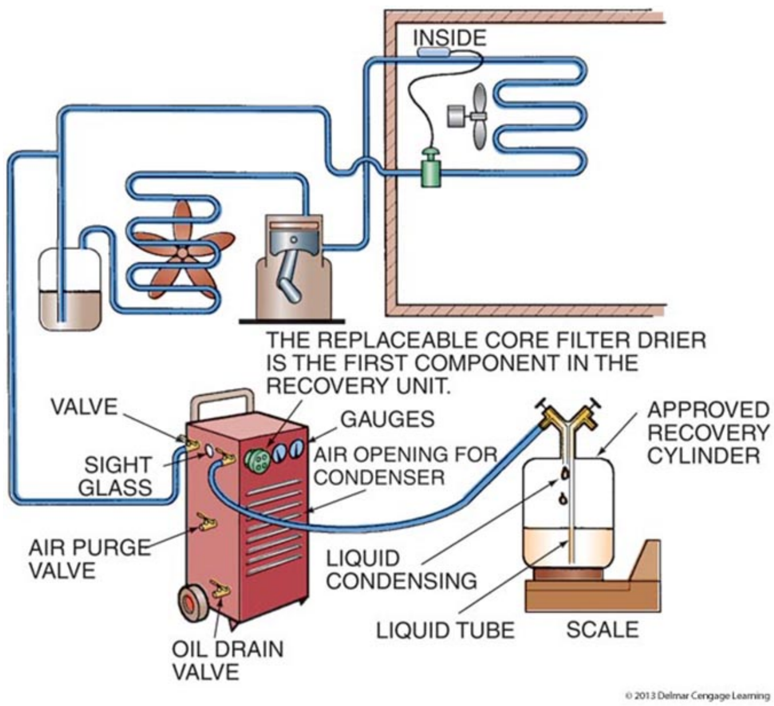


Figure 4–12. Vapor recovery.
(Courtesy Cengage Learning.)

Recovery tips

The following steps do not necessarily have to be followed in order but they should be followed for the most efficient recovery. No numbers are used in the list so you don't get confused and think you have to follow the order. Again, though, you should perform these steps.

- Use larger hoses than on your normal MGA.
- Remove Schrader valve cores from access ports and service valves.
- Use an in-line filter-drier between the system and the recovery cylinder.
- Change recovery compressor oil after recovering refrigerant from a burned out system.
- Change recovery compressor oil before it is used to recover a refrigerant different from the last refrigerant recovered.
- Also, replace the in-line filter-drier and hoses and machine should be evacuated.

Recovery cylinders

Recovery cylinders are commonly the devices we use to store refrigerant that is removed from the system. According to Air-Conditioning, Heating, and Refrigeration Institute Guideline K, a recovery cylinder should *not* be filled more than 80 percent water capacity by weight.

Water capacity is the weight of the volume of water needed to fill a recovery cylinder 100 percent. The amount is provided on a recovery cylinder's label. It is provided in pounds or kilograms. What is important is that you as a technician be able to calculate the safe amount of weight of a *specific* type of refrigerant that you can put into a *certain* cylinder.

Remember the 80 percent water capacity by weight? We use weight because different refrigerants have different densities. A lighter refrigerant will weigh less while taking up the same volume of water. A denser refrigerant weighs more while taking up the same volume as water. So we use 80 percent water capacity *by weight* to ensure we fill cylinders safely. In order to calculate this weight you need to know how to convert a percentage into a decimal. For 80 percent, imagine the number without the percentage and with a decimal after it—**80.** Now move the decimal two places to the left and you get **.80**, the number used during our water capacity by weight calculations. You need to find all of the data needed to perform the following calculation:

W = 0.8 x WC x SG

WC is the water capacity weight

SG is the specific gravity of the refrigerant

Let's follow some steps to get to W, which is the weight of refrigerant that can be safely stored in the cylinder.

1. On the cylinder, find the weight of water that would fill the cylinder to 100 percent.
2. Get the specific gravity of the refrigerant you are using from refrigerant spec sheets.
3. Plug the numbers into the equation: W = 0.8 X WC X SG.
4. The number from step 3 is the weight of refrigerant that can be safely added to the cylinder.

Let's use real numbers for an example using refrigerant R–410a.

1. On the cylinder, the weight of water that would fill the cylinder to 100 percent is 47.7 WC.
2. The specific gravity is 1.06.
3. Plug the numbers into the equation: W = 0.8 X 47.7 X 1.06.
4. The equation's result is 40.45 (rounded two decimal places). This is the weight of the refrigerant that can be added safely to the cylinder.

Some scales cannot be zeroed out and the tare weight of the cylinder must be taken into account to get the final weight of the cylinder and the refrigerant. *The tare weight is the weight of the cylinder while it is empty*. We use the same equation as we did before except we add tare weight.

1. On the cylinder, find the weight of water that would fill the cylinder to 100 percent.
2. Get the specific gravity of the refrigerant you are using from refrigerant spec sheets.
3. On the cylinder, find the tare weight.
4. Plug the numbers from steps 1–3 into the equation: W = [0.8 X WC X SG] + TW (TW is the tare weight).
5. The number from step 4 is the *final* weight the cylinder should be.

Again, let's use an example with R–410a.

1. On the cylinder, the weight of water that would fill the cylinder to 100 percent is 47.7 WC.
2. The specific gravity is 1.06.
3. The tare weight is 24.6 lbs.
4. Plug the numbers from steps 1–3 into the equation: W = [0.8 X 47.7 X 1.06] + 24.6 (TW is the tare weight).
5. The *final* weight the cylinder is allowed to be 65.05 pounds (rounded two decimal places).

Scale and cylinder features

Some refrigerant scales have convenient automatic functions. One machine operates a solenoid valve that closes the path between the cylinder and recovery machine once the maximum weight is reached. Other scales sound an alarm or have a light that indicates when the technician needs to stop recovery.

Some cylinders have a liquid level or high pressure switch wired to the recovery machine. These switches stop the recovery machine when the cylinder is 80 percent full.

If the entire charge can fit in one tank then some cylinders have a feature that turns off automatically once the designed vacuum pressure has been obtained.

Do not rely solely on these features. It is your job to monitor the safety of the recovery process *not* a switch or digital scale! If you are only using one cylinder valve you can monitor the cylinder pressure by placing a gauge on the unused valve.

Evacuation

So you recover the refrigerant, open the system to perform work and you complete your work. Now it's time to charge the refrigerant. NOT! You must first evacuate the system. Moisture or other substances could have entered the system. To remove the moisture you must evacuate the system. When you evacuate a system you are removing all vapors and fluids from the system. Evacuation should happen *after* the refrigerant has been recovered. Evacuation is performed using a vacuum. There are two types of evacuation: deep vacuum and triple evacuation.

The vacuum pump creates such low pressures that it lowers the boiling point of any substance in the system. For example, it lowers the boiling point of water in the system. The water boils and is drawn out by the vacuum pump. If you evacuate a system to remove moisture you are trying to *dehydrate* the system. Think about it, when you are thirsty and haven't had enough water you become dehydrated. If you remove water/moisture from the system you are dehydrating it.

If there is a leak in the system you will not be able to fully evacuate and dehydrate the system. Fix all leaks before you attempt to evacuate the system.

To further assist in pulling a vacuum use large hoses. Use the largest size possible. As you create a vacuum the pressure in the system drops. Using large hoses will account for the pressure drop. Also, use hoses as short as possible. Evacuation may take eight times longer with a ¼" hose than with a ½" line. It may take twice as long using a 6 foot hose than with a 3 foot hose. You need to make sure you have a set of short, large hoses for pulling a vacuum.

As you create a vacuum in the system the pressure and temperature drop. The temperature could cause moisture to freeze and not get pulled out with the pump. Warm the system evenly throughout the system with a heat lamp to ensure moisture does not freeze. Do not just heat one location, ensure you heat the entire system evenly.

Deep Vacuum

This evacuation method pulls a vacuum of 250 microns or deeper. A vacuum gauge is installed away from where the vacuum pump is connected (fig. 4–13).

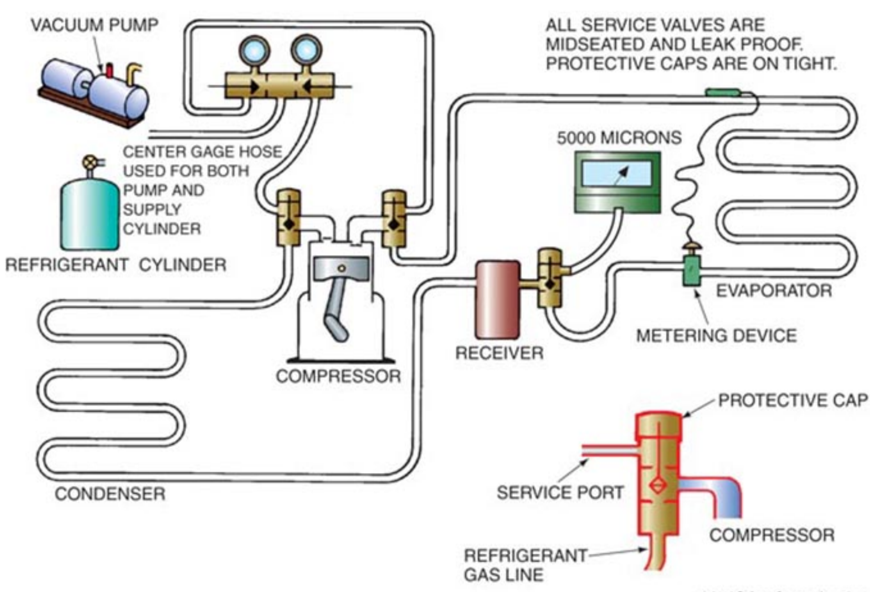


Figure 4–13. Vacuum gauge location.
(Courtesy Cengage Learning.)

Do *not* use regular refrigerant hoses, piercing valves, or have Schrader valve cores installed during the process of pulling a deep vacuum. Use hoses that are designed for pulling a deep vacuum. Do *not* use piercing valves because they create a large restriction with their small openings. Schrader valve cores are also removed because they create a large restriction. The table below provides a step-by-step guide to deep vacuum evacuation.

Deep Vacuum Evacuation	
Step	**Action**
1	Gather larger and shorter hoses used for pulling a deep vacuum.
2	Remove Schrader cores if they exist.
3	Connect vacuum gauge as directly to system as possible. (Limit fittings and hoses.)
4	Open the MGA valves 100 percent.
5	Open the service valves to the mid-position.
6	Set position of vacuum pump valves according to the manufacturer's instructions.
7	Turn on the vacuum pump.
8	Use heat gun to distribute heat to compressor and other places moisture may occur. See figure 4-14 for locations where moisture may be and figures 4-15 and 4-16 for examples of heat gun usage.
9	Pull a vacuum to 250 microns.
10	Close MGA valves.
11	Turn off vacuum pump. This isolates the system and gauge from the pump.
12	Monitor pressure reading. Pressure can raise slightly but should level off.
13	If pressure rises above 500 microns the system has a leak or it has moisture.
14	If pressure stays at or below 500 microns the system is dry and has no leaks.

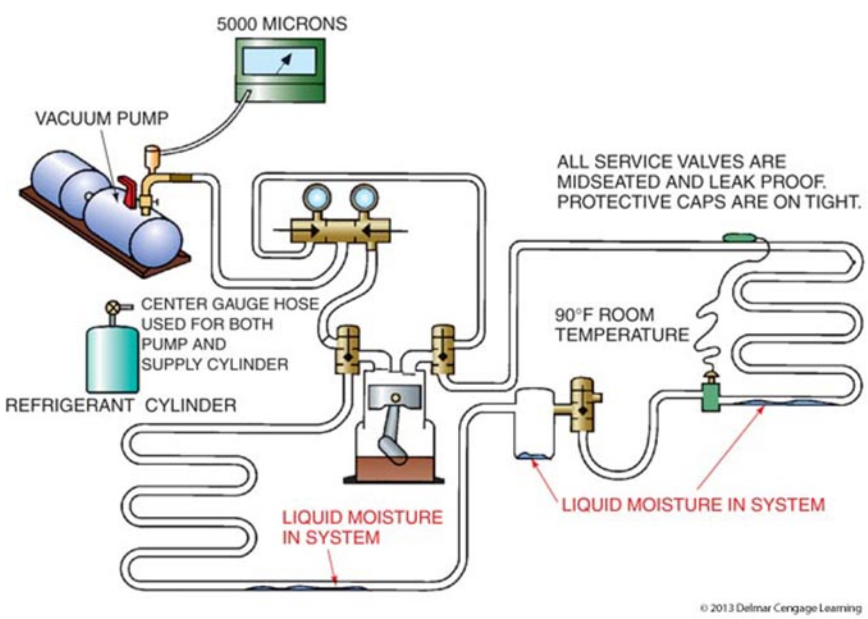


Figure 4–14. Moisture settling.
(Courtesy Cengage Learning.)

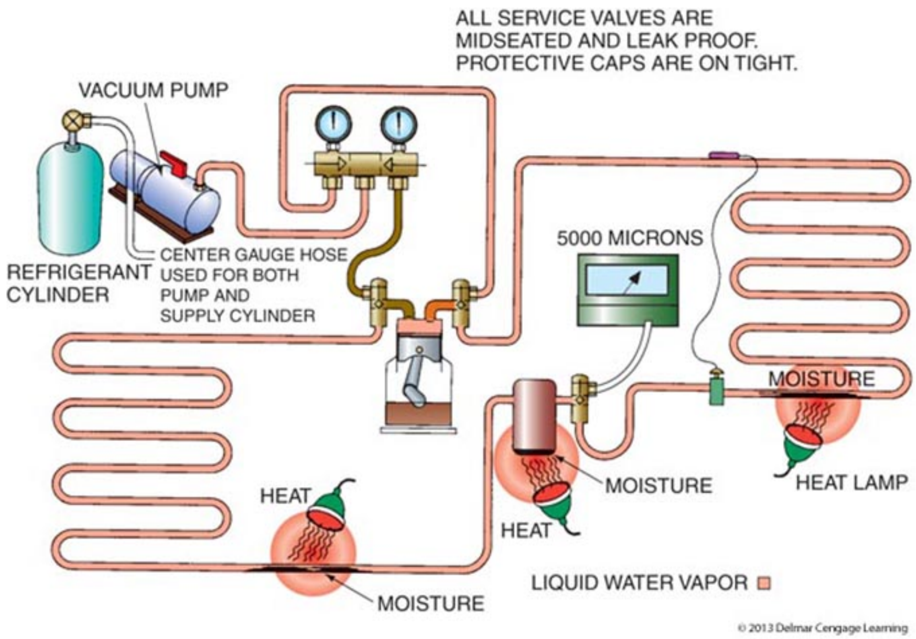


Figure 4–15. Heat gun usage.
(Courtesy Cengage Learning.)

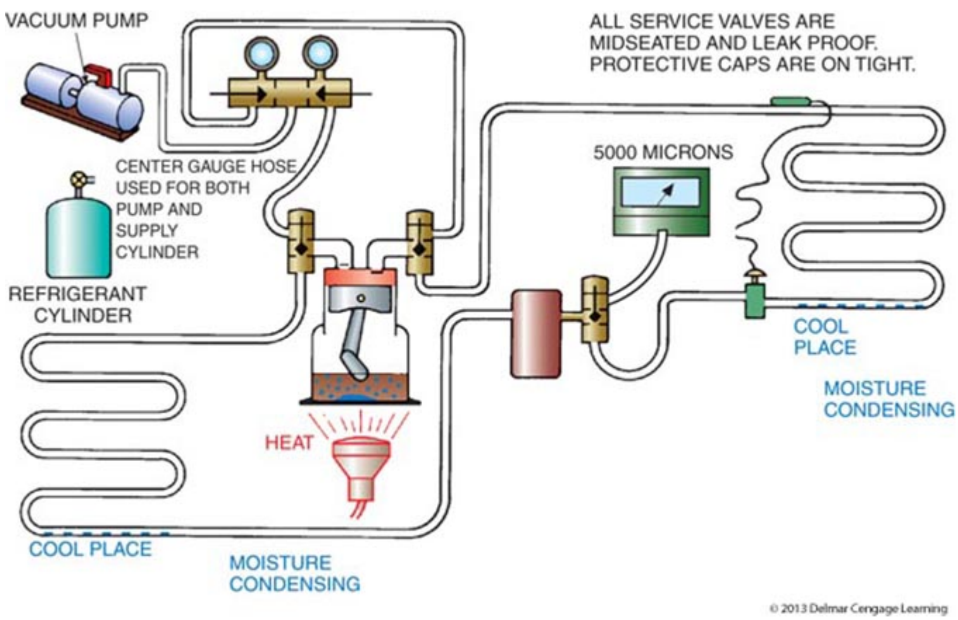


Figure 4–16. Heat gun on compressor.
(Courtesy Cengage Learning.)

Triple Evacuation Method

The triple evacuation method uses a vacuum pump to pull a vacuum of 1500 microns three times. After the first two vacuums are pulled the system is charged between 0 psig to 3 psig of vapor refrigerant or dry nitrogen. This vapor refrigerant or nitrogen absorbs moisture that remains in the system. The table below has the steps to follow when pulling a triple evacuation.

Triple Evacuation Method	
Step	**Action**
1	Gather larger and shorter hoses used for pulling a deep vacuum.
2	Remove Schrader cores if they exist.
3	Connect vacuum gauge as directly to system as possible. (Limit fittings and hoses)
4	Connect equipment as shown in figure 4-17.
5	Ensure regulator and pressure relief valves are installed on the nitrogen cylinder.
6	Ensure refrigerant or nitrogen cylinder valve between the MGA is closed.
7	Open shutoff valve between vacuum pump and gauge manifold.
8	Turn on vacuum pump.
9	Pull a vacuum of 1500 microns.
10	Close shutoff valve between vacuum pump and MGA.
11	Open shutoff valve between refrigerant or nitrogen and the system.
12	Slowly open cylinder valve. (For nitrogen, slowly open the regulator.)
13	Allow system pressure to rise to between 0 psig and 3 psig.
14	Close the shutoff valve that was opened in step 11.
15	Repeat steps 7–13 one more time.
16	Repeat steps 7–10. This pulls the system into a vacuum of 1500 microns.

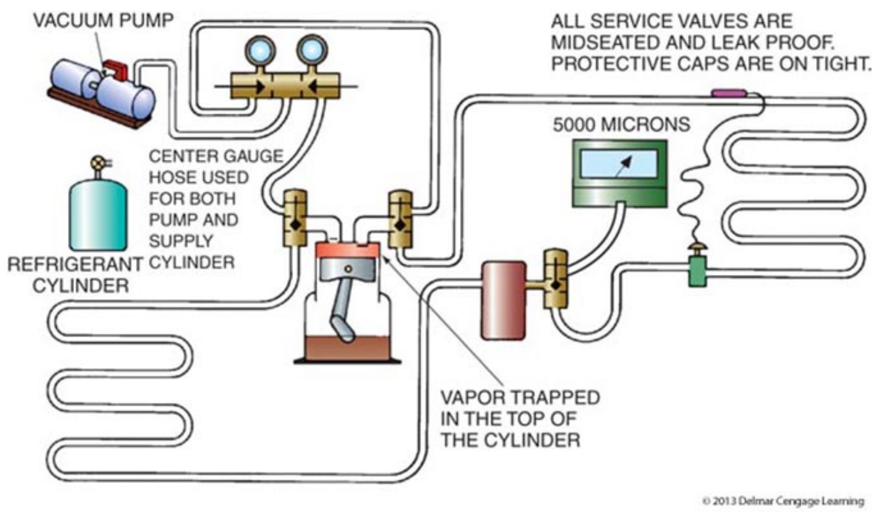


Figure 4–17. Vacuum pump hook up.
(Courtesy Cengage Learning.)

829. Pump-down procedures

A manual pump-down is a procedure that places all of a system's charge into one place—either the liquid line receiver or the condenser. A valve in the liquid line is closed and refrigerant can no longer pass the valve. As the compressor runs it pulls the refrigerant out of the low side of the system and into the high side. The pressure in the low side begins to drop because no refrigerant is passing through the valve and onto the metering device and the low side. Once the pressure reaches zero, the refrigerant is trapped in the receiver or condenser and the low side of the system is empty. The empty low side allows technicians the chance to make repairs.

