CDC 3E151

Heating, Ventilation, Air Conditioning, and Refrigeration Journeyman

Volume 4. Heating and Hot Water Systems

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THIS FOURTH VOLUME of CDC 3E151, *Heating, Ventilation, Air Conditioning, and Refrigeration (HVAC/R) Journeyman,* introduces you to heating and hot water systems.

Unit one discusses fuels and fuel systems. Topics included are oil and gas systems and fuel system leak inspection procedures.

Unit two discusses burners and combustion controls. Topics that are covered include: combustion, combustion analysis, gas burner, oil burners, flame controls and detectors and primary and programming controls.

Unit three will jump into forced air and radiant heating systems. The preventative maintenance of these two types of systems is also covered in this unit.

Unit four covers boilers. It will start with steam, steam boilers and their distribution systems. It will conclude with coverage of hot water boilers, auxiliary equipment and operation and maintenance procedures.

Unit five will conclude this volume by covering contingency heating equipment. In this brief unit, the WH-400 and 130K heater are covered.

This CDC has four additional volumes. Volume 1 HVAC/R Fundamentals, Volume 2 discusses Air and Hydronic Systems, Volume 3 Electrical and Controls Concepts and Volume 5 Cooling and Refrigeration Systems.

This course must be completed before you can obtain a 5-skill level in the 3E1X1 career field.

A glossary is included for your use.

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Acknowledgment

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Illustrations of your product in our publications to include: boilers, boilers controls, outdoor reset controls, heat exchangers, and baseboards.

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Date	Figure Title	CDC Figure Number
Oct 2016	Figure 2–5. Smoke tester.	F2-5
Oct 2016	Figure 2–10. Checking flue gas temperature/efficiency on gas installation.	F2-10
Oct 2016	Figure 2–11. Combustion analyzer.	F2-11
Oct 2016	Figure 4–30. Boiler displays and buttons.	F4-30

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.

Page

Unit 1. Fuels and Fuel Systems **1-1**
1–1. Oil and Gas Systems 1-1
1–2. Fuel System Leak Inspection 1-27
Unit 2. Burners and Combustion Controls **2-1**
2–1. Combustion and Combustion Analysis 2-1
2–2. Gas Burner Types and Operation 2-22
2–3. Oil Burner Types and Operation 2-57
2–4. Flame Controls and Detectors 2-69
2–5. Primary and Programming Controls 2-88
Unit 3. Forced Air and Radiant Heating **3-1**
3–1. Forced Air Systems 3-1
3–2. Radiant Heating Systems 3-18
3–3. Preventative Maintenance 3-24
Unit 4. Boilers **4-1**
4–1. Properties of Steam Generation 4-1
4–2. Steam Boilers and Auxiliary Equipment 4-8
4–3. Steam Distribution 4-19
4–4. Hot Water Boilers and Auxiliary Equipment 4-24
4–5. Hot Water Boiler Operation and Maintenance 4-40
Unit 5. Contingency Heating Equipment **5-1**
5–1. WH-400 5-1
5–2. 130K Heater 5-4

Glossary *G–1*

Unit 1. Fuels and Fuel Systems

1–1. Oil and Gas Systems 1–1
601. Safety and environmental concerns with flammables 1–1
602. Types and characteristics of fuel oil 1–3
603. Fuel oil distribution systems 1–7
604. Types and characteristics of gaseous fuels 1–19
605. Gas distribution systems 1–21
1–2. Fuel System Leak Inspection 1–27
606. Inspecting fuel supply systems 1–27
607. Leak inspection procedures 1–31

CONVENTIONAL HEATING SYSTEMS, whether they are hot water, steam, or warm air systems, need the combustion of fuel to produce their main source of heat. Each type of fuel has its own distinctive characteristics. Since the characteristics of each fuel are different, the methods in which they are stored, transported, and burned are also uniquely different. In this unit, we will define the properties of each fuel and fuel distribution systems. This unit will conclude with lessons on inspecting fuel systems and leak detection procedures.

1–1. Oil and Gas Systems

The safety and environmental concerns with fuels are critical because the fuel vapors can travel along the ground or can move by ventilation and ignited by sources such as pilot lights, sparks, electric motors, static discharge, or other ignition sources at locations far from the material. We will begin this section by discussing the precautions with flammable liquids.

601. Safety and environmental concerns with flammables

Flammable liquids (such as petroleum and other fuels) and solvents in industrial products (such as paint, ink, adhesives and cleaning fluids) give off flammable vapor which, when mixed with air, can ignite or explode. To protect yourself when dealing with flammable vapors you need to know the basic safety principles when working with flammables. We know that it takes heat, fuel, and air to create a fire. This lesson covers additional safety concerns that you may or may not be aware.

Safety precautions with flammables

Three conditions must exist to cause a fire or explosion—fuel vapors, oxygen, and a source of ignition. Eliminate all sources of ignition if you must work around flammables. Be sure there is adequate ventilation. Some examples of ignition sources are smoking cigarettes or cigars, electric power tools, wrenches that might cause a spark if dropped, and even spontaneous combustion of oily rags. The following list provides some precautions to take when working around flammables:

- Wear clean clothes (free of oil) so that there is no danger of spontaneous combustion.
- Remove used rags and cloths after they become oily or soiled to eliminate the danger of spontaneous combustion. Store these items in a suitable covered metal container.
- Use only explosion-proof electrical equipment in areas where flammables are present.
- Do not carry matches, lighters, or other potential ignition source to the area.
- Keep the area as clean and free of flammable materials as possible.
- Keep fire extinguishers of the proper type nearby.
- Wear non-sparking rubber-soled shoes.

- Advise everyone in the area of the hazard.
- Extinguish all pilot lights.

Static electricity

Static electricity is a constant source of danger, particularly when generated near fuels or flammable vapors. This source has been responsible for starting many fires that have resulted in extensive property damage and personnel injuries. Creation of static electrical charges happen when people walk, rubber-tired vehicles move, liquid drops through space, and petroleum products are pumped through lines and hoses. Although static charges usually are short lived; they can produce sufficient heat to ignite flammable gases, vapors, dust, or other flash point materials, particularly during dry, cool weather.

You cannot avoid generation of static electricity but grounding, bonding, or humidifying can be effective methods of control. Grounding and bonding are particularly important in the following functions: fueling operations, paint and dope shop work, aircraft and vehicle maintenance, ammunition handling, rocket and missile operations, compressed gas use, and many other daily Air Force operations.

A person cannot see static electricity and it is not common to know its potential hazards. Supervisors and operating personnel must fully understand the dangers so they can implement effective control measures.

Grounding

Grounding is probably the most practical way to control static electricity. Grounding provides a path of least resistance, through low-resistance grounding wires, over which static charges will flow easily to the ground. The wires carry off the static charges that build up within an object thorough bonding or grounding; this neutralizes the difference in electrical potential. Observe specific grounding procedures, given in applicable Air Force directives. Make grounding connections to clean, unpainted surfaces.

Bonding

Effective bonding must eliminate the differential in electrical charge potentials that may exist. By connecting the two objects with a bonding wire attached to clean, unpainted surfaces, a static electrical discharge cannot occur between these objects. Bonding is just as essential as grounding. Use bonding with a completion to static ground. Although bonding equalizes the charge between two electrically connected objects, the objects themselves may still be highly charged. By connecting a ground wire to the bonded objects, this charge drains off without danger. Conductive greases and “V” belts on shaft pulleys are examples of effective bonding.

Testing and marking

Inspect static bond and ground systems continuously for defects. Constant exposure of these systems to weather, contamination, mechanical wear, climatic changes, and other sources of damage, easily renders them ineffective. Follow the appropriate technical order (TO) when maintaining and inspecting all bonded and grounded systems and only use the equipment meeting the TO standards. Grounding points and facilities meeting the specifications of the applicable TO must be marked adequately according to existing provisions. After finding defective equipment, take it out of service immediately, and destroy the markings around defective grounding points to prevent their reuse.

Avoid leaks

Liquefied petroleum gas (LPG) will ignite only when it vaporizes and mixes with enough air to form a combustible mixture. Vapor leaks permit such mixtures to form. A leak will burn close to or at a distance from the opening depending on the gas pressure and the size of the opening. Comply with rules and regulations governing the transportation, storage, and dispensing of LPG as specified by the different states. Most petroleum derivatives, such as kerosene, gasoline, natural gas, or LPG are combustible, and, when you do not handle them carefully, they can be explosive and dangerous. When you handle them properly, house them suitably, and control them, you can use them safely.

Environmental concerns

In 1984, Congress added Subtitle I to the Resource Conservation and Recovery Act that requires the Environmental Protection Agency (EPA) to develop regulations to protect human health and the environment from leaking underground storage tanks (UST). The EPA has determined that maintenance of USTs are critical. A neglected UST could pose a very real threat to the environment. To ensure proper care of a UST, follow the regulatory guidance provided by the EPA. A UST is any tank, including the piping connected to the tank, which has at least 10 percent of its volume underground. The Federal Register has published a regulation that fully identifies the various types of tanks that are covered.

The EPA has set forth some guidelines for the installation of new USTs and for the upgrade of existing UST's. Ensure you follow these regulations while working with UST's.

The UST rules also set forth some very strict guidelines for the reporting and cleanup of petroleum spills. To list the entire reporting or cleanup procedure would be difficult because they are not standard and vary from place to place. Report a fuel spill or leak if 25 gallons or more fuel gets into the environment. Send the report to the state regulator within 24 hours.

To ensure the most complete compliance with federal, state, *and* local regulations regarding spills or leaks, contact the Civil Engineer Environmental Planning Office.

Self-Test Questions

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

601. Safety and environmental concerns with flammables

1. Why should clean clothes be worn when working with flammables?

2. How do static electrical charges happen?

3. How are grounding connections made?

4. What effect will connecting a ground wire to bonded objects have?

5. How is the most complete compliance ensured regarding spills or leaks?

602. Types and characteristics of fuel oil

Knowing oil characteristics and supply systems will give you a definite edge if you ever have the opportunity to work in an area where fuel oil is predominantly used. There are several different types of fuels used in the heating, ventilation, and air conditioning (HVAC) industry. Each has their own properties that make them unique and a good choice for a particular application.

Types of fuel oils

Significant liquid fuels include various fuel oils for firing combustion equipment and engine fuels for total energy systems. Liquid fuels, with few exceptions, are mixtures of hydrocarbons derived from crude petroleum by refining processes. Besides hydrocarbons, crude petroleum usually has small amounts of sulfur, oxygen, nitrogen, vanadium, other trace metals, and impurities, such as water and sediment. Petroleum refining produces a variety of fuels and other products. Nearly all lighter hydrocarbons are refined into fuels (*e.g.*, liquefied petroleum gases, gasoline, kerosene, jet fuels, diesel fuels, and light heating oils).

Heavy hydrocarbons are refined into residual fuel oils and other products (*e.g.*, lubricating oils, waxes, petroleum coke, and asphalt).

Classification of fuel oils for heating are broadly defined as *distillate* fuel oils (lighter oils) or *residual* fuel oils (heavier oils). American Society for Testing and Materials (ASTM) specifications for fuel oil properties subdivide the oils into various grades. Grades No. 1 and No. 2 are distillate fuel oils. Grades No. 4, No. 5 (Light), No. 5 (Heavy), and No. 6 are residual fuel oils.

Grade	Classification
No. 1	This is a light distillate intended for vaporizing-type burners. High volatility is essential to continued evaporation of the fuel oil with *minimum* residue.
No. 2	This is a heavier distillate than No. 1. It is for use with pressure-atomizing (gun) burners that spray the oil into a combustion chamber. The atomized oil vapor mixes with air and burns. Use grade No. 2 in most domestic burners and many medium capacity commercial-industrial burners.
No. 4	This is an intermediate fuel considered either a light residual or a heavy distillate. It is for burners that atomize oils of higher viscosity than domestic burners can handle. Its permissible viscosity range allows pumping and atomization at relatively low storage temperatures.
No. 5 (Light)	This is a residual fuel of intermediate viscosity for burners that handle fuel more viscous than No. 4 without preheating. Preheating may be necessary in some equipment for burning, and, in colder climates, for handling.
No. 5 (Heavy)	This is a residual fuel more viscous than No. 5 (Light), but for similar service. Preheating is usually necessary for burning and, in colder climates, handling.
No. 6	This fuel, sometimes called Bunker C, is high viscosity oil used mostly in commercial and industrial heating. It requires preheating in the storage tank to permit pumping, and more preheating at the burner to permit atomizing.

In many areas, marketing of low sulfur residual oils permit users to meet sulfur dioxide emission regulations. The production of fuel oil is by refinery processes that remove sulfur from the oil; blending high sulfur residual oils with low sulfur distillate oils; and a combination of these methods. These oils have significantly different characteristics from regular residual oils.

Characteristics of fuel oils

Characteristics that determine grade classification and suitability for application are viscosity, pour point, flash point, fire point, specific gravity, ash content, sulfur content, and water and sediment content. The main characteristics you need to be aware of are viscosity, pour point, flash point, fire point, sulfur content, and water and sediment content. Each one of these characteristics can cause problems with the heating equipment. Let's look at the characteristics of fuel oils and how they affect the operation of an oil burner system.

Viscosity

This property is the measure of the resistance of oil flowing through a pipe. A liquid that flows sluggishly, like molasses, has a *high* viscosity. A free flowing liquid, like water, has a *low* viscosity. Temperature greatly affects the viscosity of oil. By heating the oil, viscosity decreases and makes it easier to pump the oil and makes it better for atomization during the combustion stage.

Viscosity is probably the *most* important property of a fuel. It relates to the ability of the fuel to flow uniformly through the lines from the storage point to the burner, to atomize at the burner nozzle and thus become thoroughly mixed with air (which supply oxygen needed for combustion). For example, a burner oil nozzle operating at a viscosity other than design will not atomize the oil properly causing incomplete combustion, carbon residues, and soot buildup within the boiler. If the viscosity is too *low* (oil too thin), there may be erratic burning and *burner flashback* problems. Flashback is a condition in which the flame ignites but is unable to maintain combustion of the heavier hydrocarbons. Too high of a viscosity causes pumping problems and, in some cases, a loss of pump suction.

Pour point

The pour point is the *lowest* temperature at which oil will pour. Pour point is important because it indicates the *minimum* temperature at which oil will pump. This temperature is useful in handling heavy oils because oil *cannot* pump at a temperature below the pour point. In certain cases, pumping oil requires heating. When pour points are included in specifications it ensures your oil will not cause handling troubles at expected low temperatures. Cold weather can greatly affect the pour point and cause problems, such as clogged strainers and lines, incomplete combustion, carbon residues, and soot buildup within the boiler due to poor atomization. Cold weather can also cause the oil to harden and make it difficult to pump. In these cases, heating the oil to make it more fluid greatly minimizes these troubles. For example, in 2007, at a base in Korea, the weather became so cold the fuel oil at the Post Office started to solidify. The oil was not able to be pumped because of how cold it was and the building had no heat.

Flash point and fire point

The flash point is a measure of the *lowest* temperature at which a flash flame will occur. Another definition of flash point is the *maximum* temperature at which oil can be stored and handled. You can see that both definitions mean the same thing. Oil with a low flash point burns easily.

From a safety standpoint, you must keep the flash point *above* 100° to 150°F. Oils should *never* be preheated to a temperature greater than the flash point because pre-ignition in the burner results. A low flash point can also result in flashback. On the other hand, a high flash point makes starting a flame difficult in cold furnaces. State and municipal laws usually prescribe minimum permissible flash point.

The ignition point is the temperature at which vapor will continue burning after ignition. The ignition point is usually 10° to 70°F above the flash point.

Water and sediment

Water and sediment, also called bottom sediment and water (BS&W), are impurities in the oil, and while it is not economical to eliminate them, they should not occur in excessive quantities (usually not more than 2 percent). Any greater amount is usually due to external sources. This material can plug burners, burner tips, and screens and cause erratic combustion such as sparkling and flashback. BS&W are not the same as sludge because sludge is an organic material resulting from oxidation of hydrocarbons while BS&W are water and inorganic materials, such as dirt and rust. Preventive maintenance will help stop problems caused by a combination of sludge and BS&W.

Sulfur content

Sulfur is the *most* undesirable impurity in oils because it produces harmful emissions and highly acidic compounds (sulfurous acids) that attack steel boiler parts. The amount of sulfur in fuel oil can be determined with a liquid gas chromatograph. The amount depends mainly on the sulfur content of the crude oil and varies widely even for the same grade of oil. Any oil with sulfur content in excess of 1 percent is high sulfur oil. With proper oil treatment, you may utilize these oils, but pollution laws may limit combustion of high sulfur oils.

Common problems

Please study this table so that you can identify common problems related to fuel oil characteristics.

Common Problem Related to Fuel Oil Characteristics

Problem	Cause
Unable to start	No oil, sludge, and water in lines, viscosity of oil too high, flash point too high, blocked burner, preheat temperature too low, and no air.
Fluctuating flame	Water, sediment, or sludge in oil, oil viscosity too high, non-uniform air or oil flow, not enough oil, and leaky seals on strainer cover.
Spitting, sputtering, sparkling	Water in oil, too high viscosity of oil, and too much air.
Poor atomization	Too high viscosity oil, improper preheat temperature, too low atomizing or oil pressure.
Flashback	Flash point too low, water and sludge in oil, and fluctuation of atomizing fluid.
Carbonization of burner tip	Carbon residue in oil, high viscosity oil, poor atomization, high oil pressure, or temperature insufficient, and seepage of oil at burner shut-off.
Carbon in preheater	Too high preheating temperature, oil unstable, sludge in oil, and oil has asphaltic compounds.
Carbon on furnace walls	Flame impingement, oil too viscous or too light, too high oil pressure, cold furnace, and too high atomizing fluid pressure.
Blocked burner	Sludge in oil and carbonization.
Excessive soot	High ash content in oil, poor combustion, and heavy precipitated compounds in oil.
Plugged lines	Sludge in oil, congealed oil, wax, high viscosity oil, and foreign materials.

Self-Test Questions

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

602. Types and characteristics of fuel oil

1. How would you describe a liquid that had a sluggish flow?

2. How would you describe a liquid that is free flowing?

3. What is the result if a burner oil nozzle is operating at a viscosity that is different from its design?

4. What is flashback?

5. Why should oil never be preheated to a temperature greater than its flash point?

6. What effect can water and sediment have on burners?

7. What effect does sulfur have on boiler parts?

603. Fuel oil distribution systems

There is a variety of ways to design a fuel oil distribution system. Location of the tanks, burners, and pumps along with the type of fuel used will decide the factors used for design. Discussions of common designs are in the following text.

Fuel oil piping systems

One or two pipe systems transfer oil from storage tanks to the burner system. We have two types of systems because of the type of pump used and the location of the oil storage tank.

A burner cannot use all of the fuel delivered. Because of the extra oil, make provisions either to return the unused oil to the storage tank or to circulate it back to the suction side of the pump. If the oil is returned to the storage tank, we have a *two-pipe* system. If oil returns to the suction side within the pump, we need only a *one-pipe* system.

Two-pipe system

Use a two pipe system (fig. 1–1) when the oil storage tank is *below* the level of the burner. The burner is located above the tank. The pipe or line that delivers oil from the tank to the burner equipment is the suction line or feed line. The other line that returns extra oil to the tank is the return line. You should use a two-pipe system when the pump has a dual purpose: (1) to pull the oil from the storage tank and (2) to furnish the oil under pressure to the burner nozzle.

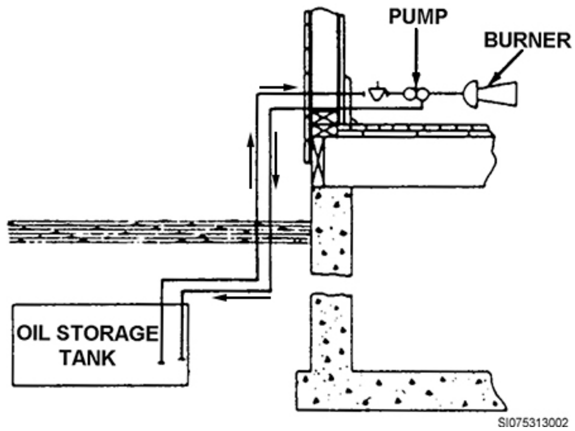

Figure 1–1. Two-pipe fuel oil systems. (Reprinted with permissions)

One-pipe system

In a one-pipe system, the oil storage tank is *above* the burner; thus, the pump does not have to exert any appreciable suction because the oil is gravity fed. By adjusting the pump, we can bypass the extra oil through the pumps internal bypass valves back to the suction side. In doing so, we eliminate the return line to the tank (fig. 1–2). An important determining factor to both a one- or two-pipe system is the type of pump used to deliver the oil.

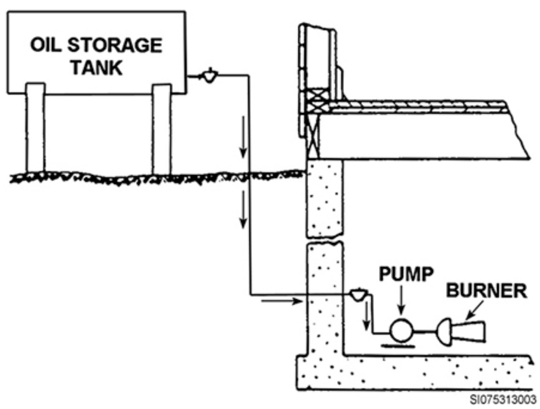

Figure 1–2. One-pipe fuel oil systems.

Oil pumps

Pumps used for the delivery of oil are of the positive displacement type, known as rotary pumps. The two types of fuel oil rotary pumps for oil burners are single-stage and two-stage, also called double-stage. The terms single- or double-stage refer to the set(s) of gears used in the pump for the separation of the suction and pressure functions within the pump.

Single-stage pump

The single-stage pump in figure 1–3 has one set of gears that takes the oil, fed by gravity, and pressurizes it for delivery to the nozzle. As shown by the arrows, fuel enters the suction port and passes through the strainer to the external gear type pump. The pump applies the fuel oil under pressure to the pressure chamber. The oil pressure applied to the bottom side of the needle valve piston unseats the needle valve letting oil discharge at the nozzle port. When the oil pressure against the bottom of the large piston exceeds the pressure determined by the pressure adjusting screw and spring acting against the upper side of the piston, the piston rises and unseats the upper end of the needle valve in the piston. This lets the excess oil recirculate through the piston, then through the bypass port, and, finally, to the suction side of the strainer. As the pressure decreases, the piston and the pressure relief valve reseat until the oil pressure again rises above the preset pressure. This modulating action between the needle valve and piston is continuous while the pump operates.

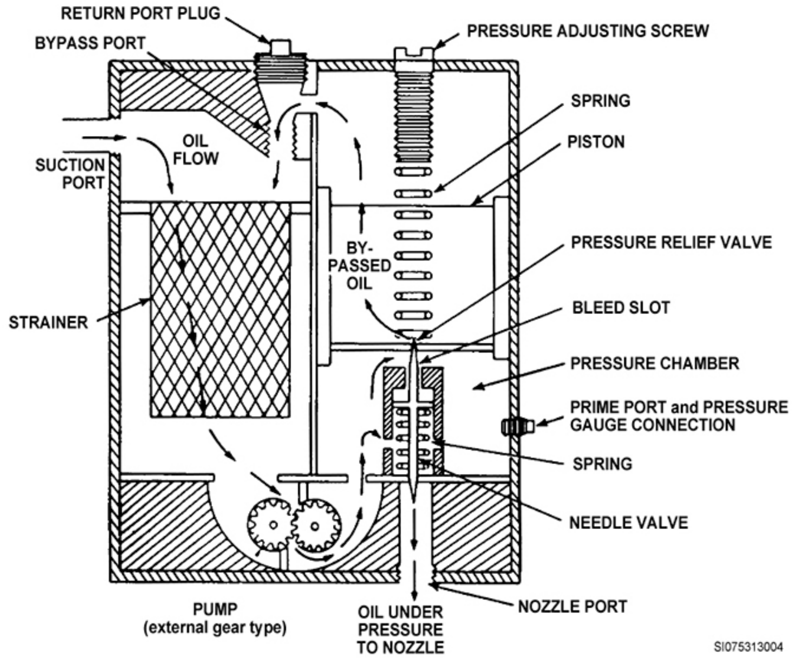

Figure 1–3. Single-stage fuel pump.

A one-pipe, gravity fed system uses a single stage pump. The gears of the pump are for the pressure delivery of oil, and relieved of any suction work, since oil delivery to the pump is gravity. Use of a single stage pump with an underground tank and two-pipe system, is possible. Major problems can arise in the quietness of operation and efficiency. To use a single-stage pump with a two-pipe system, you must change the internal bypass arrangement. Figure 1–4 shows that by adding the bypass plug insert, you closed the internal bypass flow and open the external bypass by removing the return port plug. Low-lift conditions up to 10 inches of vacuum uses this type of setup. Remember the best procedure is to use a two-stage pump with a two-pipe system on all tanks below the level of the burner for efficiency and quiet operation.

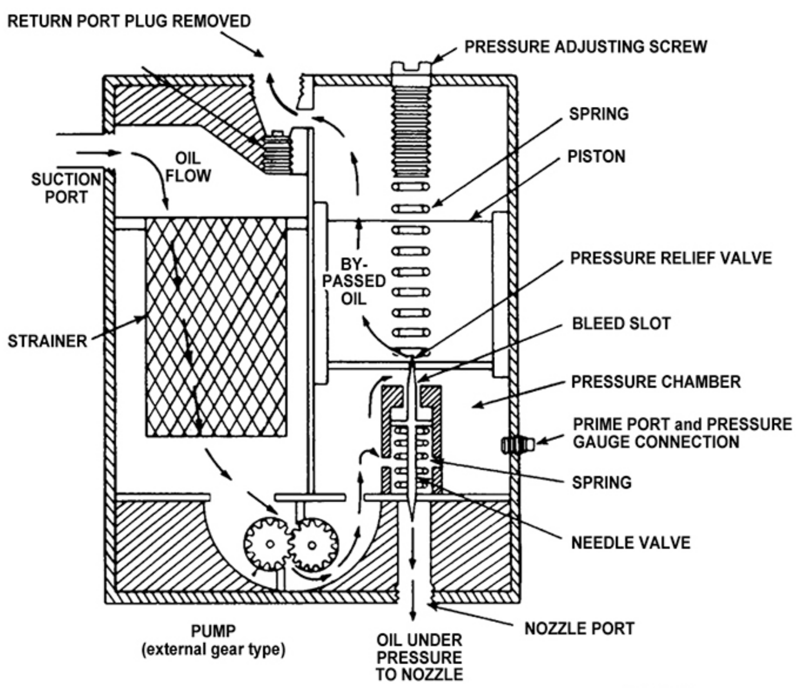

Figure 1–4. Single-stage fuel pump with bypass plug added.

Two-stage pump

The two-stage pump is much like the single-stage, except it has two complete sets of gears. One set is for pulling the oil from the tank and the other for delivering it under pressure to the nozzle. Two-pipe systems always need two-stage pumps. The suction set of gears (fig. 1–5) draws the oil from the tank and delivers it through the strainer to the second set of gears. The second set of gears picks it up and delivers it to the nozzle. With the pressure and suction functions accomplished by separate sets of gears, it becomes a two-stage pump. The pump then has greater pulling power, greater capacity, quieter operation, and longer life. Regulation of either pump is possible. The pressure adjusting screw enables the operator to vary pressure from 80 to 140 psi. See figure 1–6 for a picture of a fuel pump.

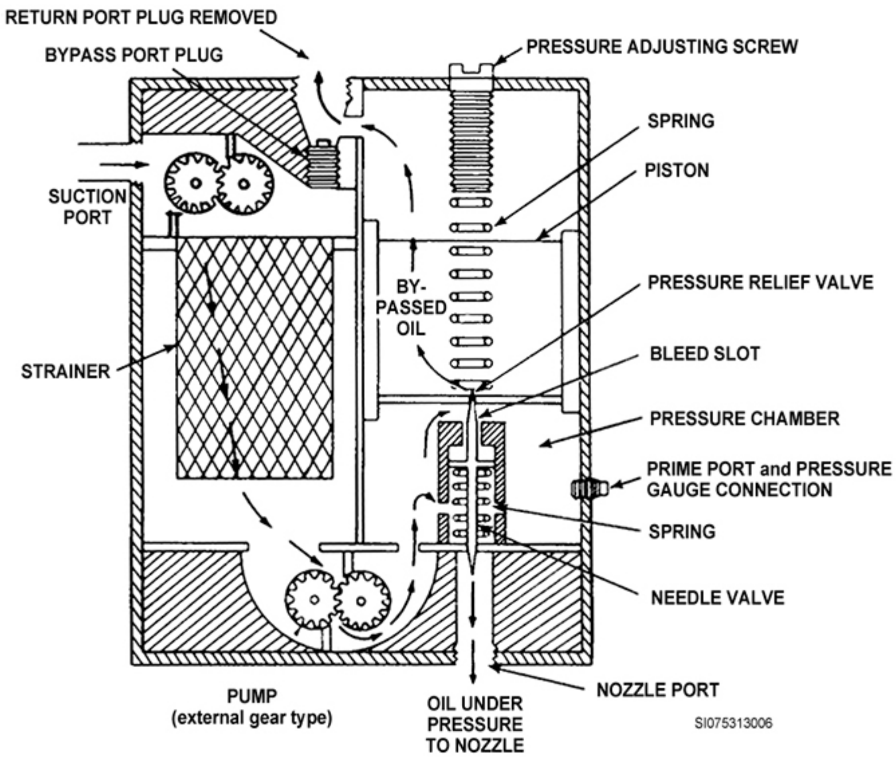

Figure 1–5. Two-stage fuel pump.

Figure 1–6. Fuel pump.

Oil deaerators

This device removes air and other gases from the fuel oil. So if any air is in the fuel it will be removed in the deaerator. There are three connections on the deaerator: (1) inlet from fuel tank, (2) outlet to oil burners fuel pump, and (3) inlet from the fuel pump return.

Take notice from the list above that there is a return from the fuel unit. This means that if there is a one pipe system the deaerator will cause it to function as a two pipe system. This is because there is now an inlet and outlet on the fuel unit. So a pipe will be going into and out of the fuel unit, hence, two-pipes.

When you install deaerators on a one-pipe system you must install the bypass plug into the fuel unit. This plug prevents oil from returning to the inlet side of the unit.

This component can also be used with an existing two-pipe system but the return line from the burner to the tank needs to be disconnected and capped.

Before the fuel arrives from the oil tank to the deaerator it must pass through a fuel filter. The reason for this is that if any impurities are in the fuel it can clog or damage the deaerator.

Fuel filter

Filters remove impurities in the oil that could cause harm to other oil system components such as the deaerator or fuel pump. Our oil needs to be as clean as possible for combustion. The cleaner the oil, the cleaner the flame will be. They are located between the tank and the pump. (As stated earlier, if there is a deaerator the filter will be place before the deaerator and after the tank.) Some filters, in-line, filters are placed after the pump outlet to reduce impurities from reaching the oil nozzle.

Fuel oil filters have an arrow on them that shows which direction the oil is supposed to flow through it. Ensure this arrow is pointing the proper way. The inlet and outlet of these filters is at the top, the fuel enters one side, the sludge and water fall to the bottom of the canister. Oil filters can also be installed in a *dual in-line* manner. This means that two oil filters are placed one after another.

Valves

There are valves placed in oil pipe systems. Some are automatic and some are manual. See figure 1–7 for an example of a manual shutoff ball-valve. These valves will be discussed later when we discuss burners in unit 2.

Figure 1–7. Manual shut off ball-valve.

Booster pumps

A booster pump will provide extra power when necessary. This instance could occur when the oil tank is far away from the burner or if the oil tank is considerably lower than the burner. In those cases the pump will move the oil to a fuel oil accumulator or reservoir tank. Booster pumps should be located as close to the tank as possible so it performs more of a push function rather than a pull function.

Oil storage tanks

Take care when considering fuel oil storage tanks. A storage tank, on the surface, may look simple. In reality, it is a complex piece of equipment that demands attention. The Environmental Protection Agency (EPA) and your maintenance schedules will be your primary guides to taking care of storage tanks. Look for any other information in your area that will direct you when working with storage tanks.

The fuel oil for oil-fired heating equipment is stored in an oil supply tank. The location of the supply tank can be inside or outside of the building, and above or below the level of the oil burner. Outside tanks can be either aboveground or underground (fig. 1–8). The location and installation of storage tanks must be in accordance with National Fire Protection Standard 31 and with local ordinances.

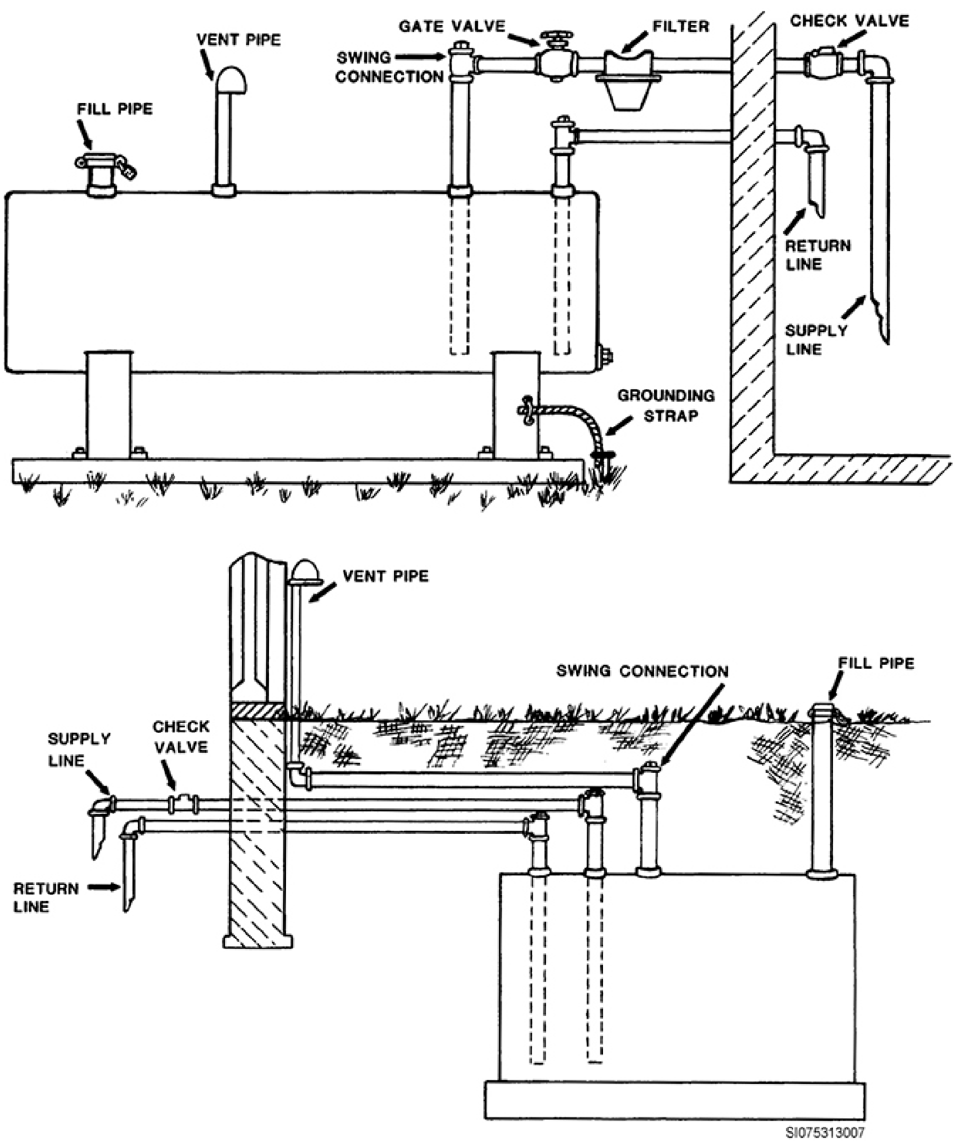

Figure 1–8. Fuel oil storage locations.

Storage capacity

Dependable and economical operation of oil-burning equipment requires ample and safe storage of fuel oil at the site. Design responsibility should include analysis of specific storage requirements, such as the rate of oil consumption, dependability of oil deliveries, and economical delivery lots. Factor balancing the cost of installing larger storage capacities against the savings indicated by accommodating larger delivery lots.

Tank size and location

Standard oil storage tanks range in size from 55 to 50,000 gal (208 to 189,500L) and larger. Steel and fiberglass storage tanks are common, but tanks for heavy oil are concrete construction. Unenclosed tanks in the lowest story, cellar, or basement should not exceed 660 gal (2,500L) each, and the aggregate capacity of such tanks should not exceed 1,320 gal (5,000L) unless each 660-gal (2,500L) tank is insulated in an approved fireproof room having a fire resistance rating of at least 2h (2 hours).

The storage tanks with the storage capacity at a given location exceeding about 1,000 gal (3,800L) should be underground whenever practical and accessible for truck or rail delivery with gravity flow from the delivering carrier into storage. When burning oil in a central plant, such as a boiler house, the storage tanks should be located, if possible, so that the oil burner pump or pumps can pump it directly from storage to the burners. In case of a year-round operation, except for storage or supply capacities below 2,000 gal (7,800L), at least two tanks are installed to facilitate tank inspection, cleaning, repairs, and clearing of plugged suction lines.

Installation of a supply tank must be near the oil-burning units when the main oil storage tank is not close enough to the oil-burning units for the burner pumps to take suction from storage. Oil pumped periodically from storage to the supply tank by a transport pump at the storage location. Supply tanks should be treated the same as storage tanks regarding location with the buildings, tank design, and the like. As a recommendation standby pumps are protection against heat loss in case of pump failure.

Since piping connections to underground tanks must be at the top, such tanks should not be more than 10 ft. 6 in (3.2m) in height from top to bottom to avoid pump suction difficulties.

NOTE: This dimension may have to be less for installations at high altitudes. The total suction head for the oil pump must not exceed 14 ft. (4.3m) at sea level.

Here is some more information taken directly from the NFPA Standard 31. “4.3.6 Oil-burning appliances and equipment shall be installed so that a minimum 3 ft. (0.9 m) separation is maintained from any electrical panelboard and a minimum 5 ft. (1.5 m) separation is maintained from any unenclosed fuel oil tank.”

Connections to storage tank

Piping connections for tanks over 275-gal (1042L) capacity should be through the top of the tank. Figure 1–9 shows a storage tank for No. 2 fuel oils. Figure 1–10 shows a typical arrangement for a cylindrical storage tank with heating coil, as required for No. 5 or No. 6 fuel oils. The *maximum* allowable steam pressure in such a heating coil is 15 psi (103.4 kPa). The heating coil is unnecessary for oils lighter than No. 5, unless a combination of high pour point and low outdoor temperature makes heating necessary.

A watertight manhole with an internal ladder provides for access to the inside of the tank. If the tank is equipped with an internal heating coil, a second manhole is required, arranged to permit withdrawal of the coil.

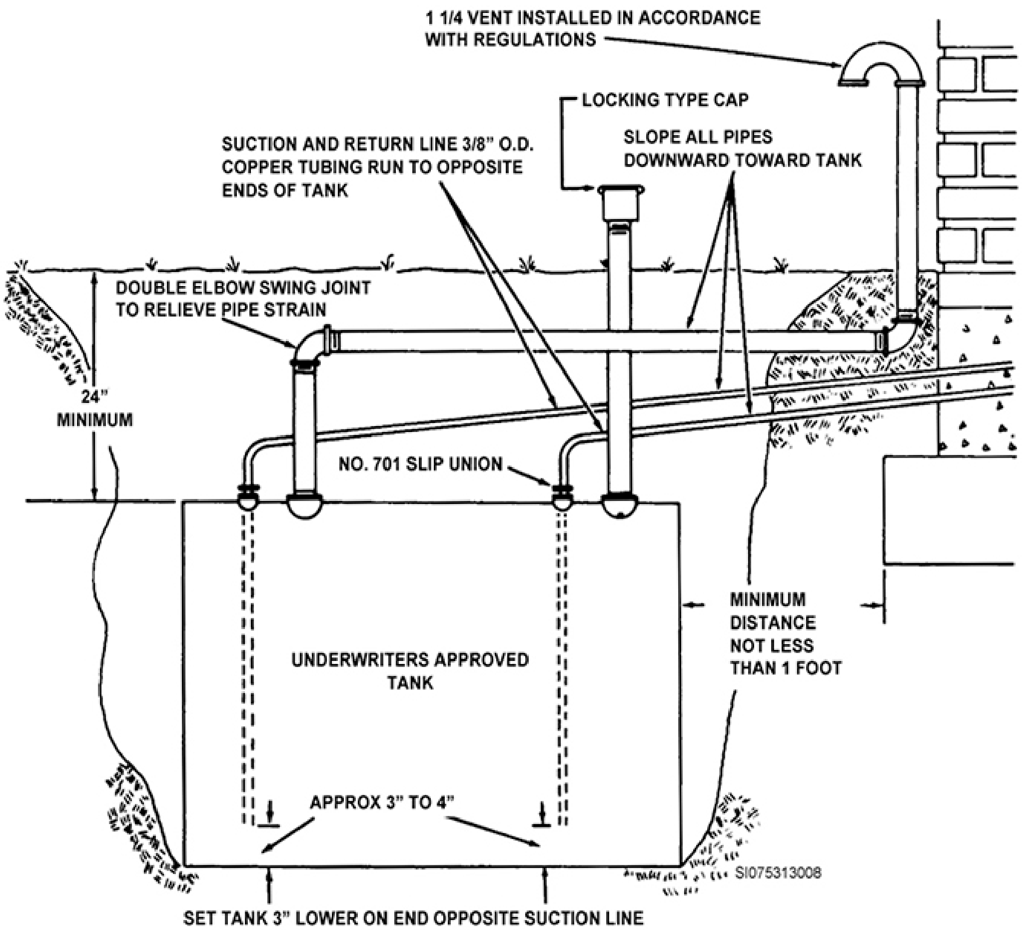

Figure 1–9. Typical oil storage tank (No. 2 oil).

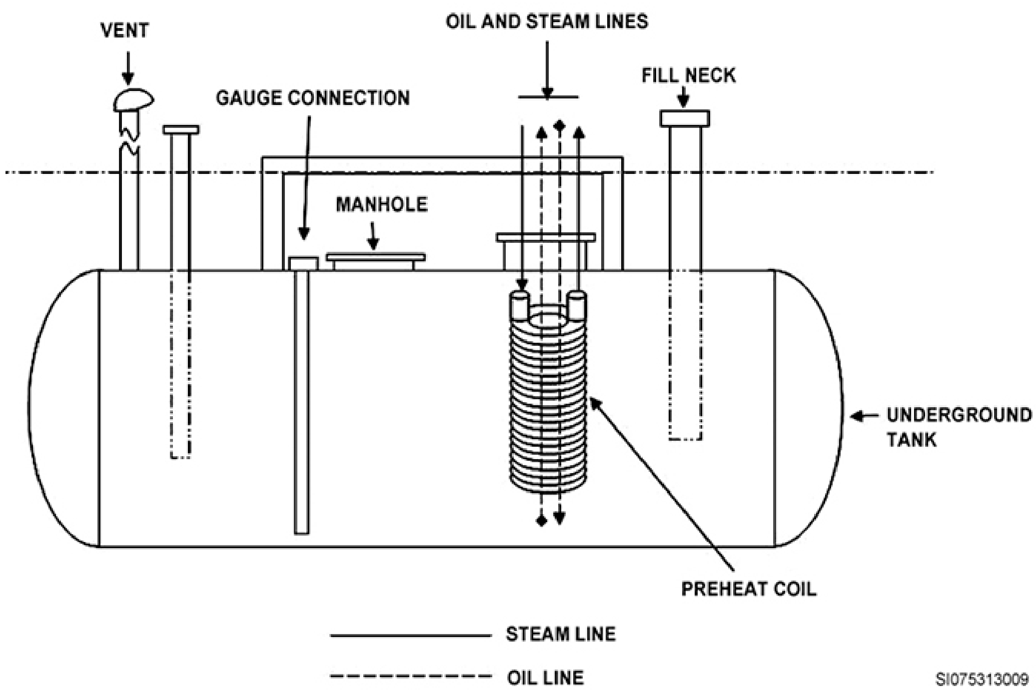

Figure 1–10. Typical oil storage tank (No. 6 oil).

Piping materials and fittings

Pipe used for fuel lines should be wrought iron, wrought steel, or brass. Do not use galvanized pipe because of corrosion problems, both copper and brass tubing may be used. An exception to the rule is piping for underground installation may be plastic, if approved for such use.

Piping for the installation of oil burners and other oil-fired appliances, except for conversion range burners, is no smaller than $^3/_8$-inch iron pipe size or $^3/_8$-inch outside diameter (OD) tubing. Use of ¼-inch pipe or $^5/_{16}$-inch OD tubing is for the suction line of systems where the top of the tank is below the level of the oil pump. The wall thickness of any copper tubing used must be at least 0.032-inch thick.

Use standard and approved fittings with all piping connections. A suitable lubricant or pipe compound should be used on threaded joints and connections. Teflon tape may be used, but do not use the following items when connecting oil lines:

- Cast iron fittings.
- Right or left couplings.
- Unions needing gaskets or packing.
- Sweat fittings employing solder having a melting point of less than 1,000°F.

You must support and protect all piping against physical damage and, where necessary, protected against corrosion. Make proper allowances for expansion, contraction, jarring, and vibration. Pipe lines (other than tubing) connected to underground tanks, except straight fill lines and test wells, must be provided with double-swing joints or flexible connectors. Otherwise arranged to permit the tank to settle without impairing the tightness of the pipe connections.

Fill lines

The fill line should be vertical and should discharge near the end of the tank *away* from the oil suction line. The inlet of the fill line must be outside the building at a point at least 2 feet from any building opening and accessible to the oil delivery vehicle unless using an oil transfer pump to fill the tank. The inlet of the fill line should be at or near grade level when filled by gravity. The inlet also should be placed to minimize spilling when the filling hose is disconnected. The fill line opening should close tightly by a locking-type metal cover when not in use. Lock the cover at all times except filling the tank. This will save you the trouble of trying to get unwanted material out of the tank.

Vent line

All fuel storage tanks must have a vent line to allow the escape of vapors and air during filling, as well as to permit the release of oil in case of overflow, without setting up excessive backpressure. Install vent pipes so that they drain back to the tank. The lower end of the vent pipe should not extend into the tank more than 1 inch to prevent the rising oil to block it.

The National Fire Protection Association Standard 31– *Standard for the Installation of Oil-Burning Equipment*   ***(Paraphrased)***
"A vent must end outside of a building and must not be closer than 2 feet in any direction from any window or other building opening. The outside end of the vent is protected with some type of weatherproof hood and it must end high enough above the ground to prevent it from being obstructed with snow or ice. Vent pipes must not be cross-connected with fill pipes or return lines from burners."

Tank openings for fill and venting

NFPA 31. 7.2.5.1 states, "All tanks shall be provided with top openings large enough to prevent abnormal pressures in the tank during normal operations (fill and withdrawal) and emergency venting (fire exposure for aboveground tanks), but not smaller than the nominal pipe sizes specified in Table 7.2.5.1." of the publication.

Capacity of Tank US Gallons	Diameter of Vent Iron Pipe Size
660 or less	1¼ inches
661 to 3,000	1½ inches
3,001 to 10,000	2 inches
10,001 to 20,000	2½ inches
20,001 to 35,000	3 inches

NOTE: Use a vent pipe not less in size than the discharge of the pump when filling tanks with a pump and through tight connections.

Suction line and other fittings

Suction lines should enter the tank on the high side and be connected to a stub extending to within 3 to 4 inches of the tank bottom (figs. 1–8 and 1–9). This allows sufficient clearance at the bottom of the tank for the accumulation of water and sludge. Consequently the water and sludge is removed through a separate pumping system and not be picked up by the pump, which can cause problems in the burner. Build the part of the suction line inside the tank as one complete piece. The reason is that joint fittings may develop leaks and admit air to the pump suction.

It is advisable in a large volume central heating plant to have two suction lines, one extending to the normal depth (3 to 4 inches from the bottom) and the other one much higher, possibly 12 inches from the bottom. This second suction line will let you continue to pump oil if the bottom accumulation of water and sludge reaches the normal suction line. If this happens just switch over to the second suction line and then pump the sludge from the tank.

Avoid foot valves on suction stubs in tanks. A good job of pipefitting will be free of suction leaks. If it is not, a foot valve is a poor correction. Foot valves work freely only as long as they are clean, and the bottom of a tank where sludge and water accumulate is hardly a clean area. A foot valve jammed by sludge or rust means an annoying and perhaps expensive service operation.

Anti-siphon valves likewise are not an expedient apparatus in an oil-burner suction line. Their principle of operation requires the pump to develop an excessively high vacuum, throwing an undue load on the pump and introducing undesirable resistance in the suction line. Unless a local condition directs that there be one, omit the antisiphon valves.

Typical practice recommends a check valve in the suction line. If there is a long underground run of suction line, insert the check valve into the line at the point *where it enters the building*. Otherwise the check valve may be located at the burner on the tank side of the strainer. Naturally the check valve serves a useful purpose only when the tank is lower than the pump. If the suction line rises upward from the pump, omit the check valve. All piping, to include suction lines, should run in the most direct and shortest route to minimize pipe friction.

Most burners are equipped with a strainer in the suction connection to the pump. Strainers prevent foreign particles in the oil from damaging pumps, valve seats, and burner tips. Install a *gate valve* on the tank side of the strainer so that the suction line is isolated when cleaning the strainer. The use of thermometers permits the correct heating of the oil. Compound gauges between the strainer and the pump suction show when the strainer needs cleaning, the suction line leaks, or the oil is getting low in the storage tank. Pressure gauges at pump discharge and oil burner headers detect improper operation of pumps and/or burners. To facilitate oil flow, run small diameter steam lines, called tracers, along with the oil lines to heat the oil and decrease its viscosity.

Return line

As a rule, the return line parallels the suction line as the two run together from the tank to the burner. At the tank, the return connection is also at the top. It is a good plan to extend the return line into the tank the same distance as the suction stub, for many reasons. The return line brings the heated oil close to the suction opening and reduces the amount of oil in storage that is kept at high temperature. Sometimes you may need to use preheated oil, so that if the return stub is already near the suction, it eases the changeover. In all cases with the return stub extended into the tank, it becomes a sort of reserve suction line so that if for some reason the original suction line becomes inoperative, as for instance by developing an air leak that cannot be immediately located, the return line can be converted into a suction line.

Provide a check valve close to the pump discharge when the return line rises from the burner. This serves to hold off the backpressure of the column of oil while the pump is inoperative, thus preventing the burner chamber from being flooded.

Tank gauges

Each storage tank must have a device for determining the oil level. One type of gauge is in figure 1–11. For tanks inside buildings, oil or vapor cannot discharge into the area. To prevent this, design and install a gauging device correctly. No storage tank should be equipped with a glass gauge or any gauge that when broken, permits the escape of oil from the tank. Gauging by a measuring stick (fig. 1–12) is permissible for outside tanks or for underground tanks.

Figure 1–11. Automatic fuel measuring gauge.

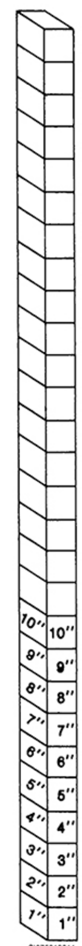

Figure 1–12. Fuel oil measuring stick.

Self-Test Questions

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

603. Fuel oil distribution systems

1. What provisions must be made for oil that the burner doesn't use?

2. What type of piping system exists if the oil is returned to the storage tank?

3. What type of piping system exists if the oil is returned to the suction side of the pump?

4. In a two-pipe system, what is the line that delivers oil from the tank to the burner equipment?

5. In a two-pipe system, what is the line that returns extra oil back to the tank?

6. When should you use the two-pipe system?

7. In a single stage oil pump, how does the piston rise and unseat the upper end of the needle valve in the piston?

8. In a single stage pump, why is pump relieved of any suction work?

9. What effect does installing the bypass plug into the fuel unit?

10. How can an oil deaerator be used with a two pipe system?

11. What must the fuel pass through after it leaves the tank but before the deaerator?

12. When is a heating coil necessary for oils lighter than No.5?

13. What is required if a tank is equipped with an internal heating coil?

14. Where should the fill line discharge?

15. When does the inlet of the fill line not have to be outside the building at a point at least 2 feet from any building opening and accessible to the oil delivery vehicle?

16. Why must a storage tank have a vent line?

17. Why should suction lines enter the tank on the high side and be connected to a stub extending to within 3 to 4 inches of the tank bottom?

18. How do anti-siphon valves affect the pump and suction line?

19. Where should the check valve be located if there is not a long underground run of suction line?

20. What effect does extending the return line into the tank the same distance as the suction stub have on the oil in the tank?

21. What can replace the suction line if it has an air leak?

604. Types and characteristics of gaseous fuels

Like fuel oil, gaseous fuels have been the backbone of our fuel supply. Unfortunately our supplies of these fuels are decreasing. Knowing that this decrease in the supply of natural gas is continuing, we should realize that it is becoming more important for us to understand the characteristics of gaseous fuels.

Fuel	Source	Heating Value Btu per cu ft	Remarks
Natural Gas	Gas wells	700-1300 average 1000	Ideal fuel, piped to point of use.
Liquefied Petroleum Gas			
Propane	Byproduct of gasoline	2500	Boiling point - 42° F Liquefies under slight pressure.
Butane	Byproduct of gasoline making	3200-3260	Boiling point 32° F. Liquefies under slight pressure.

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Figure 1–13. Comparison of gases.

Classifications of gaseous fuels are according to the source from which they originate, which, in turn, governs their chemical composition. The heat value (expressed in British thermal unit (Btu) per cubic foot) varies with the type of gas being used and will determine the quantity required for the specified capacity of the heating system. In the United States, there are several types of gases. The types principally in use are natural gas and liquefied petroleum gases; however, manufactured or mixed gases are used. The chart in figure 1–13 shows the sources and the characteristics of natural and liquefied petroleum gas (LPG) gas only.

Natural gas

This gas is a mixture of several combustible gases and, usually, small percentages of inert gases obtained from geologic formations. Natural gas is by far the most important gaseous fuel for commercial applications. It's naturally high heating value—averaging 1,000 Btu per cu ft —gives it a considerable economic advantage over relatively expensive manufactured gases. Widespread pipeline networks make it available in parts of nearly every state. From the standpoint of trouble-free performance, ease of handling, and control, natural gas offers many advantages that make it the most desirable of all heating fuels. It is generally available in a wide range of pressures to meet the requirements of both large and small installations.

Natural gas is nearly colorless and odorless in its natural form. Added mercaptan or thiol gives the gas a very distinctive odor and is a safety factor for detecting leaks. Natural gas is lighter than air and upon escaping it rises and mixes with air. The composition of natural gas varies with the source, but methane is always the major constituent. Most natural gases have some ethane and a small amount of nitrogen. Natural gas, like all gaseous fuels, mixes readily and intimately with the combustion air. Since natural gas is substantially free of ash, combustion is practically smokeless; consequently, there are no boiler slagging or air contamination problems.

Liquefied petroleum gases

Liquefied petroleum gases are higher hydrocarbon gases usually obtained as a byproduct of oil refineries or by stripping natural gas. It is heavier than natural gas. As a rule, these compounds are gaseous under usual atmospheric conditions; however, moderate pressures at normal temperatures can liquefy them. The main commercial LPG products come from natural gas or petroleum refining gas and are on the borderline between a liquid and a gaseous state. LPG gases consist mainly of propane and butane. Propane is generally available by the bottle or cylinder and in bulk form. It is the most common of the liquefied petroleum gases.

In contrast, butane is generally available in bulk form rather than in bottles or cylinders. It is quite common to have propane mixed with butane to get a desirable heat value and boiling point. At ordinary atmospheric pressure, with the necessary heat of vaporization added, butane boils or changes from a liquid to a gaseous state at 32°F. In other words, if the temperature of butane is 32°F or lower and the pressure is atmospheric, it remains a liquid. Applied heat will bring it to a gaseous state. The boiling or vaporization point of propane is minus 42°F.

LPG is gaseous at atmospheric pressure. These gases are stored and transported in the liquid state. Making LPG liquid requires pressurization. The heat necessary for vaporization comes from the surrounding atmosphere or from the ground. Never fill tanks or cylinders more than 90 percent of their capacity. The remaining 10 percent of the capacity will accommodate any expansion of the gas that may take place. Manufacturers and local gas codes design and test tanks, bottles, or cylinders used for LPG. These tanks are marked with the type and date of the next inspection.

In its natural state, LPG is odorless, colorless, and tasteless. It is odorized with the same odorant used for natural gas. Neither natural nor odorized LPG is poisonous. Exposure to a room or a pit that is full of gas causes synthetic intoxication, and finally asphyxiation (smothering).

Self-Test Questions

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

604. Types and characteristics of gaseous fuels

1. What are three results that occur because natural gas is substantially free of ash?

2. What effect does moderate pressure have on liquefied petroleum gas?

3. What is the state of liquefied petroleum gas at atmospheric pressure?

4. What is the maximum capacity a LPG tank should be filled?

5. What is the result of exposure to a room that is full of LPG?

605. Gas distribution systems

A gas distribution system is a system that will carry our gas to a place where it does work. For us, it will burn at a gas burner and produce heat. These sections discuss the basic components of a gas distribution system. An understanding of each component will make you a better technician.

Basic components

A gas-fired burner may be equipped with any number or combination of manual and automatic control devices.

Manual shutoff valve

The first and most basic component is the pipe or gas line that carries gas to the combustion chamber. Gas does not flow continuously through the pipe, so you need a manual plug cock to turn the gas on or off by hand. The plug cock is the manual shutoff valve (MSOV) (fig. 1–14). You use the manual shutoff valve to shut off the gas when the system is not in use, or when you are repairing or replacing other components. Additionally you can use it in cases of emergency. If a pilot line is used, an MSOV is required in the pilot line as well.

To light the burner, open the MSOV in the pilot line and close the MSOV in the main line. Now you can light the small pilot flame safely by hand.

When the pilot flame is going, the main MSOV opens. The pilot flame lights the main gas as soon as it enters the combustion chamber.

This manual light off system works well as long as someone constantly watches the flame. If the flame goes out because of a plugged gas line or some other undesirable occurrence, the individual can close the valves and shut down the burner.

However, if the individual does not notice a flameout situation immediately, the combustion chamber fills with unburned gas. The unburned gas, of course, creates a very dangerous situation when the burner reignites. So to watch over the flame, you need an automatic flame safeguard system within the valve train.

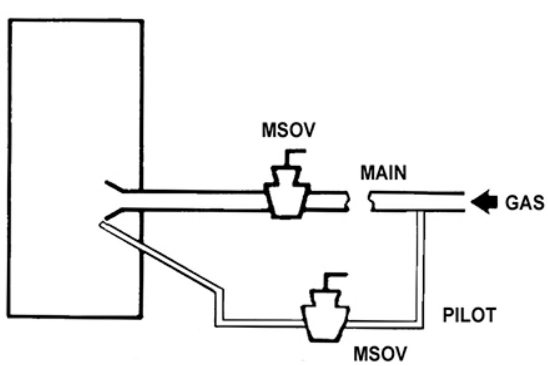

Figure 1–14. MSOV.

Safety shutoff valve

Our first component to turn the gas on and off automatically is a safety shutoff valve (SSOV) (fig. 1–15). Notice that the symbol used has a little block above it. This block represents the actuator. You will also want an SSOV in the pilot line. A programmer must tell the SSOV when to open and close the gas line. The programmer is a logic panel that includes the flame safeguard control (FSC) (fig. 1–16). This control is the heart of the flame safeguard system. Usually the panel is on the wall a few feet from the valve train and the combustion chamber. It may mount directly on the boiler. The FSC also needs something to tell it when to open the SSOV. This is the flame detector (FL DET) that watches for a flame in the combustion chamber.

To start the burner with our automatic valve train, you first open both the manual shutoff valves. Then when you need heat, the flame safeguard control opens the safety shutoff valve in the pilot line. At the same time, it turns on an ignition source for the pilot.

When the flame detector sees the pilot flame, it tells the flame safeguard control to open the safety shutoff valve in the main burner line. The pilot then lights the main burner.

Once the main burner lights, you can leave the pilot on or turn it off. If the pilot remains lit while the main burner operates, it is an intermittent pilot. In an interrupted pilot system, the flame safeguard control signals the pilot SSOV to close the gas line once the flame detector has proved the main burner flame.

If both the pilot and main flame go out, the flame detector will break its circuit. This is the safety shutoff circuit to the flame safeguard control. The flame safeguard control, in turn, will signal both the pilot and the main SSOV's to stop gas flow. This is the safety shutoff circuit.

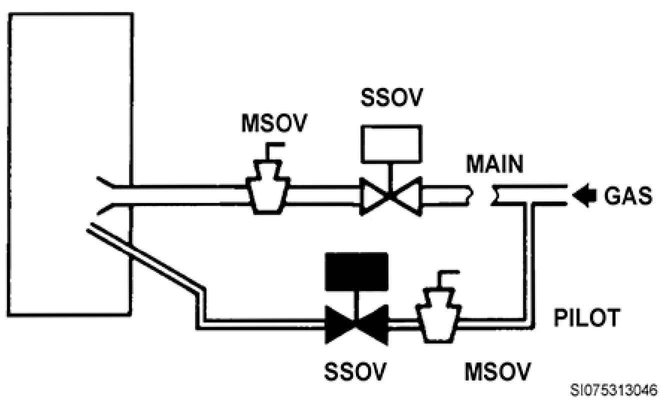

Figure 1–15. Safety shutoff valve.

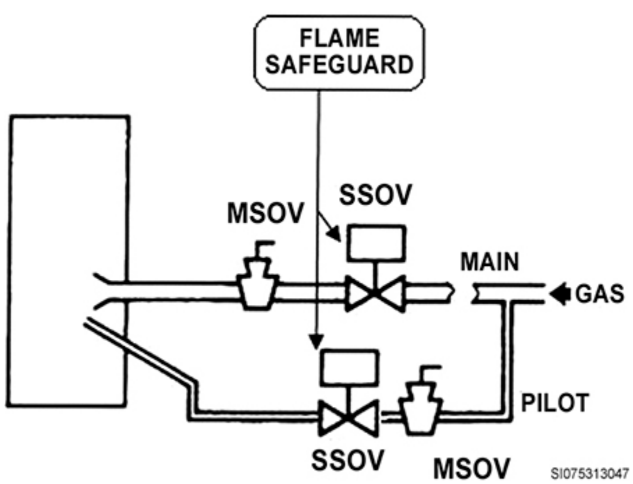

Figure 1–16. Flame safeguard control.

Gas pressure regulating valve

Another point you must consider is providing gas to the burner at the right pressure. Gas enters the valve train at a pressure as high as 10 pounds per square inch. Unfortunately gas at this pressure cannot mix properly with air and poor combustion results. For proper combustion, a typical pressure is four inches water column (WC) or only 0.15 psi. This means that the valve train must decrease the pressure considerably. So you can add a PRV. The upper part of the PRV symbol is an oval representing the diaphragm in the PRV. Because you want the PRV to cut down the pressure, you will locate it upstream of the SSOV in both the main and pilot lines. The reduced pressure increases the efficiency and life of the SSOV. If you compare the flow of gas to the flow of a river, you can see why it is located "upstream." If you located the PRV on the other side of the SSOV, it would be downstream. Now you have an automatic system for lighting the pilot and main burner.

Safety shutoff requirements

Under normal conditions, our automatic system should safely light the pilot and main burners if the SSOV does not leak. Unfortunately any valve can leak slightly if the seat does not close precisely. So if you shut down our automatic valve train for the weekend, a slight amount of gas may leak through the SSOV and continue past the open MSOV into the burner. Remember because this is an automatic system, the MSOV is open. Caution when you start the burner up on Monday morning, you may have an explosion due to a combustion chamber full of unburned gas.

To eliminate any gas leakage problem, you need a blower to get rid of any accumulated unburned gas before you light the burner (fig. 1–17). The motor that drives the blower is a burner motor. Now during startup, the flame safeguard control signals the blower to blow air through the combustion chamber and clear out the gas, this is called purging.

To purge the combustion chamber is to remove all of the unburned gas. The flame safeguard control the times the purging process takes place to provide the proper changes of air.

Purging gets rid of the gas leakage danger at light off but does nothing to prevent the accumulation of unburned gas. If you add a second SSOV, two valves would have to leak at the same time to create a problem.

For more protection, you can add another pipe between the two SSOVs leading to the outside air. Add an automatic vent valve to vent any leaking gas while the SSOVs are closed. While the SSOVs are open and gas is flowing to the burner, the vent valve is closed.

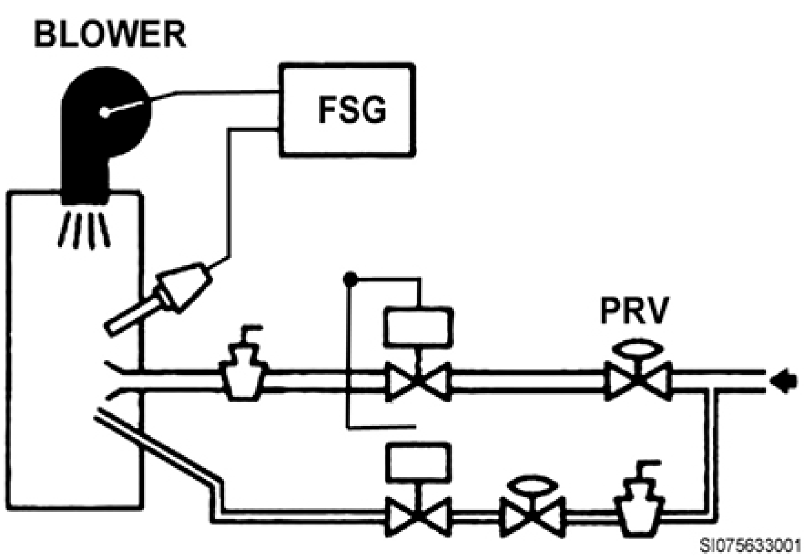

Figure 1–17. Blower location to eliminate leaking gas.

This valve arrangement is called a double-block-and-bleed (fig.1–18). While the burner is off any gas that leaks past the first safety shutoff valve escapes. It “bleeds off,” to the outside atmosphere through the vent valve. The second safety shutoff valve, just downstream from the vent valve, blocks any gas not vented.

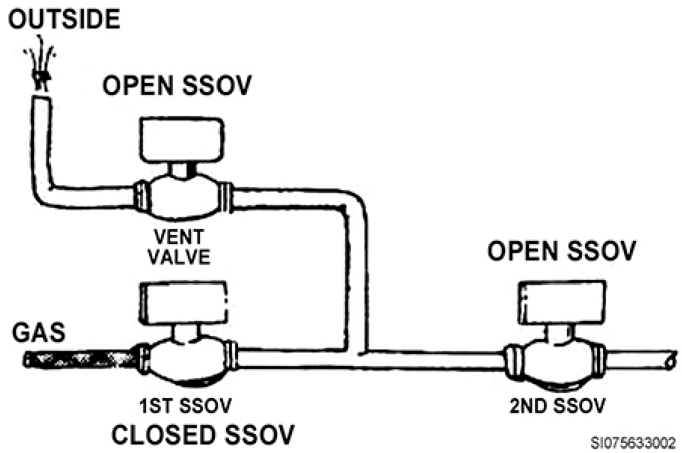

Figure 1–18. Double-block-and-bleed arrangement.

With the combustion chamber also vented to the atmosphere through its exhaust system, there is no pressure difference across the second SSOV. Even if it is a leaky valve, no gas leaks past it with this arrangement. Now when the burner is off even for several months, you can have no accumulation of unburned gas in the combustion chamber. Double-block-and-bleed is perhaps the safest of all valve arrangements. The double block and bleed also makes sense from a general safety point of view. A combustion chamber is very unlikely to fill with flammable gas during the “off” period.

Gas pressure control

Our system is still not completely safe. What if our pressure-regulating valve fails? Gas at pressures up to 10 psi could enter the combustion chamber. There is too much gas for the combustion air available, and the flame goes out. This creates a fuel-rich mixture in the combustion chamber, a situation that is always very dangerous. As conditions stand, the mixture will not ignite because there is too much gas for the air available.

Air does come into the combustion chamber naturally (because of atmospheric pressure) or mechanically (being forced in through purging). Eventually enough air enters the chamber to create a mixture that will ignite by a very low energy source resulting in the concentrated fuel-air mixture exploding.

To stop this situation, you need a high-pressure switch to notify the flame safeguard control to shut down the system. The high-pressure switch samples the gas pressure and opens an electrical circuit if the pressure rises past some preset level. This switch never blocks the gas flow; it just taps into the line to sample the pressure.

You should locate this switch near the burner because you want to keep the gas pressure at the burner within the limits for proper combustion. For this reason, the high-pressure switch is a high limit.

The high-pressure switch should be installed just upstream of the MSOV. In most valve trains, the MSOV should come last, so you can shut off the burner, but still have gas available for checking the other valves and switches.

You can let the burner restart automatically when the pressure returns to normal. You can also require someone to push a button on the high-pressure switch before the burner starts again. This is considered a manual reset. With a manual reset, someone should notice that something is wrong. Usually the operator corrects the problem before the switch is set.

Now the high-pressure situation is under control. What if the gas pressure drops too low and the burner does not get enough gas to keep going? This is considered an air-rich situation, because more air is entering the combustion chamber and there is no danger of creating an explosive mixture. However, you do want to start the burner again.

So you need a low-pressure switch or low limit to signal the flame safeguard control when the pressure falls to a preset level. The best pressure sampling location is with the high-pressure switch right next to the burner. However, with our low-pressure switch downstream of the safety shutoff valves, the switch is sensing zero pressure when the burner is not running and the safety shutoff valves are closed. With this location on a manual reset system, you have to push the button every time you want to start the burner (fig. 1–19).

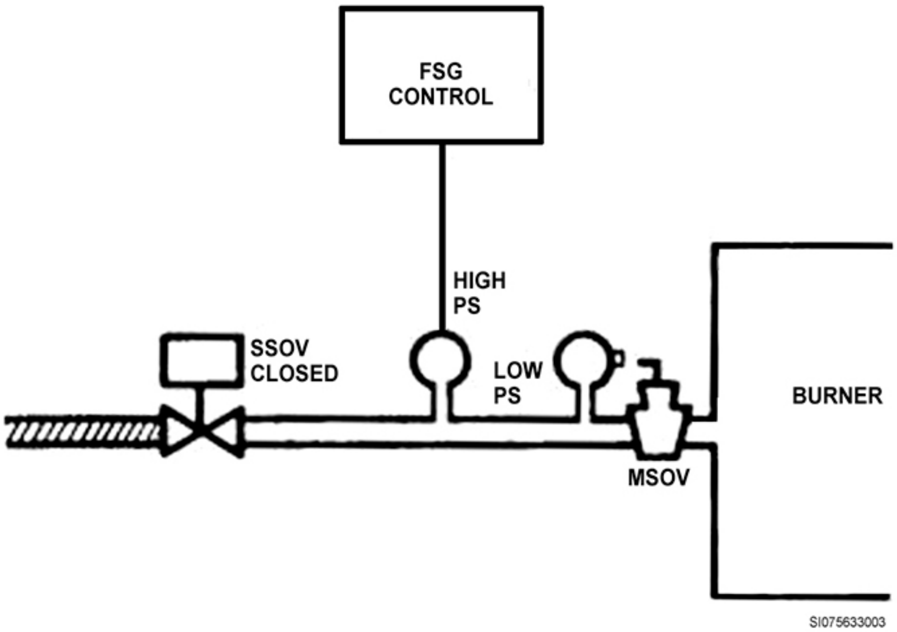

Figure 1–19. Improper location of low-pressure switch.

Consequently, then, our low-pressure switch should be moved upstream of both safety shutoff valves. Now you have two pressure switches to keep you within the limits for safe burner operation.

The MSOV is the last control in the main gas line, so you can shut off the gas supply to the burner but still have gas available for checking the other valves and switches. But if you need to replace a valve, how do you shut off the gas? You will need another MSOV at the beginning of the main burner line to shut off the gas upstream of the other valves for easier and safer replacement.

Control of gas flow

The firing rate valve is not really necessary for the safety of the valve train, but it provides a convenient method of modulating the flow of fuel. Place the valve close to the burner to get the best control. In some valve trains, you will see the firing rate valve located just after the second SSOV and ahead of the high-pressure switch. In other trains, the valve is downstream of the PRV and upstream of the low-pressure switch. The preferred location of the valve is near the burner.

Completed system operation

That completes the mechanics of our valve train. In figure 1–17 notice how much smaller the pipes are in the pilot line than in the main burner line. Also notice that the blower is located right here at the end where it can blow straight through the whole combustion chamber. This also shows the location of the flame detector or FSG. Wire the detector to a flame signal amplifier on the programming control.

Figure 1–20 is one type of programming control. This close-up of the flame safeguard control shows the flame signal amplifier that makes the electrical signal from the flame detector big enough to use. The control is a programmer with a dynamic self-check amplifier plugged into it.

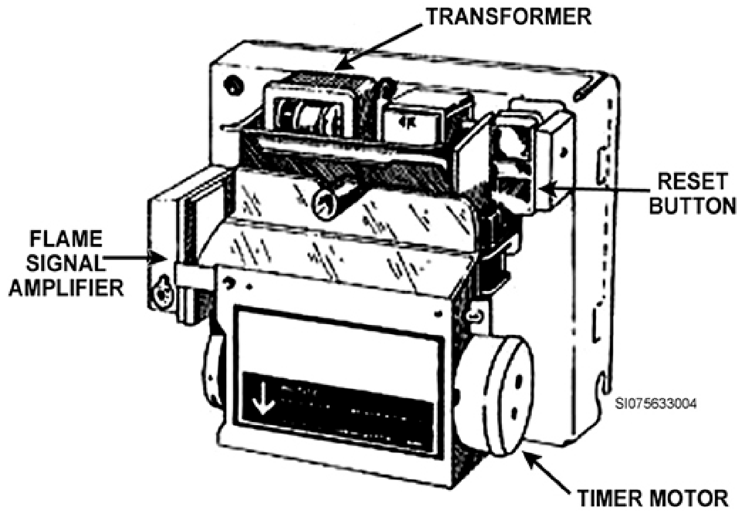

Figure 1–20. One type of flame safeguard control.

The combustion chamber is where the gas burns. The blower cleans out unburned gas and vapor before light off. The flame detector watches for the flame in the combustion chamber. The main burner line and pilot line brings in the gas and the vent line gets rid of leaking gas when the burner shuts down.

Let's discuss the pilot line a little more. When the handle on the MSOV is at a right angle from the pipe, this shows the valve is closed. If the system were operating, the valve would be open and its handle would be parallel to the pipe. The SSOV, a small solenoid, follows the pressure-regulating valve.

- The pilot MSOV lets you turn the pilot gas on and off. The pressure regulating valve keeps the pilot gas at the proper pressure for burning; and the SSOV, which closes automatically if you don't light the pilot or if the flame goes out.
- The main burner line starts out with the MSOV.
- The pressure-regulating valve is next. This valve is about 1½ feet in diameter and is identified by a flat oval shape symbol, see figure 1–17.
- Next comes the two SSOVs with the vent valve in between, forming a double-block-and-bleed. The SSOVs are fluid power actuators. The firing rate valve follows the high-pressure switch. Lastly is the MSOV (not identified).

Self-Test Questions

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

605. Gas distribution systems

1. If a pilot line is used, what is required in the pilot line?

2. What is a typical pressure for proper combustion?

3. Why is the PRV located upstream of the SSOV in both the main and pilot lines?

4. What effect does reduced pressure from the PRV have on the SSOV?

5. Why does the flame safeguard control tell the blower to blow air through the combustion chamber?

6. What effect would adding a second SSOV have on potential leaks?

7. What position is the vent valve in if the both SSOV's are open and gas is flowing to the burner?

8. What does two SSOV's with a vent valve in between form?

1–2. Fuel System Leak Inspection

Fuel system leak inspections do not simply consist of the action of checking a leak. You must have a background knowledge of fuel systems before working on them. You must know the different types of fuel supply systems along with various system layouts and pipe installation. Finally, you should know about liquefied petroleum gas storage equipment.