Why/when do I need to pump down a system?

You may need to pump down a system if you are repairing leaks or adjusting low side pressure controls. Also, pumping down a unit is useful if you need to replace low-side components such as valves or filter driers. Pumping a system down is more convenient and time saving versus recovering the entire charge of a system when you need to access components on the low-side.

Pump a system down into the receiver

Here are the steps to pump-down a system into a liquid receiver.

Pump-Down System into Liquid Receiver	
Step	**Action**
1	Allow unit to cycle off.
2	Front seat the liquid receiver service valve, LRSV. Remember this valve can be called a King valve or receiver outlet valve.
3	Attach a gauge to the low-side service valve.
5	Cycle the system on.
6	Monitor the gauge you installed in step 3.
7	When the gauge reaches 0 psi, front seat the compressor service valves. This traps the refrigerant in the receiver.
8	Cycle the system off.

Pump a system down into the condenser

The following steps demonstrate how to pump down a system's charge into a condenser.

Pump Down System Into a Condenser	
Step	**Action**
1	Allow unit to cycle off.
2	Front seat the liquid line valve.
3	Attach a gauge to the low-side service valve.
4	Cycle the system on.
5	Monitor the gauge you installed in step 3.
6	When the gauge reaches 0 psi, front seat the suction service valves.This traps the refrigerant in the condenser.
7	Cycle the system off.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

827. Charging procedures

1. Why is vapor charging effective when the system is empty?

2. How are service hoses purged before charging?

3. What valve is closed when the scale shows the proper amount of refrigerant has been added?

4. How long should the system be allowed to stabilize?

5. Where is refrigerant added when vapor charging while the system is running?

6. What is done after purging the hoses?

7. When charging by liquid, what may you have to do to the cylinder before you charge?

8. What temperature needs to be measured outdoors when using superheat charging curves?

9. How is the high side pressure converted to saturation temperature?

10. What is the *first step* when using leftover refrigerant in the hose?

828. Recovery and evacuation procedures

1. What is the *second step* in *passive recovery*?

2. What step is performed *after* the hose is connected?

3. After the refrigerant is flowing into the system, what is the next step when using passive recovery with the system's compressor?

4. Which hose is connected to the recovery device?

5. Which MGA valves are open when recovery passively *without* the compressor?

6. What is the *first step* in *vapor recovery*?

7. In vapor recovery, what is the step *after* opening both MGA valves?

8. What position are the service valves in during *liquid recovery*?

9. What position are the cylinder valves in during *push-pull recovery*?

10. What should be done with Schrader valves cores before recovery?

11. What is the water capacity by weight if a cylinder has a 25.6 WC and the refrigerant has a specific gravity of 3.1?

12. What position are the MGA valves in when pulling a *deep vacuum*?

13. What is the *next step after* a deep vacuum of 250 microns is reached?

14. What is step is performed *after* you open the shutoff valve between vacuum pump and gauge manifold?

829. Pump-down procedures

1. What is the *first step* during a unit pumpdown?

2. What step is *after* you front seat the service valve?

3. What is the next step *after* attaching a gauge to the low-side service valve when pumping down into a receiver?

4. What is the *last step* in a pumpdown?

5. What is the next step *after* attaching a gauge to the low-side service valve, when pumping down refrigerant to the condenser?

Answers to Self-Test Questions

823.

1. Entropy, Temperature, Volume, Pressure, and Enthalpy.
2. Heat intensity.
3. Specific volume.
4. Specific volume.
5. 35.7 psia.
6. Total heat content and is a measure of the amount of heat a vapor or liquid can hold.
7. British thermal units per pound.
8. Compression.
9. Thermodynamic measure of the amount of energy unavailable to do useful work in a system.
10. It stays the same when a vapor is compressed, if outside heat is not added to or removed from the vapor.
11. 80 percent.

824.

1. Increase in enthalpy.
2. Desuperheating.
3. Begins to condense.
4. The pressure and temperature drop that occurs inside the expansion device.
5. It means enthalpy doesn’t change.
6. Evaporator picking up heat.
7. No change in pressure but a change in temperature and enthalpy.
8. Convert the reading from the low-side manifold gauge to psia and then plot the evaporation line.
9. Take the reading from the high-side gauge and convert that to psia, then you can plot the condensation line.
10. Control point of TXV.
11. Inlet of expansion valve.
12. Inlet and outlet of compressor.
13. A to “V,” and Point E.

825.

1. TXVs maintain constant superheat.
2. Undercharged.
3. Gather information about the proper airflow across the evaporator and any superheat charts or curves
4. Convert to temperature using P/T chart.
5. Turned clockwise.
6. Turned counterclockwise.
7. Read new superheat.

826.

1. If the charge is acceptable.
2. Liquid line.
3. Near the metering device on the liquid line.
4. By subtracting the temperature reading of the liquid line from the temperature converted from pressure.
5. Gradually.

6. Gradually.

827.

1. Because the pressure in the system is lower than the pressure in the cylinder.
2. Cracking open the refrigerant cylinder.
3. Low side on MGA.
4. 10 to 15 minutes.
5. Low side.
6. Tighten hoses at the service valves.
7. Flip it upside down.
8. Dry bulb entering the condenser.
9. Pressure temperature chart.
10. Close the cylinder valve.

828.

1. Attach a hose to the high side.
2. With the system still off, open the high side valve on the MGA to allow refrigerant to flow from the system to the recovery device.
3. Turn on the compressor.
4. Center hose.
5. Both.
6. Run system for a few minutes.
7. Turn on the recovery machine.
8. Mid-position.
9. Open.
10. Removed from access ports and service valves.
11. W = 0.8x; WCxSG; 63.488.
12. Open.
13. Close MGA valves.
14. Turn on the vacuum pump.

829.

1. Allow unit to cycle off.
2. Attach gauge to low-side service valve.
3. Cycle the system on.
4. Cycle the system off.
5. Attach gauge to low-side service valve.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter.

82. (823) How is the pressure plotted on the pressure enthalpy (PE) chart?
    a. From top to bottom.
    b. From bottom to top.
    c. In pounds per square inch gauge (psig).
    d. In pounds per square inch absolute (psia).

83. (823) At sea level, what is the *absolute pressure* if the gauge reads 20 pressure per square inch gauge (psig)?
    a. 34.7 pressure per square inch absolute (psia).
    b. 44.7 psia.
    c. 55.7 psia.
    d. 66.7 psia.

84. (823) The pressure enthalpy (PE) chart is based on how many pounds of refrigerant?
    a. 1.
    b. 2.
    c. 10.
    d. 100.

85. (823) On the pressure enthalpy (PE) chart a *change in state* takes place
    a. inside the curve.
    b. to the left of the curve.
    c. to the right of the curve.
    d. in the area above the curve.

86. (823) What is the *condition of refrigerant* on pressure enthalpy (PE) chart if the plot is *on the right side of the curve*?
    a. Saturated vapor.
    b. Saturated liquid.
    c. Subcooled liquid.
    d. Superheated vapor.

87. (824) How many readings must be taken to fill out the pressure enthalpy (PE) chart?
    a. 3.
    b. 7.
    c. 9.
    d. 19.

88. (824) According to figure 4–5, where is the *control point* of the thermal bulb plotted?
    a. H.
    b. G.
    c. D.
    d. A.

89. (824) According to figure 4–5, the *evaporator superheat* is located between what two points?
    a. H to A.
    b. G to H.
    c. F to G.
    d. C to D.

90. (824) According to figure 4–5, the *subcooling in the liquid line* is located between what two points?
    a. C to D.
    b. F to G.
    c. G to H.
    d. H to A.

91. (824) According to figure 4–5, where is the *flash gas* located?
    a. From A to V.
    b. From F to G.
    c. Where line F stops when it goes horizontally.
    d. Where line E stops when it goes vertically downward.

92. (824) How are pressure enthalpy (PE) charts filled out if paper charts are *not* used?
    a. Graph paper.
    b. Chalkboard.
    c. Software.
    d. By hand.

93. (825) How long should the system be allowed to run *before* measuring superheat?
    a. 2 to 3 seconds.
    b. 36 hours.
    c. 2 weeks.
    d. Long enough for temperature and pressure to stabilize.

94. (825) What is the *next step* for temperature readings after cleaning the pipe?
    a. Let system stabilize.
    b. Verify proper airflow.
    c. Take condenser inlet temperature.
    d. Take temperature at the outlet of the evaporator.

95. (825) What step is performed *after* converting the pressure reading to temperature?
    a. Add saturation temperature from the suction line temperature.
    b. Add saturation temperature from the discharge line temperature.
    c. Subtract saturation temperature from the liquid line temperature.
    d. Subtract saturation temperature from the suction line temperature.

96. (825) What is determined *before* adjusting a thermostatic expansion valve (TXV) superheat?
    a. The rest of the system is functioning properly.
    b. Capillary tube length.
    c. Compressor size.
    d. Coil size.

97. (825) What direction is the thermostatic expansion valve (TXV) adjustment screw turned to *decrease* superheat?
    a. Counterclockwise.
    b. Back and forth.
    c. Up and down.
    d. Clockwise.

98. (825) Assuming everything else is working properly how is superheat *decreased* on a system *with a capillary tube*?
    a. Add refrigerant.
    b. Remove refrigerant.
    c. Block 50 percent of condenser coil.
    d. Block 50 percent of evaporator coil.

99. (826) How long should a system run *before* measuring subcooling?
    a. 2 to 3 seconds.
    b. 2 to 3 days.
    c. At least 3 weeks.
    d. Until temperature and pressure stabilize.

100. (826) When measuring *subcooling* the next step after measuring pressure at the liquid line is to
    a. measure pressure at the suction line.
    b. measure temperature at the liquid line.
    c. measure pressure reading at the subcooling point.
    d. convert the pressure reading to temperature using the pressure-temperature chart.

101. (826) Where is the high-side hose connected when using digital gauges to measure subcooling?
    a. Condenser inlet service port.
    b. Discharge line service port.
    c. Suction line service port.
    d. Liquid line service port.

102. (826) What step is performed *after* adding refrigerant to *decrease* subcooling?
    a. Turn on system.
    b. Let system stabilize.
    c. Read new superheat.
    d. Remove more refrigerant.

103. (827) What is the *first step* when topping off a system with *vapor*?
    a. Zero the scale.
    b. Purge the hoses.
    c. Start compressor.
    d. Determine proper amount of refrigerant required by measuring superheat or subcooling.

104. (827) After connecting the manifold gauge assembly (MGA) and hoses, what position are the service valves placed when topping off a system with *vapor*?
    a. Front seated.
    b. Back seated.
    c. Mid-position.
    d. Front seat the compressor discharge.

105. (827) After the proper amount of superheat has been determined from a chart you measure
    a. indoor wet bulb.
    b. outdoor dry bulb.
    c. relative humidity.
    d. the total superheat and compare it to the amount needed.

106. (828) What step is performed *before* opening the high- and low-side valves during *passive recovery not using the compressor*?
   a. Tap compressor.
   b. Heat the compressor.
   c. Place recovery device in ice bath.
   d. Open high-side manifold gauge assembly (MGA) valve.

107. (828) What is placed between the manifold gauge assembly (MGA) center port and recovery machine?
   a. In-line filter drier.
   b. High side valve.
   c. Schrader valve.
   d. Vacuum pump.

108. (828) What is the *first step* when performing a *triple evacuation*?
   a. Remove cores.
   b. Turn on the vacuum pump.
   c. Gather larger and shorter hoses.
   d. Gather smaller and longer hoses.

109. (828) When performing a triple evacuation how deep of a vacuum should be pulled the *first time*?
   a. 2 pressure per square inch gauge (psig).
   b. 6000 microns.
   c. 1500 microns.
   d. 6 psig.

110. (828) During a triple evacuation how much pressure is put into a system *after* the cylinder valves are opened?
   a. .001 to .01 pressure per square inch gauge (psig).
   b. 0 to 3 psig.
   c. 100 to 250 microns.
   d. 1500 microns.

111. (829) Pump down is performed to
   a. change out the receiver.
   b. remove the condenser coil.
   c. remove the liquid line filter-drier.
   d. make repairs to the low-side components.

112. (829) When pumping down a system what step is performed *after* the unit cycles off?
   a. Front seat the discharge service valve.
   b. Remove the expansion device.
   c. Find the liquid line receiver.
   d. Front seat the King valve.

113. (829) When performing a condenser pump down what step is performed *after* the gauge reaches 0 pressure per square inch gauge (psig)?
   a. Back seat the liquid service valve.
   b. Front seat the suction service valve.
   c. Back seat the suction service valve.
   d. Front seat the liquid line service valve.

Please read the unit menu for unit 5 and continue ➔

Student Notes

Unit 5. Refrigeration and Cooling Contingency Equipment

YOU MADE IT to last unit of this volume and now it is time for cooling contingency equipment. This unit will cover the TRICON fridge/freezer and the Field Deployable Environmental Control Unit (FDECU). These two pieces of equipment are absolutely critical to operations in a contingency environment. There are some very hot places on Earth and this equipment provides cooling capabilities anywhere our troops need to go.

Much of the material in this unit is from the technical order/technical manual (TO/TM) sections. It has been reformatted using standard CDC section and lesson numbers such as 830 continuing the sequence from Unit 4. The material has been modified with the CDC conventions in keeping with regulation guidance that prohibits duplication of training materials readily available in other sources. The information content is faithful to the information you will see in the relevant TOs and TMs for the equipment covered in this unit though the format is not.

Finally, we all know a TO should never be memorized; instead it must be used every time you work on equipment. This is well known but the specialty training standard (STS) portion of the Career Field Education and Training Plan (CFETP) for our career field directed coverage of this material in this CDC. So you will be studying and expected to know the warnings, equipment, and the theory of operation for both the TRICON and the FDECU. This will help when you are in the field working on this equipment using your technical order.

5–1. TRICON Theory of Operation

This system can operate as a fridge or a freezer. It can be used store anything you would put in a fridge or freezer and it could also be used for morgue operations. Hopefully, not though! Let's jump right into the info straight from the technical publication.

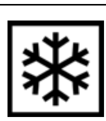
830. Warnings and equipment

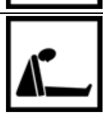
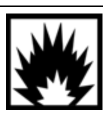
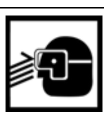
This warning summary contains general safety warnings and hazardous materials warnings that must be understood and applied while operating and performing maintenance on this equipment. Failure to observe these precautions could result in serious injury or death to personnel. Explanations of safety and hazardous material icons used within the technical manual are also included.

First aid

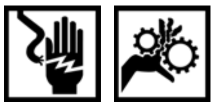
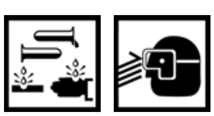
For first aid information, refer to FM 4–25.11, *First Aid*.

Safety warning icons

Explanation Of Safety Warning Icons	
	EXTREME COLD Snowflake indicates extreme cold conditions that may cause frostbite.

Explanation Of Safety Warning Icons	
	CRUSH HAZARD Moving object indicates that heavy object can crush and cause bodily injury.
	EAR PROTECTION Headphones over ears indicates that noise level will harm ears.
	ELECTRICAL Electrical wire to hand with electricity symbol running through hand indicates that shock hazard is present.
	ELECTRICAL Electrical wire to arm with electricity symbol running through human body indicates that shock hazard is present.
	HOT AREA Hand over object radiating heat indicates that part or area is hot and can burn.
	MOVING PARTS Hand with fingers caught between gears indicates that the moving parts of the equipment present a danger to life or limb.
	SHARP OBJECT Pointed object in hand indicates that a sharp object presents a danger to limb.
	HEAVY PARTS Heavy object on human figure shows that heavy parts present a danger to life or limb.
	HEAVY OBJECT Human figure stooping over heavy object shows physical injury potential from improper lifting technique.
	CORROSIVE Liquids dripping from test tube indicate chemicals that attack or corrode metals or irritate, burn, or destroy human tissue.
	SUFFOCATION Slumped over human figure indicates danger of suffocation or asphyxiation.
	HEAVY PARTS Hand with heavy object on top indicates that heavy parts can crush and harm if dropped.
	EXPLOSION Flame and burst indicates that material can explode if subjected to high temperatures, sources of ignition, or high pressure.
	EYE PROTECTION Human figure with goggles indicates that material can injure eyes.

General safety warning descriptions

General Safety Warnings Description	
	Make sure doors are secured to container frame when in open position. A gust of wind can cause unsecured doors to slam shut with great force causing severe injury or death to personnel.
	Do not operate the equipment without all grilles, guards, louvers, and covers in place and secure.
	High voltage and rotating parts are present when Mechanical Refrigeration Unit (MRU) is in operation. Make sure power cable is disconnected from power source before working on or inside MRU. Failure to comply can result in injury or death by electrocution.
	Never pressurize refrigerant lines with oxygen gas; mixture with oil could cause explosion. Failure to comply can cause injury or death to personnel. The pressure in a nitrogen cylinder can exceed 2,000 PSI (13,790 kPa). A nitrogen pressure regulator must be used to limit pressure to 500 PSIG (3,500 kPa). Failure to comply can cause injury or death to personnel.
	After unit has been operating, the refrigeration tubing can become quite hot. Allow tubing to cool since hot surfaces can burn skin. Failure to do so can result in serious injury to personnel.
	The TRCS weighs approximately 26,460 pounds fully loaded. Always use a suitable, properly rated lifting device if moving the TRCS.Make sure that the sling used during lifting is properly rated for the load, crane, or lifting device. Do not allow personnel below a suspended or swinging system if using an overhead lift. Failure to comply could cause serious injury or death to personnel, or damage to the equipment.
	Place a tie-down ratchet strap (lightly tensioned) around the container while in flight. The container door can open during rapid decompression. Failure to comply can result in serious injury or death to personnel. The emergency access door must be intentionally left open so that the container will self-ventilate in the event ofan in-flight rapid decompression.
	Compressor lubricating oil used in this equipment is caustic. Wear gloves and face protector or safety glasses in any situation where skin or eye contact is possible. If oil does contact skin, wash with soap and water. Failure to comply can cause injury to personnel.

TRCS equipment characteristics, capabilities and features

The TRICON Refrigerated Container System (TRCS) is an eight-foot by six-foot six-inch by eight-foot (8' X 6' 6" X 8') container, capable of storing and transporting temperature-sensitive cargo. Internal container air temperature is controlled by an electric motor-driven mechanical refrigeration unit (MRU), powered by an external power source. Refer to Figures 5–1 through 5–17 for a complete view of the TRCS. Refer to callouts on the figures for locations and descriptions of the exterior and interior components and essential assemblies of the TRCS.

Location and description of major components

The TRCS is composed of two main assemblies, described in the table below:

- The insulated shipping and storage container (fig. 5–1, Item 1).
- The MRU (fig. 5–1, Item 2).

TRCS Main Assemblies	
Item No.	**Description**
1	Insulated Shipping and Storage Container (fig. 5–2, Item 1) • The container is the largest of all components. • It has the MRU attached to the front, and doors used for access on the back. • The container is insulated and provides air-tight storage.
2	MRU.

Figure 5–1. TRCS.

TRCS Type I Exterior	
Item No.	**Description**
1	Insulated shipping and storage container
2	Emergency access door (fig. 5–2, Item 2) The emergency access door is located on the interior door of the container. The hatch provides a means for pressure equalization and a means of fresh air and/or opening the container door, contacting help should someone become locked in the container.
3	Lashing rings (fig. 5–2, Item 3) The lashing rings are located inside the container on the walls. The lashing rings are used to aid in securing materials inside of the container while container is being transported.
4	Floor drains (fig. 5–2, Item 4) The floor drains are located inside of the container on the floor near all four internal corners. The drains are designed using a ball float that will allow liquid to escape while floating and block the hole while not floating. This aids in securing the interior of the container from outside elements.
5	Door chains (fig. 5–2, Item 5)

TRCS Type I Exterior	
Item No.	**Description**
	Door chains are located on the exterior bottom of the container doors. The chains are used to secure the container doors in the open position.
6	Door handles (fig. 5–2, Item 6) Door handles are located on the outside of container doors. The handles aid in opening and closing the doors.
7	Chain hook (fig. 5–2, Item 7 and fig. 5–3, Item 1) To secure doors in the open position, the door chains are secured on the chain hook.
8	Locktube assembly (fig. 5–2, Item 8) Locktube assembly is located on the outside of the container doors. The locktube secures the doors closed and may be secured with an add-on padlock during transportation.
9	Container seal(s) (fig. 5–2, Item 9) The container seal(s) provide an air-tight enclosure when the doors are secured.