606. Inspecting fuel supply systems

Gas systems also need to be inspected. LPG is very flammable vapor and leaks may not be as obvious as within a fuel oil leak. Inspections will tell you if a leak exists. If you smell gas, do not create a flame or spark. You should follow your base or shop emergency procedures with common sense and caution. Find the leak and repair it immediately.

Types of supply systems

Gas lines are designated as low, medium, or high pressure. Distinguishing limits are not standardized; they vary in different localities. For our purposes, pressure is defined as "low" if less than 1½ pounds per square inch gage (psig), "high" if above 50 psig, and "medium" if between these limits.

Low-pressure systems

Low-pressure lines distribute at pressures of 3 to 8 ounces per square inch.Omit individual building gas regulators when this type of system is used. However, the omission of building regulators can be the source of serious trouble if the line pressures are subject to appreciable fluctuation. Low-pressure systems are not recommended for general use at Air Force installations if medium pressures are available.

Medium-pressure systems

For permanent construction, be sure that design pressures for a distribution system do not exceed 25 psig. In temporary construction, you may permit higher design pressures. However under no conditions may you allow the pressure to exceed 50 psig.

High-pressure systems

The main function of high-pressure lines is cross-country transmission. When necessary, they connect the distribution system with the gas company's transmission line but not used in the distribution system. Make the location selection of high-pressure carefully to minimize line breakage and to lessen fire hazards in case of line breakage.

System layouts

Gas lines should never be installed under a building or in laid in the same trench with other utilities. In lines transmitting natural gas drips should be installed at the low points immediately following reduction from high to medium pressure and at occasional low points throughout the system to provide for blowing out the line.

Install valves in the system so they are located in positions that will minimize interruptions to service. Confine interruptions to reasonably small areas. The purpose of valves in a gas distribution system is to shut off positively rather than to throttle the flow. Thus, plug valves are preferred to gate valves.

Pressure regulators are necessary at all points where equipment or design requires reduction in, or regulation of, pressure. Building regulators are usually included in the building gas system and not in the gas distribution system (fig. 1–21). The regulator is the circular object near the bottom right of the picture; it is left of the pressure gauge.

Figure 1–21. Building regulator.

The gas company generally provides a central regulating and metering station. It is usually located near the entrance to the base.

Pipe installation

Use of cast iron and steel are extensive in gas distribution systems. High-density polyethylene (HDPE) pipe specifically manufactured for natural gas or LPG is the only acceptable nonmetallic material for buried systems. Each material has advantages and disadvantages as compared with the other. If protection against corrosion is not needed, steel pipe may be less expensive. You may use either material except that you must not use cast-iron pipe in sizes smaller than 4 inches, or in systems subject to internal pressures greater than 50 psig.

In conforming to current guide specifications, you may use three types of joints with steel pipe. In order of preference, they are welded, dresser coupled, and threaded. Welded joints usually result in less leakage and maintenance difficulty than threaded joints. Dresser couplings are acceptable, but they are more expensive than welded joints, especially in larger pipe sizes. Do not use threaded joints in pipe sizes larger than 3 inches and, preferably, do not use them in sizes larger than 2 inches because of the difficulties involved.

See that joints for cast-iron pipe are for general purposes of the mechanical type. Many manufacturers have developed satisfactory mechanical joints for their pipes.

Lines should not be located in unventilated spaces under floors, in walls, or in attics, and so forth. Because a gas leak in an unventilated, confined area can result in an explosion. You can use steel pipe and fittings of malleable iron or forged steel in gas systems because of the low gas pressures. Be certain that gas pipes are fastened securely and supported with hooks, straps, bands, or hangers at intervals of not more than 8 to 10 feet. This criteria of course depends upon the pipe size.

You should grade gas lines from the main supply to the burner upward at least 1 inch for every 50 feet of pipe to prevent water from collecting in the lines. Install the main gas valve outside a building, so that it is easily accessible in case of a fire inside the building. The trend in present-day building construction places both the main gas valve and the gas meter near the outside of new construction.

Maintenance of natural gas supply systems

You need very little maintenance on natural gas fuel systems other than checking them for gas leaks, the vibration of piping, and the rusting of black iron pipe.

Liquefied petroleum gas

So far we have discussed mainly the natural gas distribution systems. Now, let’s see how LPG is stored and handled. In this state, LPG is stored and transported more easily and safely. The use of LPG in commercial applications is increasing rapidly in spite of the difficulty of seasonal storage.

Storage equipment

Most fuel supplied as LPG is propane. Equipment for handling and storing LPG is commonly designed to conform to the properties of propane. Do not use equipment designed for handling and storing butane for propane. The vapor pressure of propane at 60°F temperature is 92 psig; if the temperature rises to 100°F the vapor pressure increases to 175 psig. As these figures indicate, the pressure increases rapidly with temperature rise. Equipment design for storing and handling propane is a 250-psi rating to provide a reasonable margin of safety. When storing LPG in pressure tanks, store the liquid gas in the lower portion. Fit these tanks with a liquid line and a vapor line connected to the vaporizing equipment (if used), and a liquid line and a vapor line connected to the unloading pit.

In addition you should usually provide the tank with a safety valve, a thermometer well, and a slip-tube type of gauge for determining the liquid level in the tank (fig.1–22) and identification of the percent of gas in the tank. By reviewing past consumption records you can estimate the fuel requirements for the coming year. Vent any valve pit or other below grade location, where leakage of gas or liquid might occur, using a pipe stack tall enough to carry off the vapors. Because propane is heavier than air, be sure the vent stack has a mechanical exhauster, operated by either power or wind.

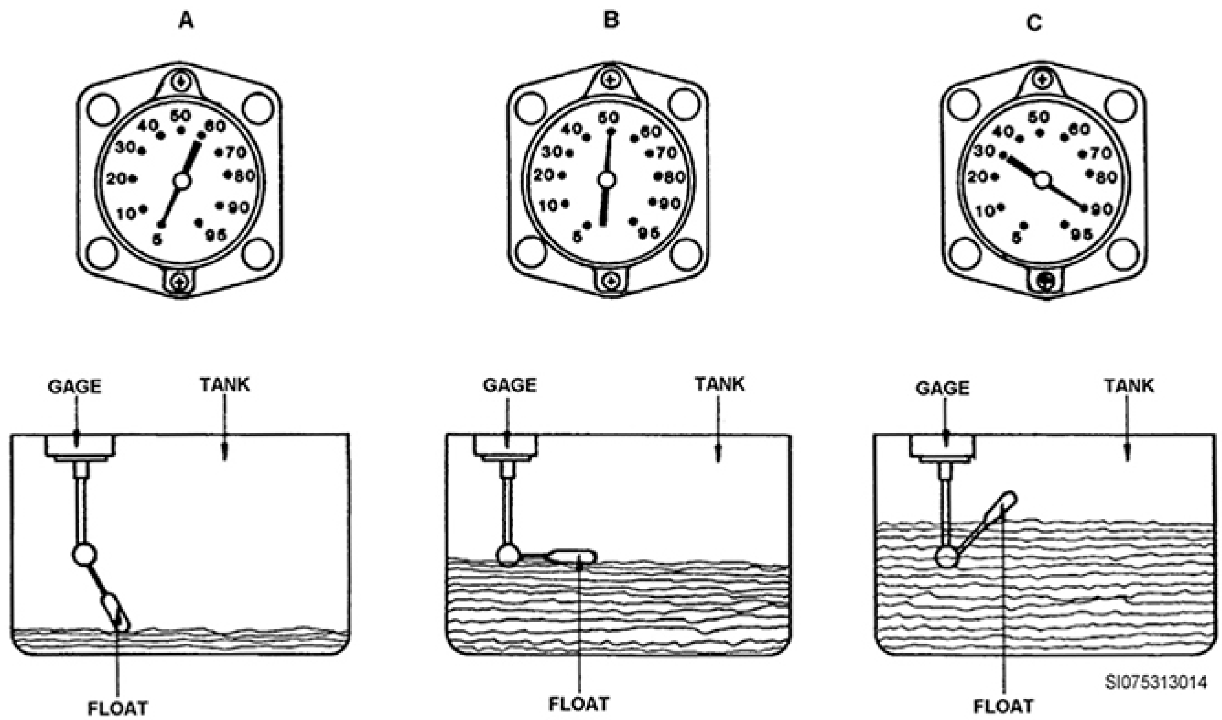

Figure 1–22. LPG tanks and gauge readings.

Self-Test Questions

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

606. Inspecting fuel supply systems

1. Why are plug valves preferred to gate valves in a gas distribution system?

2. When can cast-iron pipe not be used in gas distribution systems?

3. Why are gas lines line not located in unventilated spaces under floors, in walls or in attics?

4. How should gas lines from the main supply to the burner be graded?

5. Where are the main gas valves and gas meter located in new construction?

607. Leak inspection procedures

These general fuel leak inspection procedures could save a life! Finding a gas or oil leak is crucial. If the leak were to ignite it could cause a fire or an explosion and harm Air Force personnel. Inspections of oil leaks will be discussed first followed by gas leaks inspection procedures.

Purpose

Gas and oil systems require leak inspections for three main purposes: (1) safety, (2) efficiency, and (3) proper operation.

Oil leak inspection procedures

The following procedures are used to inspect oil distribution systems. We will cover the oil tank inspection first followed by the remaining portion of the oil distribution system.

General tank inspection procedures

The following table list inspection procedures for the general tank.

General Tank Inspection Procedures
• Clear grass, weeds and other vegetation from around the tank to make leak inspection easier.
• Check for leaks at pipe fittings around and connected to the tank. This type of above ground tank inspection includes fill pipes, vent pipes, caps, oil lines, tank legs, and oil tank gauges.
• If the fuel level is regularly checked, check to see if it has dropped more than usual.
• Perform a visual inspection for corrosion.
• Inspect oil for water using something called water finding paste. This is done be using a tank stick with water-finding paste on it. Place the tank stick in the tank to the bottom of the tank. If the paste turns a certain color then you have water in the tank. The tank stick will tell you how much water you have. For example, paste turns from green to purple and is at the five inch marker on the stick. This tells you there is five inches of water in the tank.
• Check aboveground tanks for signs of oil underneath the tank.
• If applicable, check protective anodes according the local procedures.

General oil line inspection procedures

Visually inspect fuel oil line from the main run to burner with the auxiliary pump energized and valves open. The unit will not be operational at this point. The following are inspection procedures of the general oil line:

- Ensure oil is in the oil line. For example, ensure valves are open.
- Visually inspect all fittings. You will often see a droplet of oil or a pool of oil underneath a leak. NEVER use a flame to check for leaks this could cause a fire or explosion
- Look for obvious issues such as broken or bent pipes.
- Visually inspect fuel pump for signs leaking oil.
- Check for places where vibration or rubbing of the pipes and fittings may occur.

General gas line inspection procedures

HVAC/R leak inspections begins after the pressure regulator that provide gas to our systems. Follow this list of general procedures to learn the basic concepts of gas leak inspections:

- Ensure gas is in the gas line. For example, ensure valves are open.
- Check all fittings using soapy bubbles. Do this by applying a solution of soapy water at each joint while the system is under pressure when checking for gas leaks a soap bubble will form at the joint if a gas leak exists. See figure 1–23 for an example of some fittings to check. Never use a flame to check for leaks this could cause a fire or explosion.

Figure 1–23. Gas line fittings to check.

- Look for obvious issues such as broken or bent pipes.
- Listen for a hissing sound.
- Check all flexible lines, use your ears and soapy bubbles.
- Check for places where vibration or rubbing of the pipes and fittings may occur.

For propane or butane tanks use similar procedures to oil tank system except use soapy bubbles to locate leaks.

Self-Test Questions

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

607. Leak inspection procedures

1. Above ground tanks should be checked for what areas?

2. Why should a flame never be used to check for oil leaks?

3. How is a leak identified when applying a soapy solution to fittings?

4. Why should a flame never be used to check for gas leaks?

5. What should you listen for when inspecting for gas leaks?

Answers to Self-Test Questions

601

1. So that there is no danger of spontaneous combustion.
2. When people walk, rubber-tired vehicles move, liquid drops through space, and petroleum products are pumped through lines and hoses.
3. According to given in applicable Air Force directives and made to grounding connections that are clean, unpainted surfaces.
4. The charge will drain off.
5. Contact the Civil Engineer Environmental Planning Office.

602

1. High viscosity.
2. Low viscosity.
3. It will not atomize the oil properly causing incomplete combustion, carbon residues, and soot buildup within the boiler.
4. A condition in which the flame ignites but is unable to maintain combustion of the heavier hydrocarbons.
5. Because pre-ignition in the burner results.
6. This material can plug burners, burner tips, and screens and cause erratic combustion such as sparkling and flashback.
7. It produces harmful emissions and highly acidic compounds (sulfurous acids) that attack steel boiler parts.

603

1. To return the unused oil to the storage tank or to circulate it back to the suction side of the pump
2. Two-pipe system.
3. One-pipe system.
4. The suction line or feed line.
5. The return line.
6. When the pump has a dual purpose.
7. When the oil pressure against the bottom of the large piston exceeds the pressure determined by the pressure adjusting screw and spring acting against the upper side of the piston.
8. Because oil is delivered by gravity.
9. Prevents oil from returning to the inlet side of the unit.
10. The return line from the burner to the tank needs to be disconnected and capped.
11. A fuel filter.
12. If there is combination of high pour point and low outdoor temperature makes heating necessary.
13. A second manhole is required, arranged to permit withdrawal of the coil.
14. Near the end of the tank *away* from the oil suction line.
15. If you are using an oil transfer pump to fill the tank.
16. To allow the escape of vapors and air during filling, as well as to permit the release of oil in case of overflow, without setting up excessive backpressure.
17. To allow sufficient clearance at the bottom of the tank for the accumulation of water and sludge.
18. Requires the pump to develop an excessively high vacuum, throwing an undue load on the pump and introducing undesirable resistance in the suction line.
19. It may be located at the burner on the tank side of the strainer.
20. It reduces the amount of oil in storage that is kept at high temperature.
21. The return line.

604

1. (a) Combustion is practically smokeless, (b) no boiler slagging, (c) air contamination problems.
2. It can liquefy them.
3. Gaseous.
4. 90%.
5. Causes synthetic intoxication, and finally asphyxiation (smothering).

605

1. A manual shutoff valve.
2. Four inches water column (WC) or only 0.15 psi.
3. Because you want the PRV to cut down the pressure.
4. It increases the efficiency and life of the SSOV.
5. Clear out the gas.
6. If you add a second SSOV, two valves would have to leak at the same time to create a problem.
7. Closed.
8. A double-block-and-bleed.

606

1. Because the purpose of valves in a gas distribution system is to shut off positively rather than to throttle the flow.
2. You must not use cast-iron pipe in sizes smaller than 4 inches, or in systems subject to internal pressures greater than 50 psig.
3. Because a gas leak in an unventilated, confined area can result in an explosion.
4. Upward at least 1 inch for every 50 feet of pipe.
5. Near the outside of new construction.

607

1. Oil underneath the tank.
2. It could cause a fire or explosion.
3. A soap bubble will form at the joint if a gas leak exists.
4. It could cause a fire or explosion.
5. A hissing sound.

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. (601) How is static electricity *best* controlled?
   a. 100% cotton clothing.
   b. Avoiding flammable leaks.
   c. Visually inspect static electricity.
   d. Grounding, bonding, humidifying.

2. (601) Grounded wires carrying off static charges
   a. bonds with static charges.
   b. creates an electrical hazard.
   c. increases the difference in electrical potential.
   d. neutralizes the difference in electrical potential.

3. (601) A fuel spill should be reported when how many gallons or more is leaked or spilled?
   a. 5.
   b. 10.
   c. 25.
   d. 35.

4. (601) A leak of 35 gallons should be reported to the state regulator within
   a. 24 hours.
   b. 48 hours.
   c. 72 hours.
   d. 1 week.

5. (602) When the viscosity of an oil is *decreased*, how does it affect the oil?
   a. Worse for atomization.
   b. More difficult to flow.
   c. Harder to pump.
   d. Easier to pump.

6. (602) Which type of condition could cause a blocked burner?
   a. Clean oil.
   b. Sludge in oil.
   c. Low viscosity.
   d. Very low viscosity.

7. (603) Which procedure is *best* to use for *efficiency* if the tank is *below* the level of the burner?
   a. A two-stage pump with a three-pipe system.
   b. A single-stage pump with a two-pipe system.
   c. A two-stage pump with a single-pipe system.
   d. A two-stage pump with a two-pipe system.

8. (603) Why is a galvanized pipe *not* used with fuel lines?
   a. It can cause corrosion problems.
   b. Because it will begin to conduct electricity.
   c. Galvanized pipe is too restrictive to oil flow.
   d. The galvanized steel explodes on contact with fuel oil.

9. (603) Why is a gate valve located on the tank side of the strainer?
   a. To protect the tank during cleaning.
   b. To permit greater flow to the strainer.
   c. To collect sludge before it hits the strainer.
   d. So that the suction line is isolated when cleaning the strainer.

10. (604) Liquefied petroleum gas (LPG) is stored and transported in
    a. its liquid state.
    b. its solid state.
    c. its gaseous state.
    d. a mixture of natural gas.

11. (604) Ten percent of a liquefied petroleum gas (LPG) tank is *not* filled to
    a. save gas for another tank.
    b. accommodate for expansion.
    c. accommodate for contraction.
    d. accommodate for freezing temperatures.

12. (605) The action that happens to the safety shutoff valve in the *main* burner line once a pilot flame is detected is it
    a. remains closed until a technician opens it.
    b. locks out for safety.
    c. is opened.
    d. is closed.

13. (605) Which device *removes* any accumulated gas in the combustion chamber burner?
    a. Blower.
    b. Dampers.
    c. Reset switch.
    d. Venturi effect.

14. (606) What are the three categories of gas supply systems?
    a. Low, high, and superheated.
    b. Ultralow, low, and medium.
    c. Low, mid-level, and high.
    d. Low, medium, and high.

15. (607) Identify what you would use to determine if water is in the oil.
    a. Vent caps.
    b. Oil level gauge.
    c. Five cups of water dye.
    d. Tank stick with water finding paste.

Please read the unit menu for unit 2 and continue ➔

Unit 2. Burners and Combustion Controls

2–1. Combustion and Combustion Analysis 2–1
608. Properties of combustion 2–1
609. Combustion air requirements and heat loss 2–6
610. Combustion concepts and causes of problems 2–10
611. Combustion analysis 2–17
2–2. Gas Burner Types and Operation 2–22
612. Gas valves 2–22
613. Functions of gas burners 2–27
614. Characteristics of gas burners 2–35
615. Gas pilot and ignition systems 2–44
616. Pre-operational inspection and operational test of gas burners 2–50
617. Preventative maintenance for gas burners 2–54
2–3. Oil Burner Types and Operation 2–57
618. Application of oil burners 2–57
619. Pre-operational inspection and operational test of oil burners 2–64
620. Preventative maintenance for oil burners 2–66
2–4. Flame Controls and Detectors 2–69
621. Function of flame control 2–69
622. Flame detectors 2–73
2–5. Primary and Programming Controls 2–88
623. Primary controls 2–88
624. Programming controls 2–91

BURNERS AND COMBUSTION controls are vital to every single heating system used. You must understand these concepts to be a successful heating technician. In this unit, combustion, gas and oil burners, flame, and lastly, primary and programming controls are covered. This information gives you a strong background to apply to your on-the-job training. Do not take this unit lightly, stay focused and if you have any questions, ask your supervisor!

2–1. Combustion and Combustion Analysis

Combustion and combustion analysis are two vital concepts in heating. Combustion can be referred to as the action or operation of burning, the state of being on fire, or the chemical combination of substance with certain elements accompanied by the generation of heat and sometimes light. Combustion analysis is studying combustion and verifying it efficiency.

In this section we will cover the properties of combustion, combustion air requirements, heat loss, problems with combustion and combustion analysis. Combine the job knowledge you learn in this section with the on-the-job training you are receiving and you will be a very reliable technician when it comes to the heating portion of HVAC/R.

608. Properties of combustion

This lesson discusses the properties of combustion. We will discuss the required elements for combustion, the principles of combustion, carbon dioxide, and incomplete combustion. The lesson will conclude with terms and characteristics that will increase your understanding of combustion and also prepare you for the other lessons about combustion. Let’s begin with the elements required for combustion to take place.

Elements needed for combustion

These following elements must be present before combustion can occur: (1) heat ignition, (2) fuel, and (3) air (fig. 2–1).

Figure 2–1. Elements of combustion.

Every burnable substance has a minimum temperature (heat) that it has to reach before combustion can exist. The *flash point* is the maximum safe storage and handling temperature, the fuel can be lit at this temperature, but it will only burn temporarily. The ignition point is a few degrees hotter than the flash point. The flame will continue to burn because of the fuel vapors rising off of the liquid fuel. The fuel can be any burnable substance, such as coal, wood, oil, and gas, all of which contain carbon and hydrogen. We must mix enough air with the combustible gases to provide enough oxygen to satisfy the combustion process. Each element or substance needs a certain amount of oxygen for complete combustion. For all practical purposes, these three elements (*heat, fuel, and air*) are the only ones involved. If one or more of these elements is absent, combustion will not take place.

Principles of combustion

The common fossil fuels—gas, oil, and coal—are *hydrocarbons.* They consist of hydrogen and carbon and also have minor amounts of other substances, such as sulphur. Sulphur is an impurity. The burning of such fuels is a chemical process in which complete combustion takes place when hydrogen combines with oxygen to form water, and the carbon combines with oxygen to form carbon dioxide (CO_2). During complete combustion there are no by-products; CO2 and water only. Since the combustion of fuels is a chemical process; it follows certain principles of chemical reactions concerning the number of molecules of each substance involved. Too exactly and completely burn a hydrocarbon, each molecule of carbon requires two molecules of oxygen, and each two molecules of hydrogen require one molecule of oxygen. We use terms like “pound of fuel” or “cubic foot of gas” to express larger amounts of fuel.

Carbon dioxide

The results of exact and complete combustion are that the products of combustion, or fuel gases, have no incomplete oxidized (unburned) fuel and no oxygen. Under this condition, all of the carbon in the fuel has reacted completely with oxygen to form carbon dioxide. As a result, the percentage of carbon dioxide going up the stack (the products of combustion), is the maximum attainable under an ideal condition of the particular fuel being burned. We refer to this as the maximum theoretical percentage of carbon dioxide (ultimate CO_2).

The discussion thus far has considered only the oxygen in atmospheric air. Oxygen accounts for only about 21 percent of atmospheric air, the remaining 79 percent being composed mostly of nitrogen. Nitrogen is considered an inert gas that does not enter into the combustion process—its only reactions are to form small amounts of nitrogen oxide that is an air pollutant. As there is no easy way to separate oxygen from nitrogen, the nitrogen goes through the combustion process unchanged for all practical purposes.

Since the air that enters into the combustion process is 79 percent nitrogen, the flue gases are 79 percent nitrogen. The contents of the other 21 percent of the flue gases depend on the fuel burning and the combustion process. For example coke is nearly pure carbon, and, when burned completely, the resulting product is carbon dioxide. Under the condition of complete and exact combination with oxygen, the 21 percent of oxygen in the air reacts with the carbon; since the 21 percent oxygen would otherwise remain unchanged, the products of combustion would have 21 percent carbon dioxide. Thus, the maximum theoretical carbon dioxide percent for coke is 21 percent.

Most fuels contain hydrogen as well as carbon, and some of the atmospheric oxygen will consume in combining with the hydrogen to form water vapor. The remaining oxygen then combines with the carbon to form CO_2. Thus, the maximum theoretical CO_2 percent for hydrocarbon fuels varies with the proportions of hydrogen and carbon contained in the fuel. For example, maximum theoretical CO_2 percentages are 12.1 percent for natural gas, 13.9 percent for propane, and 15 to 16.5 percent for fuel oils.

Incomplete combustion

The above discussion considers only a condition where all the carbon and hydrogen oxidizes. At the same time, the burning consumes all of the oxygen in the air. We cannot attain this theoretical condition in practice. Incomplete combustion usually occurs, in which all of the carbon and hydrogen of the fuel will not oxidize. With an incomplete combustion process, the byproducts may include pure unburned carbon (smoke and soot), carbon monoxide (CO) and aldehydes, as well as water vapor and carbon dioxide. You should avoid the production of smoke and soot for the following reasons listed:

- It is a direct waste of unburned fuel.
- Smoke emitted into the atmosphere is not only objectionable but generally is a violation of law.
- Soot on heat exchange surfaces in boilers or furnaces acts as insulation to reduce efficiency. Ultimately, restricting or stopping up smoke pipes and stacks.

It is undesirable to produce carbon monoxide because not only is it poisonous, but it can burn and its presence in flue gases represents a waste of fuel, therefore a loss in efficiency. When exposed to sufficient oxygen in the fire, carbon monoxide burns to form carbon dioxide.

Aldehydes are chemicals that produce noxious fumes in the flue gas, and also undesirable. They also can form if burning occurs under so-called “cold” conditions, such as in poorly built combustion chambers or if an excessive amount of air prevents a proper combustion mixture for a hot fire. Below are the following causes of incomplete combustion:

- Insufficient mixing of fuel and air (causing localized fuel-rich and fuel-lean zones within the fire).
- Insufficient supply of air to the flame (providing less than the quantity of oxygen required for the chemical reaction to be complete).
- Insufficient time in the combustion chamber (passage of fuel, air, and flue gases can be too rapid to permit completion of the combustion reactions).
- Flame impingement on a cold surface (which quenches the combustion reactions).
- Flame that has too low a temperature (which slows the combustion process).

Terms

These terms are used to identify the main areas in burner operations. Learning these terms in the following table will help you understand the information in later lessons.

Burner Operations Terms	
Combustion	Combustion is the act or process of burning, the rapid oxidation of fuel accompanied by the production of heat, or heat and light. To be safe, an operator or a control system must control combustion. Ignition requires a proper, mixed proportion of fuel and air (oxygen).
Air-fuel ratio	Air-fuel ratio is the ratio of air supply flow rate to fuel supply flow rate, measured in the same units under the same conditions.
Burner	This device introduces fuel and air, properly mixed, and in the right proportions, into a combustion chamber where the mixture will burn and the products of combustion removed.
Furnace	This is an enclosed chamber or structure that produces heat—the combustion chamber. The furnace is essential for good combustion because it maintains the ignition temperature.
Closed burner	A closed (sealed-in) burner mounts on a furnace in an airtight manner so that all of the air needed for combustion goes *through* the burner.
Open burner	An open burner has an opening around it so that secondary air can enter the combustion chamber. The opening distinguishes it from a closed burner. Many burners have an air register with a shutter to allow adjustment of the volume of secondary air.
Primary air	Primary air is the air supplied through a burner that mixes with the fuel before it reaches the combustion chamber; it includes atomizing and combustion air.
Secondary air	Secondary air is introduced at the point of combustion—air that is *not* mixed with the fuel before it enters the combustion chamber. This is the extra air needed to change CO (carbon monoxide) to CO_2 (carbon dioxide).

Characteristics

When starting and servicing the different types of burners, certain characteristics will aid you in your work. The following table provides you those characteristics.

Burner Characteristics	
Firing rate	Firing rate is the combustion rate. Firing rate is a rate that air, fuel, or an air-fuel mixture that a burner or furnace supplies. Volume, weight, or heat units supplied per unit of time are expressions of firing rate.
Turndown	Turndown is the ratio of the maximum firing rate to the minimum firing rate that the burner operates satisfactorily. For example, the firing rate of a burner with a 4 to 1 turndown range will vary from its maximum

Burner Characteristics	
	(100 percent) down to ¼ of its maximum (25 percent). A high turndown ratio is particularly desirable for furnaces that shut down periodically. A high firing rate can heat the furnace rapidly when it starts up again. Turn down of the firing rate can be set to normal after the furnace is heated.
Flame blow-off	Flame blow-off limits the maximum firing rate. A flame moves away from a burner when the velocity of the air-fuel mixture is greater than the velocity of the flame front (flame propagation rate). A flame will usually go out when a blow-off happens.
Flashback	Flashback limits the minimum firing rate. A flame moves back through a burner (and possibly back to the air-fuel mixing point) when the flame propagation rate is greater than the velocity of the entering air-fuel mixture.
Stability	Stability is another important characteristic. A stable burner remains lit over its normal range of pressures and air-fuel ratios while it is still cold (at room temperature during startup). Do not consider a burner stable just because it has a pilot. An unstable burner flame may go out and enough gas might accumulate to cause an explosion when the pilot reignites the burner.
Flame shape	Flame shape depends on burner and combustion chamber design. Turbulence and high velocities result in good mixing, that produces a short, bushy flame. Delayed mixing and low velocities produce a long, slender flame. In most burners, an increase in mixture pressure broadens the flame and an increase in primary air shortens the flame.

Self-Test Questions

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

608. Properties of combustion

1. How does the chemical process of combustion occur?

2. What is the result of exact and complete combustion?

3. What does the percentage of carbon dioxide going up the stack represent?

4. What is maximum theoretical percentage of carbon dioxide?

5. What happens to nitrogen during the combustion process?

6. Besides nitrogen, what determines the contents of the remaining combustion gases?

7. What are the maximum theoretical percentages of CO2 for natural gas, propane, and fuel oils?

8. What gas would be completely consumed if complete combustion was possible?

9. What happens to carbon monoxide when it mixes with sufficient oxygen during combustion?

10. What does insufficient mixing of fuel and air cause?

11. What is the air that is not mixed with the fuel before it enters the combustion chamber?

12. What is another name for firing rate?

13. What percent of its maximum firing rate can a burner operate if it has a 4 to 1 turndown ratio?

14. What does the flame shape depend on?

609. Combustion air requirements and heat loss

Complete combustion is desirable to avoid wasting unburned fuel and to prevent the production of smoke. Wasted fuel means wasted Air Force money. In this lesson we will talk about combustion air requirements, draft, combustion control, and heat loss.

Combustion air requirements

Important reasons for incomplete combustion have to do with insufficient oxygen, either an actual shortage of the chemically required quantity, or inadequate mixing. The usual method of assuring complete combustion is to supply more oxygen than is theoretically needed for exact and complete combustion of the fuel. The amount beyond that theoretically required for complete burning of the fuel is referred to as *excess oxygen*, or in the practical situation using atmospheric air, it is *excess air*.

We need excess air to ensure complete combustion. Excess air also represents a loss of heat and a consequent decrease in efficiency below the theoretical maximum. This is because both the nitrogen and the unburned oxygen become heated, and the heat passes into the flue instead of absorbing into the boiler or furnace. The amount of excess air supplied to a fire is, therefore, a compromise, and generally depends on the quality of the combustion equipment. Good equipment should need much less excess air than, for example, a poorly operating oil burner that may need 100 percent excess air to avoid producing smoke. Excess air affects the percentage of CO_2 and oxygen (O_2) in the flue gas.

NOTE: This discussion is concentrated on the CO_2 aspect of the flue gases.

For example, where the burning of coke as mentioned earlier results in a maximum theoretical carbon dioxide of 21 percent, if burned with 100 percent excess air, the carbon dioxide content would half, to 10.5 percent. Likewise, if using fuel oil capable of 15 percent maximum theoretical carbon dioxide, combustion would take place with a decrease to 7.5 percent. The measurement of the CO_2 content in the flue gas is an important practical test used to check on combustion efficiency. Figures 2–2 and 2–3 show relationships of excess air, percent CO_2, and heat loss.

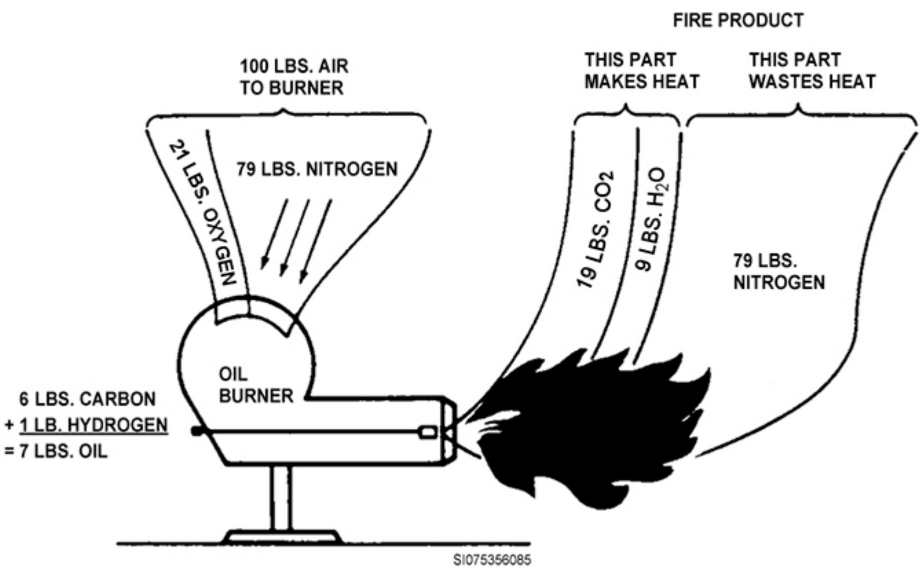

Figure 2–2. Examples of combustion using NO excess air.

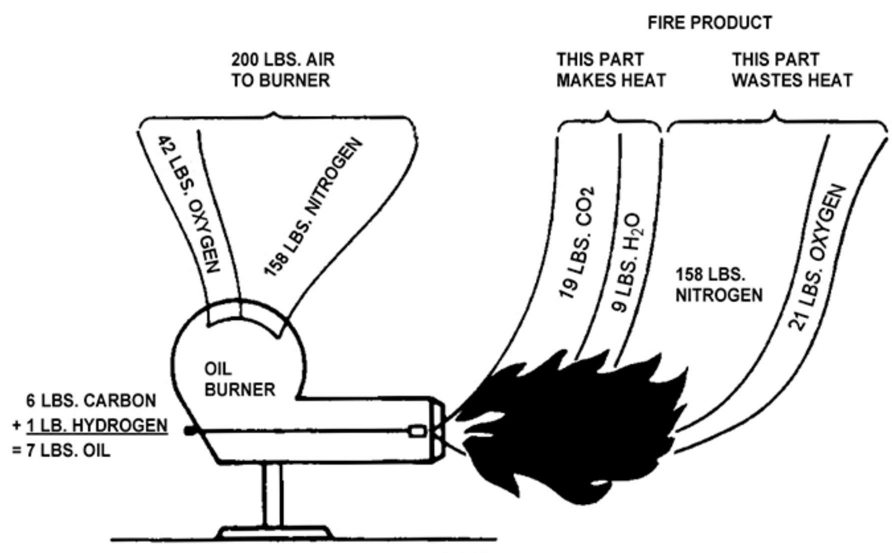

Figure 2–3. Examples of combustion using 100 percent excess air.

Figure 2–2 shows that oil burns at a rate of seven pounds per hour, and that for complete combustion with no excess air, air draws in at a rate of 100 pounds per hour. Of this, 21 pounds per hour is oxygen, giving an oxygen-fuel ratio of 21 divided by 7 or 3 pounds of oxygen per pound of fuel; or an air-fuel ratio of 100 divided by 7 or 14.3 pounds of air per pound of fuel. In this example, the CO_2 content of the products of combustion is 15 percent. Although some heat contained in the carbon dioxide and the water vapor is lost as the products of combustion pass into the stack (this is a necessary part of the combustion process), only the heat contained in the 79 pounds of nitrogen is heat that is mostly wasted.

Figure 2–3 shows the effect, using 100 percent excess air. The amount of fuel burned is the same as in figure 2–2, as are the amounts of carbon dioxide and water vapor that are actually involved in the combustion process. There is excess oxygen that does not take part in the combustion process, and nitrogen is twice as much. This excess oxygen and the doubled amount of nitrogen heat to flue gas temperature, so results in a larger waste of heat as compared to the other condition. Correspondingly the CO_2 content is 7.5 percent, half of that indicated in figure 2–2. Thus, CO_2 percent is a measure of the percentage of excess air and is the basis for a common test to check combustion efficiency. Oxygen content compliments carbon dioxide findings.

The minimum excess air needed varies from one installation to another depending on the size and refinement of the combustion equipment, the fuel used, and the adjustment of fuel feed apparatus. A realistic example for residential or small commercial oil-burning installations would be to have excess air in a range of about 25 to 40 percent with corresponding CO_2 content in the range of 10 to 12 percent. Whereas natural gas equipment with an excess air range of 20 to 40 percent has corresponding CO_2 content in the range of about 8.4 to 9.9 percent.

Draft

In the preceding paragraphs, we talked about the air required for the combustion process. We refer to this as draft. “Draft” is the pressure difference associated with the movement of flue gases and used to designate a static pressure in a furnace, a gas passage, a flue, or a stack. To avoid confusion of terms, the value of drafts or draft pressures refers to the atmospheric pressure at the same elevation, and the plus or minus sign designates whether the draft is above (positive) or below (negative) the atmospheric pressure. Natural draft is always negative and expressed by inches of water. When a fan supplies the movement of air, the draft is “forced or induced.”

Combustion control

Combustion control is the production of required heat units by regulating furnace fuel and air input to maintain constant steam pressure or water and/or air temperature, irrespective of load, and the proper relation of air to fuel supply for maximum combustion. Combustion control not only has a very important economic influence because of fuel savings, it also has a significant effect on smoke abatement since it promotes complete and efficient combustion. Individuals should study until they completely understand the purpose and functioning of the equipment combustion and safety control arrangements. This effort will substantially enhance normal operations and contribute to intelligent and safe emergency procedures. We control combustion manually or automatically. The methods depend on the following factors types of heating unit: the size, type of burner, and the fuel used:

- Varying the amount of air when the burner uses a constant fuel supply.
- Varying the amount of fuel when the burner uses a constant air supply.
- Varying both the amount of fuel and air.

Heat loss

Heat and fuel loss are factors that affect heating equipment efficiency. When we speak of heat loss at this point, we mean the heat that escapes into the atmosphere rather than heat used to convert water into steam or to heat areas where heat is required. Heat losses divide into the following major classes:

- Losses that go up the stack.
- Losses through radiation, convection, and conduction.

Stack loss

Of the three major classes of heat loss, stack loss is by far the greatest. It divides further into three subclasses: (1) excess air loss, (2) unburned fuel (smoke), and (3) excessive flue-gas temperature. Of the three subclasses of stack loss, air loss and excessive flue-gas temperature are the greatest sources of waste. Smoke is only a very small percentage of the total loss—perhaps only 2 to 3 percent. In the past, measurements and graphs were required to figure out the stack loss. Now, a digital combustion analyzer can give you the stack loss within seconds.

Heat loss from radiation, convection, and conduction

After the hot medium leaves the heating unit, we send it out and use it for heating. As this hot medium travels, there is some heat loss to areas that surround the lines or ducts. Even when the heat has reached the area where used, there is still other heat loss. To maintain a constant room or building temperature, regardless of the outside temperature, a system will supply heat at the same rate that it loses heat. Heat losses taking place in the using area classify as transmission losses and infiltration losses.

Transmission losses

Transmission heat losses through the confining walls, floors, and ceilings occur when the outside temperature is lower than the inside temperature. A system loses heat by conduction directly through the enclosure material. The amount of loss depends chiefly on the size of wall, ceiling, and floor areas to include, temperature difference between the inside and outside air, and the heat transmission coefficient. The coefficient is affected by the type of construction (kind and thickness of enclosure materials), resistance to heat flow on both sides of the enclosure, and the contained airspaces.

Infiltration losses

Infiltration heat loss is equal to the amount of heat needed to bring the outside air that leaks into the building to room temperature. Infiltration loss is affected by the volume of outside air that leaks through cracks, crevices, doors, windows, and so forth, and the temperature difference between the inside and outside air. Infiltration heat losses also include the heat required to warm the outside air used for ventilation.

A system must compensate for heat losses. We require adequate design and operation for heating systems. The heat released by people, lights, and machinery does compensate for some of these heat losses.

You recall that the greater the heat load, the more fuel it takes. There is no direct relation to transmission heat loss and infiltration heat loss from combustion. They do have a proportionate bearing on the amount of fuel consumed.

Self-Test Questions

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

609. Combustion air requirements and heat loss

1. Why does excess air represent a loss of heat?

2. What does the amount of excess air depend on?

3. What determines the minimum amount of excess air required?

4. How is combustion controlled?

5. What are the three subclasses of stack loss?

6. What is the approximate percentage of heat loss that occurs due to smoke?

610. Combustion concepts and causes of problems

Now we will talk about combustion and some common problems with combustion. We will cover combustion on oil fired equipment and discuss problems such as air-fuel distribution and over-fire draft conditions. We conclude this lesson with combustion efficiency on gas burners.

Combustion on oil fired equipment

Smoky combustion means poor burner performance and fuel waste. A degree of smoke can identify two main problems that affect the performance of an oil-fired system. First excessive smoke is evidence of incomplete combustion of the fuel. While this is an extreme condition, fuel waste up to five percent is not unusual. In a general way, the amount of heat lost because incomplete burning of fuel is small with light smoke, and the fuel waste increases as the smoke density increases.

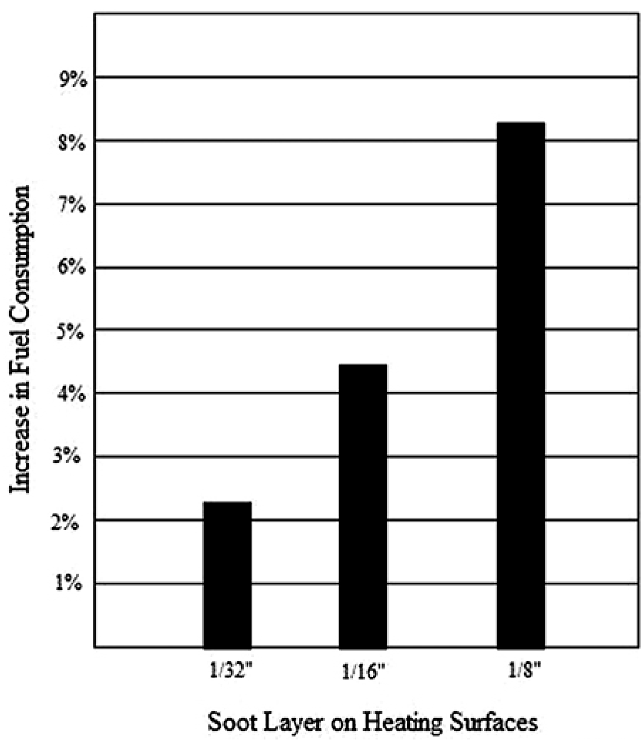

Figure 2–4. Effect of soot on fuel consumption.

Second excessive smoke results in a rapid deposit of soot on the heat absorbing areas of the furnace or boiler. Soot insulates these surfaces, prevents proper absorption of heat, results in higher flue gas temperatures, and increased heat loss to the flue. For all practical purposes, it would be as sensible to cover the heat absorption surfaces with a layer of insulating material as to tolerate accumulation of soot on these surfaces. A soot deposit $^1/_8$-inch thick may increase fuel consumption by approximately

8.2 percent (fig. 2–4). Notice that the difference from the second column to the third column is only 1/16 of an inch. Now, take the difference of the two values: 8.2 percent minus 4.4 percent = 3.8 percent. In this case, 1/16 of an inch of soot increases fuel consumption 3.8 percent, which is not efficient at all. Add the excessive maintenance and service costs caused by smoking combustion and the inferior burner performance it is easy to understand that clean combustion is a matter of substantial importance to Air Force installations.

Before defining excessive smoke, it is necessary to have a way of measuring smoke. A smoke tester shown in figure 2–5 does one type of measurement. With this method, smoke-laden flue products draw through an area of a standard grade filter paper. The color of the resultant smoke stain on the filter paper matches to the closest color spot on the standard graduated smoke scale. Extension laboratory and field tests have resulted in the recommendations shown in figure 2–6. These recommendations define the degree of soot build up and fuel waste at various smoke densities covered by the smoke scale.

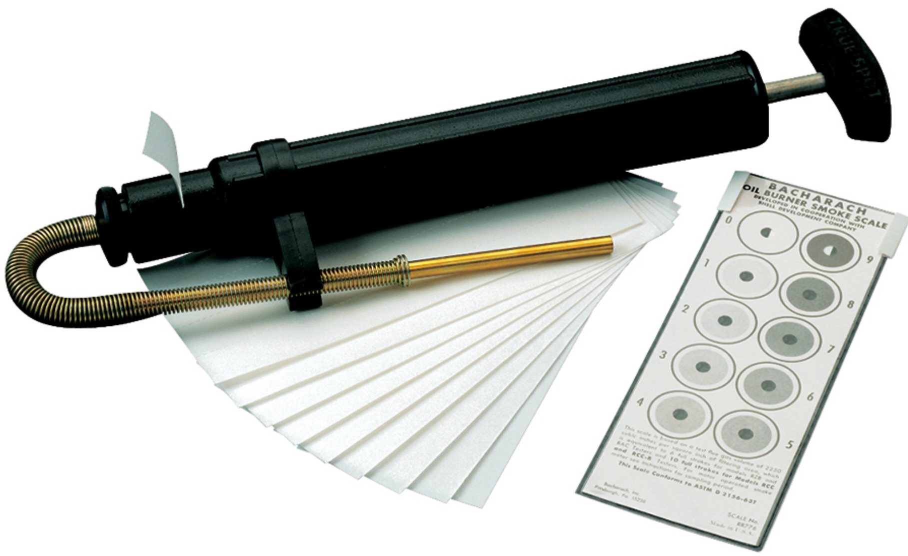

Figure 2–5. Smoke tester. (Reprinted by permission.)

The recommendations in the table have resulted from experimental testing by oil producers and burner manufacturers using the smoke tester previously described. No testers are the same. Always use common sense and manufactures’ instructions (fig. 2–6).

Effect of Smoke on Burner Performance		
Smoke Scale No.	Rating	Sooting Produced
1	EXCELLENT	Extremely light, if at all
2	GOOD	Slight sooting which will not increase stack temperature appreciably
3	FAIR	May be some sooting but will rarely require cleaning more than once a year
4	POOR	Borderline condition. Some units will require cleaning more than once a year
5	VERY POOR	Soot rapidly and heavily

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Figure 2–6. Effect of smoke on burner performance.

While the absence of smoke as indicated by the color of the smoke spot on the filter paper does prove clean combustion, it does not necessarily mean efficient combustion. As a rule, with pressure gun burners, increasing combustion air reduces smoke, but it also reduces the percent CO_2. Therefore it is quite important to check CO_2 as well as the smoke in the flue products.

Routine adjustment involving little expense may be enough. On the other extreme, it may be necessary to completely rebuild and "modernize" the installation. Reaching such a decision takes a thorough knowledge of the factors of poor combustion; the text covers these factors next. In all cases, you must use complete combustion testing procedures. Proper analysis of the problem is nearly impossible without the basic measurements of CO_2, flue gas temperature, draft, and smoke.

Causes of smoky combustion on oil fired equipment

Finding mechanical defects responsible for excessive smoke simplify to some degree by considering the four basic smoke producing combustion zone conditions. The combustion zone is composed of the space within which vaporization and burning of the oil should be complete. The combustion zone of a pressure gun burner is the space within the combustion chamber and, in some cases, a small volume above it. The basic combustion zone conditions that prevent clean, efficient combustion are listed below in the following list:

- Insufficient combustion air applied to the flame to permit clean combustion at acceptable combustion efficiency.
- Non-uniform delivery of fuel and/or combustion air to the combustion zone.
- Insufficient temperature in the combustion zone to permit proper vaporization and burning of the oil.
- Insufficient flame turbulence for the grade of oil used. In other words, this represents inadequate mixing of fuel and air during vaporization and burning.

These four combustion zone conditions apply to all types of oil burners. A common-sense examination of the burner and installation with these four combustion zone conditions in mind, usually supplies the answer. Figure 2–7 give some common causes of smoky fire.

When the main reason for smoky combustion is insufficient combustion air, the flame color usually is uniform, varying from yellow orange. The flame usually is free of sparks or streaks. Flame height commonly extends above the normal combustion zone and is of varying and irregular height.

When excessive air leaks exist in the furnace or boiler, it is impossible to increase combustion air to the flame without, at the same time, decreasing the CO_2 below acceptable limits. Seal all sources of air leakage with a good grade of furnace cement. It is also a good practice with these conditions to check the firing rate to make sure it is within the burner rating and the blower rating as well.

Causes of insufficient over fire draft

Insufficient over-fire draft resulting in deficient combustion air for clean combustion may be because the furnace or boiler flue passages may be clogged with soot or excessive baffling. These are indicated when flue draft on the furnace side of the draft regulator is to manufacturer's specification, but over-fire draft is insufficient. Where draft value is not to manufacturer's recommendation, check the adjustment of the barometric draft regulator and inspect regulators for proper operation. There should be no tendency for the draft regulator door to stick or bind. Lastly, check the flue draft between flue collar and regulator with the barometric regulator door first held open and then held closed. This check indicates a deficient or clogged stack.

If over-fire draft is adequate, inspect blower and air handling parts. Open the air shutter and if you see no improvement, inspect the blower. A corroded or clogged blower wheel or air opening may reduce blower capacity. A loose blower-motor coupling has the same effect. Figure 2–7 shows the common causes of low CO_2 and smoky fires on oil burners.

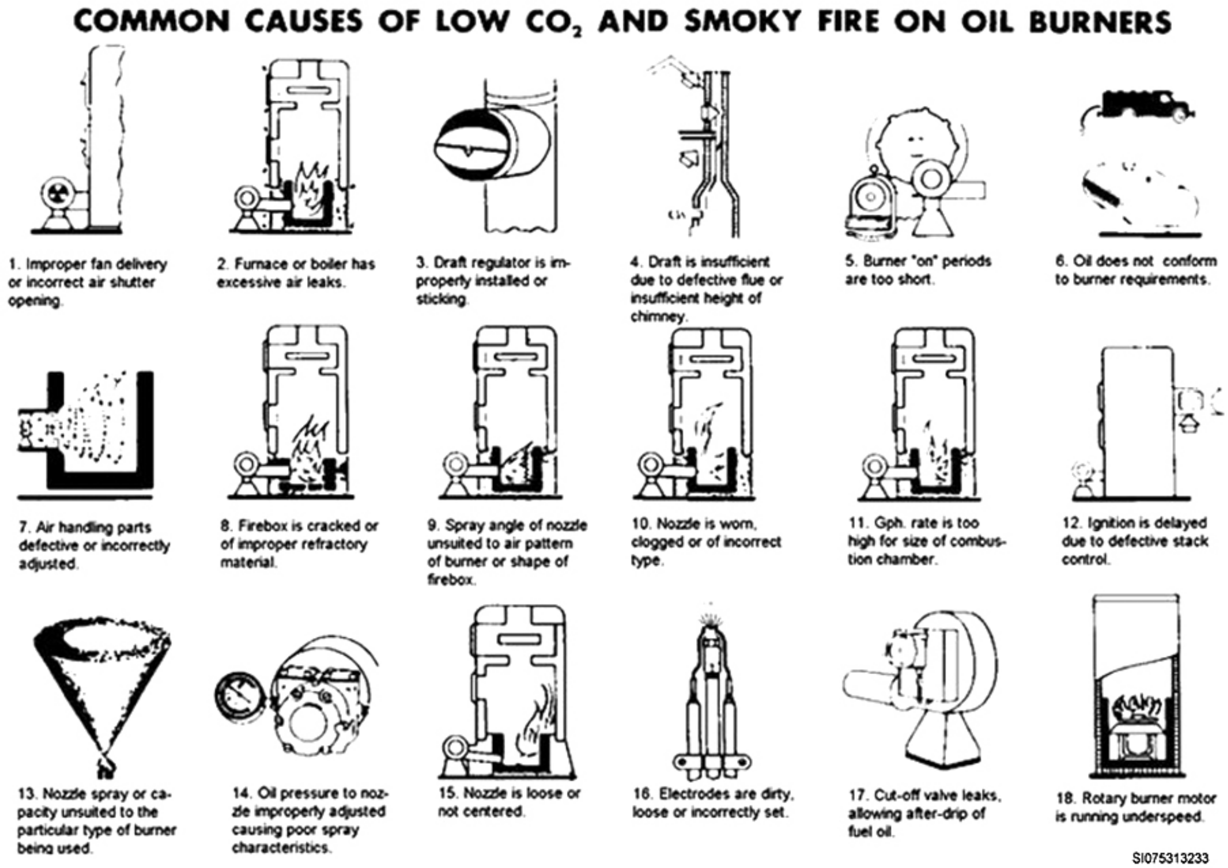

Figure 2–7. Common causes of low CO_2 and smoky fire on oil burners.

In some cases, inadequate venting to the outdoors keeps outdoor air from replacing room air supplied for combustion. The result is a negative pressure in the space from which combustion air supplies and a consequent reduction in combustion air. Check this condition with the type of draft gauge shown in figure 2–8.

Figure 2–8. Combustion draft gauge.

The importance of the barometric regulator is worth some emphasis. Too many people think all regulators do about the same job and they buy regulators largely on a price basis. It is highly important that the regulator be capable of producing a reasonably constant over-fire draft over a range of stack draft conditions.

Non-uniform air-fuel distribution

Any factor that results in delivery of more fuel or air to one part of the flame and less to some other part results in excessive smoke. As a rule, such a condition is associated with a lopsided or distorted flame shape, and there may be sparks or streaks in the flame. A partially clogged or worn nozzle or poorly adjusted electrodes can distort the atomized fuel pattern and produce this effect. Burned or warped turbulator blades can distort the air pattern with the same effect.

Fuel oil vaporizes to a gas before it can burn, and heat can to do this. Further fuel oil does not burn instantly. As the temperature in the combustion zone decreases, the speed or rate of burning decreases. It is necessary to reach and maintain a certain minimum temperature in the combustion space to ensure proper vaporization of the fuel and to make the fuel burn fast enough that combustion completes before the combustion products reach the cooler zone over the fire that will stop any further combustion.

A decided drop in smoke usually characterizes insufficient combustion zone temperature as combustion proceeds. With good operation, smoke should level off several minutes after combustion starts and the difference between starting smoke and smoke 5 or 10 minutes after combustion starts should not be more than one or two smoke numbers on the smoke scale.

Nozzle spray pattern

Match the flame shape produced by the combination of nozzle type and air pattern to the combustion chamber shape. Excessively under firing in a given combustion chamber results in lower combustion zone temperatures.

Length of firing periods

Since an appreciable interval elapses in most cases between the start of a firing period and the time when combustion space reaches proper temperature, firing periods *must not* be of too short a duration. For pressure-gun burners, most authorities agree that a given firing period should not be less than 5-minutes duration. For this reason, an extremely close thermostat setting such as one desirable for continuous air circulation is not practical for oil burners. A setting of 2°F thermostat differential is usually satisfactory. Figure 2–9 shows the relationship between “on and off” cycling of an oil burner and overall efficiency of a heating plant.

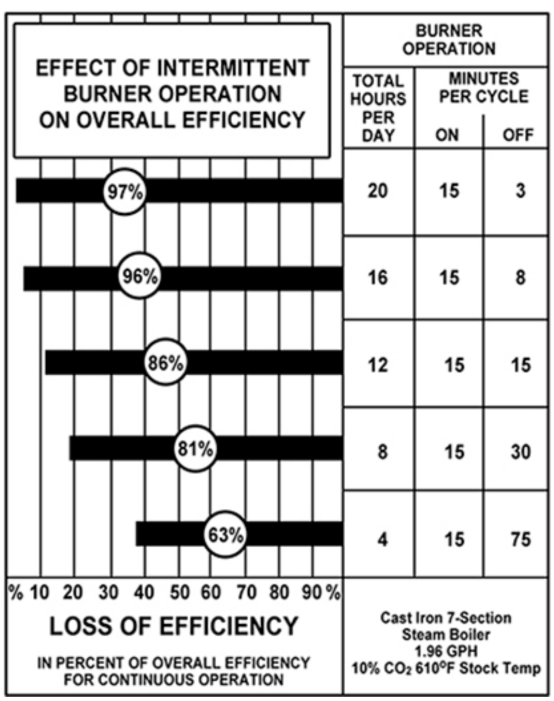

Figure 2–9. Relationship between intermittent operation and overall efficiency.

Clean combustion of fuel oil is impossible without some flame turbulence. This turbulence is essential to mix properly the gasified fuel oil and air before and during combustion. How much turbulence needed depends largely on the grade of fuel used. A pressure-gun burner achieves flame turbulence by causing the air to whirl as it leaves the gun tube. A combination of an air turbulator and an air cone does this. Burned or warped turbulator blades can prevent sufficient flame turbulence for smoke-free combustion. Improper positioning of the turbulator to nozzle can reduce flame turbulence, causing a smoky fire.

Starting and after-fire smoke

It is a common experience with pressure-gun burners to find oil discharging from the nozzle after the burner cuts off. Since the only combustion air in this case is supplied by natural draft, the after-fire oil burns with an insufficient amount of combustion air and almost no flame turbulence. After-fire smoke can be a serious source of furnace soot build up. Air trapped between the pressure cutoff at the pump and the nozzle can produce this condition as well as a leaking pressure cutoff. A loose nozzle also can cause after-fire smoke.

Use of a small solenoid-type valve in the oil line to the nozzle and with electrical connection wired in parallel with the burner motor is one foolproof way to eliminate after-fire discharge of oil. It is a decided advantage to use a solenoid valve having a delayed opening feature since this lets the blower come up to operating speed before oil is delivered. The use of a delayed opening oil valve can reduce starting smoke.

Flame impingement

Flame impingement on any cool surface will result in smoke, for the flame chills at the point of contact and further combustion ceases at that point. In effect, then, flame impingement results in a cooling of the flame at that point in the combustion zone. Causes of flame impingement in a pressure-gun burner are over firing, wrong oil spray pattern (nozzle), defective or partially clogged nozzle, improperly set electrodes, oil pressure too low, and improperly positioned burner with respect to combustion chamber.

Combustion efficiency on gas burners

Any heat in the flue gases at the sampling point represents waste to the stack. See figure 2–10 for an example of checking flue gas temperature. The higher the temperature of these flue gases the greater the loss of heat that has not been absorbed by the heat exchanger. Further these flue gases do not cool below boiler room air temperature; so that the difference between the actual flue gas temperature and boiler room air temperature (net flue gas temperature) represents a measure of the usable heat lost in the chimney.

Figure 2–10. Checking flue gas temperature/efficiency on gas installation. (Reprinted by permission.)

Percent combustion efficiency is an index of the useful heat obtained from the gas burned—expressed in percentage of the total heat produced by the burning of the gas, assuming complete combustion with no excess air. For example, a combustion efficiency of 60 percent means that the furnace has absorbed 60 percent of the total heat input. Percent stack loss is an index of the heat which, instead of being absorbed by the furnace, is wasted in the hot flue gases. Percent stack loss is obtained by subtracting the percentage of combustion efficiency from 100 percent.

A word of caution seems desirable at this point. The stack loss percentage is not a measure of what can be saved by readjustment of the equipment since the flue gases (including the amount of excess air necessary to safeguard against forming carbon monoxide) must still be allowed to escape. Further, do not confuse combustion efficiency with overall efficiency of the furnace, which must include allowance for radiation and miscellaneous heat losses.

As percent CO_2 decreases and stack temperature increases, the heat wasted to the stack increases and combustion efficiency decreases. With ultimate CO_2 (no excess air) and flue gas temperature at boiler room temperature, all available heat has been extracted and combustion efficiency would be 100 percent. Gas-burning equipment of the older models that do not have the high efficiency burners should always be capable of 75 percent combustion efficiency. Newer models have an efficiency rate in the 90 percentile. Any higher than 80 percent efficiency on the older models may cause a corrosive moisture condensate in the flue or chimney, or, at an extreme, may result in incomplete combustion.

Self-Test Questions

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

610. Combustion concepts and causes of problems

1. What effect does smoky combustion have on burner performance and fuel consumption?

2. What effect does excessive smoke have on the heat absorbing areas of a furnace or boiler?

3. What is completed in the combustion zone?

4. What indicates that the flue passages are clogged with soot?

5. What effect could a clogged blower wheel or air opening have on blower capacity?

6. What effect do burned or warped turbulator blades have on the air pattern?

7. What happens to rate of burning as the temperature in the combustion zone decreases?

8. What does burned or warped turbulator blades prevent from happening?

9. What is an effect of a loose nozzle?

10. What are causes of flame impingement in a pressure gun burner?

11. What could result from older models achieving higher than 80% efficiency?

611. Combustion analysis

Now that you have combustion concepts down let's take it to the next level. This lesson will not cover the steps of combustion analysis, but it will cover the purpose of the analysis and the concepts of the three tests that are required—a visual analysis, the smoke test, and the analysis that is performed with the digital combustion analyzer. The steps will be covered in the burner operational test section.

Visual analysis

An efficient fire is fairly clear, not dark and smoky. The flame is long, billowing, and lazy, and obtained by using a low furnace draft, but it is not long enough to enter the flue. The ideal fire does not cause carbon in the furnace, soot on the heating surfaces, or smoke from the stack. An experienced technician learns how to keep the correct ratio of air to fuel to get maximum efficiency from the firing equipment and knows the appearance of an efficient oil or gas fire.

Oil fire

An efficient oil fire has a clear, yellowish flame. The fact that the flame does not have much smoke is one indication that you have the proper fuel-air ratio. A red flame with smoky tips indicates too little air. A short, white flame indicates too much air. You may see a trace of smoke immediately after the oil ignites, but it soon disappears if the burner is set correctly. Unburned particles of fuel, called sparklers, at the edge of the flame indicate poor air distribution and improper combustion. The burner air registers control the shape of the flame. Dampers or fan speed controls the flow of air to the flame. To assure compliance with operating instructions, make a combustion analysis of the flue gas after you have observed the condition of the flame.

Gas fire

A gas flame is blue with yellow tips. With too little air, the flame is long, straggling, and yellow. With too much air, the flame is short, noisy, and tends to pull away from the burner. The flame should be stable and should not strike the burner tiles, walls, or boiler tubes. Burner air registers control the shape of a gas flame, like the shape of an oil flame. Dampers or fan speed controls the flow of air to the flame. When you have watched the condition of the adjusted flame, make a combustion analysis of the flue gas to ensure efficient operation and compliance with operating instructions.

Smoke

As we said earlier, an efficient fire is fairly clear, not dark and smoky. If there is smoke, you may have improper combustion. Black smoke shows that there is not enough air. White smoke shows that there is too much air. A light-brown, hazy smoke shows that the air-fuel ratio is about right for oil and coal. When you are burning natural gas, there is no haze with proper combustion.

Smoke test

After you make your visual analysis, you will perform a smoke test. The smoke test is another method of combustion analysis. In short, a sample of flue gas is taken and it stains a filter paper. The paper is then compared to other predetermined samples to determine the amount of smoke you have in your system.

The reason for this test is twofold. The first reason is that the formation of smoke represents incomplete combustion and can cause soot buildup in the heat exchanger. Soot buildup leads to a decrease in heat transfer in the heat exchanger. The second reason for this test is to get the smoke levels within a reasonable range before performing an analysis with a digital analyzer. Smoke and soot decreases the lifespan of digital analyzers. The smoke test provides more of a rough adjustment for the system while the digital analyzer is more of a fine tuning adjustment. Some manufacturers have a standard smoke test number that must be reached before using their digital analyzer in the system. This must be followed to preserve the life of the analyzer.

Combustion analyzers

Before we get into interpreting the combustion analysis we'll take a brief look at combustion analyzers. Since there are more than one brand and design of combustion analyzers in existence we will only cover the general facts and capabilities of digital combustion analyzers. One type will be referenced in the images to help you make the connection as you read. See figure 2–11 for an example of what one type of digital combustion analyzer looks like.

Figure 2–11. Combustion analyzer. (Reprinted by permission.)

Most analyzers are handheld, battery operated with an easy to read display and powered with AC. The size of this tool makes it easy to carry in the truck and to the job site.

There is a port where a thermocouple attaches; this thermocouple gives you the temperature of the flue gas. Modern analyzers can automatically subtract the ambient temperature from the stack temperature to give the technician the *net stack temperature.*

There is also a port located on the analyzer for the gas to enter. The gas arrives at the port via a probe and gas tube. The probe is placed in the stack; flue gas enters the probe and travels through the tube, then travels through a filter assembly and finally arrives at the gas port. Inside of the analyzer, a computer will analyze the gas and produce numbers on the screen for the technician to use.

SAFETY: The probe that enters the stack is exposed to high temperatures. Use the handle to control the probe and do not touch the probe until it has cooled down.

If the analyzer you are using comes with a carrying case, be sure to use it. This will help protect the analyzer and prolong its life and usefulness.

Analyzers should have multiple fuels to select from. Common fuels you will see in the Air Force are natural gas, light oils, butane, and propane. If charged with selecting a digital analyzer for your shop, ensure you get one that will analyze the fuels you have at your base.

The brains of the analyzer are internal. You will find CO and O2 sensors along with circuit boards that contain the software inside modern analyzers. This is where the analyzer takes inputs and produces outputs which eventually are shown on the screen.

Some models may have a USB port or even an app that allows you to transfer information from the analyzer to your personal computer or laptop. Why would an app be needed for your job? Well, a thorough and professional technician could perform a combustion analysis and send the results to the customer's email via the app. Imagine how impressive and in-touch with technology you would appear to your customers.

What does the combustion analysis mean?

Here we will interpret the results a combustion analysis gives. There are numerous readings and tests you can perform to determine the efficiency of a combustion. In addition, to the visual analysis and the smoke test, there are efficiency percentages, carbon dioxide, oxygen, carbon monoxide, percent excess air and stack temperature readings that are taken with a digital analyzer. In the past, these tests were performed by separate pieces of equipment but the digital analyzer relieves us of that issue and helps speed up the process. These readings will be discussed in the following paragraphs.

Carbon dioxide (CO2)

This measurement will be given as a percentage. It is a percentage of the total flue gases being measured. For example, an analyzer reading of 8% means the carbon dioxide makes up 8% of total flue gases.

So what is a "good" CO2 reading? Well, the maximum reading for natural gas is 11.9%, for LP gas it is about 13.9%, although these numbers are under perfect circumstances. In reality, we need excess air for complete combustion. This excess air dilutes the amount of CO2 we can have in a combustion analysis. There is not one specific number that CO2 needs to be but in general: 7.6% for natural gas and 8.9% for LP gases is the range. Always refer to the manufacturers specifications for design numbers.

According to the Boiler Efficiency Institute, oil furnaces will vary between 4.5% and 15.6% CO2. Again, refer to the manufacturer's manual for specific amounts for each piece of equipment.

There could be numerous issues causing improper CO2. Low CO2 means there is incomplete combustion. This is caused by too small of a burner nozzle, air leaking in the heat exchanger, or under firing. To high of a CO2 reading is caused by insufficient draft and over firing. There are multiple reasons CO2 readings can be off. This CDC could not possibly cover every piece of equipment and every installation. Your on-the-job training will have to provide you with additional experience and knowledge so get with your supervisor and make him/her teach you!

Oxygen content

Oxygen is brought in through the air needed for combustion and is provided as a percentage. If oxygen is too high, it may be an indication that too much excess air is being brought in. It could also mean that there is too much fuel being supplied. The average oxygen percentage is 7.5% for natural gas and LP gases.

Carbon monoxide

In short, an excessive amount of carbon monoxide read by the analyzer means there is incomplete combustion. Carbon monoxide will be given in parts per million. The maximum parts per million that the American National Standards Institute allows is 400. The manufacturer will specify the amount of ppm for their equipment.

As stated, you must make sure the products of combustion do not contain carbon monoxide. It is possible with conversion burners and gas-designed equipment (if over-fired) to have flame impingement on cold surfaces which results in CO even if excess air, CO_2 and O_2 are within acceptable limits.

Even if carbon dioxide and oxygen correct, if there is carbon monoxide present then combustion is not complete.

Percent excess air

The amount of excess air varies by the type of fuel used and the construction of the equipment. This number may vary from 5% to 50% of the theoretical air. Manufacturers will provide this number for their specific piece of equipment.

Let's look at an example, the manufacturer for your piece of equipment says 15% excess air is required. You take a reading with your digital analyzer and get 15%. This tells you the excess air is correct.

What if you obtained a reading of 30% though? This would mean there is too much excess air. Too much excess air results in *high stack temperatures* and creates a *reduction* in combustion efficiency. With more excess air, heat energy from the combustion process is used to heat the air that came from the room. This is the reason excess air reduces efficiency, but don't forget that excess air is still necessary for complete combustion.

If stack temperatures are too high, reduce the amount of excess air that is being supplied to bring *down* the stack temperature and bring *up* the combustion efficiency.

Net stack temperature

This is the temperature difference from the stack and the ambient temperature in the room. For example, a stack temperature of 800 degrees and room temperature of 80 degrees would give a *net stack temperature* of 720 degrees (800-80=720).

As stated in the previous sub-point, if the excess air is increased the stack temperature will increase, which in turn increases the net stack temperature. For example, there is a stack temperature of 600 degrees and a room temperature of 70 degrees. This provides a net stack temperature of 530 degrees. A technician increases the excess air and the stack temperature increases to 650 degrees. Now the net stack temperature is 580 (650-70=580).

Self-Test Questions

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

611. Combustion analysis

1. What three conditions will an ideal fire not produce?

2. What does a red oil flame with smoky tips indicate?

3. What does a short, white oil flame indicate?

4. What controls the shape of an oil flame?

5. What controls the flow of air to the oil flame?

6. What color is a good gas flame?

7. What effect does too little air have on a gas flame?

8. What controls the flow of air to the gas flame?

9. What does the presence of smoke indicate?

10. What effect does too little air have on the flame?

11. How do you determine the amount of smoke in a system?

12. Besides smoke indicating incomplete combustion, what is the other reason for the smoke test?

13. What effect does smoke and soot have on digital analyzers?

14. What device on the digital combustion analyzer gives you the temperature of the flue gas?

15. What device on the digital combustion analyzer analyzes the gas and produces information on the screen?

16. What will the carrying case of the digital combustion analyzer aid?

17. What must you take into consideration if you are charged with selecting a digital analyzer for you shop?

18. What does a carbon dioxide reading of 12% mean?

19. What is the result of flame impingement on gas fired or conversion burners?

20. What effect does more excess air heat energy from the combustion process?

21. If stack temperatures are too high, how is the stack temperature lowered and how is the combustion efficiency raised?

2–2. Gas Burner Types and Operation

Industrial or commercial are usually the identification types of fuel burning equipment. The processing of materials in production lines and manufacturing plants use industrial burners. They include cooking and baking ovens, drying kilns, and metallurgical furnaces. Use commercial burners to heat large offices or apartment buildings. They are generally found on boilers and heating furnaces. Industrial burners ignite manually or semi-automatically, while commercial burners ignite automatically. The *same* type of burner can be industrial *or* commercial depending on its application. You can use small size gas burners (less than four million Btuh—Btu's per hour) or oil burners (less than 3 gal per hr) as domestic (residential) burners.

612. Gas valves

Gas valves are up next! This discussion includes manually operated gas valves, solenoid valves, combination gas valves and smart valves. That is a lot of valves! After this lesson you should have a good understanding of gas valves. Take this information and apply it to your hands-on training.

Manually operated valves

Although most valve trains require automatic operation, the manual valve still provides convenient fuel shutoff for temporary maintenance or service. Use MSOVs in both the main and pilot fuel lines. This valve is also a plug cock because it has a tapered plug with a horizontal opening. As the manually operated handle turns the plug, gas flows through the opening (fig. 2–12).

Solenoid valves

Of the three automatic valves, the solenoid is the simplest and generally the least expensive. A controller opens the valve by running an electric current through a magnetic coil. The coil, acting as a magnet, pulls up the valve disc and allows the gas to flow (fig. 2–13).

Solenoid action provides fast opening and closing times, usually less than one second in models without a thermistor delay. The most common gas burner solenoid valves are the standard solenoid valve and the dual solenoid valve.

Standard solenoid valve

The standard solenoid gas valve shown in figure 2–12 is an electric type. It is suitable for use with gas furnaces, steam boilers, hot water boilers, conversion burners, and industrial furnaces. This valve operates when a controller such as a thermostat, pressure control, or aquastat closes a circuit to energize a coil. The energized coil operates a plunger causing the valve to open. When there is a current failure, the valve automatically closes causing the gas pressure in the line to hold the valve disc on its seat. To open this valve during current failure; it is necessary to use the manual opening device at the bottom of the valve. When electric power resumes, you place the manual opening device in its former position. When the valve opens with this manual opening device, all safety devices get bypassed. See figure 2–13 to help visualize the location of a solenoid on a gas valve. Notice in figure 2–13 that there are two solenoids. This design is discussed in the next paragraph.

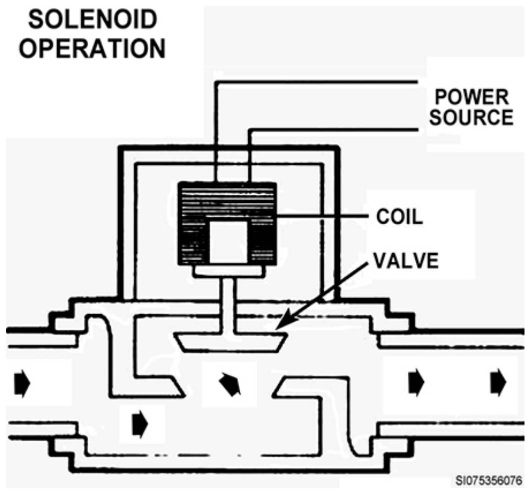

Figure 2–12. Solenoid gas valve operation.

Figure 2–13. Solenoid location on a gas valve.

Dual solenoid valve

As shown in figure 2–13, dual solenoid gas valves are designed for three-stage control (high, low, or off) of the flow of gas. To do this, use a high-fire solenoid and a low-fire solenoid in series. You could achieve the same purpose by using two separate solenoid valves and a programmer. Turn the adjusting screw clockwise (to decrease low fire) or counterclockwise (to increase it).

Diaphragm valves

Use diaphragm valves on atmospheric-type gas burners for smooth light off. These valves have a slow opening and fast closing time that depends on the amount of gas flowing over the diaphragm. The valve has a diaphragm with a weight over the valve seat. A small, internal solenoid valve blocks the gas flow to the bleed port.

When the controller is not calling for heat, the coil is de-energized. The plunger in the three-way actuator is in the DOWN position, so that the bleed port is closed and the supply port is open. Gas flows to the top of the diaphragm, while the gas pressure and the weight hold the valve closed.

On a call for heat, the controller contacts close, and the coil energizes. This pulls the plunger to the UP position, opening the bleed port and closing the supply port. The gas then bleeds off the top of the diaphragm allowing the gas pressure below to lift the diaphragm and open the valve.

When all the gas has bled off the top of the diaphragm, the valve is fully open permitting gas flow to the main burner. After the controller is satisfied, the procedure reverses. The controller contacts opens so that the coil is de-energized. The plunger releases moving to the DOWN position. This closes the bleed port and opens the supply port so that gas again flows to the top of the diaphragm. As the pressure above the diaphragm increases, the diaphragm drops closing the valve with a positive, snap action.

Diaphragm valves are quiet and have a reasonably long life. All diaphragm valves work off the same principles.

A three-way magnetic valve controls the operation of this type of diaphragm slow opening valve. This valve is equipped with a position indicator that will let you know at a glance if the valve is open or closed. It has external levers to regulate any secondary air dampers built into the burner unit. The valve will not open if the damper arm stays in the closed position. It closes even if the secondary air damper arm blocks in the open position. This diaphragm valve is used on industrial installations with 1½-inch or larger gas supply lines. Normally valves up to the 3½-inch size are the screw type. Valves four inches and larger are flanged. Even though this valve is a slow-opening valve, it will close within four to five seconds. It is suitable for use with all fuel gases and designed for an operating inlet gas pressure range of three inches WC to five psig. When installing this valve the diaphragm must be in the horizontal position for it to work correctly. The operator assembly is flange mounted on top of the valve and turned to any position in the horizontal plane to meet installation conditions.

Motorized valves

Motorized valves do two functions—safety shutoff and firing rate control. You will discuss each of the functions separately.