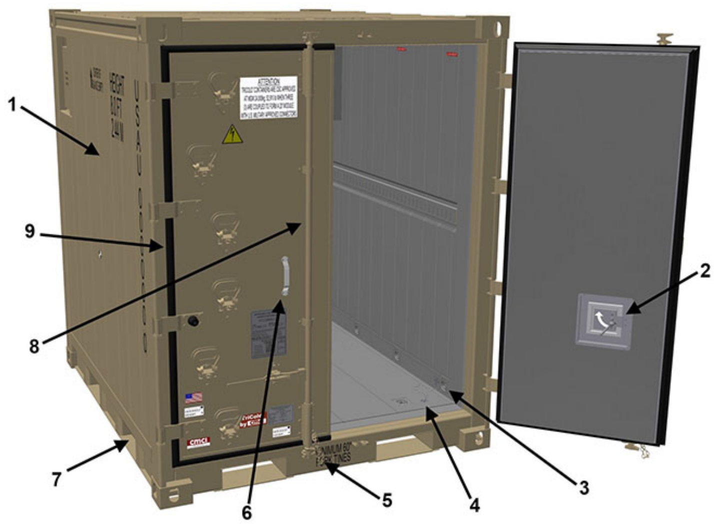


Figure 5–2. TRCS Type I rear view.

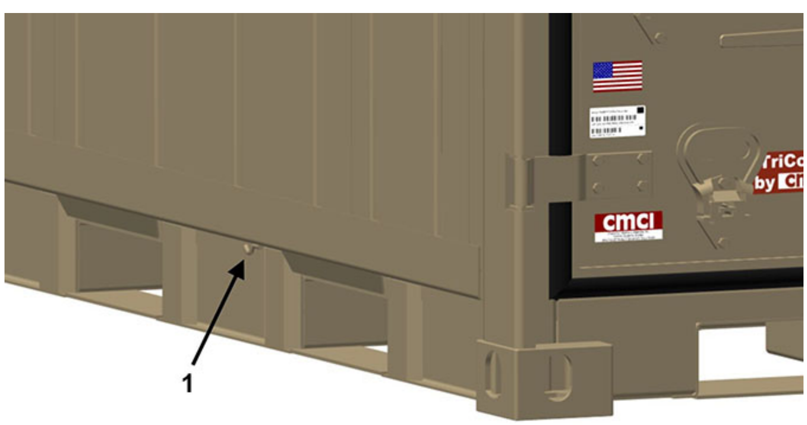


Figure 5–3. TRCS Type I chain hook.

TRCS Type III Exterior	
Item No.	**Description**
1	Extension light (fig. 5–4, Item 1) The extension light is available on the TRCS Type III only. It provides exterior illumination of the door area.
2	Quick-release door lock (fig. 5–4, Item 2) The quick-release door lock is available on the TRCS Type III only and when the telescoping lock bar (fig. 5-4, Item 2) is in the retracted position. This allows for quick access to the TRCS without compromising internal temperature, by maintaining the seal.
3	TRCS Type III container lock bar (fig. 5–4, Item 3) The TRCS Type III container lock bar telescopes to allow for the use of the quick-release door lock (fig. 5-4, Item 1).
4	Chain hook (fig. 5–4, Item 4 and fig. 5–5, Item 1) To secure door in the open position, the door chain is secured on the chain hook.
5	Container seal(s)

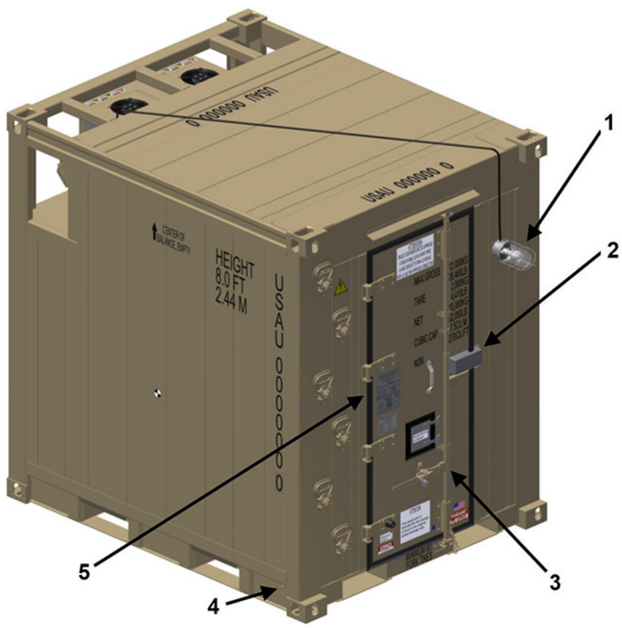


Figure 5–4. TRCS Type III rear view.

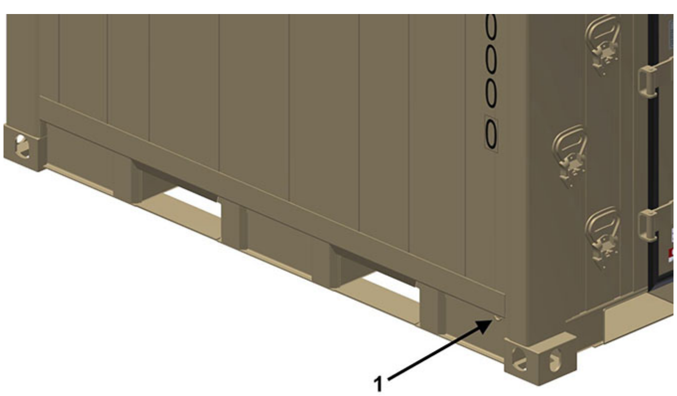


Figure 5–5. TRCS Type III chain hook.

TRCS Plastic Curtain	
Item No.	**Description**
1	Plastic curtain (fig. 5–6, Item 1) The plastic curtain is located inside the container. The curtain provides the ability to operate the unit with the doors open and still maintain refrigeration.

Figure 5–6. TRCS Type I plastic curtain.

Manual holder

The manual holder (fig. 5–7) is a watertight box that houses the TRCS technical manuals (TM).

Figure 5–7. Manual holder.

Electrical Box	
Item No.	**Description**
1	Electrical plug connector The electrical box (fig. 5–8) on the TRCS Type III accepts the external power input via the electrical plug connector (fig. 5-8, Item 1) and distributes power to the MRU and container lighting system.
2	Circuit breaker A circuit breaker (3CB1) (fig. 5–8, Item 2) is available on the electrical box for power control.
3	GFCI Two 115 VAC convenience GFCI outlets (fig. 5–8, Item 3) are located on the electrical box exterior.

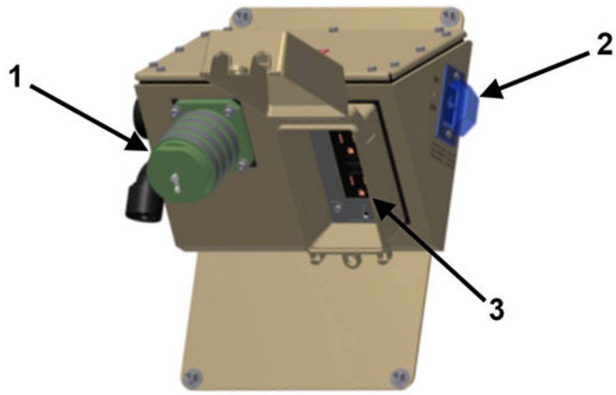


Figure 5–8. Electrical box.

Shelving unit

For the TRCS Type III, up to two shelving units (fig. 5–9) can be installed within the container. The individual shelf load rating is a distributed 600 lbs per shelf.

Figure 5–9. Shelving unit, Type III.

Light assembly

For the TRCS Type III, blue and white 100 W interior lights (fig. 5–10) are mounted above the container door. The lights are activated by the switch located on the interior back container wall.

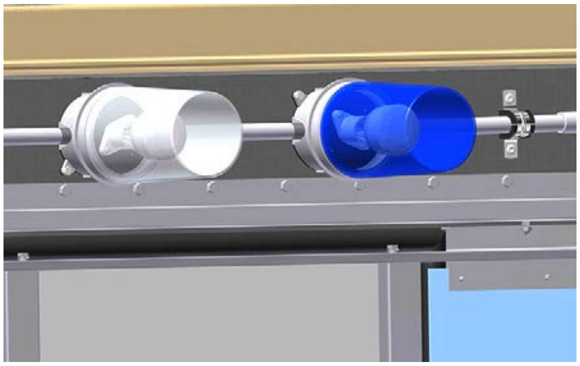


Figure 5–10. Light assembly, Type III.

Location and description of MRU major components

MRU Major Components	
Item No.	**Description**
1	Evaporator Fans (fig. 5–11, Item 1) There are three evaporator fans located inside the container on the evaporator side of the MRU. In cooling mode, the fans draw interior container air through the evaporator coil, where the air is cooled and dehumidified then discharged out in a radial fashion to the container. In heating mode, the fans draw interior container air through the warm evaporator coil (heated by tubular electric heaters pressed into the evaporator fins), heating the container air and discharging the warmed air in a radial fashion to the container.
2	Power Cable (fig. 5–11, Item 2) The MRU power cable originates in the electrical box for TRCS Type III units, and an external power cable is provided for the TRCS Type I units.
3	Control Box (fig. 5–11, Item 3) The control box is located on the front of the MRU. The control box houses most of the repairable electrical components and also acts as a control panel for user interface.
4	Condenser Coil (fig. 5–11, Item 4) The condenser coil is located in the front of the MRU above the control panel. During cooling operation, the condenser rejects refrigerant heat to ambient air.
5	Sight Glass (fig. 5–11, Item 5) The sight glass is located on the accumulator/receiver and is visible from the left side of the MRU. The sight glass can indicate low refrigerant charge or moisture in the system. The sight glass can also be used to determine the appropriate fill level when adding refrigerant to the system.
6	Condenser Fans (fig. 5–11, Item 6) There are two condenser fans located on the condenser access panels on top of the MRU. They are used to draw ambient air through the condenser coil to aid in the cooling of the refrigerant. The fans then exhaust the heated air vertically through the top of the MRU condenser section.
7	Condenser Access Panels (fig. 5–11, Item 7) The condenser access panels are located on top of the MRU and may be opened while the MRU is installed in the container. The condenser access panels provide easy access to components inside the MRU condenser section for ease of maintenance.

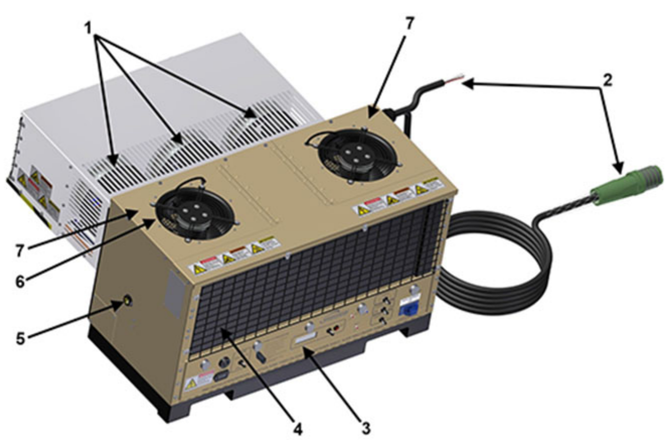


Figure 5–11. MRU major components.

Service Ports, Switches, Thermostatic Expansion Valve	
Item No.	**Description**
1	Thermostatic expansion valve (TXV) (fig. 5–12, Item 1) The TXV regulates the flow of liquid refrigerant into the evaporator coil. The TXV also separates the high-pressure side of the system from the low-pressure side. The TXV consists of three main components: the body, the thermostatic element, and a cartridge insert that contains the orifice for expansion.
2	High-pressure switch (fig. 5–12, Item 2) The switch is located on the compressor discharge line, between the compressor and condenser in the condenser section. The switch is normally closed. If discharge pressure rises above 570 PSIG, the switch opens, de-energizes the power relay coil, and shuts the MRU down to prevent damage. When pressure drops below 410 PSIG, the switch will close allowing unit operation.
3	High-pressure service port (fig. 5–12, Item 3) The high-pressure service port is located on the compressor discharge line after the high-pressure switch. This service port is provided for measuring pressure and the recovering, charging, and purging of refrigerant.
4	Low-pressure service port (fig. 5–12, Item 4) The low-pressure service port is located on the accumulator/receiver input line after the low-pressure switch. This service port is provided for measuring pressure and the recovering, charging, and purging of refrigerant.
5	Low-pressure switch (fig. 5–12, Item 5) The switch is located on the compressor suction line between the accumulator/receiver and evaporator in the condenser section. The switch is normally closed. If suction pressure drops to a level below 5 psig, the switch opens causing the contactor to open, and shuts down the MRU. The switch automatically closes when pressure rises above 30 psig.

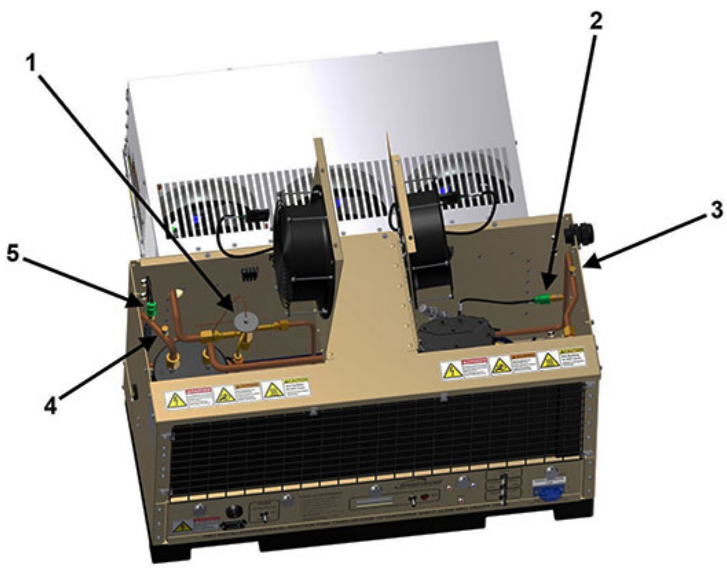


Figure 5–12. Service ports, switches, TXV.

Evaporator Section	
Item No.	**Description**
1	Thermistor (fig. 5–13, Item 1) The thermistor is attached to the evaporator grille that protects the evaporator coil. The thermistor senses the internal temperature of the container and controls the operation of the unit by controlling the power and heat relays.
2	Evaporator coil (fig. 5–13, Item 2) The evaporator coil is located inside the TRCS and is protected by a grille. When refrigerant passes through the evaporator, it absorbs heat and condenses water vapor from the air, cooling and dehumidifying the air.
3	Condensate drain line heater (fig. 5–13, Item 3) The condensate drain line heater is located inside of the condensate drain lines. It provides heat when the TRCS air temperature is less than 50 °F and the unit is operating in defrost mode to prevent condensate from freezing in the condensate drain lines.
4	Condensate drain lines (fig. 5–13, Item 4) The condensate drain lines are connected to the drip pan on the evaporator section of the MRU. The drainage system of the TRCS allows for the discharge of condensation directly outside of the TRCS.
5	Drip pan (fig. 5–13, Item 5) The drip pan is located on the bottom of the evaporator section. The drip pan catches condensation and directs the water to the condensate drain lines, to be discharged outside of the TRCS. The drip pan can be easily removed for the majority of maintenance required in the evaporator section.

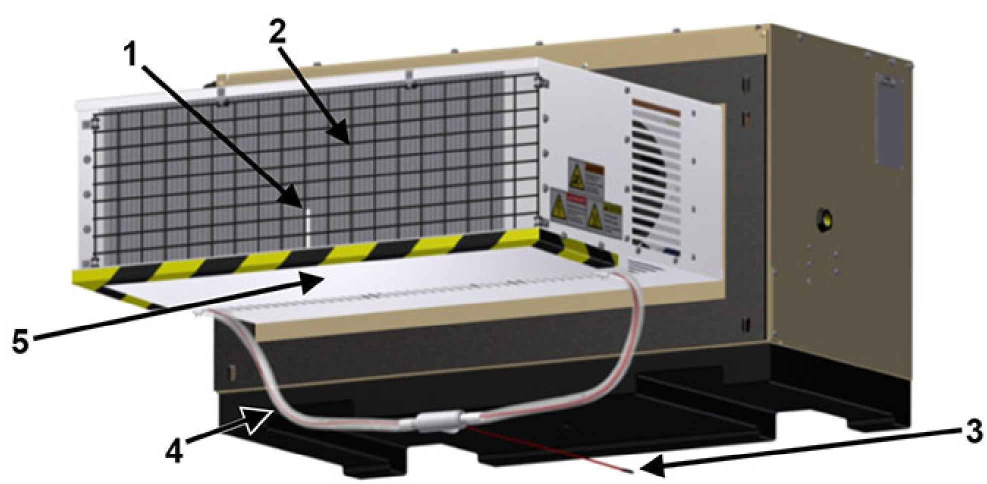


Figure 5–13. Evaporator section.

Drip pan heater

The drip pan heater is attached to the inside face of the drip pan. The drip pan heater provides heat when the unit is in DEFROST mode, to prevent frozen condensate from accumulating in the drip pan.

Condenser Section	
Item No.	**Description**
1	Accumulator/Receiver (fig. 5–14, Item 1) The accumulator/receiver is located in the condenser section of the MRU. The accumulator/receiver's purpose in the system is to prevent transient liquid slugs of refrigerant exiting the evaporator coil from entering the compressor. Rapid operating changes, TXV changes, and other factors can occasionally result in a temporary operating condition where not all the refrigerant exiting the evaporator is a vapor, and remains liquid. Since a compressor cannot compress liquids, this could strain, damage, or overload the compressor. The suction line accumulator temporarily traps this liquid, and the liquid is evaporated by the warm, subcooled liquid refrigerant that surrounds the accumulator to prevent slugging.
2	Compressor (fig. 5–14, Item 2) The compressor is located in the condenser section of the MRU. The compressor is responsible for raising the temperature and pressure of the refrigerant vapor.
3	Pressure-relief valve (fig. 5–14, Item 3) The pressure-relief valve will open if the refrigerant pressure gets too high. This will prevent damage to the system.
4	King valve (fig. 5–14, Item 4) The King valves are used to isolate the compressor from the refrigeration circuit. There are two King valves on the compressor: one on the suction side (fig. 5–15, Item 2) and one on the discharge side (fig. 5–15, Item 1).
5	Filter-drier (fig. 5–14, Item 5) The filter-drier is located between the accumulator/receiver and the TXV in the condenser section. The filter-drier filters out particles and removes moisture to prevent it from circulating through the system.

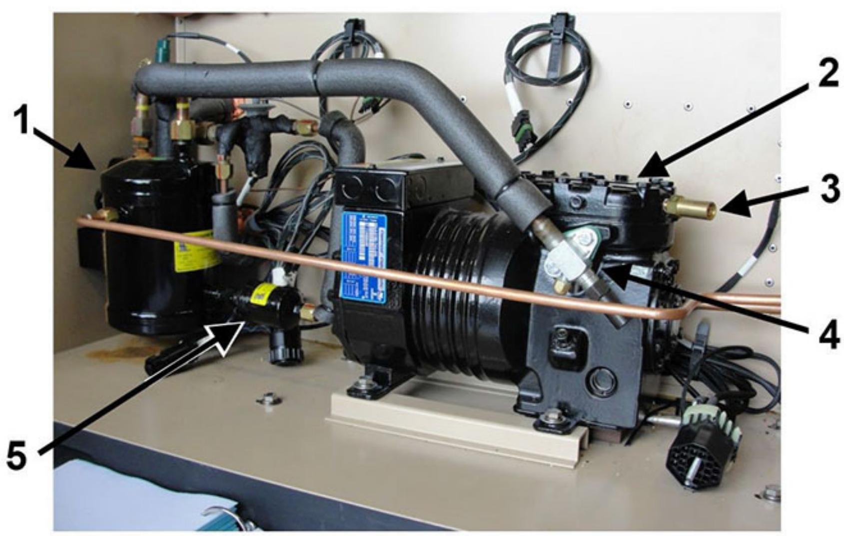


Figure 5–14. Condenser section.