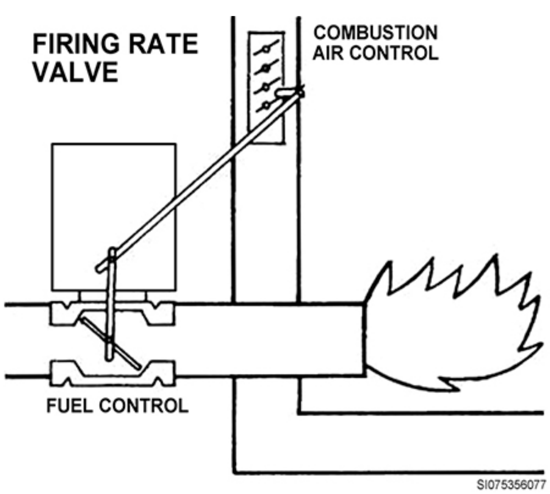

Figure 2–14. Operation of firing rate valve.

Safety shutoff valves

Safety shutoff valves are for large gas burners that require tight close off and accurate control of large amounts of fuel. Safety shutoff valves are controlled by either an "ON-OFF," "OFF-LO-HI," or a modulating actuator.

Firing rate (butterfly) valves

By controlling the amount of fuel entering the burner, this valve determines the rate of combustion or firing rate. At the same time, the valve actuator controls a damper that in turn controls the flow of combustion air to the burner (fig. 2–14).

Other names for the combination firing rate valve and actuator are burner-input control valve, combustion control valve, metering valve, modulating valve, operating valve, and throttling valve.

The butterfly valve has a rotating hinged plate that resembles the opened wings of a butterfly. This valve has a high flow capacity and relatively constant relationship between fuel flow and the angle of valve opening. This feature is useful for close modulation of air and fuel gases to large furnaces. A modutrol actuator controls the valve while simultaneously operating a combustion air damper. Together the valve and actuator provide a stable mixture of air and fuel.

Combination gas valves

Figure 2–15 shows a combination gas valve. It is a "combination" gas valve because it has a manual main valve, solenoid valve, a pressure regulator, and adjustment and safety shutoff for the pilot.

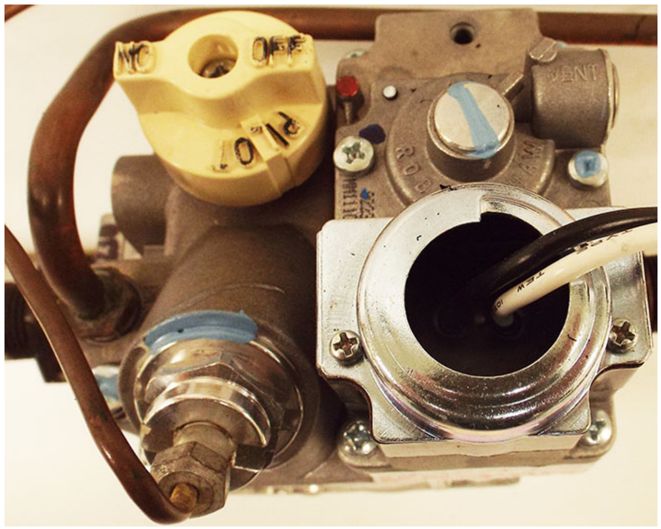

Figure 2–15. Combination gas valve.

The combination of the manual and automatic control functions are made up of this one unit required in a gas burner fuel assembly. In other words, this single unit replaces the manual gas valve, the pressure regulator, the pilotstat, the individual pilot line, and the automatic gas valve. LP gas valves will often have a separate pressure regulator.

Manufacturers of gas controls offer a complete line of electrical combination gas valves—each type designed for a particular type of application or installation. Manufacturer's valves will differ usually on the basis of the controller voltage or voltage source, valve application or function, Btu capacity required for the installation, and the type of gas used. They all operate in the same manner.

There are three main automatic combination gas valves; they are (1) standing pilot, (2) intermittent pilot and (3) the direct burner type.

Since there are so many different gas valves we will cover their general operation. Basically, the valve will receive a signal to open and close. In modern times, this signal is commonly sent from a control board. See figure 2–16 and figure 2–17. Figure 2–16 shows an orange wire and the yellow wire right next to it.

NOTE: Look inside the green circle of figure 2–16.

These orange and yellow wires are attached to the valve shown in figure 2–17. The board will close the valve when the space is satisfied or if there is a safety condition that requires the valve to be closed.

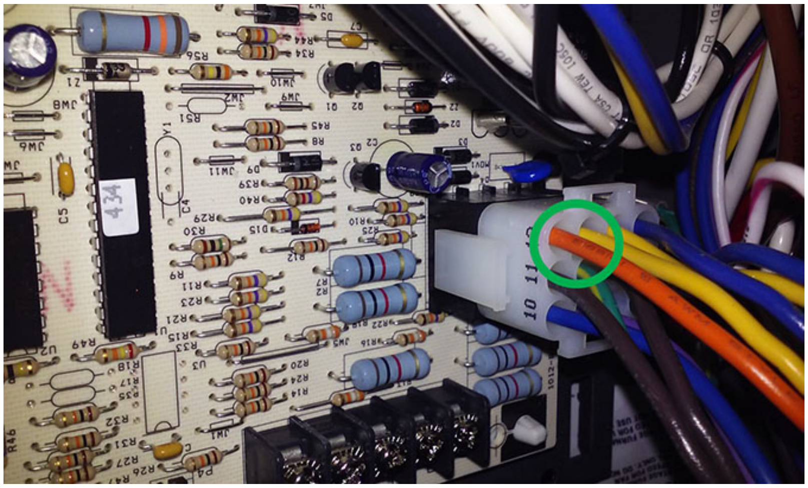

Figure 2–16. Control board gas valve connection.

Figure 2–17. Gas valve wires from control board.

As a technician, you need to know the order of operations and the relationship between the controls and the control board for the specific system you are working on. Once you are familiar with the system, you can determine when current will be sent from the board to the valve and when it is not. This is vital to you working with gas valves.

Smart valves

This type of valve consists of the gas valve and an electronic control module combined. The electronic control module is the "brains" of this device and it operates the system using its logic. The logic will light a 24 volt hot surface igniter. Once the flame is proved the electronic fan timer is energized. This timer determines when the blower fan comes on or off.

This valve is simple to troubleshoot because of the way the connections are made. You will start to see more of these valves in the field.

Self-Test Questions

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

612. Gas valves

1. Where should MSOV's be used?

2. What valve should be used if fast opening and closing times are required?

3. How is a solenoid coil energized?

4. How is the position of a slow opening diaphragm valve determined?

5. What is the relationship of a butterfly valves' fuel flow and angle of valve opening?

6. When will you be able to determine when current is being sent from a circuit board to the valve?

613. Functions of gas burners

The functions of gas burners vary. You must understand the functions of each gas burner in order to relate these devices to the rest of the heating systems. Let's start by listing the functions.

Functions

All burners must be able to do the following functions:

- Deliver fuel to the combustion chamber.
- Deliver air to the combustion chamber.
- Mix the fuel and air.
- Ignite and burn the mixture.
- Remove the products of combustion.

Regardless of the type of fuel used, the burner must do all five functions. In the case of liquid and solid fuels, the first function also includes preparing the fuel so that it burns. Classification of burners usually is based on the means of doing one or more of the burner functions. At times, a combination type burner will describe a burner completely. Classifications used in these lessons are typical; although you may encounter others.

Delivering fuel to the combustion chamber

Gas may be blown into the combustion chamber, pulled in (aspirated) by high velocity air, or permitted to escape into the chamber under its own distribution pressure. The delivery of gas under its own pressure is widely used. Additionally a pressure-regulating valve (PRV) in the gas supply line controls the amount of gas that escapes into the combustion chamber. An orifice or by a manual valve in the gas line controls the gas flow.

Gas distribution gauge pressures at the burner vary from a few ounces per square inch gauge (osig) to as many as 50 pounds per square inch gauge (psig). The pressure is generally classified as low, intermediate, or high. The following list provides an explanation of the differences in the three:

- Low—2 to 8 osig
- Intermediate—8 osig to 2 psig
- High—2 to 50 psig.

When the gas distribution pressure is high, many burners can be satisfactorily adapted to a wide range of capacities by installing different sizes of gas orifices. Another advantage of high-pressure gas is that smaller orifices may be used. Smaller orifices and higher gas velocities develop higher burner-head pressures that give greater working range or turndown range. A turndown ratio of about 5:1 is usually required. For higher ratios, several small burners are an option rather than a single large burner, this allows some burners to turn off.

Fuel delivery is horizontal or vertical. The terms are in relation to the combustion chamber. A horizontal flame is an *inshot burner* (fig. 2–18). A vertical flame is an *upshot burner* (fig. 2–19).

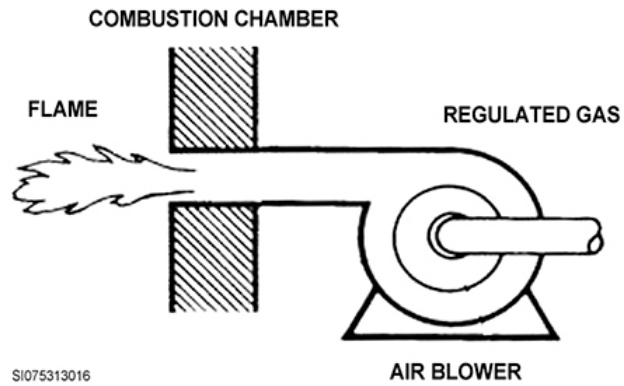

Figure 2–18. Typical inshot burner.

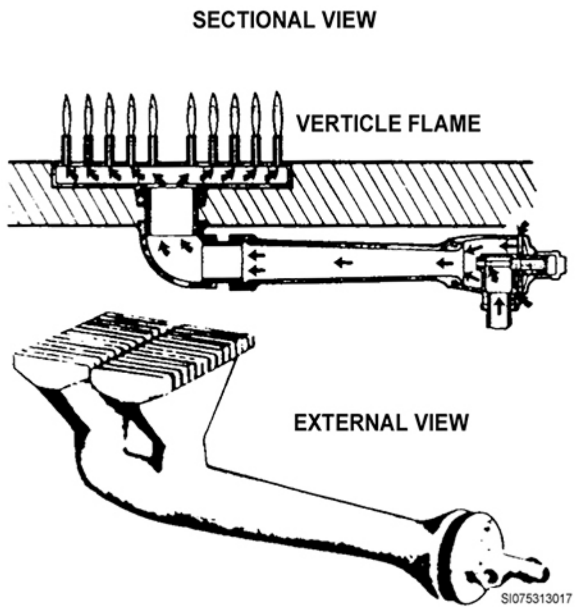

Figure 2–19. Typical upshot burner.

Delivering air to the combustion chamber

A gas burner may simply rely on atmospheric pressure to bring in combustion air, such as with an atmospheric burner. Machinery can also bring in combustion air, such as with a mechanical-draft burner, or power burner. The third method is known as a pulse-burner and introduces the gas and air in operating phases through flapper valves. These three delivery types are discussed further in this lesson.

Atmospheric burners

An atmospheric burner simply permits the air required for combustion to enter the combustion chamber, or the burner draws air into the combustion chamber from the area surrounding the burner. Two methods are used to draw air into the combustion space—natural-draft or inspiration. A typical atmospheric burner combines both methods.

A natural-draft burner (fig. 2–20) depends on the products of combustion escaping up the chimney or stack to pull in secondary air. The taller the column of hot stack gases, the greater is the natural draft.

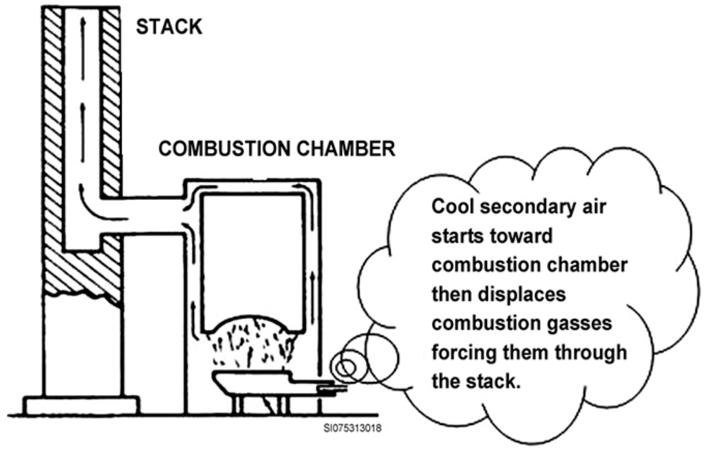

Figure 2–20. Natural-draft burner.

An inspirating burner (fig. 2–21) uses venturi action to bring in primary air. Fuel gas escapes into the constricted throat of a venturi tube. The constriction increases the gas velocity, which lowers the pressure in the throat of the tube. The slight vacuum that's developed in this process draws air into the tube. The amount of air entrained increases as the gas pressure and velocity increase. Large industrial and commercial burners require high gas pressures. Venturi mixing is another name for inspirating burner.

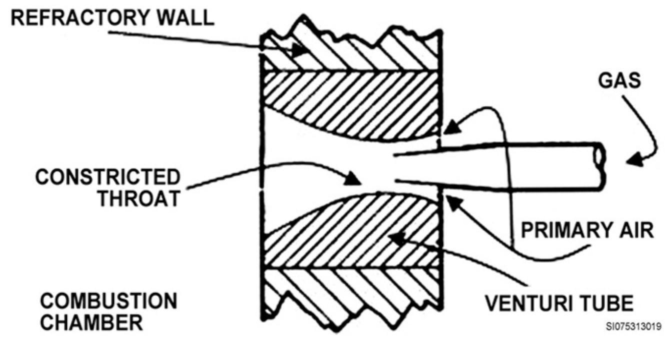

Figure 2–21. Inspirating burner.

Mechanical-draft burners

A mechanical-draft burner or power burner uses machinery to deliver air to the combustion chamber. Two general methods are used—forced draft or induced draft.

Forced-draft burner

A forced-draft burner (fig. 2–22), commonly called a power burner, uses a motor-driven fan or blower at the inlet of the combustion chamber to blow air into the combustion chamber. If required, this burner can provide more air by natural draft or by venturi action. Many of the larger industrial and commercial burners are power burners.

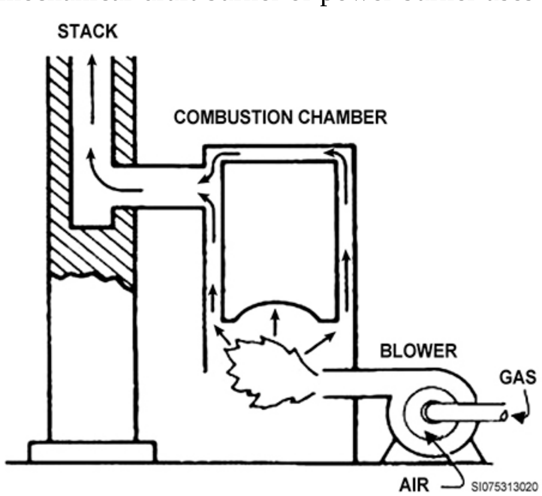

Figure 2–22. Forced-draft (power) burner.

Induced-draft burner

An induced-draft burner (fig. 2–23), uses a motor driven fan or blower at the outlet of the combustion chamber to create a slightly partial vacuum within the chamber. This process causes a suction that draws in air.

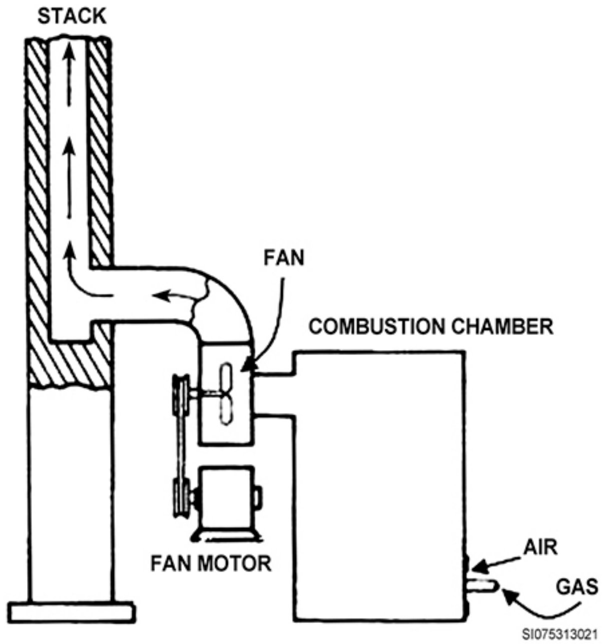

Figure 2–23. Induced-draft burner.

Fan mix burner

A variation of this method is the fan mix burner (fig. 2–24), in which the fan is not motor driven and is located at the inlet to the combustion chamber. A mechanical coupling attaches the fan to a propeller like blade. The burner is mounted on a free-spinning shaft, with the edges of the blades having orifices drilled into them. High-pressure gas (10 to 50 psig) escaping into the combustion chamber through the orifices causes the blades to spin. The spinning blades rotate the fan that draws in air.

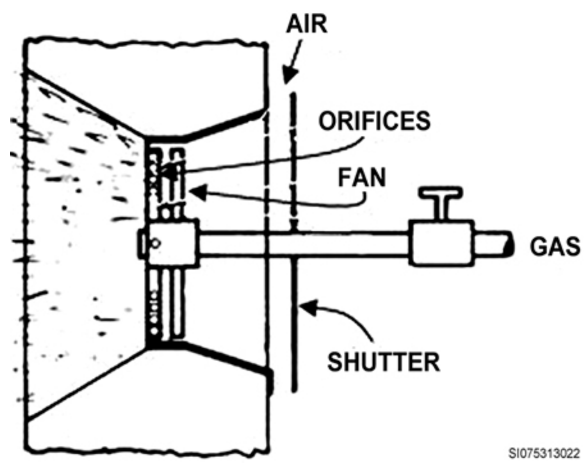

Figure 2–24. Fan mix burner.

Pulse-burners

In the first two types of gas burners, the steady flow of gas and air enables them to operate continuously. The design of a pulse burner introduces the gas and air in the following three operating phases (fig. 2–25).

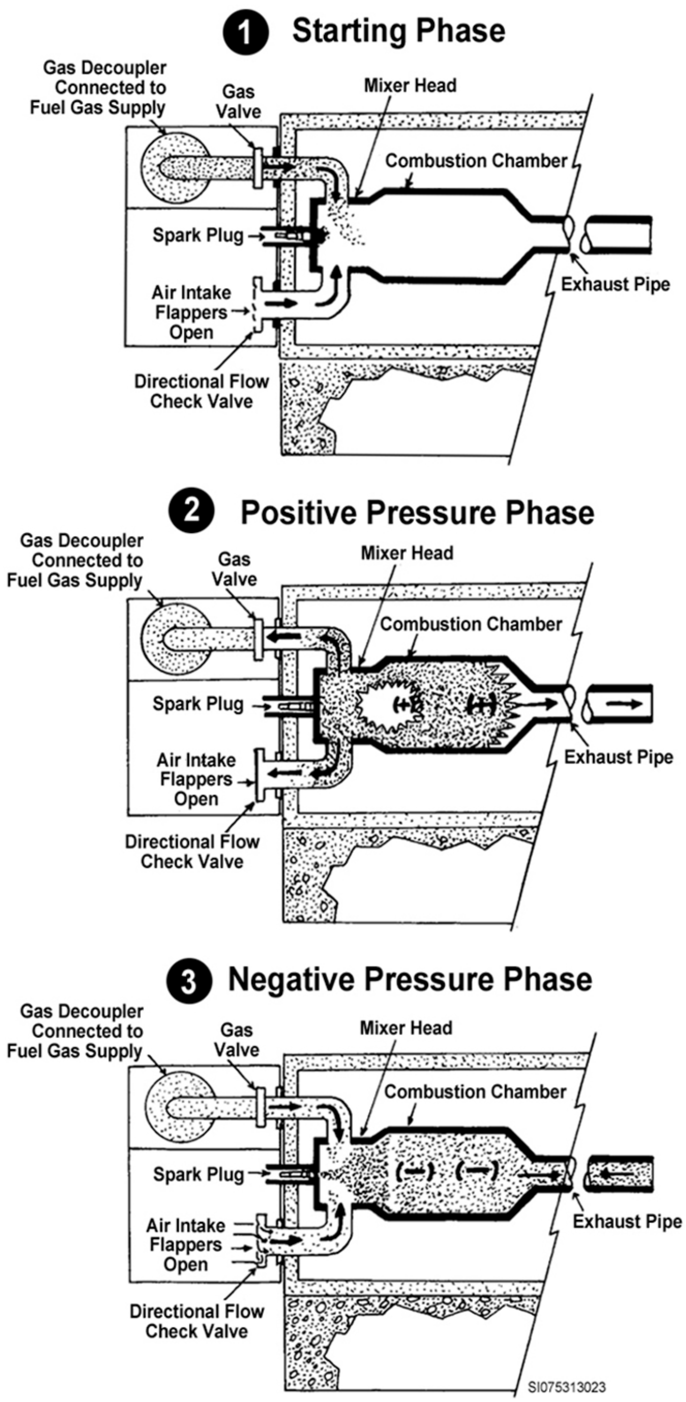

Figure 2–25. Pulse burner.

- Phase 1, (starting phase)—a charge of gas and air enters through flapper valves into a burner/heat exchanger sized and shaped as a Helmholtz resonator that oscillates at a suitable frequency. The charge ignites (first by electric spark).
- Phase 2, (positive pressure phase)—the pressure increases and closes the flapper valves. The hot gases drive out the open end of the burner, and the outward momentum of the hot gases causing the pressure to drop below atmospheric pressure (positive pressure phase).
- Phase 3, (negative pressure phase)—the flapper valves are then sucked open to admit a fresh charge (negative pressure phase), and the cycle repeats at a natural frequency that depends on the geometry of the pulse combustor. This is just the basic operating principles of a pulse-burner.

Closed and open burners

The amount of combustion air supplied through the burner, gives rise to more terms regarding the delivery of air.

A closed or sealed-in burner mounts on a furnace in an airtight manner so all of the air required for combustion travels through the burner. This permits accurate control of the air-fuel ratio, wide range of furnace operating pressure, and a wide range of firing rates (turndown).

An open burner has an opening around it so secondary air can enter the combustion chamber. Open burners permit greater capacities by virtue of this added air. However, a correspondingly larger fuel capacity must also be available.

Many burners have an air register around them with an adjustable shutter to permit operation as either an open or closed burner. The shutter adjusts to control the volume of secondary air, see figure 2–25.

Mixing the fuel and air

One method of classifying gas burners is according to where the gas and air are mixed. In premixing gas burners, gas and primary air mixes *before* they reach the burner port(s).Partial-premix burners require secondary air. As the name implies, in nozzle-mixing gas burners, the gas and air are keep separate within the burner itself, but the nozzle orifices provides rapid mixing of the fluids as they leave. In delayed-mixing gas burners, the rate of mixing the gas and air is very low so that they travel a considerable distance from the burner before mixing and burning.

The thoroughness of mixing determines largely on the characteristics of the flame. Turbulence and high velocities result in good mixing, that produces a short bushy flame. Delayed mixing and low velocities produce a long slender flame.

Several types of burner names come from the manner that they mix gas and air. These are premixing, nozzle mixing, and delayed-mixing gas burners.

Igniting and burning the fuel-air mixture

A small gas burner called a pilot ignites large industrial and commercial gas burners. A continuous pilot (constant, standby, or standing) burns without turndown through the entire time the burner is in service, whether or not the main burner is firing. An interrupted pilot (ignition pilot) automatically turns on each time there is a call for heat, and automatically cuts off at the end of the main burner flame-establishing period. An intermittent pilot automatically turns on each time there is a call for heat and maintained during the entire run period. It shuts off with the main burner at the end of heat demand.

In a manually ignited burner, ignition is under the supervision of an operator. In an automatically ignited burner, fuel is automatic; it does not require the presence of an operator. An automatic burner starts, runs, and stops automatically, while a semiautomatic burner requires some manual operations—starting, igniting, and stopping.

NOTE: Approval agencies definitions vary; refer to the specification/standard for the particular agency.

Both types are purged, sequenced, and modulated automatically, with certain steps and conditions supervised by safety interlocks. Industrial burners are usually semiautomatic (or manually ignited), while commercial burners are usually automatic. Regulation of the primary and secondary air controls the flame characteristics.

Rich mixtures (too little air) do not burn completely until secondary air mixes completely with the fuel. A rich mixture results in a long, cool, yellow flame. Lean mixtures (too much air) burn more rapidly than perfect mixtures because they produce a higher flame propagation rate. However, the excess air decreases the efficiency of the burner because the rapid burning allows too much heat to escape up the stack. A lean mixture results in a short, cool, blue flame.

Removing the products of combustion

The products of combustion will move from the combustion chamber because of supplying combustion air. In review, these methods include the following:

- Natural draft—products of combustion escape up the chimney or stack and pull in secondary air.
- Inspirating—venturi action brings in primary air that mixes with the gas and displaces the products of combustion.
- Forced draft—a fan or blower blows air into the combustion chamber that forces out the products of combustion.
- Induced draft—a fan or blower creates a suction that draws in air and removes the products of combustion.

Other factors affecting gas burner design

In addition to the five basic functions just discussed, several other requirements may affect the design of gas burning equipment. A few requirements may be (1) modulation of burner input to match load, (2) prevention of flashback, and (3) provision of smooth ignition.

Modulation of burner input to match load

In many cases, it is desirable to modulate the fuel input to the burner. This is in response to changes in load. To maintain efficiency under modulating control, it is necessary to modulate the fuel and air supplies simultaneously. The range of firing rates over which satisfactory combustion covers refers to the turndown range of the burner. Modulation may be continuous throughout this range, or it may involve only high and low fire positions. You use several means to get modulation, five of those means are provided in the following list:

1. Simultaneous adjustment of the air register or draft damper and the gas valve—it usually is difficult to obtain a wide range of turndown by this means, chiefly because of the nonlinear characteristics of dampers and valves.
2. Varying the gas pressure—this is particularly effective where all air for combustion is inspirated in a venturi section by the energy of a high-pressure gas stream. It is also effective in other atmospheric burners.
3. Varying the air pressure—this means provides a large turndown ratio in aspirating type burners where the gas entrains by the high velocity air stream.
4. Proportional mixing in a blower—a large turndown ratio can be obtained by this means with units having specially designed air and gas valves controlling fuel and air input to a mechanical blower.
5. Varying the gas pressure to change the speed of a gas-driven fan that is inducing air for combustion (fan mix burner).

Prevention of flashback

Valves and premixing burners are subject to flashback under some conditions. Flashback occurs when the velocity of the air-gas mixture through the burner ports is less than the flame propagation rate. It often occurs at minimum firing rates. Flashback may also result from—low gas pressure, leaking gas valve, lean gas-air mixture, burner ports or pipes too large, excessive temperature of the gas-air mixture, excessive temperature of the burner ports or pipes, insufficient draft, and insufficient combustion space.

Provision of smooth ignition

Among the factors that influence ignition of a gas burner are— the location and number of pilots, opening characteristics of the gas valve, manifold charging time, and burner draft conditions combustion chamber temperature, and flame propagation rate. Here are a few of the many ways to provide smooth, quiet ignition:

- Slow-opening gas valves.
- Multiple pilots for simultaneous ignition at several points.
- Pilot location at point of first gas delivery.
- Low-fire operation until stack and combustion chamber are warm.

Self-Test Questions

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

613. Functions of gas burners

1. How is the classification of boilers usually accomplished?

2. How is gas introduced into the combustion chamber?

3. What type of flame makes a burner an inshot burner?

4. What type of flame makes a burner an upshot burner?

5. What effect does the constriction of the venture tube have on gas velocity and the pressure in the throat of the tube?

6. What effect does a motor driven fan have if it is placed at the outlet of the combustion chamber?

7. What flame is produced by turbulence and high velocities?

8. When does an intermittent pilot shut off?

9. How is air introduced into the combustion chamber on a forced draft system?

10. How is air introduced into the combustion chamber on an induced draft system?

11. What is the range of firing rates over which satisfactory combustion covers?

12. When does flashback often occur?

13. What are the causes of flashback?

14. What factors influence ignition of a gas burner?

15. Where should the pilot be located to ensure a smooth and quiet ignition?

614. Characteristics of gas burners

There is not always a sharp distinction between the many types of gas burners. In fact most burners are a combination of two or more types depending on the methods of classification. Gas burners range in capacity from about 20 to more than 100,000 cubic feet of gas per hour. Depending on the heating value of the gas used, this range is from about 10,000 Btuh for small domestic burners to over 300 million Btuh for large industrial and commercial burners. Most gas burners adapt to wide ranges of capacity, gas pressure, and gas heating value just by changing orifice sizes and air register opening. Therefore it is difficult to assign a size range to a particular type of burner.

Some convenient classifications of gas burners covered in this lesson are the draft-types, port-type, mixing-type, and pulse-type. Another convenient classification sometimes used is the physical shape of the burner.

Draft types

The main assembly of these burners has a gas manifold, spud, orifice, air shutter or spoiler, venturi, burner head, and ports, (fig. 2–26). These types of burners use the flow of low-pressure gas through the orifice into the venturi where it creates a gas vacuum. This gas vacuum also draws primary (combustion) air into the burner. The gas and primary air then mix inside the venturi portion before reaching the burner head. The design of the burner head reduces the gas velocity and allows for the complete mixing of the gas and primary air before the mixture exits the burner ports. As the mixture leaves the ports, a standing pilot or spark ignition is located next to the burner head and lights the mixture. Another component that plays an important role on how efficiently the burner operates are air shutters.

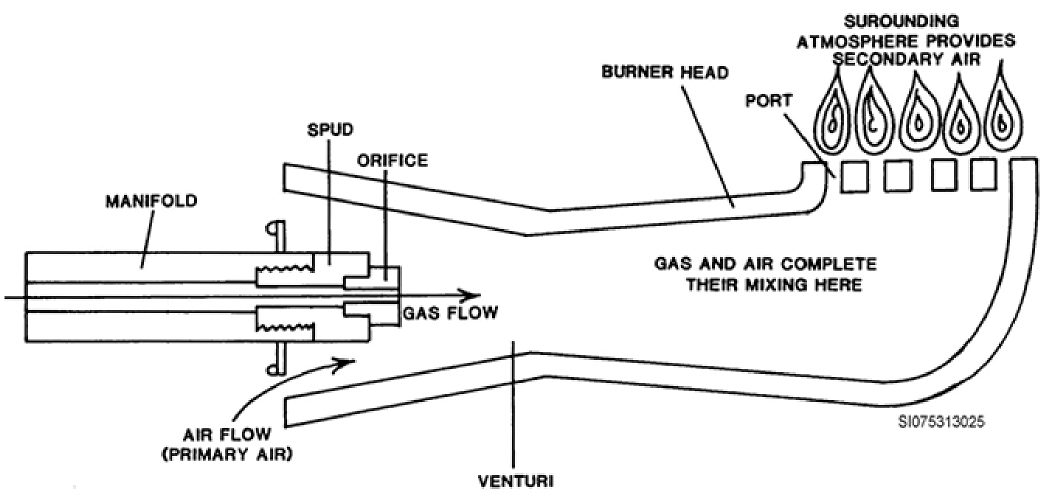

Figure 2–26. Components of an atmospheric gas burner.

Air shutters

Installation of air shutters gives adjustment to the amount of primary air going to the burner. An air shutter installation is in front of the venturi opening. In this design, all the primary air going to the burner must pass through the shutter. Position the air shutter to enlarge the venturi opening or to make it smaller, letting more or less primary air enters the burner. Figure 2–27 shows a typical air shutter.

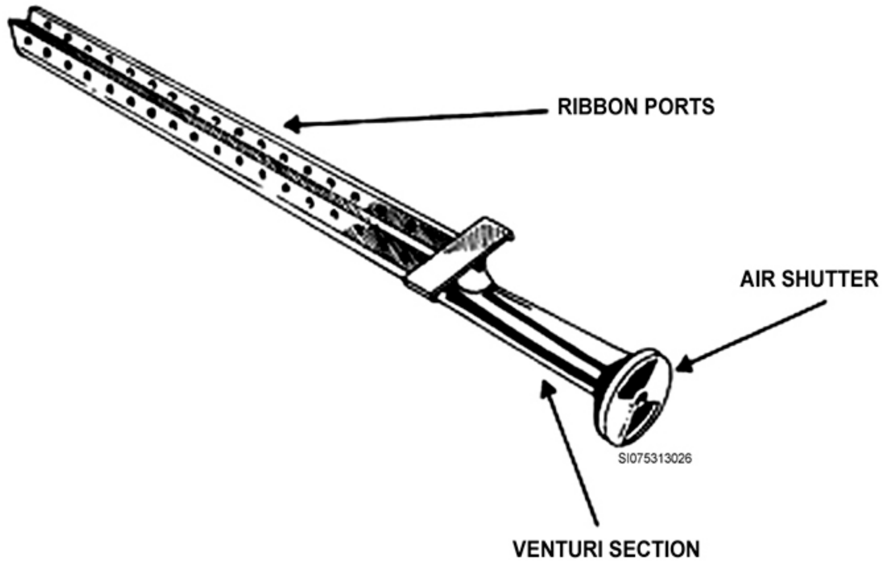

Figure 2–27. Typical air shutter on an atmospheric gas burner.

Port types

Small port, large-port, or tile-port burner is a further classification of a gas-air mixing burner.

Small-port (ported manifold) burners

A small port burner (fig. 2–28) has a manifold with a series of holes (ports) smaller than and including a No. 28 drill size (0.1405-inch diameter). This type of burner usually uses an inspirating-type premixer. It is usually very quiet, which is why it is popular among domestic gas burners. If the flame on one part of the burner blows out, the flame from another part may act as a pilot to reignite it if the ports are close together.

A great disadvantage is its physical structure, which does not permit high heat release rates as well as limiting the temperature of the material that is heated. Therefore, its industrial use is limited to low temperature applications, such as space heating, varnish kettle heating, drying ovens, baking ovens, food roasters, and deep-fat vats.

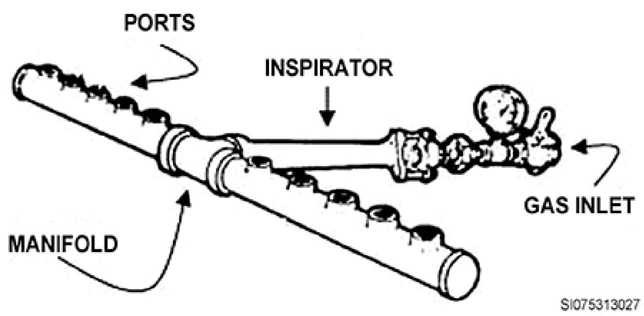

Figure 2–28. Typical small-port (ported manifold) burner.

Large-port (pressure-type) burners

Large commercial and industrial furnaces require burners that permit a high rate of heat release within a relatively small space. High-density heat generation requires higher gas pressures; the range of 1 to 25 psig meets the requirements of most burners.

Many designs exist for special applications, but this type of burner is generally characterized by a single port (or nozzle) larger than a No. 28 drill size (0.1405-inch diameter). When multiple nozzles are used, they are often installed with a separate mixer for each port, although a single mixer with the right manifold may supply several ports.

Pressure burners often use flame retention (stick-tight) nozzles to avoid flame blow-off from the large ports. A series of small bypass ports encircle the main nozzle. Because these bypass ports have greater resistance to flow than the main port, the velocity of the gas through them is less. This low velocity practically eliminates flame blow-off at these bypass ports. If the main flame blows off, the small port flame acts as a pilot to relight it.

Mixing types

Another convenient gas burner classification is the position and the way the gas and combustion air mix together. They are classified as premixing, nozzle-mixing, or delayed-mixing burners.

Premixing burners

In a premixing burner, the gas and primary air mix before they get to the burner port(s). The mixer may be an inspirating, aspirating, or fan-mixing type. The burner port(s) serves only as a flame holder maintaining the flame in the desired location. Theoretically if the velocity of the gas-air mixture equals the flame propagation rate, the flame stands stationary at any point at which ignition is applied. A relatively cool burner nozzle (or port) is the flame stabilizer. The cool port quenches the flame if it advances too far into the port because a momentary fluctuation in mixture velocity. Air and gas mix in a premixing burner resulting in a short, hot flame with high heat release.

Inspirating burner

The inspirating burner, also called injection burner or venturi mixing burner uses venturi action to bring in primary air. The high velocity of the gas escaping into the constricted throat of a venturi tube lowers the pressure and draws in (entrains or inspirates) primary air. This is the only type of mixer that does not require an air blower.

In the single-stage mixer shown in figure 2–29, high-pressure gas discharging from the spud (gas orifice) forms a high velocity jet in the throat of the venturi-like body. The gas jet inspirates air in proportion to the gas flow, and the gas and air are mixed. The gradual enlargement of the body results in the mixture velocity returning to static pressure. Adjusting the position of the disc produces the desired air-fuel ratio.

In domestic and low-duty industrial burners, the low gas pressures available for general use are adequate to inspirate enough primary air. Larger burners require much more primary air and therefore higher gas pressures.

For proportional air inspiration at high mixture pressures, the venturi throat must be machined smooth and aligned carefully with the spud. The size of the venturi throat limits the range of workable spud orifice diameters. For thorough mixing of gas and air in a short length and for a more constant air-fuel ratio, use a two-stage inspirator with two venturi tubes on high-pressure gas lines.

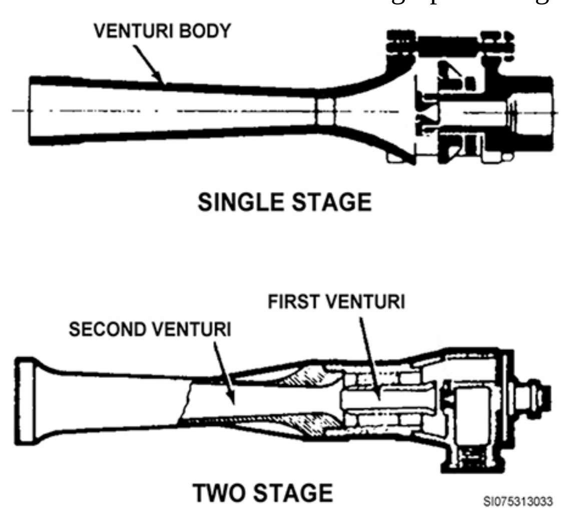

Figure 2–29. Inspirating burners.

Use inspirating mixers with either open or sealed-in burners on any oven or furnace having a steady combustion chamber pressure. A negative chamber pressure increases inspirator capacity, retards flashback, while a positive chamber pressure reduces inspirator capacity and increases the probability of flashback. Because the inspirator must induce a large volume of air with a small volume of gas, the range of turndown is limited. Capacities range from about 100 to 8,000 cubic feet of gas per hour.

Aspirating burner

The aspirating burner also uses venturi action, but the air draws in (aspirates) the gas instead of the gas inspirating the air. This makes it easy to get air-fuel ratios of 10 to 1 or higher, so the aspirating mixer is the most used premixer today.

Gas usually is supplied at atmospheric pressure (zero gas) maintained by a zero governor, which is why this type is also known as a zero governor burner. A fan or blower blows air through the venturi at a pressure usually below one psi. The throat of the venturi draws no gas into the air stream in direct proportion to the airflow. Therefore after an initial adjustment of a sensitive gas valve to get the desired ratio, the air-fuel ratio will remain constant over a wide range of turndown, regardless of the air volume. For this reason, this mixer is a proportional mixer. Air adjustment alone controls the firing rate.

Fan-mixing burner

As the name implies, in a fan-mixing burner (fig. 2–30 and 2–31) a fan mixes the gas and primary air. In the mechanical-premix type (fig. 2–31), a motor-driven blower does the premixing and gas is supplied at low pressure. Simultaneous modulation of gas and air permits a wide range of turndown, limited only by the requirement that the velocity of the gas-air mixture exceed the flame propagation rate to prevent flashback.

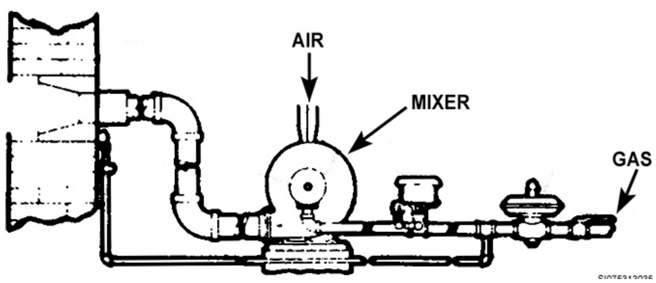

Figure 2–30. Mechanical premix burner (fan mixing).

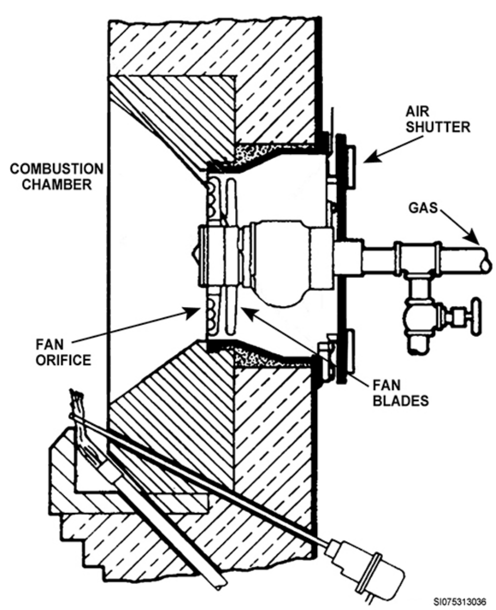

Figure 2–31. Fan-mix burner (fan mixing).

The fan-mix burner is an unusual design. The fan is not motor-driven but mechanically coupled to propeller-like blades mounted on a free-spinning shaft. Orifices are drilled at an angle along the edges of the blades. High pressure gas (10 to 50 psig) escaping into the combustion chamber through the orifices causes the blades to spin. The spinning blades rotate the fan that draws in the primary air. The speed of the fan varies with the gas pressure, thereby, automatically adjusting the air volume to maintain an optimum air-fuel ratio. Release of gas from a large number of small orifices at near right angles to the fast-moving air stream produces an intimate gas-air mixture. This type of burner has a good turndown characteristic. The big problem is locating the pilot to meet the requirement of proving the pilot in the path of the fan-burner flame.

Nozzle-mixing burners

Nozzle-mixing burners are the most typical type burner used today. As the name implies, the gas and combustion air do not mix until they leave the burner port. The two fluids remain separate within the burner itself, but the nozzle orifice's design allows rapid mixing of the fluids as they leave. See figure 2–32 for an example. Because combustion starts at the point of mixing, flashback cannot occur. Other advantages of this burner includes greater turndown range, greater adaptability to special configurations (including combination burners), and sometimes lower pressure requirements for blowers. External regulators or proportioning valves are required to proportion the gas and air.

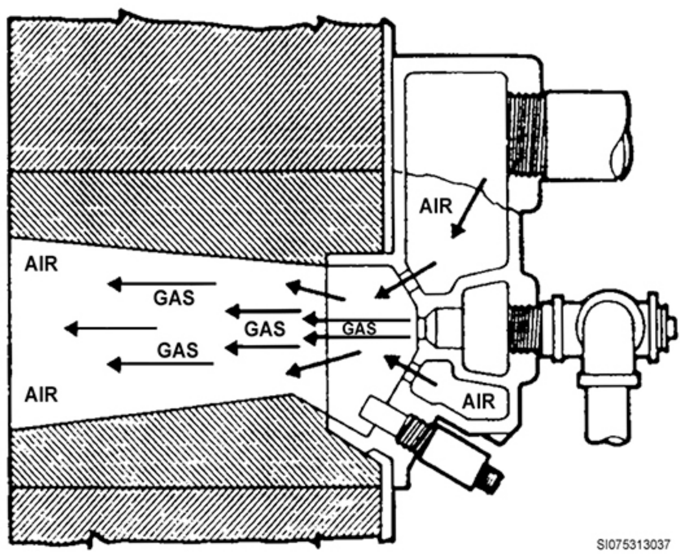

Figure 2–32. Nozzle-mixing burner.

Another type mixes both gas and air at high velocities, while yet another concentrates the air in a single jet so the air will partially entrain the gas, thus, requiring very low gas supply pressures. As you can see, there are multitudes of variations in nozzle-mixing burners.

Delayed-mixing burners

As the name implies, in delayed-mixing burners the gas and air leave the burner port unmixed and, thereafter, mix relatively slowly and largely through diffusion. This results in a long and luminous flame.

Long-flame burner

The long-flame burner (fig. 2–33) is the most common delayed-mixing burner. The mechanical action of the burner produces both long and luminous flames. In fact, it is difficult to produce one without the other. Therefore, the long-flame burner is a luminous flame burner, a yellow flame burner, or a diffusion flame burner.

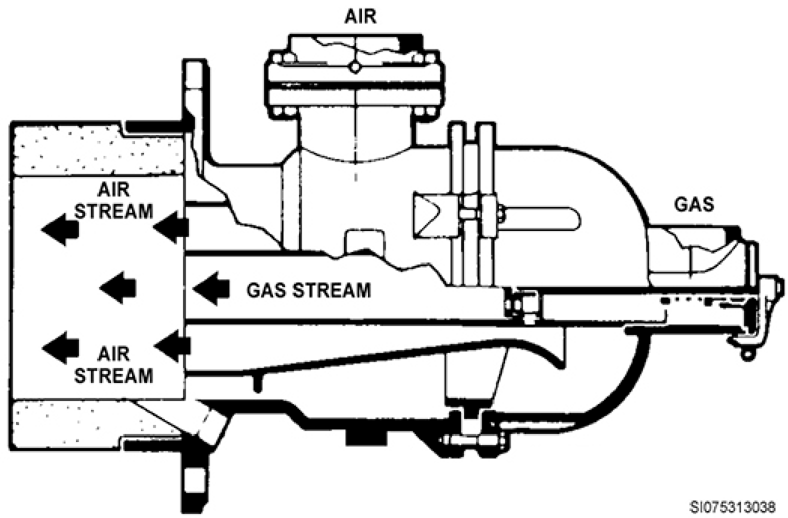

Figure 2–33. Long-flame burner (delayed mixing).

The long flame is produced by injecting low velocity, non-turbulent, parallel and adjacent gas, and air streams into the combustion space. This provides a low mixing rate because mixing occurs *only* at the interface between the parallel gas stream and air streams. The two fluids travel a considerable distance from the burner before mixing and burning. The combustion that occurs at the gas-air interface radiates heat to the gas stream causing it to crack and produce luminous carbon particles. Use long flame burners in wide or extremely long furnaces where direct flame radiation over a large area is desirable. Poor heat distribution (hot spots and cold spots) would be obtained from ordinary clear flame combustion because it could not be spread over a large space.

Pulse-type burners

As mentioned earlier, a pulse burner operates in phases with the use of a flapper valve. The flapper valve has two plates with openings, a flapper that moves back and forth between them, and a spacer that sets the gap between the plates.

When the pressure inside the burner rises because of active burning, the flapper drives against the inlet plate, figure 2–34, part 2. This closes off the inlet end of the burner and forces combustion products to flow out through the exhaust pipe. The pressure in the burner then falls below atmospheric pressure. This causes the atmospheric pressure of the air outside the air valve to exceed that inside the burner, thus, causing the air valve flapper to move in the opposite direction, uncovering the inlet ports, and admitting a fresh charge of air, figure 2–34, part 3.

The same thing happens at the gas valve when the pressure in the gas line supplying the burner exceeds the pressure inside. The gap between the two plates acts as a flow-controlling orifice. A spacer governs the size of the gap. A properly sized spacer in the two valves admit both the desired flow of gas and the right amount of air to burn the gas completely.

To start a pulse burner, a small blower and a spark plug, (fig. 2–34, part 1) provides an initial flow of air. At that point the gas valve opens and ignition occurs. The burner immediately starts a resonant operation producing the negative pressure valleys that draw in successive charges of air and fuel. The starting blower switches off as soon as a detector senses that combustion is ongoing. The spark switches off at the same time.

Each cycle of burning leaves a pocket of flame that ignites the next charge of gas-air mixture entering through the flapper valves. To allow for the possibility of an unsuccessful starting try, a pulse burner will try several automatic starting sequences. Well-designed burners usually start the first time.

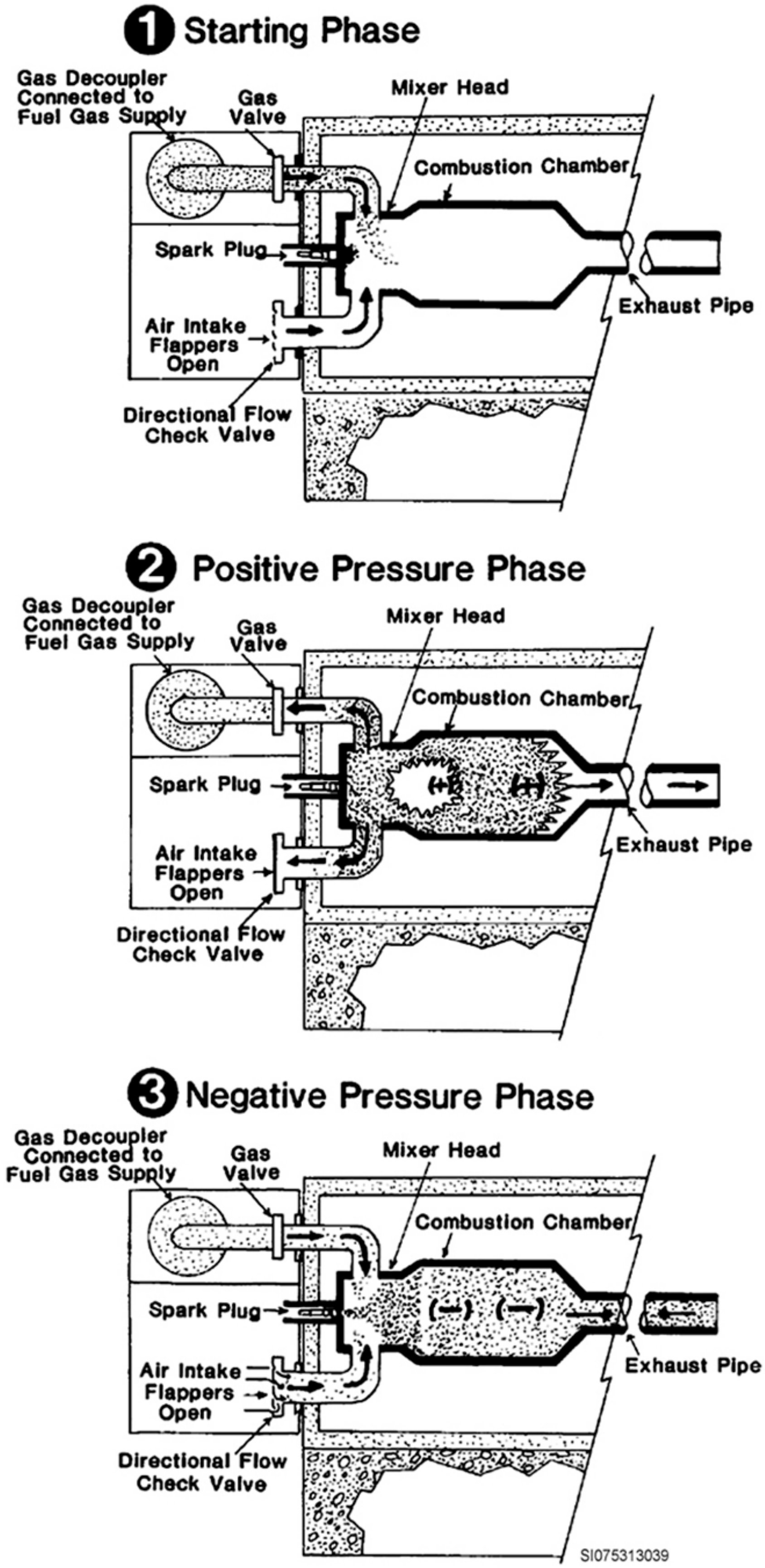

Figure 2–34. Typical pulse operation.

Physical shapes of gas burners

The physical shapes often classify gas burners. Some common types are gun burner, ring burner, line burner, ribber burner, and spread burner.

Gun burner

The gun burner (fig. 2–35) is a power burner that ejects gas at pressures up to 15 psig from a spud (or spuds) in the center of a turbulent air stream resulting in good mixing. A fan or blower blows the air at high velocity past vanes (or turbulators) to provide the swirling air motion.

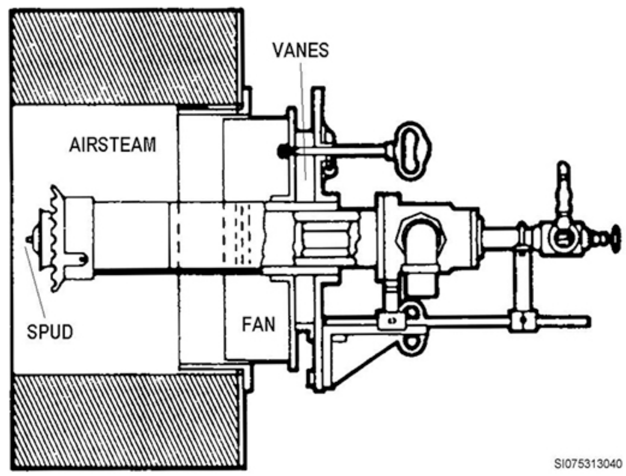

Figure 2–35. Typical gun burner.

Ring burner

The ring burner (fig. 2–36) is similar to the gun burner except that the gas ejects into the turbulent air stream from spuds located at the outside of the air stream instead of in the center. The gas releases from a number of ports around the inner periphery of a ring at the mouth of the burner.

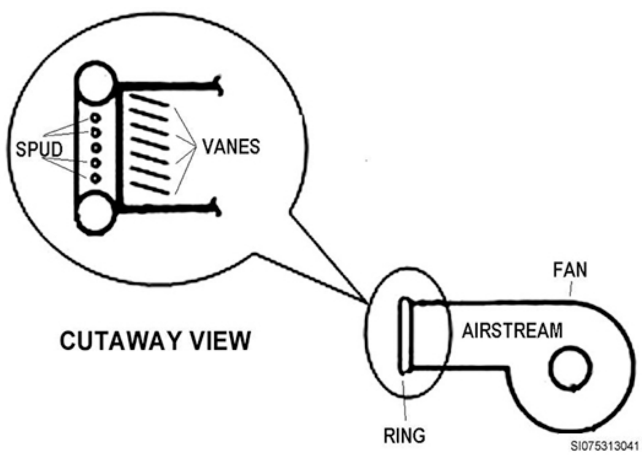

Figure 2–36. Typical ring burner.

Line burner

The line burner (fig. 2–37) is a small port (ported manifold) type of burner. A mixture of gas and air feeds through the bottom of the cross or through one of the end flanges. The bottom of the flame trough has rows of small holes that emerges the gas-air mixture. This burner is for application in an open setting and occurs in a variety of forms for pattern heating. Small industrial ovens use this burner. This type of burner operates at a low mixture pressure (not over ½ inch of water, or 0.018 psi), preferably with a rich air-fuel mixture, and always in a location where secondary air is available to stabilize the flame. Temperatures should not exceed 300°F (149°C).

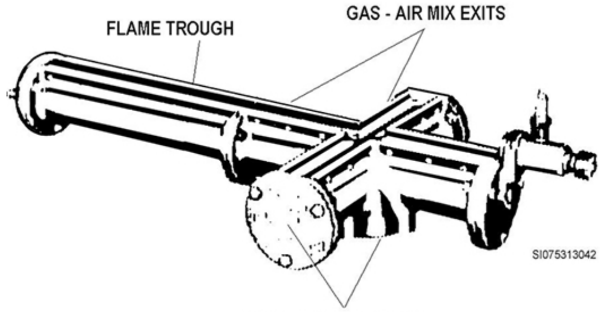

Figure 2–37. Typical line burner.

Ribbon burner

The ribbon burner (fig. 2–38) is just another form of line burner with a built-in metallic ribbon to increase the number of openings and produce a more continuous flame.

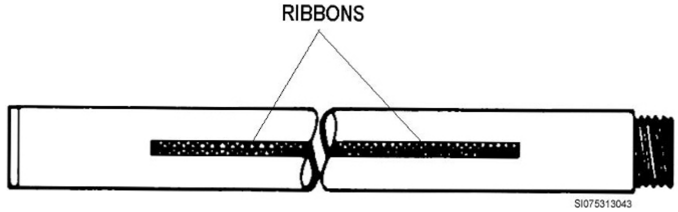

Figure 2–38. Typical ribbon burner.

Spreader burner

The spreader burner (fig. 2–39) is a low-pressure burner that uses venturi action to inspirate part of the air required for combustion. The venturi delivers the air-gas mixture to a large, vertical port. Here, a spreader plate (that gives the burner its name) spreads the flame toward the outside wall of the combustion chamber. Burners of this type range in size from 100 to 300 cubic feet of gas per hour.

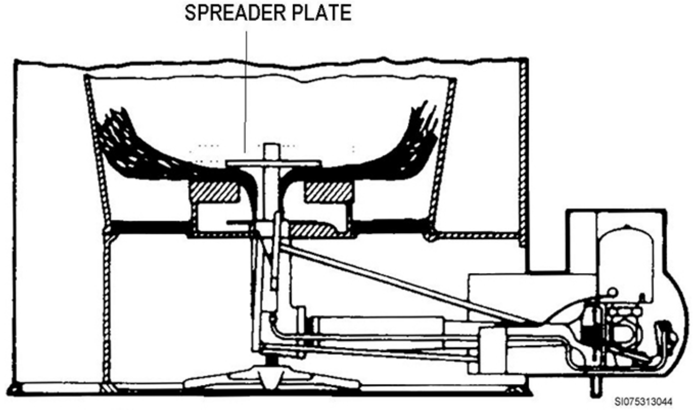

Figure 2–39. Spreader burner.

Self-Test Questions

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

614. Characteristics of gas burners

1. Where is the gas and primary air mixed on a venture type burner?

2. What is the result of air and gas mixing in a premixing burner?

3. On an inspirating burner, what is the result of the gradual enlargement of the gas and air body?

4. On a fan mixing burner, what effect does the high pressure gas have on the blades of the fan?

5. What effect does the nozzle orifice have on the gas and air as they leave the burner?

6. How is the gas-air mixture continually ignited in a pulse type burner?

7. Where is the gas ejected on a ring type burner?

8. What effect does the spreader plate have on the flame on a spreader-type burner?

615. Gas pilot and ignition systems

The starting of a gas burner requires a safe and automatic way of igniting the fuel. When working with gas burners some of the common ignition methods available are the flame rectifier pilots, the pilot light, thermocouple, automatic pilot ignition systems, and pilotstats.

Pilot light

The gas pilot burner in a domestic gas-heating unit is a small burning flame that lights the main burner during normal operation of the heating unit. The pilot light is located near the main burner. A small, manually operated gas shutoff valve on the main gas line before the main gas valve supplies the gas flow to the pilot burner on some older systems. In newer systems, the gas comes from a pilot tapping off the automatic gas valve (fig. 2–40). In some heating units, a separate line that has a pressure regulator and a pilot solenoid valve supplies the gas for the pilot light. The pilot burner is actually a small gas burner. The aerated and non-aerated pilot burners are the most common types used today.

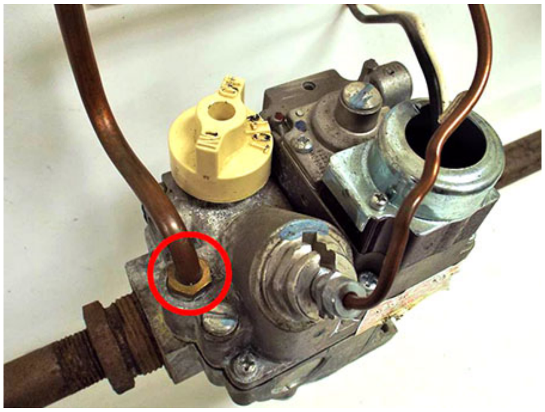

Figure 2–40. Automatic gas valve with pilot taping.

Aerated pilot

An aerated pilot is one that injects primary air through an air intake opening into the gas stream. The air and gas mixes before burning. An aerated pilot burner produces a very stable flame. For this reason, these pilots are used where the pilot location is hard to reach. Although the flame produced by an aerated pilot burner is more stable than one produced by a non-aerated type, an aerated pilot burner does have some disadvantages. An important one to remember is the tendency for the small primary air openings to clog with lint and dirt. Frequent cleaning is required particularly when using these pilots in areas having a large amount of foreign material in the air.

Non-aerated pilot

A non-aerated pilot does not inject primary air. As a result the air and gas are not premixed, and the combustion process completes with secondary air only. This results in a less stable flame than the one produced by an aerated pilot. On the plus side, a non-aerated pilot requires less maintenance than the aerated pilot does.

A pilot burner assembly has the pilot bracket, pilot orifice, primary air intake, lint screen, mixing chamber, pilot ports, and pilot hood.

The pilot bracket is a device used to mount the pilot in a fixed relationship to the burner. Some pilot brackets also contain means for mounting the thermocouple or pilot generator so that the hot junction is located directly in the path of the pilot flame (fig. 2–41).

The pilot parts are the openings that gas (in non-aerated pilot burners) or the gas and air mixture (in aerated pilot burners) pass before burning. The gas and air premix in the mixing chamber of aerated pilot. The air injects into the mixing chamber of aerated pilot through a hole or opening called the primary-air intake. The amount of primary air is controlled by adjusting an air shutter that covers the primary air intake opening.

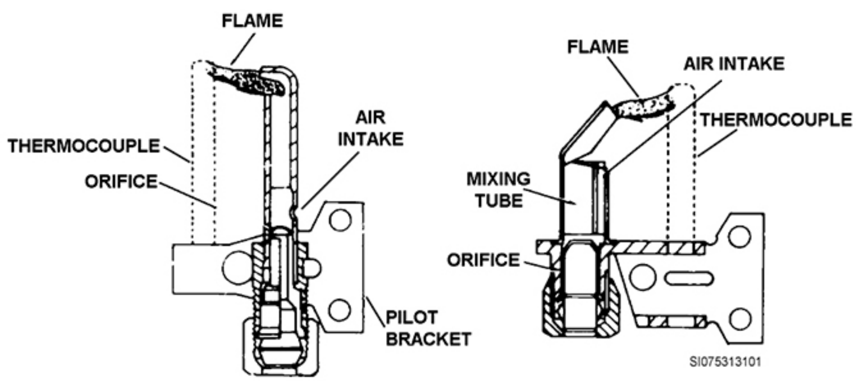

Figure 2–41. Pilot bracket with means for mounting thermocouple.

Thermocouple and thermopile

Thermocouples are used as pilot flame sensors. The thermocouple is a miniature generator that can convert heat (from the pilot flame) into millivolts of electricity. Then the electricity is sent to open the gas valve; let’s see how this occurs.

- Manufacturers make a thermocouple by welding wires of dissimilar metals together. In theory heat added to one end of this circuit when the other end remains (relatively) cold will generate a small electric voltage (DC). A small electric current will flow in the circuit.
- The heated junction is the “hot” junction, and the other junctions are “cold” junctions. The voltage generated by the thermocouple is dependent on the temperature difference between the hot and cold junctions. As the temperature difference between the junctions varies, the power generated by the thermocouple changes in direct proportion. The Seebeck effect is the concept that the thermocouple is based on. This concept deals with the conversion of thermal energy to electrical energy.

Figure 2–42 shows a typical thermocouple and its circuit. Note that the cold junction does not need to be a common junction. The load shown is the power unit coil. The copper leads shown are the thermocouple to power unit connection. These leads do not alter the thermocouple effect but simply complete the electrical circuit between the power source (thermocouple) and the load (power unit coil).

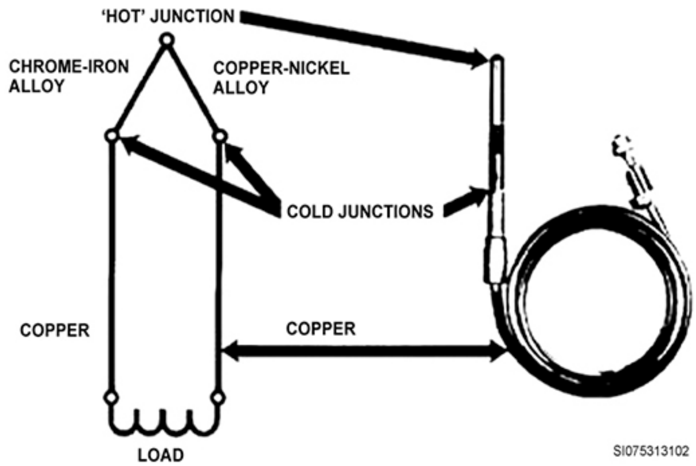

Figure 2–42. Basic thermocouple construction.

It is possible to connect a number of thermocouples in series, while greatly increasing the available power, figure 2–43 shows this. A series of thermocouples is a thermopile. When used in combination with a suitable pilot burner, the combination becomes a pilot burner generator.

A single thermocouple can produce about 15 to 30 DC millivolts while thermopiles can produce approximately either 250 or 750 DC millivolts (typical). In essence, a 250-millivolt thermopile is 10 thermocouples in series; a 750-millivolt thermopile is 26 thermocouples in series. As a point of reference, 750 millivolts is half the voltage of a 1½ volt, D-size, dry-cell battery.

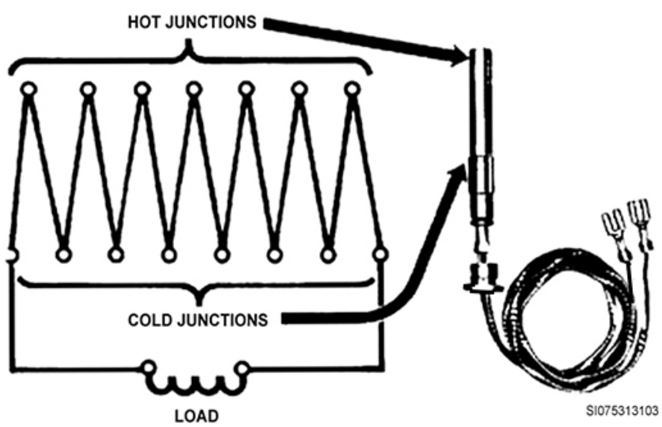

Figure 2–43. Basic thermopile construction.

Note that the outer sheath of the copper lead is one leg of the circuit; the other leg is an insulated wire inside the copper outer sheath. The attaching nut provides the electrical connection between the thermocouple and the power unit. Since this is an electrical connection, it is important not to use pipe dope. When installing the thermocouple, the nut should be finger-tightened plus about a one-fourth turn to provide a good connection. Never bend a thermocouple lead within a half inch of either end to avoid damage. Most thermocouple failures are from oxidation of the inner element. The oxidation at the hot junction increases electrical resistance and subsequently reduces the milli-voltage output (Ohm's Law). Excessive hot junction temperatures accelerate the oxidation process and reduce the pilot generator life. The structure of the thermopile is like that of the thermocouple except that the unit is made of many hot and cold junctions.

Ignition systems

The development of ignition helps eliminate the wasting of fuel during the “main burner off” portion of the heating cycle. With the growing shortage of fuel, the ever-increasing costs of the fuel and increased technology, it is now profitable to use these systems. There are four main types of ignition systems, the following list identifies them:

1. Standing-pilot
2. Intermittent-pilot ignition.
3. Hot surface ignition.
4. Direct-spark reignition system.

Standing-pilot ignition

The pilot light is a small flame used for ignition. A standing-pilot system has a pilot that is designed to burn continuously. A sensing element, such as a thermocouple, detects the standing-pilot and helps to determine if it is lit and lit correctly. If the pilot is not lit, the main gas valve will not open.

Let’s break this concept down a little. The thermocouple produces a small electrical current that rises and falls depending on the amount of heat produced by the pilot flame. Since the pilot is constantly lit the thermocouple is constantly sensing the flame and sending a signal to the control module. The main gas valve will open on a call for heat from the thermostat. If the pilot goes out, then the thermocouple will no longer be sensing the flame and it will cool down causing the voltage it produces to change. The ignition control will shut the main valve if it is open.

This ignition system wastes fuel by keeping the pilot lit at all times. The pilot is lit during off cycles also. This ignition setup will more than likely only be seen on older systems.

Intermittent-pilot ignition

In this ignition system the pilot is only lit when the thermostat is calling for heat. When heat is called for, the ignition control opens the pilot gas valve and attempts to ignite the gas; at the same time, it attempts to sense the flame. Once the pilot flame has been established the ignition control opens up the main gas valve and the burners light.

Hot surface ignition

Hot surface ignition relies on 24 to 120 volts for operation. These ignitors are made of either silicon carbide (older models) or silicon nitride (newer models). These materials have a high resistance to electricity so when current passes through them they produce heat. Hot-surface ignitors are placed in a location in which gas will pass over it when the gas valve opens. As the gas passes over this hot surface ignitor, the gas ignites. Hot surface ignitors can be referred to as glow coils. To get you used to the hearing both, this discussion will use the two terms interchangeably.

Hot surface ignitors cannot stay energized continuously without risking a burnout. Therefore it must be de-energized within 4 to 11 seconds to prevent any possible damage. When the thermostat calls for heat the ignition control module starts the combustion blower. After a brief delay it sends a signal to energize the glow coil. Once the coil heats up, the main gas valve is opened and the gas ignites. The signal from the control module to the main gas valve can be on a time delay or it also has the ability to measure the resistance of the glow coil to determine if it is hot enough to ignite. Within a few seconds of the gas valve opening, the glow coil should turn off. Remember, if it doesn’t turn off, it can burn out. Glow coils can be used to light pilots or the main burner. Care must be taken when handling hot-surface ignitors. They are fragile and can be broken very easily.

Direct-spark reignition systems

Direct-spark reignition systems automatically light the pilot. There are many spark ignition systems on the market, although each manufacturer have its own design, the basic operation is the same. The systems are usually available for input power of 24, 120, 208, or 230 volts. Regardless of the input voltage, a network of solid-state components converts this supply into a high-voltage potential (20,000 volts) at the output terminal. This potential conducts to an electrode by a high-tension cable.

The gas passes through the electrode (fig. 2–44). It is positioned on the pilot burner to provide an electric spark gap. When the device energizes, the high potential at the electrode tip creates an electric spark across the gap to the grounded surface of the pilot. This spark continues firing until the pilot gas ignites.

The solid-state device detects the presence of a flame and turns the spark off. This is because the pilot flame conducts the current to the grounded pilot thus, the sparking stops. While the pilot is on, the spark remains off.

If the pilot flame goes out, current flow to ground interrupts and the spark again jumps across the gap in an effort to relight the pilot.

Direct-spark ignition can be used to ignite the main flame also. See figure 2–45 for an example. This example is for a radiant tube burner, which will be discussed in section 3–2 in the next unit. For now, look at the color coded arrows in figure 2–45. The green arrow points to where the gas would come out of the nozzle. The orange arrow is the grounding rod and the red arrow points to the high voltage electrode.

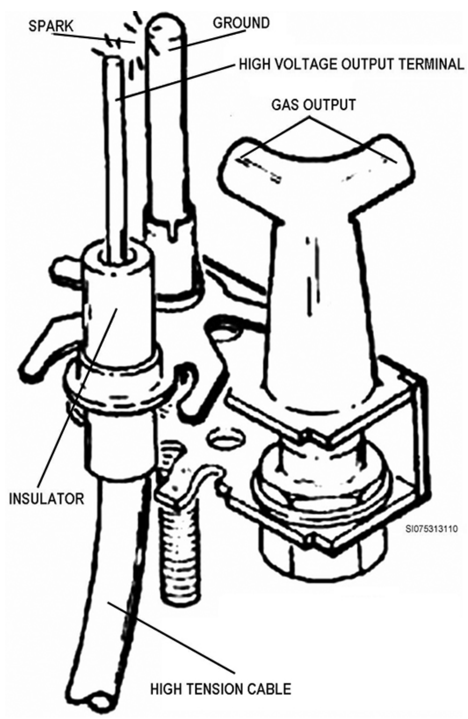

Figure 2–44. Spark electrode.

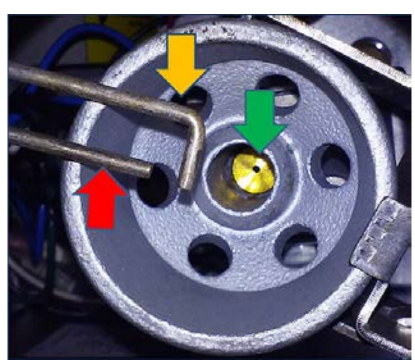

Figure 2–45. Direct spark ignition for flame.

Pilotstats

A pilotstat is a safety device used to shut off the flow of gas to the main burner if the pilot light fails. Domestic units normally use pilotstats.

The thermoelectric pilotstat is an integral (internal) part of a complete combination gas control, or it may exist as a separate unit.

Both of these controls are the electric-switch type (thermoelectric). They are not piped into the main gas manifold, but are panel-mounted devices that interrupt the electrical circuit to the main gas valve on power unit dropout.

Some controls are used for main gas shutoff only. This is called non-100% shut-off. Other controls are similar, except they provide shutoff of gas to the main burner and the pilot burner if the thermocouple does not sense a pilot flame. This type of system is called 100% shut-off. Complete shutoff (100 percent gas shutoff) is required on liquefied petroleum gas (LPG) installations or any gas that is heavier than air because these fuels can accumulate in low places. Some local codes require natural gas systems to be 100% shut-off even though it is lighter than air.

Both of these controls interrupt the electric circuit to the main valve during the pilot lighting procedure to prevent gas from flowing to the main burner should the thermostat be called for heat while the unit is being manually reset.

Self-Test Questions

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

615. Gas pilot and ignition systems

1. Where does the gas for the pilot come from on newer systems?

2. What is an important disadvantage to remember about the aerated pilot?

3. What effect does the air and gas not being premixed on a non-aerated pilot have on the flame?

4. What does a thermocouple convert heat into?

5. What is the result of heat being applied to one end of a thermocouple circuit and the other end staying relatively cold?

6. What is the name of the heated junction of thermocouple?

7. Why is pipe dope not used when connecting a thermocouple?

8. What is the cause of most thermocouple failures?

9. When does the standing pilot light burn?

10. How is the pilot gas valve opened on an intermittent pilot system?

11. What effect does the main gas valve opening have on the burner after the pilot has been established?

12. What is the result of electricity flowing through the material of a hot surface ignitor?

13. What is another name for a hot surface ignitor?

14. When must hot surface ignitors be de-energized?

15. What results from the high potential at the electrode tip on a direct spark ignition system?

16. When would the pilotstat shut off the flow of gas to the main burner?

17. What type of system shut off the gas to the pilot and main burner if no pilot is sensed?

616. Pre-operational inspection and operational test of gas burners

Now that you understand the working mechanics of gas burning equipment, you must put this information to use by ensuring the equipment runs properly. In this lesson we'll look at the instruments at our disposal to ensure we can ensure the proper operation of our gas burners. The instruments that we use to ensure proper operation of our burners are pre-operational inspection and operational test for burners.

Pre-operational inspection

Remember the purpose of a "pre-op" is to prove that the burning equipment is mechanically sound and safe to operate. The following list of 10 items contains areas the pre-op inspection covers:

1. Make a visual inspection to eliminate fire and other safety hazards by ensuring all installation, repairs, and cleanup work is completed. Also, ensure there are no chlorine or fluorine products stored near the unit. If these products get into the combustion air they can cause corrosion.
2. Close all main and pilot manual fuel valves. Make sure that the room in which equipment is in is free from gas. The gas can be accumulated through leakage, accidental opening of a fuel

valve, and pilot failure. You can detect odorized gas by smell, but some gases are odorless and require an explosive gas-detection meter to detect them.

3. Check the power source and control wiring to make sure burner control panel, motors, and valves comply with the wiring schematic, local codes, Underwriters' requirements, and National Electrical Code. Check all fuses for correct rating to meet code requirements. Check limit and operating controls for calling position. If high and low gas pressure switches are used, the low gas pressure switch should be open until the main manual gas valve opens.
4. Remove covers or panels to gain access to the burner components. Check for gas leaks of all the fitting connections on the gas line and gas manifold by using a soap solution. Check inside combustion chamber to see that no tools or other items are inside. Install burner and tighten all lock clamps to make sure the burner seals tight.
5. Inspect burning equipment stack and breeching to make sure there are no obstruction for flue gases. Check breeching or stack damper and/or barometric for operational and proper position for firing.
6. Check the ignition system and the burner itself to make sure everything is clean, carbon free and properly positioned.
7. On an atmospheric burner, inspect the placement of the pilot burner and the burner head. This is extremely important when the burner incorporates multiple burner heads. In an installation like this, the pilot burner will ignite the gas at one burner head only. The flame from that burner head will then ignite the gas leaving the other burner heads. If the pilot burner and burner head alignment are wrong, a delayed ignition or furnace explosion may occur during start up. See figure 2–46 for proper installation.