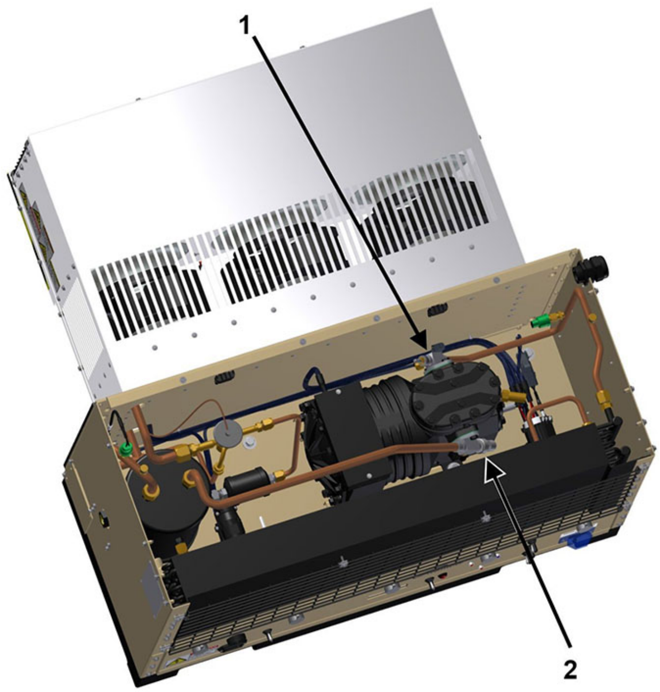


Figure 5–15. King valves.

Evaporator heating elements

Heating elements are located in the evaporator section (fig. 5–16, Item 1), mounted to evaporator coil. Evaporator heating elements are resistive electric heaters that provide 1,050 watts of heating under all required operation conditions. Evaporator heating elements are used to maintain acceptable temperatures in the container, keep foods from freezing, and defrost the evaporator coil.

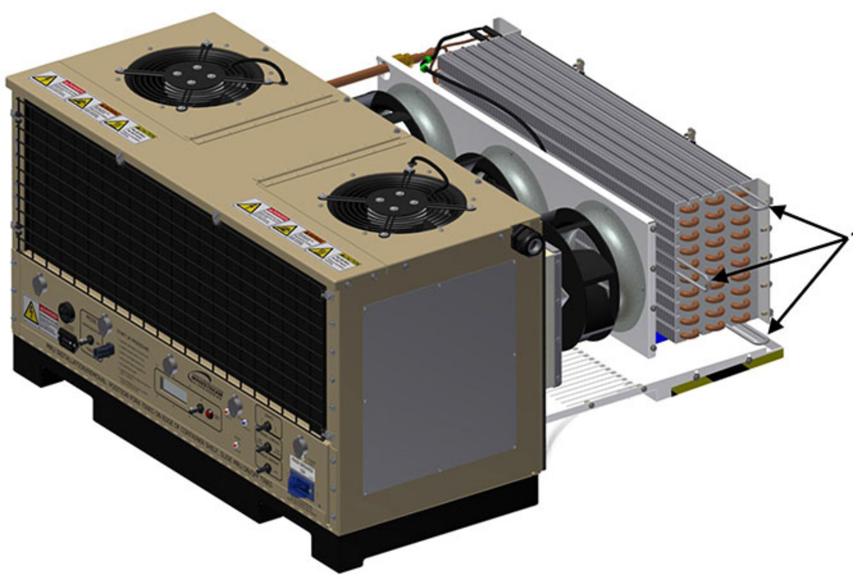


Figure 5–16. Evaporator heating elements.

Control box

The control box (fig. 5–17) is mounted on the front face of MRU and contains user interface and electronics. The user interface located on the control box cover includes circuit protection, user inputs, and fault indication which are described in the following table.

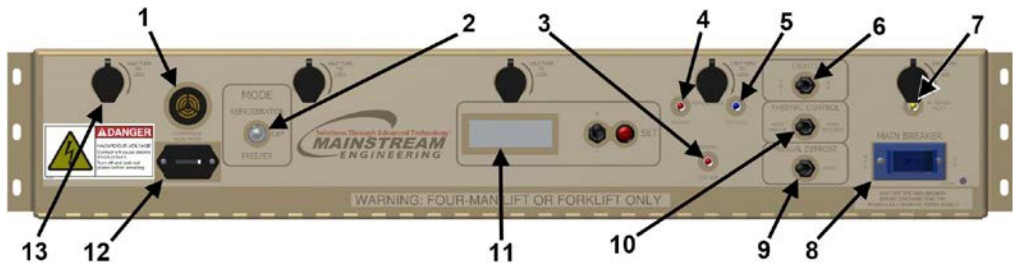


Figure 5–17. Control box major components.

Control Box Major Elements	
Item No.	**Description**
1	Monitor alarm (fig. 5–17, Item 1) The monitor alarm provides audible indication when the TRCS air temperature is outside the acceptable range.
2	MODE switch (fig. 5–17, Item 2) Allows user to select REFRIGERATOR, OFF, or FREEZER modes.
3	FREEZER TOO HOT LED (fig. 5–17, Item 3) Lights when the MRU is in FREEZER mode and the container air temperature is too high.
4	REFRIGERATOR TOO HOT LED (fig. 5–17, Item 4) Lights when the MRU is in REFRIGERATOR mode and the container air temperature is too high.
5	REFRIGERATOR TOO COLD LED (fig. 5–17, Item 5) Lights when the MRU is in REFRIGERATOR mode and the container air temperature is too low.
6	LIGHTS switch (fig. 5–17, Item 6) LIGHTS ON will allow the LCD and fault LEDs to light. When LIGHTS OFF is selected, the LCD and fault LEDs will not light.
7	AC WIRING FAULT LED (fig. 5–17, Item 7) Lights when the 208 VAC, 3-phase input power has a fault and must be fixed.
8	MAIN BREAKER (fig. 5–17, Item 8) Disconnects input power downstream of circuit breaker. Circuit breaker input post and power cable are still electrically hot when circuit breaker is OFF.
9	MANUAL DEFROST switch (fig. 5–17, Item 9) Manual defrost may be initiated when the MANUAL DEFROST switch is temporarily moved into the START position. Manual defrost will occur for the user selected defrost duration (selected using LCD).
10	THERMAL CONTROL switch (fig. 5–17, Item 10) MORE EFFICIENT operation will automatically change the set point temperature periodically to maximize efficiency. This could lead to a container temperature that is colder than what the user desires. MORE PRECISE operation will always keep the internal air temperature at the set point that the user sets.
11	LCD and setting switches (fig. 5–17, Item 11) Temperature set points and defrost durations can be selected using the LCD, SET switch, and ± switch, located to the right of the LCD. Press SET switch to scroll through the options. When the desired setting is blinking, use the ± switch to increase or decrease the value.

Control Box Major Elements	
Item No.	**Description**
12	COMPRESSOR HOUR METER (fig. 5–17, Item 12) Indicates the run time over the life of the compressor.
13	Rim latches (fig. 5–17, Item 13) Five rim latches are used to secure the control box front panel to the control box.

Differences between TRCS Type I And Type III models

The differences between the TRCS Type I and Type III are described in in the following:

Differences Between Models		
Differences	**MRU Type I**	**MRU Type III**
	Model TQ340412C	Model TQ34043P
Power Cable	12' SOOW 10/5 power cable with 60A, Class L straight plug	3' SOOW 10/5 power cable with pigtail leads
Container Doors	Two with locking bars	One with one telescoping locking bar
Container Lighting	None	Interior lighting plus extension light with external interconnecting box
Container Shelving	None	Two shelving assemblies with hold-down straps
Technical Manual Holder Location	Left side, front	Right side, front
Ladder Location	Rear, on left door	Rear to left of door
Door Lock	Manual	Automatic locking system integrated into door
Labels and Decals	See WP 0005	See WP 0005

Equipment data

The TRCS Type I system specifications are described below:

TRCS Type I System Specifications	
Insulated Container Model	CMCI 24
Manufacturer	Charleston Marine Containers, Inc. (CMCI)
Length	96 inches
Width	78 Inches
Height	96 inches
Empty weight with MRU and 3 interconnects (TARE)	3,880 pounds
Max gross weights with MRU, 3 interconnects (MGW)	26,460 pounds
Internal Volume	270 cubic feet
Shipping Cube	416 square feet
Cargo Weight Capacity	20,545 pounds

The following table lists the TRCS Type III system specifications:

TRCS Type III System Specifications	
Insulated Container Model	CMCI 256
Manufacturer	Charleston Marine Containers, Inc. (CMCI)
Length	96 inches
Width	78 inches
Height	96 inches
Empty weight with MRU and 3 interconnects	4,630 pounds
Max gross weights with MRU, 3 interconnects	26,460 pounds
Internal Volume	270 cubic feet
Shipping Cube	416 square feet
Cargo Weight Capacity	19,592 pounds

The MRU system specifications are described below

MRU-TQ3-404 System Specifications	
Refrigeration Unit Model	MRU-TQ3-404
Manufacturer	Mainstream Engineering Corp.
Type	Mechanical refrigeration unit (MRU)
Volts, Frequency, Nominal Amps	208 VAC, 3-phase, 50/60 Hz
Length, Width, Height	21 $^{3}/_{8}$ inches x 36 ¾ inches x 38 inches
Weight	350 pounds
Cooling Capacity, Refrigeration	4100 BTU/hr (1200 watts) at 0 to 100 °F
Heating Capacity	1050 watts
Maximum Power Consumption	2500 watts
Refrigerant Type and Quantity	6 pounds, 8 ounces (2.9 kg) R-404A
Refrigerant Oil Type and Quantity	EMKARATE RL 32-3 MAF POE Oil or equivalent, 20 fluid ounces

831. Theory of operation

Now that you are familiar with the equipment and safety warnings we jump into the theory of operation. Again, directly from the technical publication to ensure not information is lost in translation.

Basic vapor-compression refrigeration principles

Basic vapor-compression refrigeration systems consist of four major components: compressor, evaporator, condenser, and expansion device.

Refrigerant absorbs heat energy (provides cooling) as it evaporates; that is, as it boils and turns from liquid to vapor. If the refrigerant evaporates at a constant pressure, then evaporation occurs at a constant temperature while both liquid and vapor are present. Likewise, refrigerant rejects heat energy (gives off heat) as it condenses from vapor to liquid. Once again, if the condensation occurs at a constant pressure, then the condensation will occur at a constant temperature until all the vapor has condensed to a liquid. Therefore, for evaporation or condensation, the temperature and pressure are related by the pressure/temperature saturation curve.

NOTE: When discussing pressure in psi (pounds per square inch), psig means pounds per square inch gauge, and psia means pounds per square inch absolute. The two numbers differ by approximately 14.7 psi. A refrigeration gauge normally reads in units of psig; that is, in normal air, it will read a pressure of zero. However, an absolute gauge would read a pressure of about 14.7 psia in this same location. Likewise, we normally use inches of mercury to discuss vacuum levels, with 29.9 being a complete vacuum (0 psia). Some saturation charts for refrigerants are using the absolute pressure instead of the combination of gauge pressure and vacuum in inches of mercury.

To convert psia to psig, simply subtract 14.7 (or round to 15) from the psia reading to get the psig reading. For example, 14.7 psia is 0.0 psig; normal atmospheric pressure, 164.7 psia can be referred to as 150 psig. As a simple rule of thumb, to convert inches of mercury (the symbol for mercury is Hg) to psia, simply divide the value in inches of mercury by 2 and subtract it from 15 to get the approximate psia reading. For example, 5" Hg is about 12.5 psia (actually it is 12.2 psia), 10" Hg is about 10 psia (actually it is 9.8 psia), and finally 15" Hg is about 7.5 psia (actually it is 7.3 psia).

Slightly sub-cooled refrigerant leaves the condenser at high pressure, and the pressure is dropped via the thermostatic expansion valve (TXV), before it enters the evaporator.

The refrigerant enters the evaporator as a two-phase mixture (liquid and vapor) and evaporates or boils at low temperature, absorbing heat. Slightly superheated refrigerant vapor exits the evaporator. The TXV is an automatically adjusting valve that slightly increases or decreases its opening depending on the superheat of the refrigerant exiting the evaporator. If the superheat is too large, it will increase the valve opening to increase the flow rate. Alternatively if the superheat is too little, it will close the TXV valve slightly. After the evaporator, the superheated vapor enters the compressor where the pressure and temperature are increased as the compressor compresses the refrigerant vapor.

The vapor leaving the compressor is a superheated vapor, and the compressor discharge is the hottest point in the cycle. This refrigerant is cooled and condensed in the condenser where heat is rejected to the environment, and the refrigerant condenses to liquid. Refrigerant leaves the condenser slightly sub-cooled to assure condensation has been complete. Any non-condensable vapors in the system will be unable to condense in the condenser and will appear as gas bubbles in the condensed liquid stream. These non-condensables may collect in the condenser and displace refrigerant from the condenser heat exchanger, thereby reducing the effective surface area of the condenser.

Weights and ratings

Weights and ratings are listed in Equipment Data, Equipment Description and Data (WP 0002, Tables 13 through 15).

Airflow

There are two major paths for airflow:

- Ambient outside air is drawn in and flows across the condenser coil to condense the refrigerant and is then returned to the outside.
- Warm air from the container interior is drawn in and across the evaporator coil to cool the air. The cooled air is returned to the interior of the container.

Wire marking

All wiring is marked to indicate points of origin and termination, using nomenclature consistent with the wiring diagrams and electrical schematics. All wires outside the control box are bundled with nylon shrouding into individual wiring harnesses, and each harness is labeled with the name of the component that it connects with.

All wires terminating with a capital A are wires located inside a wire harness and located external to the control box. All wires terminated with only a number are located inside the control box. Wires in the control box lettered "xyz" will normally be designated "xyzA" when leaving the control box.

All Neutral wires start with a 4; therefore, any 4xy wire number is a Neutral wire inside the control box, and any 4xyA is a Neutral wire outside of the control box.

All Ground wires start with a 5; therefore, any 5xy wire number is a Ground wire inside the control box, and any 5xyA is a Ground wire outside of the control box.

Low voltage 12 volts, direct current (VDC) Positive wires all start with a 6; therefore, any 6xy wire is a Positive 12 VDC wire inside the control box, and any 6xyA is a Positive 12 VDC wire outside the control box.

Low voltage DC ground wires all start with a 7; therefore, any 7xy wire is a DC Ground wire inside the control box, and any 7xyA is a DC Ground wire outside the control box.

There are three main wiring harnesses outside of the control box:

- 2W1 branches out and carries low-voltage DC control signals and information to the control box from the high-pressure switch (2S2) and low-pressure switch (2S1) as well as temperature information from the evaporator-in thermistor (2RT1) and the evaporator-out thermistor (2RT2).
- 2W2 which branches out and supplies AC power to the three evaporator fans (2B1 through 2B3), the two condenser fans (2B4 and 2B5), the condensate drain line heater (2HR5), and condensate drip pan heater (2HR6).
- 2W3 branches out and supplies AC power to the three tubular heaters (2HR1 through 2HR3), the crankcase heater (2HR4), and the compressor (2B6).

Control board (1U1) operation

The MRU is controlled by a printed circuit board (PCB) referred to as the control board (1U1). The control board (1U1) monitors the temperature of the TRCS, and controls the compressor (2B6), heaters, and fans, in order to reach the set point temperature. The temperature indicator and all other controls on the MRU are sand-intrusion-tight and waterproof. The temperature-sensing element, used to measure TRCS temperature, (evaporator-in thermistor (2RT1)) is located at the inlet side of the evaporator and attached to the evaporator grille.

The control board (1U1) also has four relays as shown in Figure 5–18.

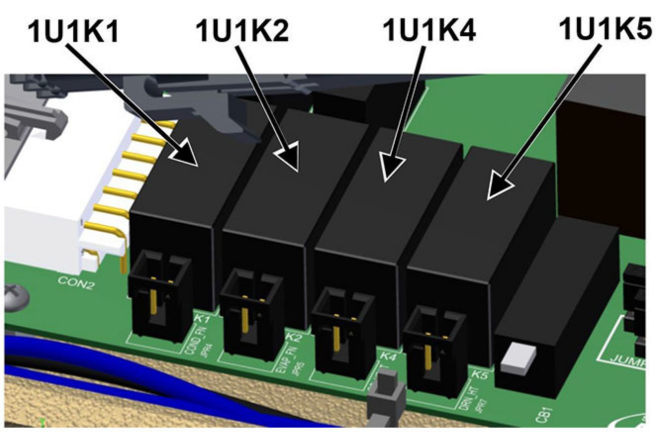


Figure 5–18. Location of relays on the control board (1U1).

These relays control the following equipment.

Control Board (1U1) Relays	
Relay	**Controls**
1U1K1	Condenser fans (2B4 and 2B5)
1U1K2	Evaporator fans (2B1 through 2B3)
1U1K4	Crankcase heater (2HR4)
1U1K5	Condensate drain line heater (2HR5)

Control Board Relays: Relay 1U1K1

Relay (1U1K1) powers the two condenser fans (2B4 and 2B5) by supplying line power to the BLK center post of the fan capacitor bank (1C2) via wire 120. The neutral for these 120 VAC fans is supplied to the WHT terminal on the capacitor bank, via wire 425, and ground for these fans is supplied to the ground GRN post on the fan capacitor bank via wire 520.

Relay 1U1K1	
Controls	**Description**
Condenser Fan (2B4)	The neutral wire (wire 427) for condenser fan (2B4) runs from WHT terminal to pin 8 of CON2_AC connector (1W1J2). The start wire (wire 124) for condenser fan (2B4) runs from YEL terminal to pin 7 of CON2_AC connector (1W1J2). The run wire (wire 122) for condenser fan (2B4) runs from BLK terminal to pin 6 of CON2_AC connector (1W1J2). The ground wire runs from the GRN terminal to pin 9 of CON2_AC connector (1W1J2) via wire 522.
Condenser Fan (2B5)	The neutral wire (wire 426) for condenser fan (2B5) runs from WHT terminal to pin 3 of CON2_AC connector (1W1J2). The start wire (wire 123) for condenser fan (2B5) runs from RED terminal to pin 2 of CON2_AC connector (1W1J2). The run wire (wire 121) for condenser fan (2B5) runs from BLK terminal to pin 1 of CON2_AC connector (1W1J2). The ground wire runs from the GRN terminal to pin 4 of CON2_AC connector (1W1J2) via wire 521.

Relay (1U1K2)

Relay (1U1K2) powers the three evaporator fans (2B1 through 2B3) and supplies line power to the BLK center post of the evaporator capacitor bank (1C1) via wire 130. The neutral for these 120 VAC fans is supplied to the WHT terminal on the capacitor bank, via wire 430; and ground for these fans is supplied to the ground GRN post on the fan capacitor bank via wire 530.

Relay 1U1K2	
Controls	**Description**
Evaporator Fan (2B1)	The neutral wire (wire 431) for evaporator fan (2B1) runs from WHT terminal to pin 14 of CON2_AC connector (1W1J2). The start wire (wire 134) for evaporator fan (2B1) runs from RED terminal to pin 13 of CON2_AC connector (1W1J2). The run wire (wire 131) for evaporator fan (2B1) runs from BLK terminal to pin 12 of CON2_AC connector (1W1J2). The ground wire runs from the GRN terminal to pin 15 of CON2_AC connector (1W1J2) via wire 531.
Evaporator Fan (2B2)	The neutral wire (wire 432) for evaporator fan (2B2) runs from WHT terminal

Relay 1U1K2	
Controls	**Description**
	to pin 19 of CON2_AC connector (1W1J2). The start wire (wire 135) for evaporator fan (2B2) runs from YEL terminal to pin 18 of CON2_AC connector (1W1J2). The run wire (wire 132) for evaporator fan (2B2) runs from BLK terminal to pin 17 of CON2_AC connector (1W1J2). The ground wire runs from the GRN terminal to pin 20 of CON2_AC connector (1W1J2) via wire 532.
Evaporator Fan (2B3)	The neutral wire (wire 433) for evaporator fan (2B3) runs from WHT terminal to pin 23 of CON2_AC connector (1W1J2). The start wire (wire 136) for evaporator (2B3) runs from BLU terminal to pin 22 of CON2_AC connector (1W1J2). The run wire (wire 133) for evaporator fan (2B3) runs from BLK terminal to pin 21 of CON2_AC connector (1W1J2). The ground wire runs from the GRN terminal to pin 24 of CON2_AC connector (1W1J2) via wire 533.