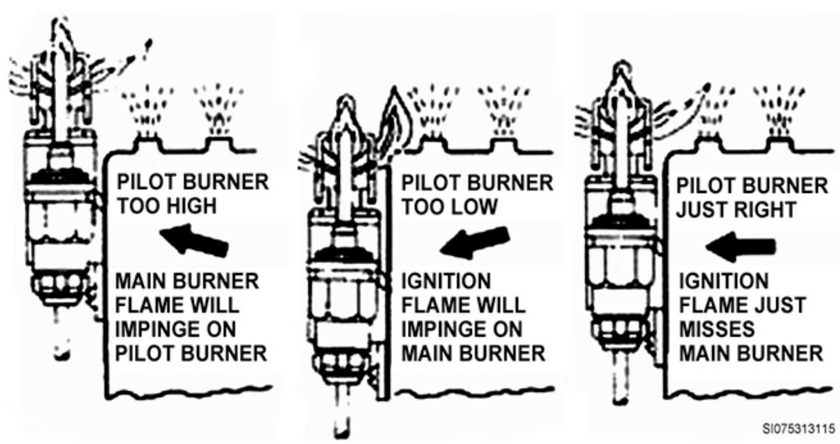

Figure 2–46. Location of pilot burner.

8. Check all linkage for proper setting and looseness and tighten if necessary.
9. Inspect the thermocouple on a standard pilot for carbon deposits, corrosion, or heat damage. The hot junction of the thermocouple must be in direct contact with the pilot flame. If the burner uses an electronic spark ignition, you need to make sure that position of the electrode is good to ignite the gas as it leaves the pilot burner. Also check the high-tension lead for damage and wear. The flame rod of the ignition control must be in the right place so that it touches the pilot flame.
10. This is a final checklist before starting up a gas burner:
    a) Is air purged from the gas line?
    b) Are all piping connections and pipe plugs tight and in place?
    c) Have pipe lines been cleaned and tested for leaks?
    d) Are fuses of proper size?

e) Is voltage and phasing correct?
f) Is burning equipment clean and dry?
g) Are all obstructions removed from the burning equipment?
h) Is stack clean and clear, and damper sufficiently open?
i) Is there adequate and permanent air opening provision to the burning equipment?
j) Are pilot ignition electrodes in the correct position and free from defects?
k) Is there correct gas line pressure?

Before starting the equipment, always follow the manufacturer's instructions when inspecting and preparing the burner for start-up.

Operating gas burners

Once the gas piping, venting, and wiring are in place, all connections checked, and the air vented from the gas line, you may light the unit. To start the system, observe the procedures discussed below in the following table.

Procedures to Start the Gas Burner System
1. Turn the thermostat to its lowest setting and place all electrical power for the unit to the "OFF" position.
2. Close the gas valve. This is done one of two ways: (1) by turning a knob or handle on a valve to the closed position. (2) if equipped with a switch, turn the gas valve switch off.
3. Wait 5 minutes to allow gas to clear out of the combustion chamber.
4. Open the gas valve. This is done one of two ways: (1). by turning a knob or handle on a valve to the open position. (2). if equipped with a switch, turn the gas valve switch on. **NOTE**: When you turn on the main gas, make sure nobody is standing directly in front of the burner. If there is any substantial puff back, or an explosion, shut off power to the burner immediately and secure the manual gas valve serving the burner. Find and repair the problem before trying to restart the burner.
5. Replace any panels that have been removed.
6. Turn on all electrical power to the unit. Don't forget switches like the one in figure 2-xx.
7. Set the thermostat to the desired setting.
8. Upon initial startup or seasonal start up, the unit may not come on immediately because of air in the gas line. Steps 1-8 may need to be repeated.

Now that you know how to start the burner we now will discuss what to look for while it is running in the following table.

Follow up Area to Check Once the Gas Burner System is Running
1. After the flame establishes on the pilot, check it against the manufacturer's instructions and adjust it if necessary.
2. Monitor the burner for clean and quiet operation.
3. Next check all gas connections and lines after the gas valve with a soap and water solution for gas leaks. **NOTE:** Never check for leaks with a flame.

Follow up Area to Check Once the Gas Burner System is Running
4. Now that the unit's burners are firing, check to be sure that all products of combustion are being carried up the chimney and not spilling into the room. Place your hand in close proximity to the joints of the stack, if you feel warm moist air on your hand this indicates a flue gas leak.
5. Perform a combustion analysis. All this requires is placing the analyzer probe into the stack and taking readings. Adjust the system as required.
6. Ensure the thermostat shuts the unit down when the setpoint is reached.

Adjusting air and gas

In operating equipment using gas burners, the total airflow needs to be controlled. On large industrial gas burners, this is done by adjusting the dampers or by changing the fan speed. Never use the burner air registers to control the volume of air. Their use is strictly for controlling the shape of the flame. Controlling the primary airflow of the smaller domestic gas burners is done by adjusting the primary air shutter. Keep the gas-air flow ratio adjusted to obtain the maximum excess air with manufacturers designed CO_2 in the flue gas. Additionally, you should maintain a correct furnace draft (normally about 0.10 inch of water—negative).

Because the gas pressure regulator regulates the gas supply to the gas unit, you can control the firing rate by changing the gas pressure, changing the burner orifices or, in the case of the industrial burner; you can also change the number of burners in service to meet the demand. Keep the main burner flame as *blue* as possible. It should be stable and not in contact with the burner, tiles, ports, walls, or boiler tubes. Noisy flames, slow burning flames, or yellow flames will indicate either an improper primary air or gas pressure adjustment.

Lastly you should monitor the automatic function of the burner to see that the burner shuts off when the operating control reaches its set temperature. The burner should cycle back on as the temperature or pressure drops below the operating controls set point. Never leave the job site just because "the burner turned on". Always watch it cycle on and off automatically. To shut down a burner refer to the manufacturers manuals.

Self-Test Questions

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

616. Pre-operational inspection and operational test of gas burners

1. How can odorized gas be detected?

2. What must the power source and control wiring comply with?

3. In what position should the low pressure switch be until the main manual gas valve opens?

4. How is the gas valve closed if it is equipped with a switch?

5. How should all gas connections and lines be leak checked?

6. What is the 5th step to perform after the burner is running?

7. What is the correct furnace draft that must be maintaining during the operational test?

8. What will noisy flames, slow burning flames, or yellow flames indicate while you are adjusting the air and gas?

617. Preventative maintenance for gas burners

Servicing gas-heating equipment is an important task in that it contributes to efficient operation, and it provides an added safety factor. Within this lesson we will look at items that should be lubricated, adjusted, and cleaned when servicing a gas burner.

Lubricate

Motors are usually the only items on a gas burner that may require lubrication. Some motors have sealed bearings and do not need any lubrication. Always check the manufacturer's recommendations for the type of oil and amount.

Adjust

Some adjustments done during preventive maintenance on gas systems are accomplished on gas pressure, pilot burner, and main burner.

Gas pressure adjustment

Since a burner works at a specific pressure, it is necessary to get gas pressure at a certain number of pounds per square inch. Also it is more economical to use gas at a low pressure provided the heating unit produces maximum heat. Usually the gas pressure adjusts at the pressure regulator or combination gas valve. You can use various vacuum and pressure gauges to measure gas pressure. A more modern way of checking gas pressure is with a digital monometer (fig. 2–47).

Figure 2–47. Digital manometer.

See figure 2–48 and figure 2–49 to see where gas pressure would be checked and adjusted on a pressure regulator. In figure 2–48, the red arrow points to the plug that must be removed. In figure 2–49, the blue plug (1) was removed to reveal the pressure adjustment screw (2).

Figure 2–48. Regulator plug.

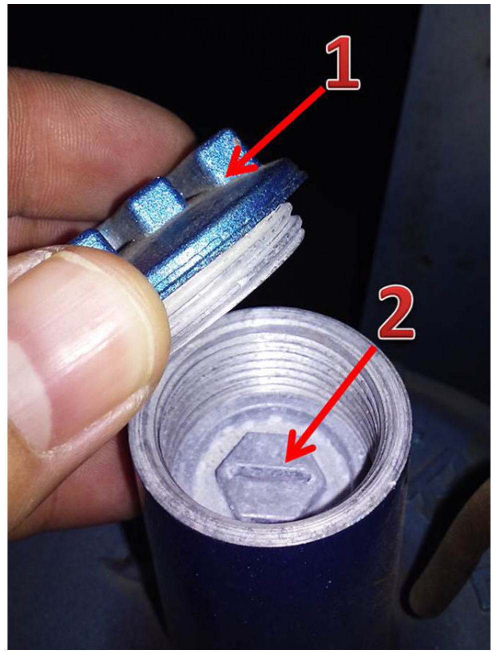

Figure 2–49. Adjustment screw.

See figure 2–50 to see where gas pressure would be checked and adjusted on a combination gas valve.

Figure 2–50. Gas ports.

The procedures for gas adjustment will not be covered in this lesson, but basically, you would check the pressure and correct any deficiency using the adjustment screw.

Pilot burner adjustment

Directly or indirectly, the pilot light is usually the cause of most inoperative gas burners. Improper positioning of the thermocouple or thermopile, and excessive flue and chimney draft conditions account for the greater share of faulty pilot light troubles. The pilot flame should be long enough to heat the thermocouple or thermopile and ignite the main burner immediately (fig. 2–51). The pilot flame should be blue, without a yellow tip. A yellow flame shows improper combustion and inturn forms soot on the thermocouple, insulating it from the heat of the pilot light. Besides being blue in color, a good pilot flame should be a steady, non-blowing flame that engulfs the upper ⅜ to ½ inch (9.5 to 12.7 mm) of the tip of the thermocouple or thermopile (fig. 2–51).

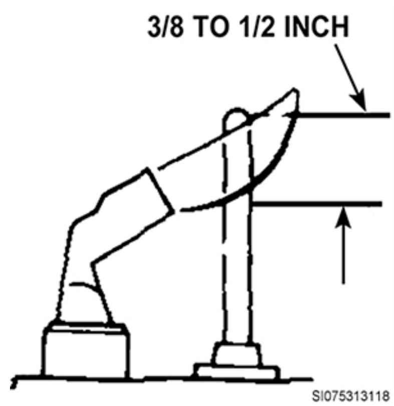

Figure 2–51. Proper position of the pilot flame.

Main burner adjustment

After adjusting for correct manifold gas pressure, adjust the flame with the air shutters and draft regulation until all jets burn blue. If you cannot get a blue flame from the jets, check the available draft for proper operation, brush scale or soot off the burner head, clean the interior of mixer or burner parts, and examine gas orifices replacing them if necessary.

A burner adjustment is correct whenever the height of the inner cone is about 70 percent of the maximum visible cone height. The flow of gas out of the burner ports should be fast enough so that the flame cannot travel or flash back into the burner head. However the velocity of the gas should not be so great that it blows the flame away from the burner ports.

Clean

You need to inspect gas burners periodically to note the appearance of the gas flame. A yellow flame indicates a poor air-fuel mixture; you should also know that carbon is forming as a result of incomplete combustion. Such formations indicate poor flame adjustment. Therefore you must remove the carbon. Remember if a good clean proper flame is not present, the unit becomes carbonized and sooted; a regular, complete cleaning is always necessary.

Remove, dismantle, and clean a main burner and pilot burner at least once a year. In addition remove foreign matter, such as soot deposits and scale. Clean burner ports or orifices with a soft material, such as a toothpick and never enlarge or damage a burner port or orifice. Compressed air may also be used.

NOTE: Wear goggles and a mask when working with compressed air.

Self-Test Questions

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

617. Preventative maintenance for gas burners

1. How is the type and amount of oil determined when lubricating motors?

2. What is usual directly or indirectly the cause of most inoperative gas burners?

3. What is the greater share of reasons for pilot light troubles?

4. How long should the pilot flame be?

5. What actions should be performed if you cannot get a blue flame from the jets of a gas burner?

6. How are burner ports and orifices cleaned?

2–3. Oil Burner Types and Operation

There are many types of oil burners, but within this section we will only discuss the vaporizing, mechanical atomizing, horizontal rotary oil burners, and combination burners. Within the following lessons we will look at the types of oil burners and the components of a valve train system.

618. Application of oil burners

The application of oil burners includes functions, classifications and the different types of burners. This lesson begins with the functions of oil burners.

Functions of oil burners

As in gas, oil burners do the five basic functions mentioned earlier in this unit. Let us discuss these functions as they apply to oil burners.

Delivering fuel to the combustion chamber

Delivery of oil usually is sent to the burner under pressure provided by a fuel pump. Exceptions are small domestic burners and one type of vertical rotary burner; the oil tank is mounted higher than the burner so the oil flows downward to the burner by gravity.

Heavy oil (No. 4, 5, or 6) may need preheating in a tank to lower its viscosity so that it will pump to the burner. A No. 5 or 6 oil may also need more preheating near the burner to lower its viscosity so that it atomizes easily, and to raise its temperature closer to the ignition point. No. 6 oil usually needs preheating, for handling and for burning.

Unlike gas, oil must be prepared for burning. It must be vaporized (converted to the gaseous state) before it can be burned. Some small burners vaporize oil in a single step by applying heat alone. Such burners are called vaporizing burners. Large capacity commercial and industrial burners use two methods to get the oil into combustible form—atomization plus vaporization. Atomization is the reduction of the oil into many tiny droplets that vaporize at a high rate. Burners that use high pressure or an atomizing medium to do this are called atomizing burners.

Delivering air to the combustion chamber

Oil burners use the same methods as gas burners to bring in combustion air, with the exceptions of the inspiring burner and the fan mix burner. The methods used are natural-draft, forced-draft, and induced-draft. Vanes (turbulators) are often used to give the air a swirling motion; this provides a more intimate mixture of the air and oil and aids in flame shaping.

Mixing the fuel and air

In vaporizing burners, mixing usually takes place by diffusion. Air pulled in by a natural draft surrounds the flame and intermingles with the vaporized oil. Burners used in central heating use forced draft to increase their oil-burning capacity.

In mechanical-atomizing burners, a blower or fan supplies air. The air mixes with the droplets of atomized oil just beyond the burner nozzle(s). Vanes or turbulators give the air a rapid swirling motion for more thorough mixing.

Igniting and burning the fuel-air mixture

Most pot type vaporizing burners used in central heating systems atomizing burners usually use direct spark ignition. A high-voltage electric spark (10,000 volts minimum), which leaps a gap between two electrodes located in close proximity to the nozzle(s), ignites the fuel-air mixture.

Larger industrial and commercial burners using heavy oil need a gas pilot; a spark lights the pilot. Burners using heavy oil often have a timed ignition or interrupted pilot to let the combustion chamber heat up. When the ignition or pilot extinguishes, the heated chamber helps sustain the flame. Like gas burners, industrial oil burners can be semiautomatic (or manually ignited), while commercial burners are usually automatic.

Removing products of combustion

Small oil burners seldom need more than natural draft to remove the products of combustion from the combustion chamber. Larger oil burners usually need induced or forced-draft fans. Some newer burners recirculate some of the products of combustion to reduce smoke.

Oil burner classification

Methods of oil burner classification are how they prepare the oil for burning. In a vaporizing burner, vaporization occurs from the surface of a pool or layer of liquid on the bottom of a combustion chamber. In a mechanical-atomizing burner, vaporization occurs from the surface of mixture droplets of liquid floating in air as a spray or cloud, within the space enclosed by the combustion chamber. Combination burners, also known as dual-fuel burners, use either gas or oil fuels.

Gun burners

Gun burners depend on high oil pressure produced by an oil pump to force oil through nozzles that produce a fine mist for more complete fuel combustion in the furnace. In this lesson, you will learn the characteristics and components of atomizing oil burners.

Characteristics

All large capacity commercial and industrial oil burners use two methods to get oil into a combustible form—atomization and vaporization. By first atomizing the oil into millions of tiny droplets, the exposed surface area has increased many times so the oil will vaporize at a much higher rate. For good atomization and vaporization, burners need the mixing of large volumes of air with the oil particles. The air must be turbulent to produce a scrubbing action on the surface of the oil particles.

This type of oil burner atomizes the oil by delivering it at a high pressure (a minimum of 100 psig to as high as 300 psig) to a specially designed nozzle that breaks it into a spray of fine droplets. Its characteristic parts are the oil pump and nozzle. Both are precision-made and do a remarkable job in breaking up the oil fine enough so that it mixes well with air to burn properly.

Components

The term “mechanical-atomizing” is synonymous with “pressure-atomizing.” Gun type burners fit into these terms. Figure 2–52 shows the components of a domestic high-pressure gun-type burner. Besides the oil pump and nozzle, it has a fan to deliver the air necessary for a burnable oil-air mixture, a motor to drive the pump and fan, an ignition transformer and ignition assembly, and burner housing to which all the components are mounted. Vanes (turbulators) give the air a whirling motion. Action of the nozzle, plus the impact of the rotating air stream from the fan, mixes the oil and air. A high voltage electric spark (10,000 volts minimum), is supplied by the ignition step-up transformer to the ignition electrode, and ignites the mixture. Figure 2–53 shows a burner installed on an oil fired furnace.

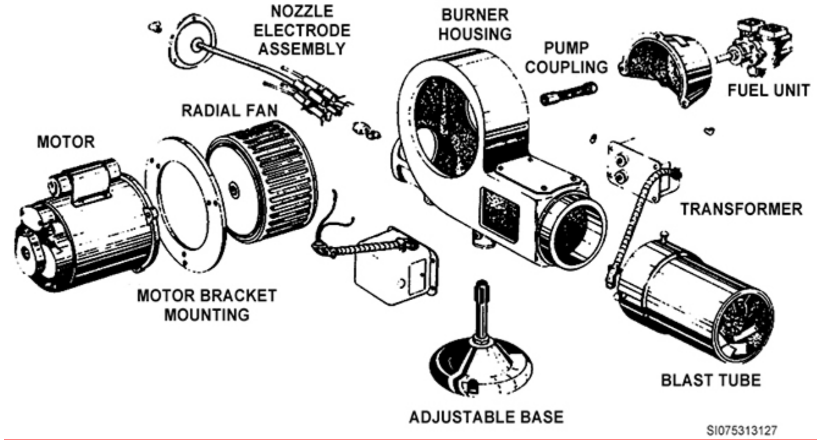

Figure 2–52. Domestic, high-pressure atomizing, gun-type burner.

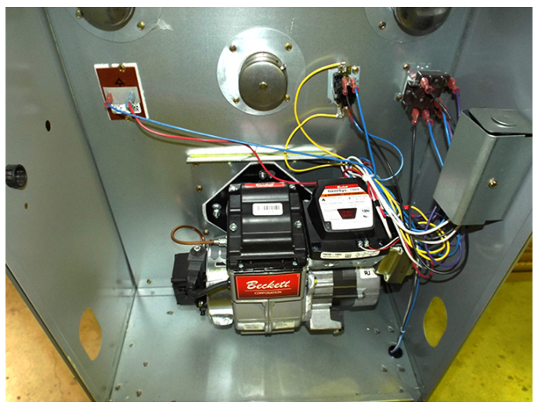

Figure 2–53. Oil Burner for furnace.

Burner motor

This motor is usually of the split-phase or permanent split capacitor type, mounted to the burner housing by a two-, three-, or four-bolt flange. It usually has an RPM rating of 1,725 or 3,450. The motor will usually run off of 120 volts and 60 hertz. If you need to replace a motor, use an identical unit with the same rotation, frame size and RPM. When running, the motor will turn the fan and the fuel pump.

Burner blower

This is a radial fan or squirrel cage, (fig. 2–54). Located in the burner fan housing and driven directly from the motor shaft, it provides the air to support combustion. An adjustable air shutter (on the housing) that controls the air intake to the burner readily controls the volume of air it handles. The blower mounts on the motor shaft, with the drive coupling affixed to either the blower hub or an extension of the motor shaft. Take care not to bend the fan's curved blades, as this would unbalance it and damage the burner motor bearings or make it rub on the burner housing.

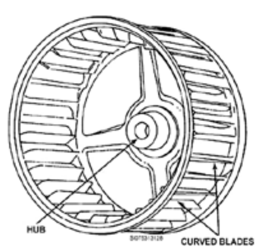

Figure 2–54. Radial or squirrel cage fan.

Ignition transformer

This is usually at one side or on top of the burner, and it provides the "step-up" from the line voltage of 120 volts to a higher voltage for ignition. The higher voltage created ranges from 10,000 to 14,000 volts for ignition. Figure 2–55 shows an ignition transformer that is opened up. The orange arrows point to springs that contact the electrodes when the transformer is closed. The red arrow shows you where the power for ignition is coming from. The image on the right of the figure shows a yellow arrow. This arrow is showing you where the spring from the transformer meets the electrodes after you completely flip the transformer in its place. The spark jumping across the gap between the electrodes provides heat to ignite the oil spraying from the nozzle.

The ignition sequence may be constant or interrupted, depending on the type of flame safeguard control. *Constant ignition* continues as long as the burner motor operates on a call for heat. In *interrupted ignition*, the spark takes place only during the initial startup of the burner and then shuts off. The primary or programming control determines the time for ignition.

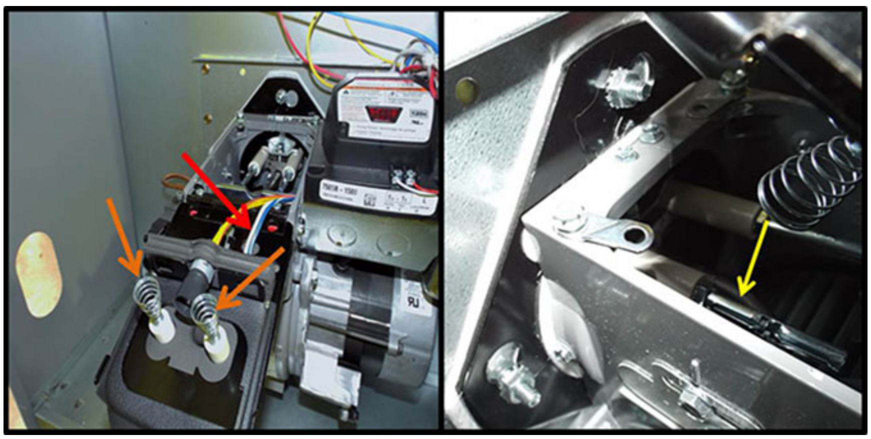

Figure 2–55. Ignition transformer.

Solid-state igniters

Solid state mean (of a device) making use of the electronic properties of solid semiconductors (as opposed to electron tubes). Newer burners use solid-state ignition to ignite the oil. High voltage is produce from electronics instead of a transformer. The range for these igniters is 14,000 to 20,000 volts. They are more efficient because the higher spark temperature that is created from the higher voltage lights more of the oil.

Nozzle and electrode assembly

This includes oil pipe, nozzle holder, nozzle and strainer, electrodes, insulators around the electrodes, a supporting clamp for all parts, and a static disk (fig. 2–56). In figure 2–57, the yellow circles represent where the ignition transformer will connect the electrodes and the arrows represent electricity flowing. Eventually the electricity will reach the tips of the electrodes and spark. The high-pressure, gun-type nozzle has its rating in GPH stamped into its side. The nozzle selected depends on the size of the furnace or boiler. The nozzle has the angle of spray stamped on its side as well (fig. 2–58).

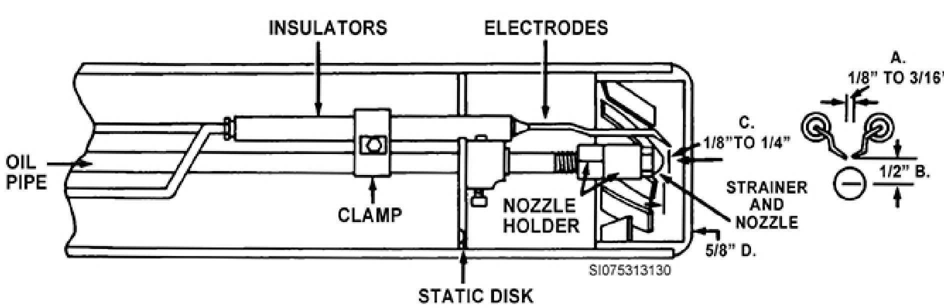

Figure 2–56. Nozzle and electrode assembly.

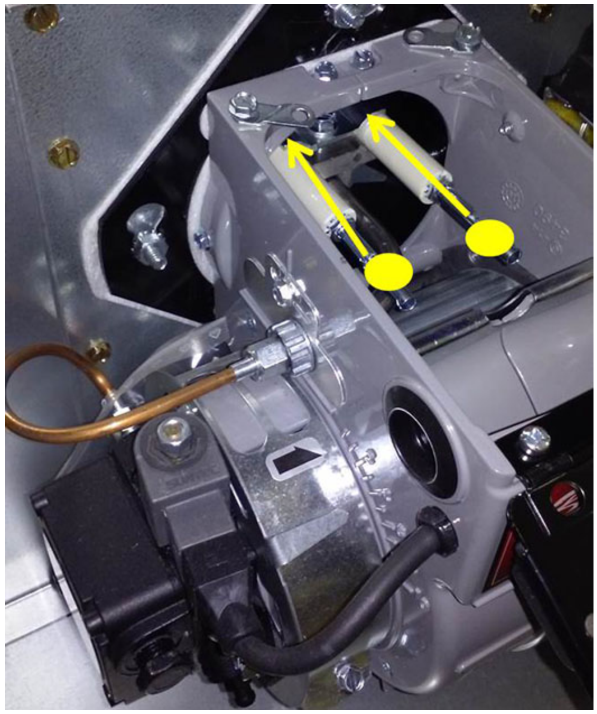

Figure 2–57. Electrodes connections.

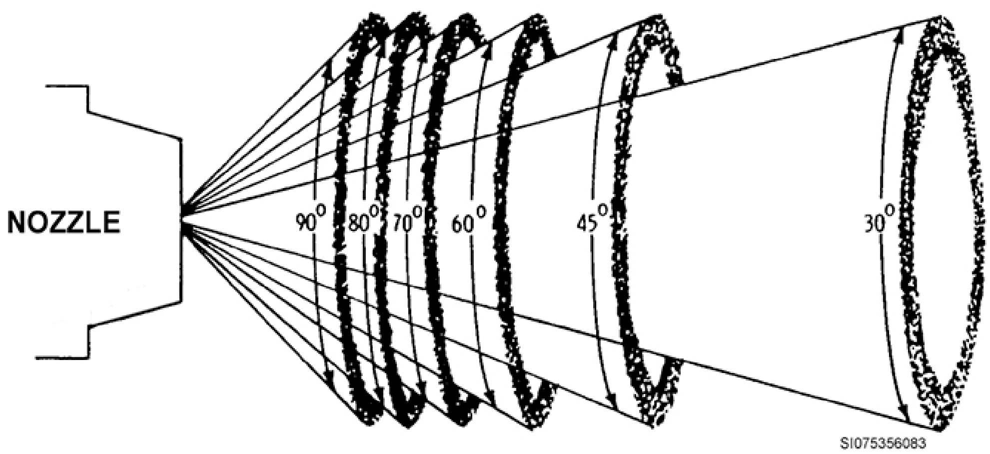

Figure 2–58. Angle of spray.

The design of the combustion chamber (firebox) determines the angle of spray. A long, narrow firebox takes a smaller spray angle than a short, wide firebox. When you select a nozzle, be sure the angle of the spray will not make the flame strike the sides or back of the firebox (fig. 2–59). Figure 2–60 is a cutaway view of an oil burner nozzle. The nozzle also has the type of spray pattern stamped on it. Figure 2–61 shows the four spray patterns. Always refer to the nozzle manufacturer to cross-reference nozzle spray patterns. The electrode assembly includes two separate electrodes, partially covered by glazed porcelain insulators. A supporting clamp, or static disk or stabilizer, holds the electrodes and the fuel tube firmly together inside the blast tube. When you replace nozzles, be sure to use the same type.

Fuel oil pumps or fuel units

The fuel oil pumps can be either single-stage or two-stage. Both types come in different sizes and designs that meet the requirements of most oil burners.

The oil burner is the most economical type of atomizing burner, as far as initial and operating costs are concerned. We use these in small, residential heating plants as well as in some of the largest boiler plants requiring high firing rates.

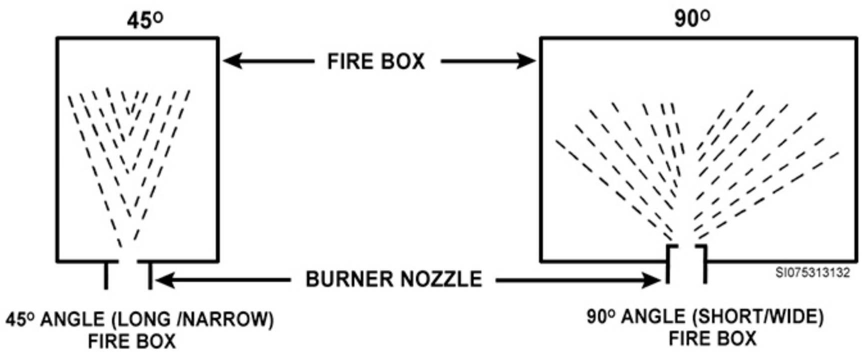

Figure 2–59. Fire box (combustion chamber) shapes.

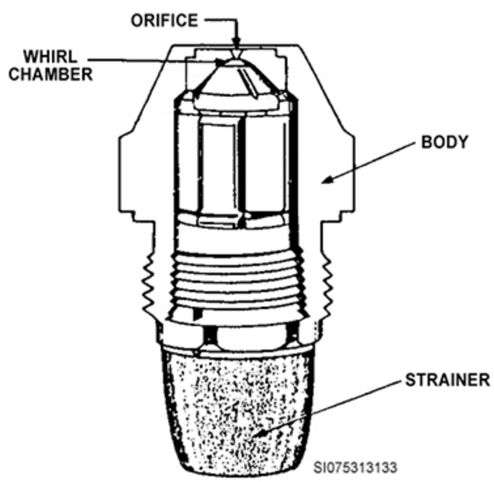

Figure 2–60. Nozzle (cutaway).

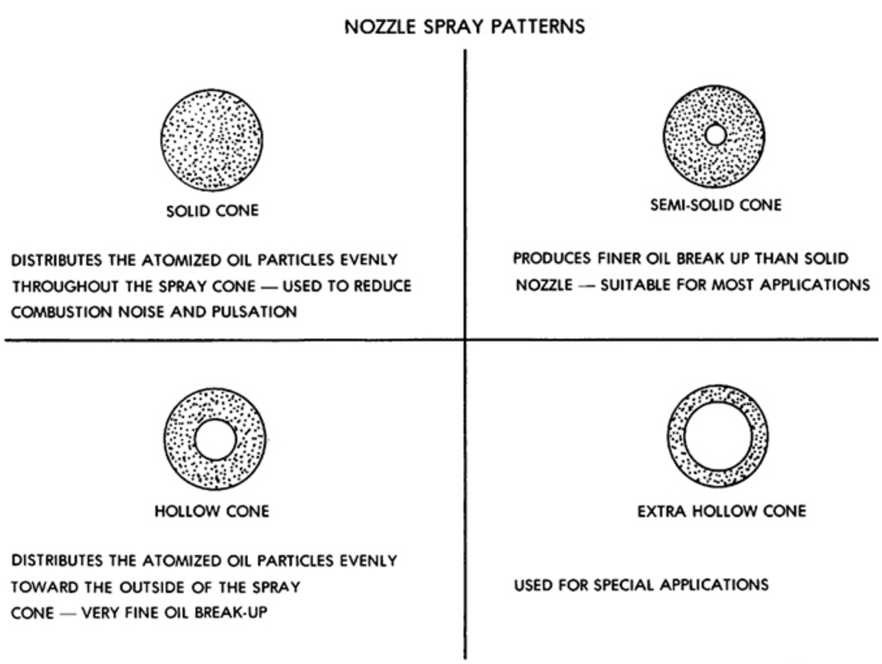

Figure 2–61. Nozzle spray patterns.

Combination burners

Many boilers that burn gas generally have combustion equipment suitable for two or more kinds of fuel. The use of multiple fuel burners (combination) makes it possible to take advantage of market conditions, provides for shortages in supply, and guards against possible transportation difficulties.

Dual-fuel, combination gas/oil burners, is forced-draft burners that incorporate, in a single assembly, the features of the commercial-industrial grade oil and gas burners described in the preceding sections. These burners have a three-position switch that permits the manual selection of gas, oil, or a *center-off* position. This switch has a positive center, stop or delay to ensure that the burner flame relay or programmer cycles the burner through a post-purge and pre-purge cycle before starting again on the other fuel. The burner manufactures of larger boilers design the special mechanical linkages needed to deliver the correct air-fuel ratios at full-fire, low-fire, or any intermediate rate. Smaller burners may be straight *on-off* firing. Larger burners may have low-fire starts on both fuels and use a common flame scanner. Smaller dual-fuel burners usually include pressure atomization of the oil.

The dual-fuel burner is fitted with a gas train and oil piping that connects to a two-pipe oil system. Automatic changeover requires a reserve of fuel.

Self-Test Questions

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

618 Application of oil burners

1. What effect will preheating have on No. 4,5 and 6 oils?

2. Why would No. 5 and No. 6 oil need more preheating near the burner?

3. What must be done to oil before it can be burned?

4. What is atomization?

5. What effect does a high voltage electric spark have on the fuel-air mixture?

6. What effect does turbulent air have on oil particles?

7. What voltage and frequency do burner motors typically use?

8. When does the spark occur during interrupted ignition?

9. How is the time for ignition determined?

10. How is the fuel selected on a combination burner?

619. Pre-operational inspection and operational test of oil burners

Oil burner operation is, for the most part automatic. Although to keep an oil burner operational, you, as a heating, ventilation, air conditioning/refrigeration (HVAC/R) systems specialist, you need to understand how to do a pre-operational inspection and an operational test. This lesson should help you in improving your knowledge of these areas and job accomplishment.

Pre-operational inspection

These 10 pre-operational inspection procedures in the following table are general in nature and apply to starting most oil burners.

Pre-operational Inspection Procedures
1. Perform a visual inspection to eliminate fire and other safety hazards by ensuring all installation, repair, and cleanup work has been completed.
2. Do a system check. See that the oil supply system, burner, and pump installation is proper and leak free.
3. Inspect burner assembly parts for proper installation, make sure they are in good condition, and ready for service.
4. Check power sources and control wiring to the burner control panel for compliance with the wiring schematics and local codes.
5. Inspect boiler stack and breeching to ensure there is no obstruction for flue gases. Check breeching or stack damper and/or barometric for operational and proper position for firing.
6. Inspect combustion chamber for pools of unburned oil. **NOTE:** An explosion could occur if you try to ignite the burner with a flooded combustion chamber. Never start an oil burner with a flooded combustion chamber. If it is flooded, soak up the oil with rags and purge the combustion chamber of oil fumes. Wipe up any oil found on the floor. This is a fire and slipping hazard. (Always follow the manufacturer's instructions when inspecting oil burners).
7. Check all wires to controls, motors, and valves for proper wiring installation and conditions according to the Underwriters' requirements, the National Electrical Code and local ordinances, using wiring schematics. Check all fuses for correct rating to meet code requirements. Check all limit and operating controls for calling position.
8. Check ignition system and the burner itself to ensure everything is clean, carbon free and properly positioned.
9. Check all linkage for proper setting and looseness, and tighten if necessary.
10. Adequately fill oil tanks with the right fuel.

Now that you know how to start the burner we will discuss what to look for while it's running.

Operational test

The main consideration when operating oil burners is to follow the recommendations and procedures furnished by the manufacturer of the specific unit. For gun-type burners, the starting procedure is usually a control that calls for the burner to come on. The burners operate on their own once all adjustments are complete, according to the manufacturer's instructions. These three start-up procedures in the following table are general in nature and apply to most oil burners.

Start Up Procedures
1. Open all oil supply and return valves serving the burner.
2. Turn on the electrical power to the burner. The burner should start its firing cycle. If not, check the operating control, which can be an aquastat, pressure control, or thermostat, and ensure the set point can turn on the burner. These controls when closed will activate a primary control on the burner and start the system. **NOTE**: When the burner starts its firing cycle, stand well away from the front of the burner in case there is a flashback or explosion when the oil ignites. If this occurs, *immediately* shut down the electrical power to the burner.
3. As the burner is operating, monitor oil pressure, draft flow, stack emission, and the burner firing cycle response to the type of control. Check to ensure that the burner shuts off when reaching the proper temperature or pressure. If everything operates properly, wait until the system comes back on to ensure a complete cycle of the burning equipment.

In the event of a flame failure, (which can be caused by lack of ignition, incorrect oil pressure adjustment, improper air shutter adjustment, dirty nozzle, etc.), the primary control shuts down the burner and locks out the burner control function. To restart the burner, you must press the reset button installed on or inside the cover of the primary control. You may press it once to try to relight the burner, but, if the flame does not light the second time, you probably have a mechanical or electrical problem with the burner. You should not continuously reset the button; this could create a residual buildup of fuel oil in the combustion chamber.

If the burner does not relight the first time after resetting the primary control, shut down the burner and try to find the cause of the flame out. As a HVAC/R specialist, you will get a call to service an oil burner in a situation where the building manager or occupants have taken it upon themselves to reset the primary control several times before calling for help. So before you reset the control, always check the combustion chamber for residual buildup of oil, and do a thorough pre-operational inspection, before try to start it.

Let's use a *real life example* to drive home this idea.

In 2007, at an air base in South Korea, an Airman received a no heat call for a building that had an oil fired gun type burner. After speaking with the facility manager, the Airman felt confident the unit had not been reset or adjusted by the facility manager. The Airman went to the burner and pushed the reset button. The system rumbled and a ball of fire was seen going up the stack. The boiler nearly exploded! This was a close call and could have injured or killed many people. So, even though the facility manager said the unit was not tampered with, someone went into the mechanical room and reset the system multiple times. It does not hurt to visually inspect the system regardless of what you have been told.

Safe shutdown checks

The safe shutdown checks are the limit action, flame failure, and power failure checks, all made with the burner operating.