Relay (1U1K4)

Relay (1U1K4) powers the crankcase heater (2HR4) via wire 138, which supplies line power to pin H of CON1_AC connector (1W1J3). The neutral is supplied to pin I of CON1_AC connector (1W1J3) via wire 435.

Relay (1U1K5)

Relay (1U1K5) powers the condensate drain line heater (2HR5) via wire 162, which supplies line power to pin 11 of CON2_AC connector (1W1J2). The neutral is supplied to pin 10 of CON2_AC connector (1W1J2) via wire 462.

AC jumpers

For troubleshooting purposes, control board (1U1) includes jumpers that let the maintainer bypass the control board relays and disable audible alarms. Figure 5–19, shows the locations of the jumpers on the control board (1U1). When not needed, these jumpers are stored in JUMPER HOLDER AREA located next to control board circuit breaker (1U1CB1).

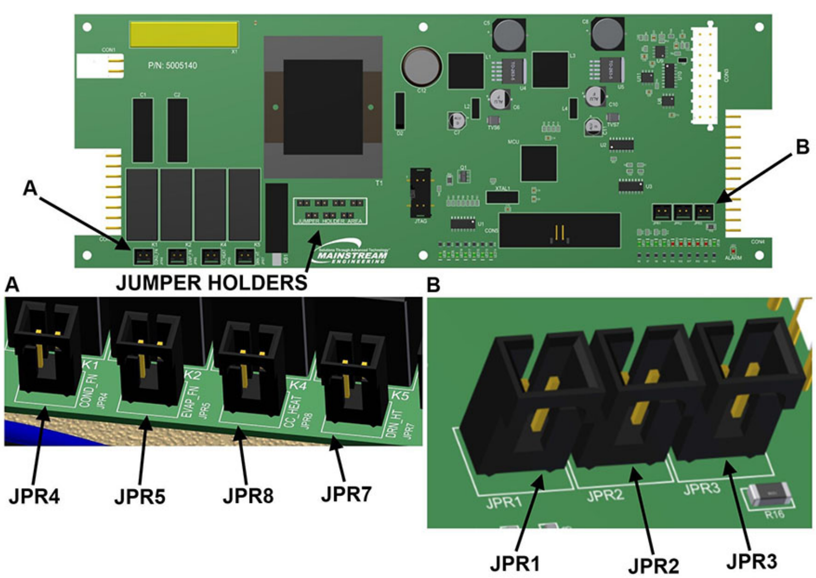


Figure 5–19. Location of jumpers on the control board (1U1).

AC Jumpers	
Jumper	**Purpose**
JPR1	High-pressure override. When a jumper is inserted into JPR1, the MRU will not shut down under a compressor high-pressure fault.
JPR2	Low-pressure override. When a jumper is inserted into JPR2, the MRU will not shut down under a compressor low-pressure fault.
JPR3	Audible alarm enable. When a jumper is inserted into JPR3, the MRU audible alarm (1LS1) will sound under "refrigerator/freezer too hot," "refrigerator too cold," or "heater overheat" conditions. If no jumper is inserted, the audible alarm will be disabled. JPR3 is not installed from the factory.
JPR4	(bypasses relay 1U1K1): condenser fans (2B4 and 2B5)
JPR5	(bypasses relay 1U1K2): evaporator fans (2B1 through 2B3)
JPR7	(bypasses relay 1U1K5): condensate drain line heater (2HR5)
JPR8	(bypasses relay 1U1K4): crankcase heater (2HR4)

LEDs

The control board (1U1) contains 18 LED indicators to simplify maintenance. The LEDs indicate helpful troubleshooting information, such as the status of the pressure cutouts, thermal cutouts, compressor, heater, and temperature sensors. Figure 5–20, shows the location of the LEDs.

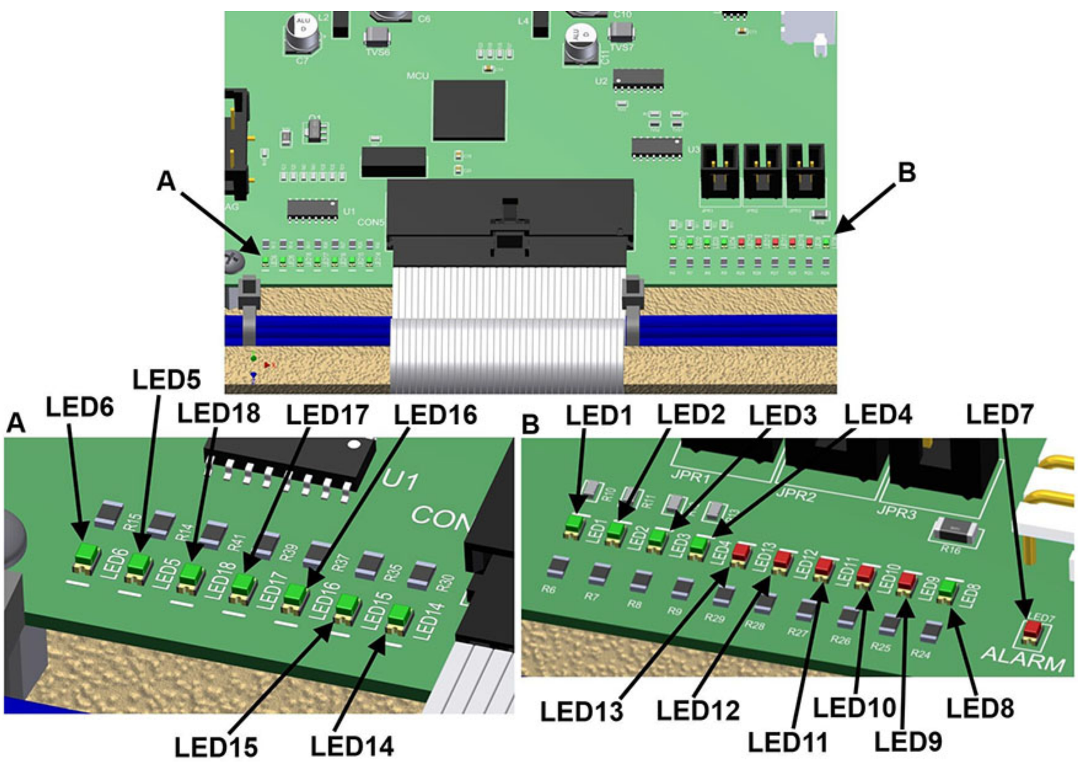


Figure 5–20. Location of LEDs on the control board (1U1).

When an LED is lit, the following conditions exist:

Lit LED Conditions	
LED	**Condition**
1	Thermal control switch (1S5) set to MORE EFFICIENT.
2	MODE switch (1S1) set to REFRIGERATOR.
3	MODE switch (1S1) set to FREEZER.
4	Manual defrost switch (1S4) set to START.
5	Compressor relay coil energized.
6	Evaporator heater relay coil energized.
7	Alarm (1LS1) on.
8	Automatic or manual defrost on.
9	Compressor low-pressure fault because the suction side pressure went below 5 - 15 PSIG and has not yet risen above 20 - 30 PSIG to automatically reset.
10	Ambient thermistor (1RT1) is out of range, because it is indicating a temperature that is either above 250 or below -50 °F.
11	Compressor high-pressure fault because the discharge side pressure went above 550 - 570 PSIG and has not yet dropped below 410 - 440 PSIG to automatically reset.
12	Evaporator-in thermistor (2RT1) is out of range because it is indicating a temperature that is either above 250 or below -50 °F.
13	Evaporator-out thermistor (2RT2) is out of range because it is indicating a temperature that is either above 250 or below -50 °F.
14	Condenser fan control board relay (1U1K1) energized.
15	Evaporator fan control board relay (1U1K2) energized.
16	Tubular heater over-temperature alarm. Thermistor (2RT3) recorded a temperature above 100 °F.
17	Crankcase heater control board relay (1U1K4) energized.
18	Condensate drain line heater control board relay (1U1K5) energized.

Safety switches

The MRU has automatically resetting high-pressure, low-pressure, and compressor over-temperature switches. The MRU incorporates both a high-pressure switch (2S2) and a pressure-relief valve to prevent mechanical failure due to excessively high-pressure. The high-pressure switch (2S2) will electrically halt the compressor operation at 550–570 psig, and the pressure-relief valve will vent refrigerant at higher pressures (582–618 psig) if the high-pressure switch (2S2) fails. The pressure-relief valve vents into the condenser airflow path. The high-pressure switch (2S2) will automatically reset when the refrigerant pressure falls below 410–440 psig. The pressure-relief valve will automatically reset when the pressure falls below 465–495 psig; however, because the refrigerant is a blend, the refrigerant charge must be replaced if the pressure-relief valve should vent refrigerant.

The MRU incorporates a low-pressure switch (2S1) to prevent mechanical failure due to excessively low pressure.

The low-pressure switch (2S1) will disable compressor operation at 5–15 psig and will automatically reset when refrigerant pressure rises above 20–30 psig.

The high- and low-pressure switches are wired to the control board (1U1), each with a dedicated LED that will indicate an open circuit (which disables the compressor (2B6), simplifying troubleshooting and maintenance procedures (LED9 compressor low pressure, LED11 compressor high pressure).

The compressor (2B6) is protected by an automatically resetting thermal overload protector (current/temperature safety switch) that trips on compressor over-current or over-temperature.

The MRU has an automatically resetting heater high-limit switch (evaporator-out thermistor (2RT2) that is wired to the control board (1U1).

MODE switch

The MODE switch (1S1) allows the user to switch the MRU to FREEZER, REFRIGERATOR, or OFF mode. In FREEZER mode, the MRU will cool the container to maintain a temperature at or below the cooling set point. The heating set point is OFF (disabled) when in FREEZER mode. The LCD (1DS1) shows the current temperature inside the container along with the current set point (SP) temperature. The MRU will cool the container to the COOLING SP temperature.

In REFRIGERATOR mode, you can set the heating set point in addition to the cooling set point. The refrigerator mode set points will not allow you to select temperatures below 35 °F. This prevents accidental freezing of the contents of the container. The controllers will assure that the heating set point; that is, the internal container temperature, at which heat is added into the container, is not too close to the cooling set point. **The heating set point maximum value is always 5 °F below the cooling set point.**

Defrosting

The MRU has both an automatic and manual defrost system. When the MRU is defrosting, the LCD (1DS1) DEFROST MODE, in place of the ADVANCED SETTINGS line on the display, and LED6 is illuminated. The automated MRU defrost cycle has two user-defined parameters. These parameters allow the MRU to automatically start defrosting for a prescribed time duration (DEFROST FOR _______MINUTES) at a prescribed interval (DEFROST EVERY_HOURS). To change the defrost settings, press the red SET switch (1S3) on the front panel until ADVANCED SETTINGS is blinking. At this point, you can change the DEFROST FOR setting from 1 to 30 minutes, in increments of 1 minute. You can change the DEFROST EVERY setting from 1 hour to 12 hours in increments of 1 hour. The default settings are defrost for 20 minutes every 10 hours.

Manual defrost is initiated by toggling the two-position momentary MANUAL DEFROST switch (1S4) on the front panel. When a manual defrost is initiated, the duration of the manual defrost will be the same as the duration set (in the Advanced Settings Menu) for an automatic defrost. The MANUAL DEFROST switch (1S4) is a momentary toggle switch (a spring-loaded switch) that automatically returns to the OFF position to eliminate the possibility of the user accidentally leaving the manual defrost switch on.

Factory reset

The MRU menu has an option to restore all temperature and defrost settings to their factory defaults. This feature is useful to quickly restore the system settings to factory condition.

Crankcase heater (2HR4)

The MRU has an electric heater that heats the compressor (2B6) in cold ambient temperatures. This prevents refrigerant migration into the compressor oil and promotes oil circulation. The crankcase heater (2HR4) is active whenever the compressor (2B6) is not operating.

Hour meter

The MRU has an hour meter (1M1) to track the number of hours that the compressor (2B6) has operated. The hour meter (1M1) only records the time the compressor (2B6) is actually running, not the time the entire MRU is operational.

Thermal control feature (energy saving option)

The MRU has a thermal control feature that can be used to save energy when the MRU is operating in FREEZER mode. In REFRIGERATOR mode, it is defeated. In remote and/or hazardous deployment sites, the cost of fuel can be prohibitively high; Therefore, relatively small increases in system efficiency result in major cost savings over time. The THERMAL CONTROL switch (1S5) takes advantage of the temperature difference between daytime and nighttime (and the fact that the MRU is more efficient at cooler ambient temperatures). The THERMAL CONTROL switch (1S5) allows the user to choose between MORE PRECISE and MORE EFFICIENT. When the switch is set to MORE PRECISE, the MRU will cool the container to the cooling set point temperature and maintain that temperature within 2 °F.

When the switch is set to MORE EFFICIENT and the MRU is in FREEZER mode, once the ambient air temperature exceeds 100 °F in the past 48 hours, the MRU will change its cooling set point to 0 °F when the ambient air temperature drops below 70 °F, or to 15 °F, when the user has set the cooling set point below 15 °F and the ambient air temperature is above 70 °F. If the ambient air temperature has not exceeded 100 °F in the past 48 hours but has gone above 70 °F and is currently above 50 °F, the MRU will use half the current user defined cooling set point as the new set point. In all other situations, the MRU will use the user defined set point as normal.

Front panel alarms

The MRU alerts the user to the current state of the system using color-coded alarm Light-Emitting Diodes (LED). The four LEDs used in the system are:

MRU Front Panel Alarm LEDs	
LED	**Description**
Refrigerator Too Hot	In REFRIGERATOR mode, a red LED (1DS2) is lit when the container temperature is greater than 47 °F, when the cooling set point is below 40 °F, or when the cooling set point is above 40 °F and the container temperature is 7 °F above the current user set point.
Refrigerator Too Cold	In REFRIGERATOR mode, a blue LED (1DS4) is lit when the container temperature is lower than 29 °F.
Freezer Too Hot	In FREEZER mode, a red LED (1DS3) is lit when the container temperature is greater than 34 °F.
AC Wiring Fault	The MRU is designed to be powered from military generators. Because the MRU is wired to these generators in the field, wiring errors are possible and represent a significant safety issue. The MRU is designed to check for a hot neutral, lock out the system, and notify the operator by illuminating a red LED (1DS5). This notification will protect personnel and equipment from damage. Operation of the unit is “locked out" until the wiring is corrected. The MRU-TQ3 is not sensitive to phase-sequence reversal. The system will operate with both forward and reverse phase-sequences.

Audible alarm

The MRU includes an audible alarm (1LS1) that will sound when one of the alarm LEDs is not attended to in 20 minutes. This alarm (1LS1) can be jumpered into or out of the alarm circuit by maintenance personnel. This feature is disabled from the factory. To enable this feature, install a jumper into JPR3.

Lights (black-out) switch

In tactical situations, the LIGHTS switch (1S6) can be turned OFF. This switch turns off all visible light emitted by the MRU, allowing black-out operations. The audible alarm, if jumpered into the circuit, remains active. While the LCD back light is off, the LCD (1DS1) can still be read with a flashlight or other ambient light. All four alarm LEDs are disabled.

Input power

Three-phase 208 VAC power is supplied via a 5-wire, 12 gauge SOOW cable into the main MRU enclosure and then into the sealed MRU control box. Inside the control box, the three, hot power leads 101, 201, and 301 connect to the MAIN BREAKER (1CB1) and then this power is carried to the main terminal board 1TB1-2, 1TB1-4, and 1TB1-6 via wires 102, 202, and 302. The neutral of the 5-wire SOOW cable terminates at 1TB1-9 of the main terminal board and is jumpered to terminals 1TB1-7 and 1TB1-8. The ground of the 5-wire SOOW cable terminates at 1TB1-10 of the main terminal board (1TB1) and is jumpered to side panel ground lug via wire 511 and then on to front panel ground lug via wire 512.

Hot terminal 1TB1-2 is jumpered to 1TB1-1 and 1TB1-1 provides a 120 VAC via wire 112 (with the neutral wire 411 from 1TB1-8) to the control board (1U1) in the control box. The control board (1U1) is grounded via wire 502 from terminal TB1-10.

Control box relays

Relay RLY1 (1K2), inside the control box, controls the compressor (2B6). Compressor power is supplied to the normally-open relay from terminals 1TB1-2, 1TB1-4, and 1TB1-6, via wires 103, 203, and 303. The coil of RLY1 (1K2) is activated by 12 VDC from the control board (1U1), which is supplied to the relay via wires 601 and 710.

Relay RLY2 (1K1), inside the control box, controls the heaters (2HR1, 2HR2, 2HR3, and 2HR6). Heater power is supplied to the normally-open relay from terminals 1TB1-3, 1TB1-5, and 1TB1-3, via wires 215, 317, and 251.

The coil of RLY2 (1K1) is activated by 12 VDC from the control board (1U1), which is supplied to the relay via wires 601 and 710.

All other control relays are located on the control board (1U1).

Modes of operation

The modes of operation include OFF, REFRIGERATOR, FREEZER, and DEFROST.

OFF mode operation

When not operating, the MRU should remain connected to power and the MAIN BREAKER (1CB1) powered ON, so that the crankcase heater (2HR4) can prevent refrigerant from absorbing into the oil during the compressor idle period. The crankcase heater (2HR4) is actually activated at all times that the compressor (B1) is not operating.

If the MODE switch is set to OFF, the control board (1U1) will turn on the crankcase heater (2HR4). LED17 will illuminate, indicating that control board relay 1U1K4 has been closed, and 115 VAC is supplied to pin H (hot) and pin I (neutral) of CON1_AC connector (2W3P1). The 115 VAC flows through wires 435A and 138A of this wire harness, terminating at pins A and B on CCHTR connector.

REFRIGERATOR mode operation

The MRU will provide cooling in REFRIGERATOR mode, if the following conditions are met:

- The 4-hour initialization has completed.
- The MODE switch (1S1) is set to REFRIGERATOR, thereby closing the connection between wires 802 and 803 in the control box, pin 2 and pin 3 of CON4 connector on the control board (1U1). LED2 will be illuminated.
- The container internal temperature measured by the evaporator-in thermistor (2RT1) on the intake grille of the MRU is above the cooling set point. This temperature is determined on the control board (1U1) from the thermistor resistance present across wires 607 and 716 (pins 7 and 16 of CON3 connector on the control board (1U1)).

- The high-pressure switch (2S2) is closed, indicating normal pressure; that is, the connection between wires 605A and 714A (pins 1 and 4 on CON3_DC connector (2W1P1)) are closed.
- The unit is not calling for a DEFROST cycle.
- The evaporator-in thermistor (2RT1) and evaporator-out thermistor (2RT2) have not failed.

If the above conditions are met, the control board (1U1) will provide 115 VAC to activate the evaporator fans (2B1 through 2B3) and condenser fans (2B4 and 2B5), provide 12 VDC to the RLY1 (1K2), and turn off the crankcase heater (2HR4) as detailed below:

LED indicator 17 will extinguish, indicating the control board (1U1) is calling for the crankcase heater (CCHTR) to turn off, by removing 115 VAC power from pins 6 and 14 of CON2 on the control board (1U1) and connected pins H and I in CON1_AC connector (1W1J3), at the rear of the control box, via wires 138 (hot) and 435 (neutral).

LED indicator 14 will illuminate, indicating the control board (1U1) is calling for the condenser fans to turn on, by supplying 115 VAC power to the RUN terminal on the Condenser Capacitor Bank (1C2) in the control box, by activating relay 1U1K1 on the control board (1U1) (as described in the relay 1U1K1 discussion).

LED indicator 5 will illuminate 5 seconds after the condenser fans turn on, indicating the control board (1U1) is calling for the compressor to turn on, by supplying 12 VDC to the compressor relay (RLY1 [1K2]) in the control box (as described in the compressor relay discussion). A compressor bump start routine is used to flash trapped refrigerant from the compressor oil during start up. The compressor (2B6) is bump started, 1 second powered on and 2 seconds off, three times before the compressor remains on continuously.

LED indicator 15 will illuminate 20 seconds after the condenser fans (2B4 and 2B5) turn on, indicating the control board (1U1) is calling for the evaporator fans (2B1 through 2B3) to turn on, by supplying 115 VAC power to the RUN terminal of the evaporator capacitor bank (1C1) in the control box, by activating relay 1U1K2 on the control board (1U1) (as described in the relay 1U1K2 discussion).

The MRU will provide heating in REFRIGERATOR mode, if the following conditions are met:

- The MODE switch (1S1) is set to REFRIGERATOR, thereby closing the connection between wires 802 and 803 in the control box, pin 2 and pin 3 of CON4 connector on the control board (1U1). LED2 will be illuminated.
- The container internal temperature measured from the evaporator-in thermistor (2RT1) on the intake grille of the MRU is below the heating set point. This temperature is determined on the control board.
- (1U1) from the thermistor resistance present across wires 607 and 716 (pins 7 and 16 of CON3 connector on the control board [1U1]).

If the above conditions are met, the control board (1U1) will provide 115 VAC to activate the evaporator fans (2B1 through 2B3) and condenser fans (2B4 and 2B5), provide 12 VDC to the compressor relay RLY1 (1K2), and turn off the crankcase heater (2HR4) as detailed below.

LED indicator 17 will extinguish, indicating the control board (1U1) is calling for the crankcase heater (2HR4) to turn off by removing 115 VAC power from pins 6 and 14 of CON2 on the control board (1U1) and connected pins H and I in CON1_AC connector (1W1J3) at the rear of the control box, via wires 138 (hot) and 435 (neutral).

LED indicator 14 will illuminate, indicating the control board (1U1) is calling for the condenser fans (2B4 and 2B5) to turn on, by supplying 115 VAC power to the RUN terminal on the condenser capacitor bank (1C2) in the control box, by activating relay 1U1K1 on the control board (1U1) (as described in the relay 1U1K1 discussion).

LED indicator 5 will illuminate 5 seconds after the condenser fans (2B4 and 2B5) turn on, indicating the control board (1U1) is calling for the compressor (2B6) to turn on, by supplying 12 VDC to the relay RLY1 (1K2) in the control box (as described in the control box relays discussion). A compressor bump start routine is used to flash trapped refrigerant from the compressor oil during start up. The compressor is bump started, 1 second powered on and 2 seconds off, three times before the compressor is actually started.

LED indicator 15 will illuminate 20 seconds after the condenser fans (2B4 and 2B5) turn on, indicating the control board (1U1) is calling for the evaporator fans (2B1 through 2B3) to turn on, by supplying 115 VAC power to the RUN terminal of the evaporator capacitor bank (1C1) in the control box, by activating relay 1U1K2 on the control board (1U1) (as described in the relay 1U1K2 discussion).

FREEZER mode operation

The MRU will provide cooling in FREEZER mode, if the following conditions are met:

- The 4-hour initialization has completed.
- The MODE switch (1S1) is set to FREEZER, thereby closing the connection between wires 801 and 803 in the control box, pin 1 and pin 3 of connector CON4 on the Control Board (1U1). LED3 will be illuminated.
- The container internal temperature measured by the evaporator-in thermistor (2RT1) on the intake grill of the MRU is above the cooling set point. This temperature is determined on the control board (1U1) from the thermistor resistance present across wires 607 and 716 (pins 7 and 16 of CON3 connector on the control board [1U1]).
- The low-pressure switch (2S1) is closed, indicating normal pressure; that is the connection between wires 604A and 713A (Pins 2 and 3 on connector CON3_DC connector [2W1P4]) are closed.
- The high-pressure switch (2S2) is closed, indicating normal pressure; that is, the connection between wires 605A and 714A (pins 1 and 4 on CON3_DC connector [2W1P5]) are closed.
- The unit is not calling for a DEFROST cycle.
- The evaporator-in thermistor (2RT1) and evaporator-out thermistor (2RT2) have not failed.

If the above conditions are met, the control board (1U1) will provide 115 VAC to activate the evaporator fans (2B1 through 2B3) and condenser fans (2B4 and 2B5), provide 12 VDC to the RLY1 (1K2), and turn off the crankcase heater (2HR4) as detailed below.

LED indicator 17 will extinguish, indicating the control board (1U1) is calling for the crankcase heater (CCHTR) to turn off, by removing 115 VAC power from pins 6 and 14 of CON2 on the control board (1U1) and connected pins H and I in CON1_AC connector (1W1J3), at the rear of the control box, via wires 138 (hot) and 435 (neutral).

LED indicator 14 will illuminate, indicating the control board (1U1) is calling for the condenser fans to turn on, by supplying 115 VAC power to the RUN terminal on the Condenser Capacitor Bank (1C2) in the control box, by activating relay 1U1K1 on the control board (1U1) (as described in the relay 1U1K1 discussion).

LED indicator 15 will illuminate 20 seconds after the condenser fans (2B4 and 2B5) turn on, indicating the control board (1U1) is calling for the evaporator fans (2B1 through 2B3) to turn on, by supplying 115 VAC power to the RUN terminal of the evaporator capacitor bank (1C1) in the control box, by activating relay 1U1K2 on the control board (1U1) (as described in the relay 1U1K2 discussion).

LED indicator 5 will illuminate 5 seconds after the condenser fans turn on, indicating the control board (1U1) is calling for the compressor to turn on, by supplying 12 VDC to the compressor relay (RLY1

[1K2]) in the control box (as described in the compressor relay discussion). A compressor bump start routine is used to flash trapped refrigerant from the compressor oil during start up. The compressor (2B6) is bump started, 1 second powered on and 2 seconds off, three times before the compressor remains on continuously.

DEFROST operation (during REFRIGERATOR or FREEZER mode operation)

The MRU will provide defrost when operating in either REFRIGERATOR or FREEZER mode, if the following conditions are met:

- The 4-hour initialization has completed.
- The MODE switch (1S1) is set to REFRIGERATOR or FREEZER mode.
- The manual or automatic defrost has been initiated.
- The container internal temperature measured from evaporator-in thermistor (2RT1) on the intake grille of the MRU is measuring a temperature that is below 45 °F.

If the above conditions are met, the control board (1U1) will provide 12 VDC to activate the heater relay (RLY2 (1K1), and turn on the crankcase heater (2HR4) as detailed below.

LED indicator 17 will illuminate, indicating the control board (1U1) is calling for the crankcase heater (2HR4) to turn on, by providing 115 VAC power to pins 6 and 14 of CON2 on the control board (1U1), which is connected to pins H and I of CON1_AC connector (1W1J3), at the rear of the control box, by wires 138 (hot) and 435 (neutral).

LED indicator 14 will extinguish, indicating the control board (1U1) is calling for the condenser fans (2B4 and 2B5) to turn off.

LED indicator 15 will extinguish, indicating the control board (1U1) is calling for the evaporator fans (2B1 through 2B3) to turn off.

LED indicator 6 will illuminate, indicating the control board (1U1) is calling for the tubular heaters (2HR1 through 2HR3) and drip pan heater (2HR6) to turn on, by supplying 12 VDC to the heater relay (RLY2 (1K1), in the control box (as described in the 1K1 relay discussion).

LED indicator 18 will illuminate, indicating the control board (1U1) is calling for the condensate drain line heater (2HR5) to turn on, by supplying 115 VAC power to pins 7 and 16 of CON2 on the control board (1U1), which is connected to pins 11 and 10 of CON2_AC connector (1W1J2), at the rear of the control box, by wires 162 (hot) and 462 (neutral).

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

830. Warnings and equipment

1. What does the slumped over human icon indicate?

2. What should be placed around the TRCS container during flight?

3. Where is the high-pressure service port located?

4. How is the control box front panel attached to the control box?

831. Theory of operation

1. How are wires in the control box designated when leaving the control box?

2. What does relay 1U1K4 power?

3. What does LED8 indicate?

4. How are compressors run time hours tracked?

5–2. FDECU Theory of Operation

The FDECU has been around awhile longer than the TRICON has but it is still a reliable piece of equipment. This section covers its warnings, equipment and theory of operation. The warnings and equipment are described to give you a background before jumping into the theory of operation. Let's start with warnings.

832. Warnings and equipment identification

When working with the FDECU, you as an HVAC/R technician should be able to recognize the components as well as the hazards associated with this piece of equipment. Ensure that you follow all safety precautions to prevent damage to the unit as well as yourself.

General safety instructions

The TO/TM describes physical and/or chemical processes which may cause injury or death to personnel, or damage to equipment, if not properly followed. This safety summary includes general safety precautions and instructions that must be understood and applied during operation and maintenance to ensure personnel safety and protection of equipment. Prior to performing any specific task, the WARNINGs, CAUTIONs, and NOTEs included in that task shall be reviewed and understood.

Warnings, cautions, and notes

WARNINGs and CAUTIONs are used in the TO/TM to highlight operating or maintenance procedures, practices, conditions, or statements which are considered essential to protection of personnel (WARNING) or equipment (CAUTION). WARNINGs and CAUTIONs immediately precede the step or procedure to which they apply. WARNINGs and CAUTIONs consist of four parts: heading (WARNING, CAUTION, or icon), a statement of the hazard, minimum precautions, and possible results if disregarded. NOTEs are used in the TO/TM to highlight operating or maintenance procedures, practices, conditions, or statements which are not essential to protection of personnel or equipment. NOTEs may precede or follow the step or procedure, depending upon the information to be highlighted. The headings used and their definitions are as follows:

Warning, Caution, and Notes
WARNING Highlights an essential operating or maintenance procedure, practice, condition, statement, etc., which if not strictly observed, could result in injury to, or death of, personnel or long term health hazards.
CAUTION Highlights an essential operating or maintenance procedure, practice, condition, statement, etc., which if not strictly observed, could result in damage to, or destruction of, equipment or loss of mission effectiveness.
NOTE Highlights an essential operating or maintenance procedure, condition, or statement.

SECTION 1. EQUIPMENT DESCRIPTION AND DATA

1.1 Characteristics, Capabilities, and Features

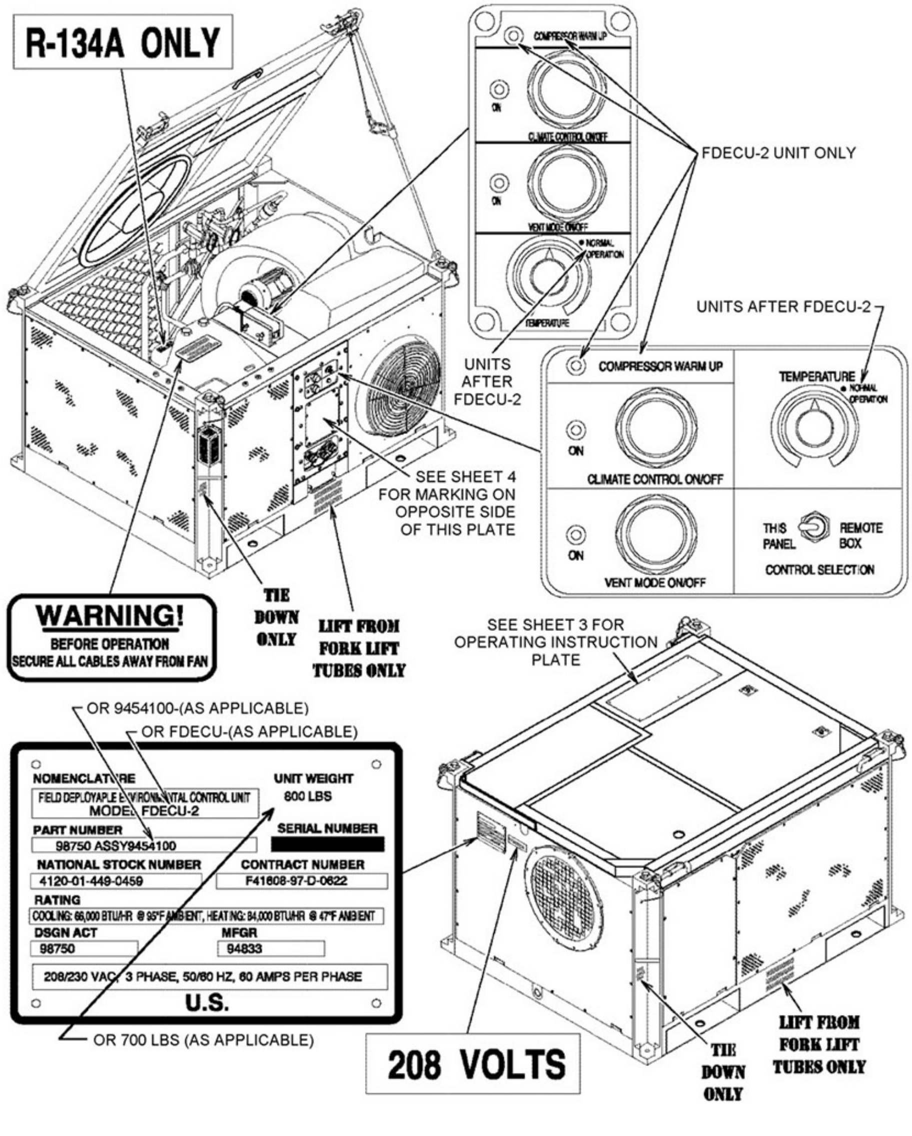
The FDECU is a horizontally configured electric motor driven heat pump. The unit uses integral supplemental resistance heaters during system defrost and low ambient temperature conditions. The unit will circulate and filter the air as well as provide fresh make-up air as desired. The unit is designed for use while directly exposed to the environment and will operate with filter blower overpressure systems developed for use in Nuclear/Biological/Chemical (NBC) environments.

1.2 Differences Between Models

The FDECU-2 uses two compressor crankcase heaters that are wrapped around the compressor and a compressor warm up indicator light on each of the control panels to indicate heater operation. Units after the FDECU-2 do not have compressor crankcase heaters or compressor warm up indicator lights. Most of the FDECU-2 units have undergone field modifications to disable the crankcase heater. The FDECU-4 and thereafter are lighter weight due to manufacturing process changes and the use of a lighter compressor. The new compressor is placed on resilient mounts and stabilized with a cushion clamp to reduce vibration and sound levels. The FDECU-5 incorporates a redesigned compressor with a deeper oil sump that improves the reliability of the compressor. The FDECU-9 incorporates a redesigned evaporator compartment assembly, a redesigned lid assembly and a new compressor.

1.3 Identification Plates

Refer to figure 5–21 for identification plates.



FDECU-2, -3, -4, AND -5

Figure 5–21. Identification plates (Sheet 1 of 4)

1.4 Location and Description of Major Components

Refer to figures 5–22 through 5–27 for the location and description of major components.

Location and Description of FDECU Major Components		
ID	**Equipment**	**Description**
1.4.1	Inside Coil Assembly	The inside coil assembly (1) carries either warm or cool refrigerant depending upon the mode of operation. The refrigerant either heats or cools the shelter air as necessary.
1.4.2	Inside Blower	The inside blower(s) (2) circulates the shelter air through the FDECU.
1.4.3	Outside Coil Assembly	The outside coil assembly (3) carries either cool or warm refrigerant depending upon the mode of operation. The refrigerant is either heated or cooled by the outside (ambient) air as necessary.

Location and Description of FDECU Major Components		
ID	**Equipment**	**Description**
1.4.4	Outside Fan Assembly	The outside fan assembly (4) circulates outside (ambient) air through the FDECU.
1.4.5	Compressor	The compressor (5) compresses refrigerant vapor in the system. Low-pressure refrigerant vapor is drawn from the system through the suction port and high-pressure refrigerant vapor is released back into the system through the discharge port.
1.4.1	Electrical Resistance Heaters Assembly	The electrical resistance heaters assembly (6) contains two banks of electric resistance heaters that are used independently or together to supplement the refrigerant system heating capacity in low outside (ambient) temperature conditions.
1.4.2	Air Filter	The air filter (7) removes dust and debris from the shelter air as it passes through the FDECU.
1.4.3	Master Control Panel	The master control panel (8) is incorporated into the FDECU and provides all the operator controls needed to start, operate, and stop the system as well as maintain desired shelter air temperature.
1.4.4	Remote Control Panel and Cable	The remote control panel and cable (9) is mounted inside the shelter and provides all the operator controls needed to start, operate, and stop the system as well as maintain desired shelter air temperature.
1.4.2	Insulated Flexible Ducts	The insulated flexible ducts (10) connect between the FDECU and the shelter to circulate shelter air through the system.
1.4.3	Electrical Power Input Cable	The electrical power input cable (11) is used to connect the FDECU to a source of electrical power for operation.
1.4.4	Condensate Drain Hose	The condensate drain hose (12) is used to carry condensate collected by the inside coil during cooling operation to a suitable drain or collection area.
1.4.5	Sight Glass	The sight glass (13) allows for a visual inspection of the liquid refrigerant passing through the system and is used to aid in diagnosing possible refrigerant system problems. The sight glass also contains an indicator that changes color depending upon the amount of moisture contained in the refrigerant.

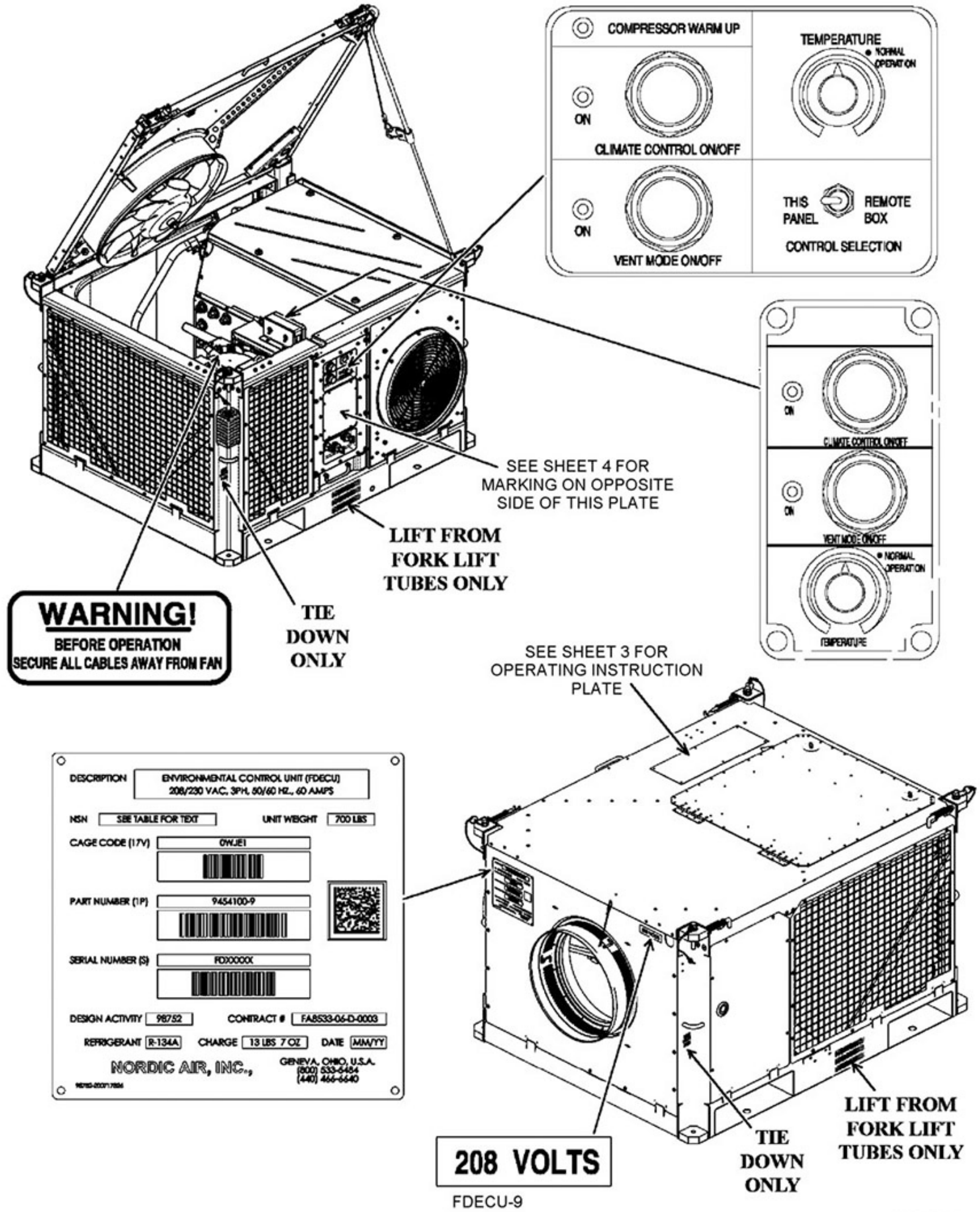


Figure 5–22. Identification plates (Sheet 2 of 4).

Operating Instructions

I. Setup

1. Position FDECU on a level surface, at least (4) feet from any obstructions. Ensure that ducts can be attached between the FDECU and shelter without kinks or sharp bends.
2. Open top cover by removing pins, and secure in open position with rod provided. Insert safety pin through rod.
3. Remove insulated ducts and drain hose.
4. Unwind power cable and guide cable through opening on side panel.
5. If remote control box is used, unwind remote cable and guide remote control box and cable through opening on side panel. Locate remote control box inside shelter through appropriate hole in shelter and install at eye level, away from drafts or supply air opening.
6. Close top cover and secure with pins provided. Make sure cables cannot interfere with fan.
7. Remove return air duct by rotating the adapter counter–clockwise to unlock. Flip the adapter so that the perforated ring projects beyond the FDECU, and lock the adapter by rotating it clockwise. Connect the 7–foot duct to the adapter and to the shelter opening. Note airflow direction arrow on duct. The arrow must point toward the FDECU.
8. Remove the panel covering the supply duct. Uncoil Condensate drain hose then pass it through hole in frame located in front of drain fitting and route to appropriate drainage area. Remove the retaining pins that secure the heater assembly, and slide the assembly forward. Replace the panel and connect 9–foot–duct to the heater assembly and to the shelter opening. Note airflow direction arrow. The arrow must point toward the shelter.
9. Connect power cable to a three–phase, 208 Volt alternating current (VAC), 60 Amp power supply with ground.

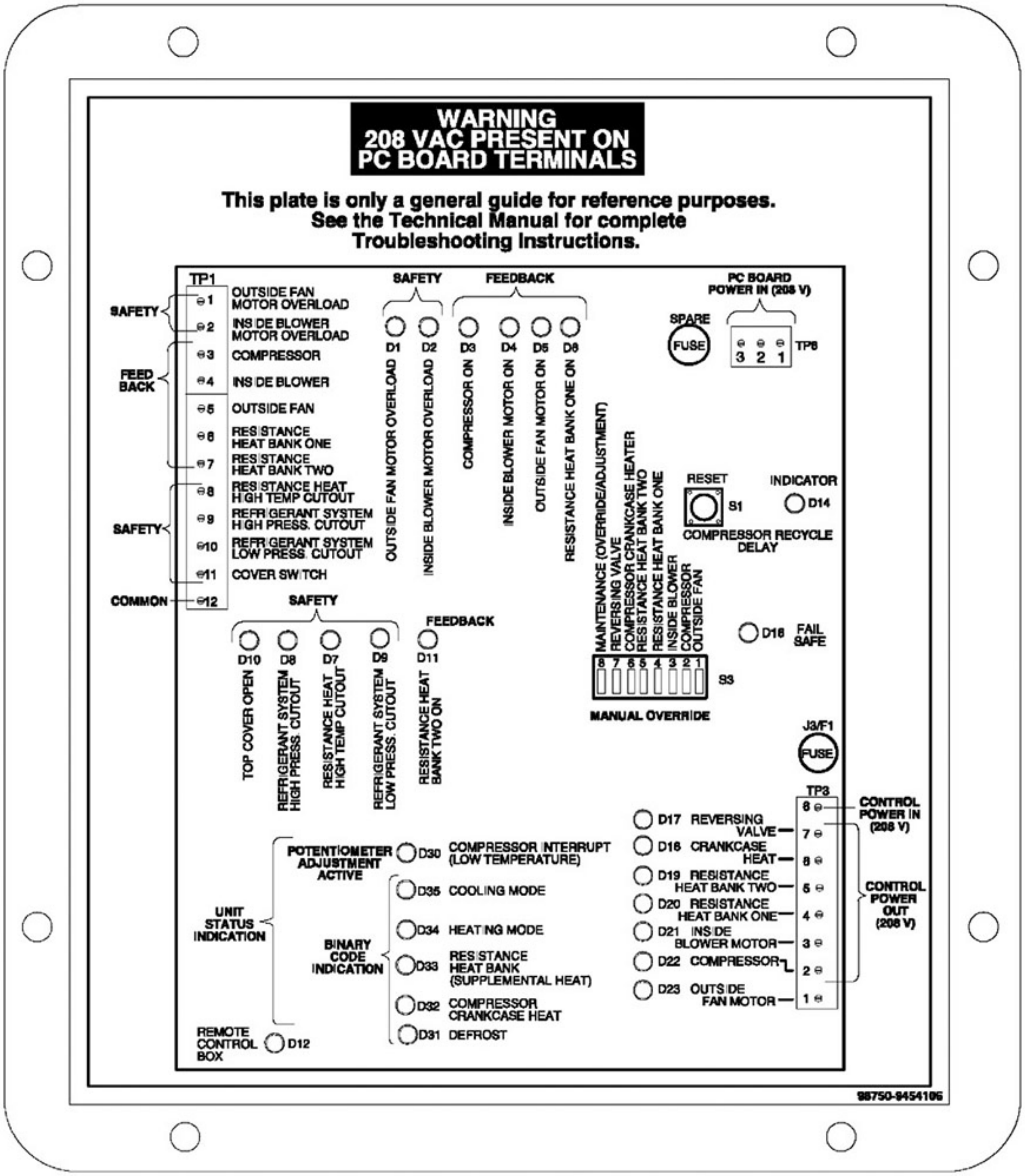
II. Operating Modes

1. Push the "VENT MODE ON/OFF" button for vent mode, and/or the "CLIMATE CONTROL ON/OFF" button for automatic climate control. The corresponding "ON" indicator light will illuminate.
2. Check for proper phasing of power supply. Fan must spin in direction of arrow.
3. Set the adjustable "TEMPERATURE" knob to the position desired. HOT or COLD. Turning the knob clockwise increases the temperature (WARMER), and counter–clockwise decreases the temperature (COOLER).

III. Shutdown

1. To turn unit off, push the VENT MODE ON/OFF and/or the CLIMATE CONTROL ON/OFF button(s).

Figure 5–23. Identification plates (Sheet 3 of 4).



Note that LED D18 (CRANKCASE HEAT) was removed from circuit board used on FDECU−4 and thereafter.

Figure 5−24. Identification plates (Sheet 4 of 4).

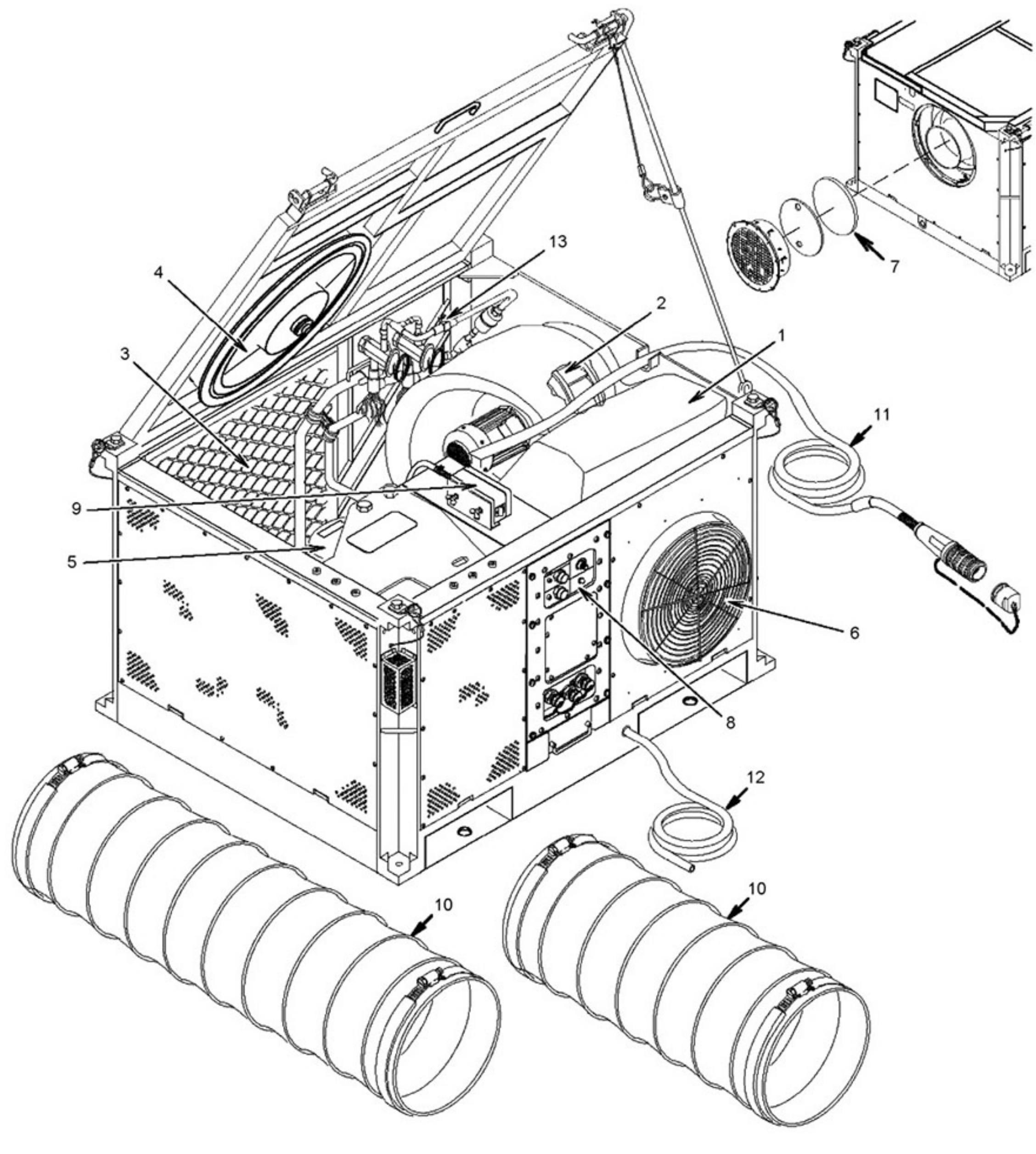


Figure 5–25. Major components (Sheet 1 of 2).

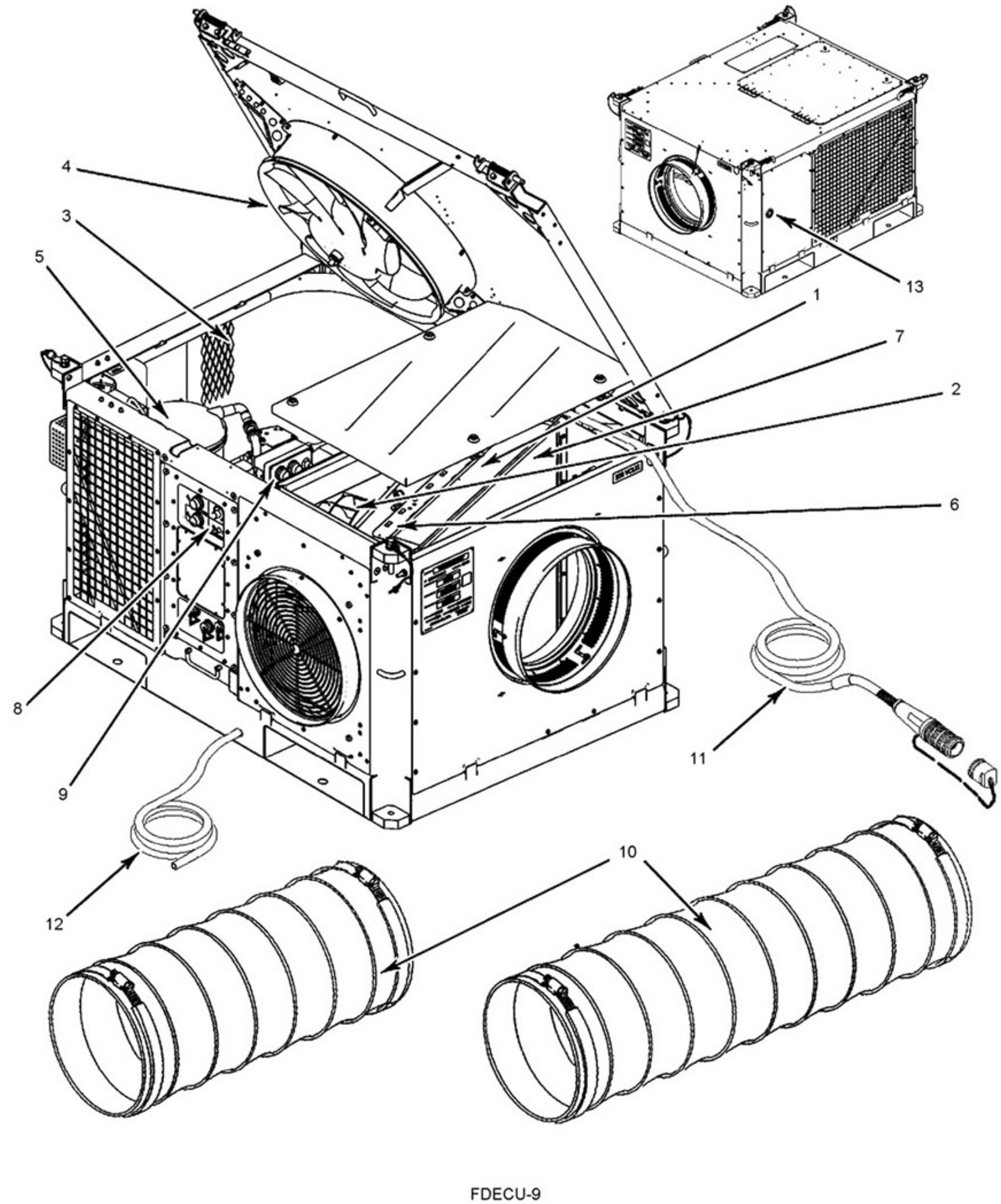


Figure 5–26. Major components (Sheet 2).

1.5 Equipment Data

Item	Characteristics
Dimensions:	
Width	52.0 inches
Height	32.5 inches
Allow an additional 38.0 inches to permit opening of top cover	
Length	42.0 inches
Refrigerant:	
Type	Tetrafluoroethane, R-134a
Charge (FDECU-2, FDECU-3, FDECU-4 and FDECU-5)	14lb
Extreme Heat Weather Charge (FDECU-2, FDECU-3, FDECU-4 and FDECU-5)	12lb
Charge (FDECU-9)	13 lbs 7oz
Weight (Maximum) (FDECU-2 and FDECU-3 only)	800 lb
Weight (Maximum) (FDECU-4 and thereafter)	700 lb
Power Requirements:	
Voltage	208 Vac (191 to 218)
Frequency	50/60 Hertz
Phase	3
Configuration	4-wire (plus ground)
Power Factor	0.95 (+5%, -0%)
Wattage (Maximum):	
Ventilating Mode	2.3 Kw
Cooling Mode	15.0 Kw
Heating Mode	14 Kw
Airflow:	
Total	2200 SCFM
Makeup Air	0 to 500 SCFM (Adjustable)
Capacities:	
Cooling BTU/Hour	55,000 (Minimum), 67,000 (Maximum)
Heating BTU/Hour	40,000 (Minimum), 84,000 (Maximum)
Tilted Operation (Any Direction)	10°
Noise Level:	
Maximum	75 Db at 1,000 Hertz
Environmental Limits:	
Non-Operational (Storage):	
Temperature Range	-60 °F to 160 °F
Relative Humidity	100%
Altitude Pressure Range (in Hg)	3.4 to 30
Operational:	
Temperature Range Cooling	50 °F to 125 °F
Temperature Range Heating	-25 °F to 75 °F
Altitude Range (feet)	6,000

Figure 5–27. Table 1–1. Equipment data.

1.6 Equipment Configuration

The FDECU can be configured for use in either normal environmental conditions or NBC environmental conditions. Use in NBC environmental conditions requires using the NBC adapter kit and two M-28, or other approved NBC filter blower assemblies. Refer to figure 5–28 shows equipment configurations.

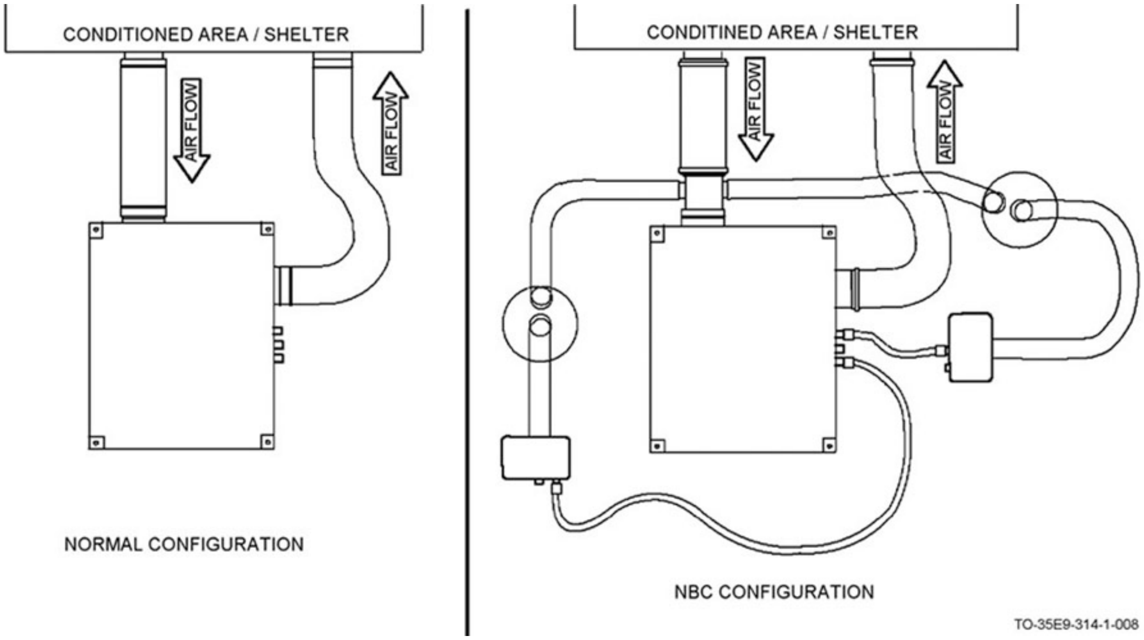


Figure 5–28. Equipment configurations.

833. Theory of operation

Let's jump into the theory of operation of the FDECU. This piece of equipment provides cooling in some very hot environments. Your ability to understand this is vital to contingency operations whether they are in peace time or war.

Section II. Principles of Operation

General

The FDECU is a horizontally configured electric motor driven heat pump. It has a nominal cooling capacity of 60,000 btu/hr and contains integral resistance heaters. The heaters are used as a supplemental heat source during system defrost and low ambient temperature conditions. The unit will circulate, filter, provide fresh make-up air, cool and de-humidify, or heat the air in various types of portable shelters or vans. The unit is designed for use while directly exposed to the elements and is placed outside the shelter. The unit is connected to the shelter by flexible ducts.

Air circulation

Air from the shelter is drawn in through a flexible duct to the unit (fig. 5–29). The air then passes over a replaceable filter then into the inside blower. The air is pushed through the inside coil and the resistance heaters, for models FDECU-2 through FDECU-5. The air is pulled through the inside coil and the resistance heaters in the FDECU-9 model. The air is then pushed out of the unit through the flexible duct and back into the shelter. Fresh make-up air is supplied by sliding the flexible duct back on the perforated inside blower inlet collar. This will expose the perforations and allow outside air to be drawn into the air circulation system. In Nuclear/Biological/Chemical (NBC) environments, the unit can be fitted with NBC filters that are attached to a special inside blower inlet collar and flexible ducts. This system draws contaminated outside air into the NBC filter using integral blowers. The blowers push clean filtered air through flexible ducts to the adapter collar to over pressurize the air circulation system to prevent the infiltration of NBC contaminants into the shelter. The outside fan is automatically activated whenever outside ambient airflow is needed across the outside coil. Air is drawn in through the outside coil by the outside fan and blown out the unit top.

Cooling and dehumidifying

Air is cooled and dehumidified by a reversing mechanical refrigeration system called a heat pump (fig. 5–29).

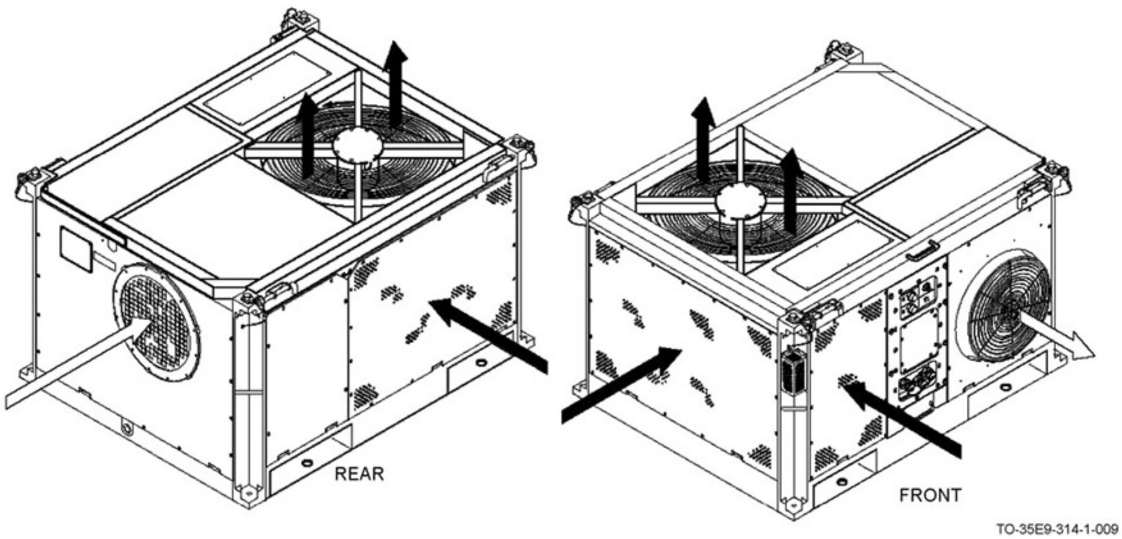


Figure 5–29. Air circulation system.

Cooling

When in the cooling mode of operation, the compressor (1) moves the refrigerant through the refrigeration system by raising the pressure of the incoming gas from the inside coil (evaporator) (2) and discharging it as a high-pressure gas. The high-pressure gas passes through the reversing valve (7) that controls the refrigerant flow depending on the operating mode. In this mode, the refrigerant is routed toward the outside coil (condenser) (3). The high-pressure gas enters the outside coil (3) where heat is released to the outside ambient air passing across the coil. This will cause the high-pressure gas to condense to a high-pressure liquid. The high-pressure liquid reaches the outside expansion valve (10) outlet that will not allow flow in this direction. It then passes through the outside check valve (13). The inside check valve (13) will not allow flow in this mode of operation and the high-pressure liquid is forced through the filter drier (12) where any moisture that may be in the refrigerant is absorbed and any debris is removed. The high-pressure liquid then passes through the liquid indicator (15) where the condition of the refrigerant can be visually inspected. The outside expansion valve (10) inlet and outlet pressures are equal in this mode of operation preventing flow through it. The high-pressure liquid will then pass through the inside expansion valve (10) which causes a pressure drop and automatically meters the amount of liquid passing through it. The rapid drop in pressure causes the liquid to cool. The cool, low-pressure liquid passes through the inside coil (evaporator) (2) where heat is absorbed from the shelter air passing across it causing the low-pressure liquid to evaporate to a low-pressure gas. The low-pressure gas then returns to the compressor (1) to begin the cycle again.

Dehumidifying

When the shelter air passes across the inside coil (2) it will be dehumidified. This is a result of the rapid drop in temperature causing moisture to condense out of the air and collect on the coil.

Heating

A schematic of a cooling, dehumidifying, and heating system is shown in figure 5–30. Air is heated primarily by a reversing mechanical refrigeration system called a heat pump. Supplemental electric resistance heat is provided for use during system defrost mode and operation in low ambient temperature conditions.

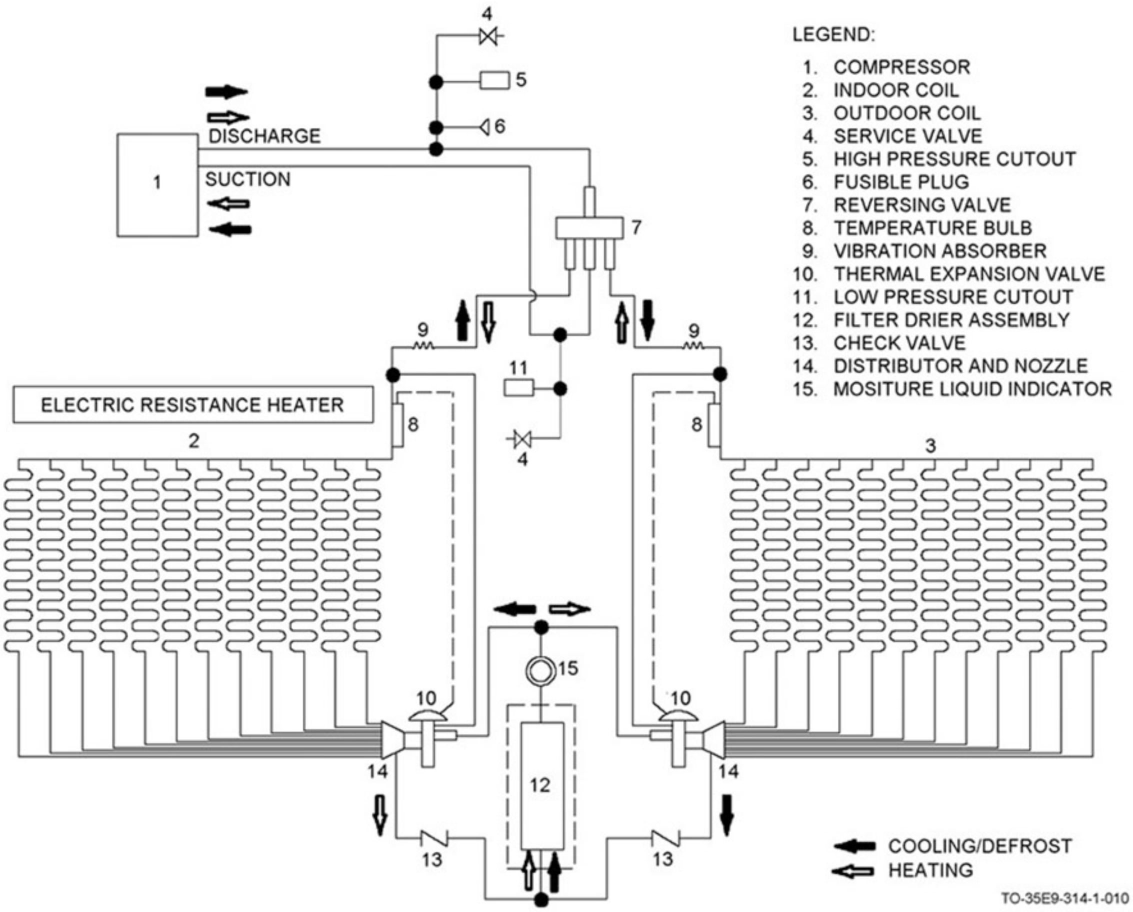


Figure 5–30. Cooling, dehumidifying, and heating system schematic.

Heating mode

When in the heating mode of operation, the compressor (1) moves the refrigerant through the refrigeration system by raising the pressure of the incoming gas from the outside coil (evaporator) (3) and discharging it as a high-pressure gas. The high-pressure gas passes through the reversing valve (7) that controls the refrigerant flow depending on the operating mode. In this mode, the refrigerant is routed toward the inside coil (condenser) (2). The high-pressure gas enters the inside coil (2) where heat is released to the shelter air passing across the coil. This will cause the high-pressure gas to condense to a high-pressure liquid. The high-pressure liquid reaches the inside expansion valve (10) outlet that will not allow flow in this direction. It then passes through the inside check valve (13). The outside check valve (13) will not allow flow in this mode of operation and the high-pressure liquid is forced through the filter drier (12) where any moisture that may be in the refrigerant is absorbed and any debris is removed. The high-pressure liquid then passes through the liquid indicator (15) where the condition of the refrigerant can be visually inspected. The inside expansion valve (10) inlet and outlet pressures are equal in this mode of operation preventing flow through it. The high-pressure liquid will then pass through the outside expansion valve (10) which causes a pressure drop and automatically meters the amount of liquid passing through it. The rapid drop in pressure causes the liquid to cool. The cool, low-pressure liquid passes through the outside coil (evaporator) (3) where heat is absorbed from the relatively warmer outside ambient air passing across it causing the low-pressure liquid to evaporate to a low-pressure gas. The low-pressure gas then returns to the compressor (1) to begin the cycle again.

Defrost cycle

By lowering the temperature on the outside coil (evaporator) (3) to a point below freezing, any moisture that accumulates on the outside coil (3) will freeze and prevent proper air circulation through the coil. The defrost cycle is automatically controlled by an outside air temperature sensor and outside coil temperature sensor in the electrical system. When an iced coil condition is sensed, the outside blower stops and the outside coil (3) is defrosted as high-pressure gas is sent from the compressor (1) into the coil (cooling mode). Supplemental electric resistance heat is energized to compensate for the cooling of shelter air when in this mode. The defrost cycle will continue until the temperature sensors terminate it. If the outside ambient air temperature drops to 28 °F ± 2 °F or below, the compressor (1) and outside blower will be disabled and the FDECU will rely solely on supplemental electric resistance heat until the outside ambient temperature rises above this point. Models prior to FDECU-5 are set at 18 °F. Use Keco Industries field adjustment procedure 5595 to update this setting.

Control

A control system is shown in figure 5–31. The power box (1) is where the incoming power supply is connected and distributed to the various components in the FDECU. Power distribution is controlled by various relays and protective circuits. The control box (2) contains the control circuit board as well as the unit mounted operator controls and indicators. The control circuit board monitors the various sensors and operator controls in the FDECU and controls the power distribution relays as necessary. The remote box (3) duplicates the operator controls and indicators on the control box and can be remote mounted within the limits of the attached 35 foot interconnecting cable.

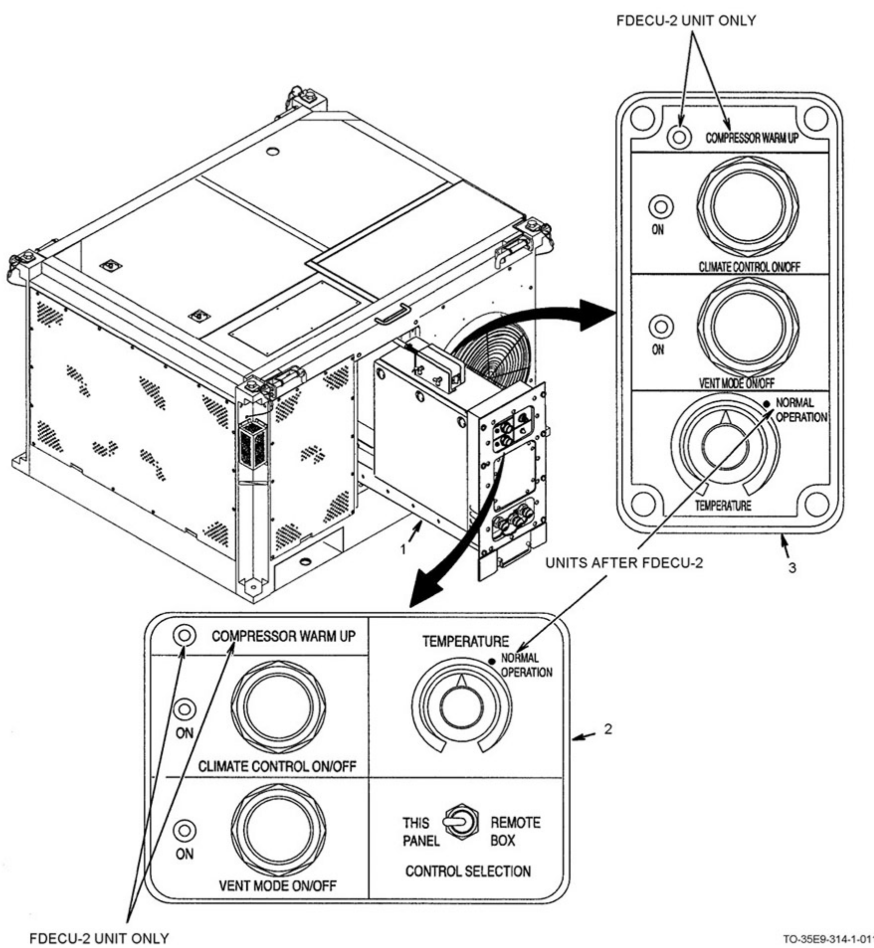


Figure 5–31. Control system.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

832. Warnings and equipment description

1. What newer features are on the FDECU-5?

2. How is dust and debris removed from the shelter?

3. How is condensate removed from the system?

4. How is the liquid refrigerant viewed in the system?

833. Theory of operation

1. Where is the hot refrigerant gas directed towards during cooling mode?

2. How does moisture get removed from the air?

3. How is heat absorbed in the outside coil during heat mode?

4. Where is the control circuit board located?

Answers to Self-Test Questions

830

1. Danger of suffocation or asphyxiation.
2. Tie-down ratchet strap. (lightly tensioned).
3. On the compressor discharge line after the high-pressure switch.
4. Rim latches.

831

1. "xyzA."
2. Crankcase heater.
3. Automatic or manual defrost is on.
4. 1M1 hour meter.

832

1. Redesigned compressor with deeper oil sump.
2. Air filter.
3. Condensate drain hose.
4. Sight glass.

833

1. Outside coil.
2. Rapid drop in temperature.
3. Relatively warmer outside ambient air passing across it causing the low-pressure liquid to evaporate to a low-pressure gas.
4. Control box.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter. When you have completed all unit review exercises, transfer your answers to the Field-Scoring Answer Sheet.

Do not return your answer sheet to the Air Force Career Development Academy (AFCDA).

114. (830) What does the TRICON Refrigerated Container System (TRCS) *explosion icon* indicate?
   a. Material is made to withstand mortar attacks.
   b. Extreme cold conditions may cause frostbite.
   c. Material can explode if subjected to high temperatures.
   d. Poor fire conditions exist and the system could explode.

115. (830) If the ball float on the TRICON Refrigerated Container System (TRCS) is floating what effect does it have drainage?
   a. Allows liquid to escape.
   b. Prevents liquid from escaping.
   c. As the ball drops, so does the pressure.
   d. Heats the condensation to allow vapor to escape.

116. (830) What is the purpose of item 1 in figure 5–6?
   a. Protects inside product from enemy sights.
   b. Allows operation of unit with doors closed.
   c. Protects inside product during black out procedures.
   d. Allows operation of unit with the doors open and maintain refrigeration.

117. (830) Why is item 3 in figure 5–12 provided?
   a. To access evaporator pressure.
   b. To access evaporator temperature.
   c. To allow quick release of entire charge of refrigerant.
   d. Measure pressure, recover, charge, and purge refrigerant.

118. (831) What is indicated if a TRICON Refrigerated Container System (TRCS) wire marking starts with a 6?
   a. The wire is high voltage, 2 volts DC positive power.
   b. The wire is low voltage, 2 volts DC negative power.
   c. The wire is low voltage, 12 volts DC positive power.
   d. The wire is high voltage, 12 volts DC negative power.

119. (831) What does TRICON Refrigerated Container System (TRCS) relay 1U1K2 power?
   a. The compressor.
   b. 1 evaporator fan.
   c. 3 evaporator fans.
   d. 4 condenser fans.

120. (831) What it the relationship between the TRICON Refrigerated Container System (TRCS) thermal control switch (1S5) and the daytime and nighttime temperatures?
   a. The switch increases system usage during the day.
   b. The switch limits operation of the evaporator fan only.
   c. The switch runs the condenser fan only during the day.
   d. The switch takes advantage of the difference in daytime and nighttime temperatures.

121. (832) How can a technician determine if the Field Deployable Environmental Control Unit (FDECU) crankcase heater is energized?
   a. Touch the compressor suction line.
   b. Touch the compressor discharge line.
   c. The fault 3E1 will read on the display.
   d. A compressor warm-up indicator light on the control panel.

122. (832) What is the relationship between the Field Deployable Environmental Control Unit (FDECU)–2 and compressor crankcase heaters and lights?
   a. It has two crankcase heaters that illuminate.
   b. It does not have a crankcase heater or light.
   c. It has one low amperage heater that is off during operation.
   d. It has two low amperage/volt heaters that are off during operation.

123. (833) How does the Field Deployable Environmental Control Unit (FDECU) *inside check valve* affect refrigerant flow in *cooling mode*?
   a. Sends the cool refrigerant to the outdoor coil.
   b. Sends the hot refrigerant to the indoor coil.
   c. Allows flow to all components.
   d. Does not allow flow.

124. (833) How is the Field Deployable Environmental Control Unit (FDECU)–5 ability to shut down the compressor and condenser fan based on outside air updated from 18 to 28 °F?
   a. Using Keco Industries field adjustment procedure 4.
   b. Using Keco Industries field adjustment procedure 5595.
   c. Using Messineo Industries field adjustment procedure 54.
   d. Using Messineo Industries field adjustment procedure 5590.

Glossary of Abbreviations and Acronyms

A/C	air conditioning
AB	alkylbenzene
AEV or AXV	automatic expansion valve
ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineers
AWG	American wire gauge
BAS	building automated system
CDC	career development courses
CFC	chlorofluorocarbon
CFETP	Career Field Education and Training Plan
COP	coefficient of performance
DC	direct current
DDC	direct digital controls
DOT	Department of Transportation
DX	direct expansion
EER	energy efficiency rating
EEV	electronic expansion valves
EPA	Environmental Protection Agency
EPR	evaporator pressure regulator
FDECU	field deployable environmental control unit
GWP	global warming potential
HCFC	hydrochloroflurocarbon
HFC	hydrofluorocarbon
HPMC	high-pressure motor control
HPSS	high-pressure safety switch
HSPF	heating seasonal performance factor
HVAC/R	Heating, Ventilation, Air Conditioning and Refrigeration
ID	inside diameter
LAC	low-ambient control
LED	light emitting diode
LPMC	low-pressure motor control
LPSS	low-pressure safety switch
MGA	manifold gauge assembly
MOP	maximum operating pressure
MP	medium pressure
MRU	mechanical refrigeration unit
MSDS	material safety data sheet
NCO	noncommissioned officer
NTC	negative temperature coefficient
OA	outside air

OD	outside diameter
ODP	ozone depletion potential
OPMC	oil-pressure motor control
OPSS	oil-pressure safety switch
ORD	open on a rise in differential
ORI	open on a rise of inlet pressure
P/T	pressure/temperature
PAG	polyalkylene glycol
PE	pressure-enthalpy
PI	proportional integral
POE	polyol ester
psig	pounds per square inch gauge
PTAC	packaged terminal air conditioner
PTC	positive temperature coefficient
PWM	pulse width modulating
PXV	Pulse width modulating expansion valve
RA	return air
rpm	revolutions per minute
RTU	roof top unit
SEER	seasonal energy efficiency ratio
SP	set point
STS	specialty training standard
TD	temperature difference
TEV or TXV	thermostatic expansion valve
TITI	time-initiated, time terminated
TM	technical manual
TO	technical order
T-P	temperature-pressure
TRCS	TRICON refrigerated container system
TXV	thermostatic expansion valve
UV	ultraviolet
VAC	volts alternating current
VFD	variable frequency drive
VRF	variable refrigerant flow

Student Notes

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