Limit action check

Lower the high-limit setting to simulate an overheated boiler or furnace; the system should shut down. The burner should re-light after you restore the normal limit setting. Manual reset limits are desirable with the primary control to keep the system from cycling off the high limit and to detect the condition that causes the limit action as soon as possible.

Flame-failure check

Close the manual fuel valves to simulate a flame failure. The system should lock out in safety-switch timing. After the safety switch has cooled, open the manual valves and reset the safety switch; the burner should restart.

Power failure check

Open and then immediately close the line switch to simulate a power failure; the burner should shut down. After a short delay for component check, the burner should restart and operate normally.

Self-Test Questions

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

619. Pre-operational inspection and operational test of oil burners

1. What step of the pre-operational inspection will eliminate fire and other safety hazards?

2. What could happen if you ignite the burner with the combustion chamber flooded?

3. What step should be taken if oil is found on the floor?

4. What are the linkages inspected during the pre-op?

5. What should be done after the electrical power to burner is on but the burner did not start?

6. What should be monitored during burner operation?

620. Preventative maintenance for oil burners

In servicing mechanical-atomizing oil burners, the main items of interest are the burner motors, fan, electrode assembly, and pumps. We will discuss the maintenance procedures for these items such as lubrication, adjustment, and cleaning. Remember, preventative maintenance is the term to use when referring to the service of oil burners.

Motors

Motors usually are the only item on an oil burner that may need lubrication. Some motors have sealed bearings and need no lubrication. Always check manufacturer’s recommendations for the type of oil and amount.

Fan adjustment

The blower unit takes little if any attention, but you must keep the vanes clean; excessive dirt accumulation may reduce the output of air.

Electrode adjustment

The electrodes light the fuel oil. The best way to keep from delayed ignition (or no ignition) is to adjust the spark gap to the proper dimension. There are four dimensions you must check. In order of importance, they are the gap between the electrodes, the height of the electrodes above the center of the nozzle, the distance of the electrode tip forward from the nozzle center, and the distance of the nozzle from the end of the blast tube. No part of the electrodes should be closer than ¼ inch to any metal part of the burner. The following list adjustment requirements:

- The spark gap between the electrodes (dimension A in figure 2–56) will depend on the size of the nozzle.
- Adjust this gap to the dimension shown unless the manufacturer states otherwise.
- Dimension B, the distance between the electrode tips and the center of the nozzle, is ½ inch.
- The distance of the electrode tip forward of the nozzle center (dimension C) varies slightly according to the nozzle angle.
- For nozzles with a spray angle between 70 degrees and 90 degrees, $^1/_8$ inch is enough, and for nozzles with angles less than 70 degrees, ¼ inch will do.
- The distance between the nozzle tip and the end of the blast tube (dimension D) should not be more than $^5/_8$ inch, and the nozzle should never project past the end of the blast tube.

You can use these dimensions with some confidence but if the burner has a special combustion head or specific unique air-handling parts, follow the burner manufacturer's spark dimension specifications.

At no time must the tips of the electrodes be in the path of the oil spray. This dangerous condition results in a bridge of hard carbon across the gap. It shorts out the electrodes and kills the spark. The tips should be slightly behind the spray. The air from the fan will blow the spark into the path of the oil spray.

Air adjustment

An air shutter on most burners adjusts burner air. Larger burners have air dampers or shutters above or below the burner. Follow up any air adjustments by flue gas analysis to ensure proper combustion.

Pump adjustment

Attach a pressure gauge to the pump's optional nozzle line opening (fig. 2–62). The pressure should be about 80-125 psi for most domestic gun-type burners, 100-300 psi for most mechanical pressure-atomizing burners, and 30-100 psi for most steam pressure atomizing burners. See figure 2–63, for an example of the gauge connected to a domestic gun type fuel unit. You can connect a vacuum gauge to the pump's optional inlet opening to check for vacuum leaks in the suction line from the fuel oil storage tank. If the tank is above the burner and the oil feeds by gravity, the gauge should read zero unless there is a problem. If the tank is below the burner, get a reading on the gauge. A zero reading indicates a vacuum leak in the suction line from the storage tank.

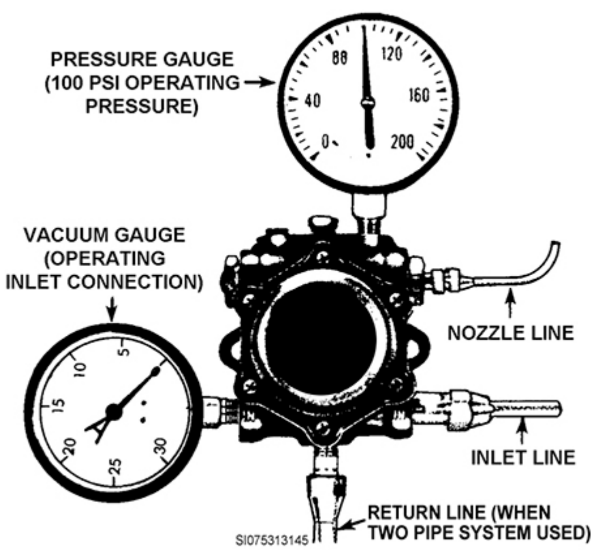

Figure 2–62. Adjusting pump pressure.

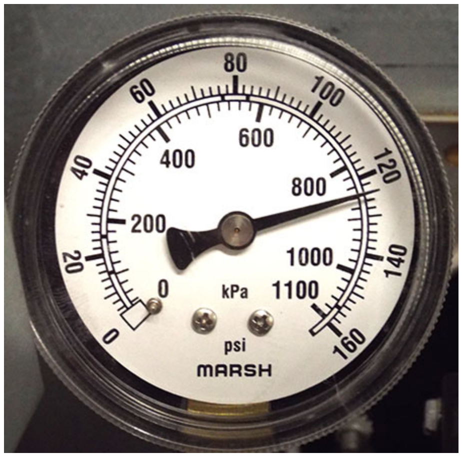

Figure 2–63. Over 120 psi for domestic burner.

You can increase the oil pressure going to the burner by turning the pressure adjusting screw, on the fuel pump clockwise. To decrease the oil pressure that the burner receives, turn the pressure adjusting screw counterclockwise. Any adjustment to the pump pressure may cause you to readjust the primary air going to the burner. Follow any air or oil pressure adjustments with a flue gas analysis to ensure proper combustion.

Pump cleaning

All oil burners and components need a general cleaning at regular intervals. Clean oil supply strainers at least monthly, or if fuel oil shipments are unusually dirty. You can clean permanent supply line strainers with low-pressure steam, hot water, or solvent. If the strainer is disposable, replace it; if not, remove it and clean it the same way you do the supply line strainer. Remove and clean nozzle strainers. Most nozzles rated below 15 gph have strainers. If the nozzle rating is above 15 gph, any small debris that passes through the fuel supply strainer or pump strainer can pass through the orifice in the nozzle and burn with the fuel oil. Never clean the nozzle orifice with anything larger than the orifice size. You can use a toothpick or low-pressure air the nozzle orifice.

The burner housing should be dust-free and wiped of any oil inside and outside. Remove any carbon deposits. Air shutters must be clean and clear of debris.

Dismantle the electrode assemblies and remove any carbon deposits from the electrode, insulators, static disk, nozzle holder, and air cone (at the end of the blast tube on gun-type burners). Readjust the electrodes when you finish cleaning. Wipe the flame detector clean with a soft cloth to remove any deposits that may interfere with flame sighting. The last step in oil burner preventative maintenance is to make a general cleanup of the furnace or boiler room to prevent slipping and fire hazards.

Self-Test Questions

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

620. Preventative maintenance for oil burners

1. How far away should the electrodes be from any metal part of the burner?

2. What should be performed after an air adjustment was made?

3. How is a fuel oil tank checked for a vacuum leak in the suction line?

4. How is the oil pressure to the burner decreased?

5. When should oil supply strainers be cleaned?

6. How is an oil fuel nozzle cleaned?

2–4. Flame Controls and Detectors

Flame safeguard, control system, and combustion safeguard all mean the same thing. In their broadest sense, they cover all the controls of burners and their associated equipment. This includes the flame-sensing device used to detect the flame, operating and safety devices used to start and stop the burner, valves to control fuel flow, sequencing relays, and auxiliary controls used in conjunction with the safety control system. If we had to define these terms, the definition might be: *A set of control equipment used in a system to provide safe control of burner operation as required by the burner application.* If you are thinking that definition is hopelessly broad, you are right but remember that it must include controls for all types of systems from simple continuous (standing) pilot systems all the way to complex, sequencing control systems for large burners.

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621. Function of flame control

Flame control systems are used to keep burners safe when they are operating. Designs of the controls are usually varied, depending on the application and versatility that you want to incorporate. The following text discusses functions of flame controls.

Major causes of boiler furnace explosions

Most furnace explosions come during the starting-up period. The next major condition causing explosions is decreasing or stopping the fuel feed (which causes loss of ignition) immediately followed by a resumption of the fuel feed without the proper lighting-off cycle. A third major cause is operating furnaces with inadequate air supply, thus letting unburned fuel accumulate in the furnace or flues. This unburned fuel can then ignite when the proper air ratio restores, or if supplied too much air, suddenly. This third condition sometimes happens in manual or semiautomatic furnaces. We want to stop these conditions before they can happen. Let us look at the control systems that prevent these conditions.

Operation and types of flame control systems

The modern flame control system on a residential, commercial or industrial system must provide a safe means of starting and stopping the burner, manually or automatically. It must start the burner in the right sequence and supervise the burner flame during operation. It must guard the system against excessive pressure or temperature conditions. Last, on larger systems, it must regulate the burner-firing rate and maintain burner readiness during the burner-off cycle. Let us look at the various types of controls.

Controllers

The controller may be an automatic temperature- or pressure-sensing device designed to operate the burner to maintain (depending on the medium heated) set limits of pressure, water temperature, or air temperature. It may also be a start/stop station that lets the operator start and stop the burner manually. In modern equipment, it sends a signal to a circuit board which is the brains of the system. The board can let you know the status of these controllers and it can start and stop the system depending on the feedback it gets from them (fig. 2–64). As you may notice, there are many wires and devices on these boards.

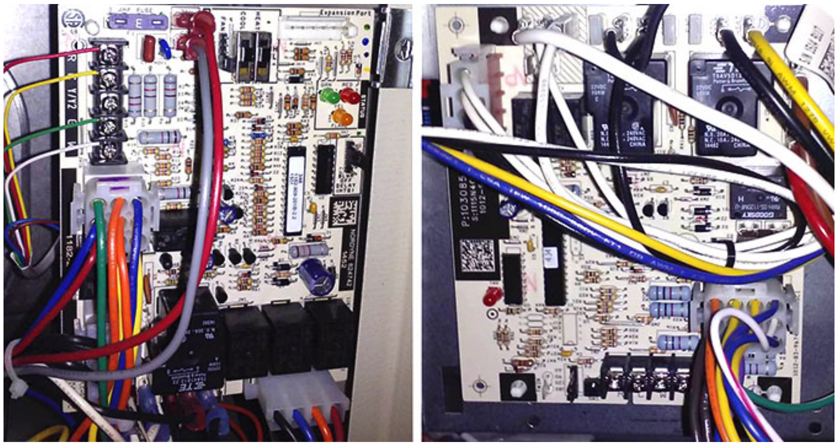


Figure 2–64. Control boards for gas furnaces.

Limit and safety controls

The controller must have a pressure or temperature limit control that keeps it from operating beyond a certain point. Steam and hot water boilers must also have a low-water cutoff to prevent burner operation below safe limits. If the boiler has a feed water or condensate return pump, it must start before the low-water cutoff activates to raise the water level. As stated above, these controls will commonly be connected to a circuit board. The board in figure 2–65, shows a connection on the circuit board for a damper. This board is for a boiler and the connection may consist of inputs the board is receiving and outputs the board is sending.

Figure 2–65. Damper connector on circuit board.

Burner interlock controls

An interlock is simply a control that coordinates the function of different components. Burner interlock controls prove that the conditions for combustion are established and that the burner is ready for starting. They also prove that conditions are satisfactory for burner operations to continue. Three classes of burner interlock controls are start interlocks, running interlocks, and lockout interlocks. The following list provides a description of each:

- Start interlocks—Include valve-closed interlocks, damper positioning controls, fuel pressure switches, electrical start interlocks, and oil preheater controls.
- Running interlocks—Include fuel pressure switches, combustion air controls (airflow switch), and draft controls (low and high fire proving switches).
- Lockout interlocks—Include airflow and fuel pressure switches. Use these with flame safeguard controls incorporating a lockout interlock circuit. They would replace similar running interlocks. Smaller burners do not need all of these interlocks, but larger burners would use most of them.

Firing rate controls

Most commercial and industrial burners have a way to vary the firing rate according to the load demand. This is usually done electrically or electronically and it involves changing the firing rate (both air and fuel quantities simultaneously) from high fire to low fire, or modulating the firing rate as the system demand changes.

When firing rate controls are of the high/low or modulating type, you may need a low fire start for a smooth startup.

Fuel valves

Fuel valves open, close, and sometimes modulate the fuel supply. Some oil burning systems may have delayed-opening features. Another characteristic of fuel valves is gas valves may be slow or fast opening.

Primary and programming controls

The primary and programming controls, with their associated flame detectors, are the heart of the control system. They start the burner in its proper sequence, sense that the flame establishment, and it also supervise the flame during burner operation.

An electronic flame safeguard control has three functions that interlock so that a failure indication in any of the three will make the system shut down or recycle. These functions (fig. 2–66) are sensing a satisfactory flame; sequencing the burner system operation; and checking the system components.

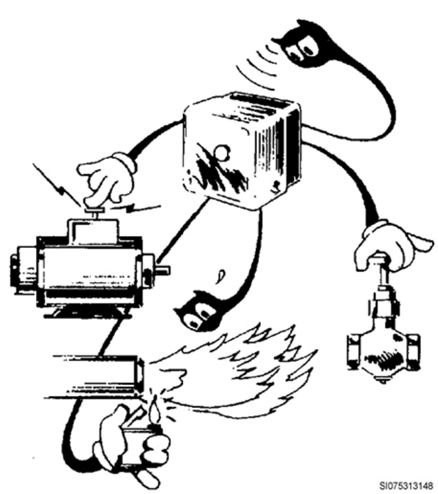


Figure 2–66. Electronic flame safeguard functions.

Sensing a satisfactory flame.

A flame safeguard must distinguish a safe flame, an unsafe flame, and something that is not a flame at all, but merely has some of the characteristics of flame (for instance, hot refractory). It must function faster and more accurately than you could do it, or the result may be unsafe. Without this complete ability, a flame safeguard system is worse than useless—it is downright dangerous.

Sequencing the burner system operation.

The burner system's motors, blowers, ignition, and fuel valves must be energized only when they are needed and in the right sequence. On a shutdown (normal or because of flame failure) these components must be de-energized in the right sequence to keep unburned fuel from accumulating in the combustion chamber, where it could be hazardous. When a start button is pressed or an automatic controller calls for heat, something must make sure the burner gets fuel and ignition at the right time for a good ignition. Power applies to start motors, open valves, and to provide ignition. If some component or interlock shows that the system is dangerous, the flame safeguard system must stop the sequence and shut down the burner system safely. It may have other duties too, such as purging or sounding alarms. To do this it must not only sense the presence or absence of a satisfactory flame, but also control the operating sequence of all burner system components.

Checking its own components

By a built-in safe-start check, the flame safeguard checks itself for unsafe failures on every start and every time power reapplies. If there is a flame-simulating failure, the safe-start check will keep the burner from starting. If this task isn't performed then continued operation may not have been safe. A shutdown on a marginal flame condition is not a nuisance shutdown; the flame safeguard is functioning, as it should. A flame safeguard system considers safety first and convenience second.

The primary control has the relays and contacts that start and stop the burner under orders from the operating controller, limit controller, interlocks, and flame detector. The generalized flame safeguard system in figure 2–67 is representative of all flame safeguard systems. As you can see, the primary control starts the burner system on signal from the controller, and it lets operation continue under control of two feedback loops. The flame detector monitors flame conditions and signals the burner to stop if flame is lost, or if there is a failure in the detection system. The limits and interlocks monitor conditions other than the presence of flame; they shut down the system if conditions exceed limit or interlock settings.

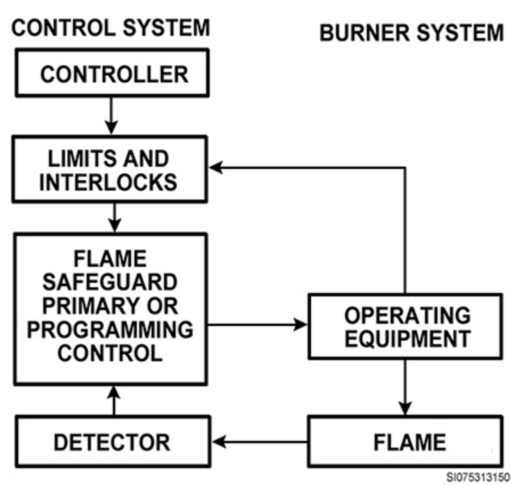


Figure 2–67. Flame safeguard control system.

A programming control is the same as a primary control, except that, as the word "programming" implies, it provides timed sequencing of the burner functions. It may also control such other functions as prepurge, postpurge, timed trial for ignition, and firing rate selection. We will discuss the primary control and the programmer in more detail in a later lesson.

Self-Test Questions

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

621. Function of flame control

1. When do most furnace explosions occur?

2. After explosions during start-up, what is the next major condition that causes explosions?

3. What do burner interlocks prove?

4. How does a flame-simulating failure effect the burner’s operation?

622. Flame detectors

Flame detectors are devices that tell our controls whether or not a flame has been established. Numerous detectors are covered in this lesson.

Purpose of flame detectors

Flame detectors (sensors) are flame detection system components that detect the presence or absence of a flame. As far as the flame detector is concerned, there is no such thing as a partial flame. If the flame is above a certain threshold, the detector signals “flame.” If it is below this level, the detector signals “no flame.” The detector’s safety feature is its ability to determine, with absolute certainty, when the flame goes out and to signal the primary control or the programmer accordingly. All flames have the following characteristics in common:

- Production of heat.
- Expansion of gases.
- Production of by-products.
- Emission of light (infrared to ultraviolet).
- Ionization of the atmosphere in and around the flame.

Different flame detection systems use several of these characteristics. The flame detecting part of the system emits a signal or originates some physical action in the presence of the detected characteristic. As we said, many flame detection systems for domestic heating use the flame’s thermal effect for detection. The flame for the system to operate must heat the detecting elements. This is true whether heat conversion to a physical force, as in a bimetal or hydraulic pilot sensor, or to electrical signals, as in a thermocouple. The main problem with these sensors is that it takes time for the sensor to heat (and to cool after loss of flame). Large systems (used in central heating plants and large heating systems) need faster flame-proving techniques. Fast-response systems use the flame’s light (infrared, visible, or ultraviolet) and ionization characteristics.

Rectifying photocell flame detectors

In this lesson we will cover one flame detector that falls into the visible light range—the rectifying photocell. In a rectifying flame detection system, alternating current (AC) applies to the flame (F) and ground (G) terminals of the primary control, but the operation of the electronic network depends on direct current (DC). It is the flame detector's job to allow current flow and to convert AC to DC when it senses a flame.

Photocell operation

The rectifying photocell is a high-vacuum photocell that is practically a perfect rectifier. The rectifier tube cathode's coating is a material that emits electrons whenever light strikes it. Thus, in the presence of an oil flame, visible light striking the cathode causes the emission of electrons.

Consider what happens when alternating voltage applies to the cell (fig. 2–68). At the instant photocell's anode, positively charges with respect to the cathode, the negatively charged electrons attract to the positively charged anode, so current will flow. The magnitude of the current depends on the intensity of the light reaching the cathode, which in turn determines how many electrons emit from the cathode's active coating. A fraction of a second later, when the AC flow reverses, the anode is negative and the cathode positive. The anode, which does not have active material, cannot give off electrons; during this part of the cycle, no current will flow. In this way, the photocell acts as a true rectifier, changing AC to DC when there is a flame and not letting current flow when there is no flame.

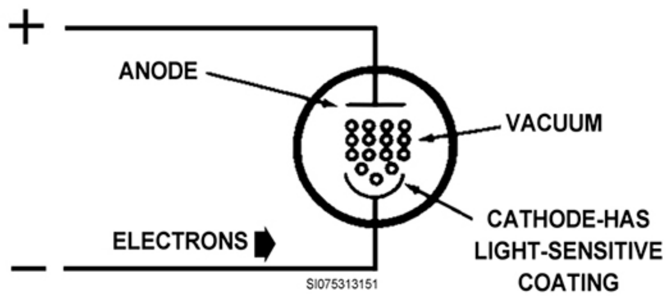


Figure 2–68. Construction of the rectifying photocell.

The rectifying photocell has one very important advantage over the non-rectifying cadmium sulfide and infrared (lead sulfide) detectors, in that it protects against a false flame signal from a high-resistance short. A high-resistance short across the photocell provides an alternate current path, and only AC will flow in the circuit. The relay will drop out and the burner will shut down, because only DC operates the relay's electronic network.

Application

Designers use photocells with large oil burners that need the added safety of shorted lead protection. Do not use photocells to detect gas flames, because a well-adjusted gas flame emits too little visible light. The following are four basic requirements for a good photocell application:

1. Photocell must have a good view of the flame. The rectifying photocell must continuously sight a stable part of the flame. Photocells may view the burner flame through a hole in the combustion chamber wall, from inside the blast tube of a gun-type burner; or from some other location the manufacturer selects for adequate sighting. Cell housing designs adapt the plug-in-type photocell to any of these applications.
2. Protect photocells from the light emitted by the hot refractory. Glowing refractory surfaces emit visible light. If the photocell responds to this light, the flame relay will hold in at the end of the firing cycle, and the burner cannot restart until the flame relay drops out. Aim the photocell at a part of the refractory that will stay relatively cool. You can use an orifice or filter with most cell mounts to restrict the viewing field of the cell or to cut down the total light reaching the cell face. Systems should be designed to meet these requirements so you shouldn't have to worry too much about this from a technician's perspective. This requirement may be of concern to you if someone tried to modify the system or during troubleshooting.

3. Temperature at the photocell must stay under the manufacturer's specifications. The coating on the cathode of rectification photocells will break down at higher ambient temperatures. You can tell a photocell damaged by excessive heat because its cathode face will have a cracked, bluish appearance.
4. Use the correct wire for the flame lead. Using the wrong wire for the flame detector lead can cause signal loss due to moisture in the insulation, can cause actual insulation damage due to high temperatures, or can cause capacitance effects between the flame lead and ground.

Mounting the photocell

On gun-type oil burners, the photocell mounts in the blast tube itself behind the oil nozzle and ignition electrode (fig. 2–69). In this position, the cell cools down by the air stream in the blast tube. If too much heat is reaching the cell, you can add a filter to cut down the heat on the cell face or to restrict the visible refractory light that strikes the cell face. If the photocell signal is weak, you can add a magnifying lens to get a better view of the flame.

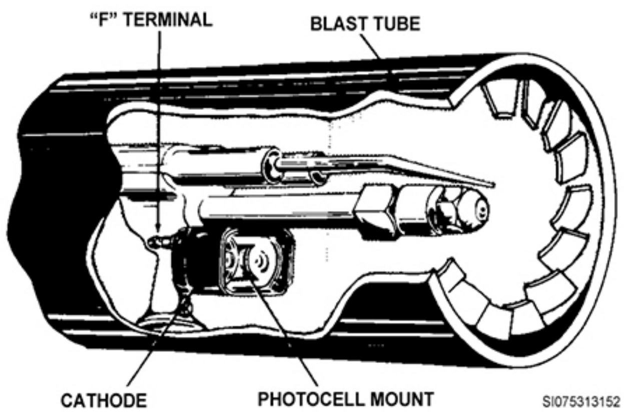


Figure 2–69. Blast tube mounting of photocell.

Burner manufacturers have tested mounted photocells for proper line of sight and protection from excessive heat. If a burner-mounted photocell fails or is damaged, it is best to replace it with a similar cell mounted in the same place. The photocell, in an appropriate holder, mounts on a sighting pipe to view the oil flame from a location remote from the burner itself.

Cadmium sulfide flame detector

The cad cell uses light-sensitive cadmium sulfide to detect the light emitted by an oil flame. Cadmium sulfide's electrical resistance changes with varying light intensity. In darkness, its resistance is high, and it acts like an electrical insulator. As light intensity increases, its resistance drops. When there is enough light, cadmium sulfide conducts electricity. Look at the graph in figure 2–70. Note that as the illumination striking the cell increases, the resistance of the cell drops. Very slight illumination produces a considerable drop in cell resistance, but enough light must reach the cell to lower its resistance to its normal operating range.

Look at the green circle and it shows were a little over 6,000 ohms intersects with .4 foot candles. A foot candle is a measure of luminance or light intensity. This means at .4 foot candles the cadmium sulfide flame detector has a resistance of 6,000 ohms. Now take a look at the red circle, here the foot candles increased to 4 and the resistance dropped to under 600 ohms. Now you should understand how the graph demonstrates that as the light goes up, the resistance of the detector goes down.

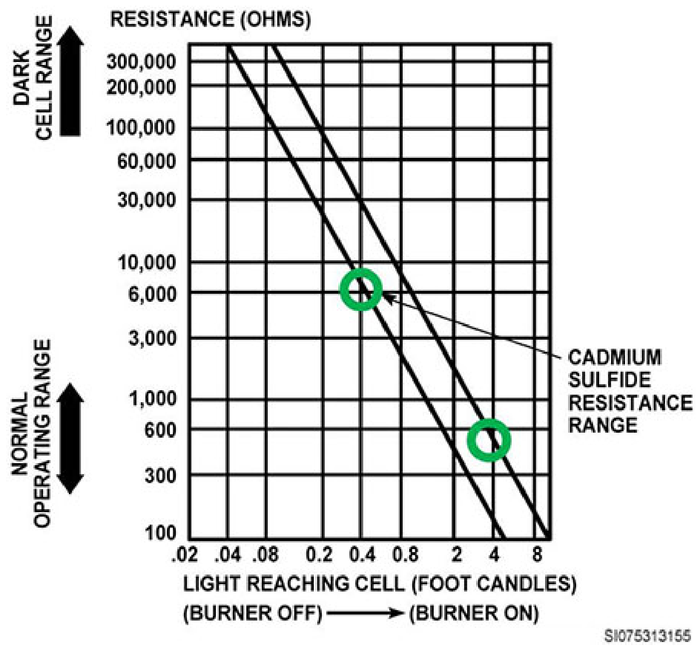


Figure 2–70. Cad cell response to light.

The cad cell responds to any light in the visible range, including both daylight and artificial light. The cell does not react to gas flames, since most of the light emitted is not in the visible range. The wavelength of hot refractory is somewhat above the cell's peak response range, so hot refractory does not affect the cell.

Cad cell construction

The heart of the cad cell (fig. 2–71) is a ceramic disc coated with a layer of cadmium sulfide (cds) and overlaid with a conductive grid. The disc has electrodes attached to it. While the conductive grid is S-shaped to condense the area it takes up, and it gives the effect of two bare wires a few inches long, parallel, with cadmium sulfide between them.

Manufactures complete cell construction with an evacuation and filling of clean, dry air. They seal the cell with a glass to metal bonding process. This seal is important because humidity will deteriorate the cadmium sulfide. Glass sealing is rather expensive but less expensive "potting" seals, such as plastic or epoxy will let moisture diffuse through to the cadmium sulfide in a relatively short period. The result is an increase in cell resistance, which eventually will keep the sensitive relay or electronic network from pulling in, causing a nuisance safety shutdown of the primary control.

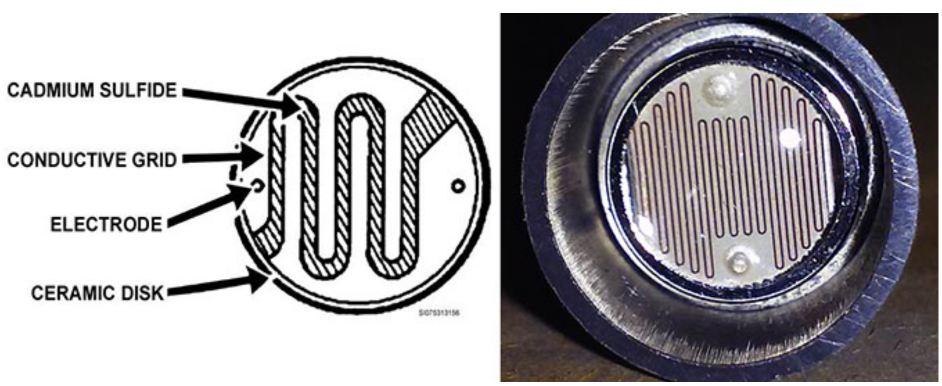


Figure 2–71. Face of the cad cell.

Cad cell application

The cad cell-flame detector assembly consists of a two-piece socket-and-receptacle arrangement designed specifically for easy application in the fan housing or rear part of a burner's blast tube. The receptacle is usually factory installed; do not change position unless it is apparent that the cell is not sighting the flame properly. The socket assembly has the cell, which you can simply unplug from the receptacle for cleaning or replacement.

The lead wires on the receptacle are color coded yellow, and they are class 1, so they can run in with the line voltage wires without extra insulation or barriers. Cad cell hookup is very simple—you just connect the lead wires to the flame detector terminals (F-F) on the primary control (fig. 2–72). Older models have F terminals labeled "S," and the cell leads may be blue, rather than yellow.

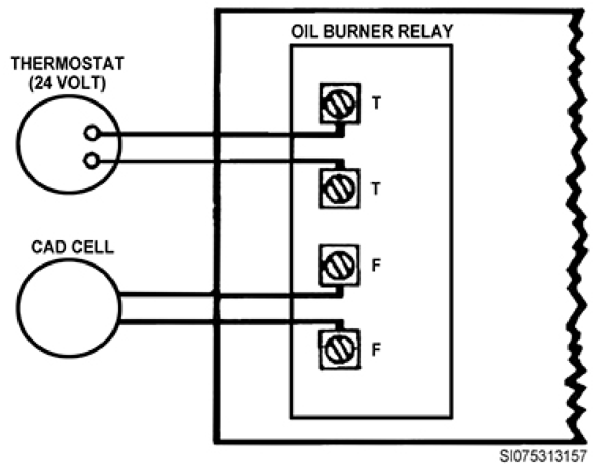
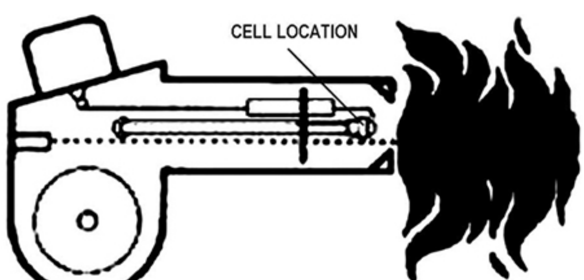


Figure 2–72. Typical cad cell hookup.

Cad cell location

Location is a critical factor in cad cell performance. Figure 2–73 shows the proper location of the cad cell along with five cell location factors you should check. To "see" the oil flame, the cad cell mounts in the burner where it has a direct open line of sight to the flame.



1. Cell requires a direct view of the flame.
2. Adequate light from the flame must reach the cell.
3. Cell must be protected from external light.
4. Temperature must be under 140° F.
5. Location must provide adequate clearance.

Figure 2–73. Cell location.

For proper operation, the cell must see enough light from the burner flame to lower cad cell resistance to the normal operating range. Dirt buildup or external light interference will adversely affect cell operation. Dirt buildup in the burner tube could cause repeated safety lockout if it is bad enough to block the cad cell's view of the flame. In some applications, the cell views the flame through a hole in the static disc. Keep this hole free of dirt buildup. The cad cell is not extremely sensitive to stray ambient light (an uncovered light bulb would have to be reflected almost directly on the face of the cell to have an effect), but intense ambient light will keep the burner from starting.

Ambient temperatures at the cell location must be under 140°F. Heat, like moisture, has a deteriorating effect on cadmium sulfide. Protect the cell from high ambient temperature by locating it in the back of the burner, although it may be located farther forward in the blast tube where it cools from the blower air. The cell must have adequate clearance from metal surfaces that could affect it by movement, shielding, or radiation.

Checking cad cell performance

Cad cell resistance varies with exposure to light, so a check of cell performance requires the use of an ohmmeter. First, remove the cad cell lead wires from the primary control (fig. 2–74). Then, start the burner and jump the F-F terminals before the control can lock out on safety. If you jump the terminals first, you cannot start the burner. The jumper will bypass the safety switch, letting the burner run.

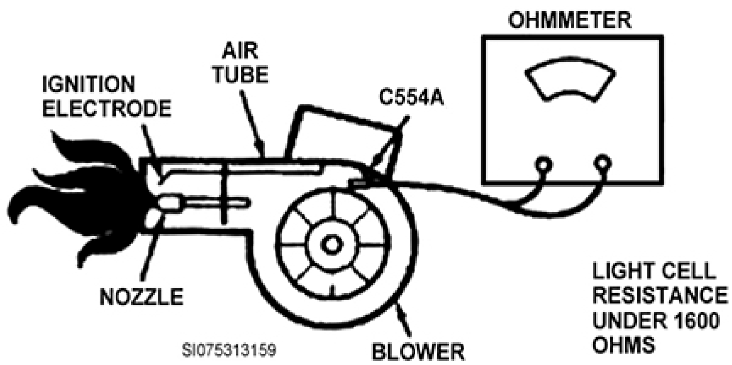


Figure 2–74. Checking the light cell.

NOTE: Remember, you have bypassed a safety switch—do not leave the burner alone and running while the jumper wire is on.

Now connect the ohmmeter directly across the cad cell leads and measure the resistance. With the burner operating, cell resistance should be 300–1,000 ohms if you have adjusted the burner properly. Resistance may be as high as 1,000–16,000 ohms on a poorly adjusted burner. In any case, resistance must be less than 1,600 ohms for reliable performance. As always, manufacturer’s recommendations take precedence.

After checking the light cell, check the dark cell resistance to be sure the external light is not affecting the cad cell (fig. 2–75). Stop the burner and remove the F-F jumper. If you leave it in place, you cannot start the burner. Dark cell resistance should be over 100,000 ohms.

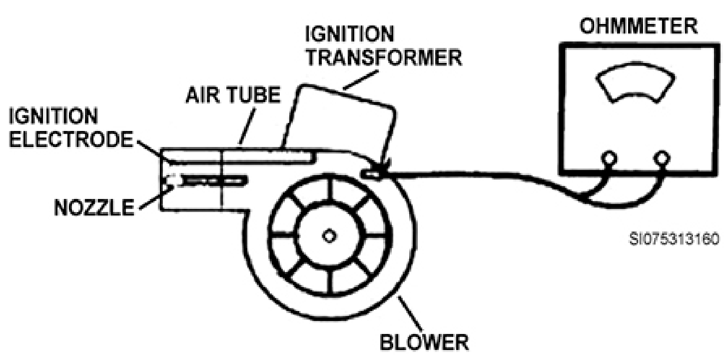


Figure 2–75. Checking dark cell.

There is little actual service that you can do on the cell itself. If you think there is an open circuit in the flame detector circuit, check the cell for proper seating in its receptacle. Vibration could make the cell work loose. You can clean the cell surface with a soft cloth to remove soot or dust buildup that may affect its view of the flame. You can as well replace the plug-in part of the cell simply by removing the old cell and plugging the new one into the old receptacle (fig. 2–76). If you replace the cell, use the checkout procedure to check its operation.

Figure 2–76. Plugging in new cad cell.

Infrared flame detector

Infrared detectors, unlike rectifying photocells and cadmium sulfide detectors, may be used with either oil or gas flames. Since more than 90 percent of the flames total radiation is infrared, these detectors receive ample radiation of quite high intensity, and so will operate with very weak flames, as well as with very hot ones.

The infrared detector can respond to infrared rays emitted by a hot refractory, even after it stops glowing visibly. However, infrared radiation from a hot refractory is steady, but radiation from a flame flickers. The infrared detection system responds only to a flickering infrared radiation and rejects a steady signal. The refractory signal could appear to be fluctuating if the smoke or fuel mist is reflected, bent or blocked. Therefore, you must be sure the infrared system is responding to the flame only.

Cell construction and operation

The sensitive material used in the infrared detector is lead sulfide. The lead sulfide cell is a semiconductor, and its electrical resistance drops when it is exposed to infrared radiation. If you apply a voltage across the lead sulfide, current flows while exposing the cell to infrared radiation.

When a DC voltage is impressed across the cell and a series resistor, the fluctuation of flame radiation produces a fluctuating voltage across the cell. This voltage is termed “flame signal” and an amplifier uses the signal. The amplifier responds to a fluctuating voltage but not to a steady one. Therefore, it responds to a fluctuating flame signal, but not to a steady refractory signal. Further, it is “tuned” for maximum response at a frequency of 10 hertz (Hz)—a fluctuation rate found in all flames—and has relatively little response at power line (60 Hz) and very low (1 Hz) frequencies. When the amplified flame signal exceeds a given magnitude, it energizes the flame relay. Even though the system does not “detect” hot refractory, excessive steady radiation reduces flame signal. The same effect results from excessive scanner temperature. To avoid nuisance shutdowns, it is important to avoid sighting hot refractory and to keep scanner temperature low.

Application of scanner

The scanner must be located so that its line of sight will cross the intersection of the pilot flame axis and the main flame. The cell should be as close to the burner as possible to sight the maximum depth of the flame, reducing the effects of flame pattern variations. The scanner must have an unobstructed view of both the pilot and the main flames. Be sure it does not sight on refractory that will become incandescent during burner operation. The scanner should not get too hot to grasp comfortably in the hand—never over 125°F.

Ultraviolet flame detectors

Ultraviolet (UV) flame detection systems depend on the sensing tube's ability to respond to ultraviolet radiation and remain insensitive to radiation in the infrared and visible light range. The UV sensing tube consists of two electrodes sealed in a gas-filled quartz glass envelope. (Normal glass blocks UV radiation, so the tube must be made of quartz glass.)

Figure 2–77 shows a drawing of the anode and cathode arrangement of the sensing tube of one type of flame detector. Other UV flame detectors', operating principles are similar. The figure is simply a schematic representation of tube construction; the actual power tube sensor has four-pin construction for increased resistance to vibration.

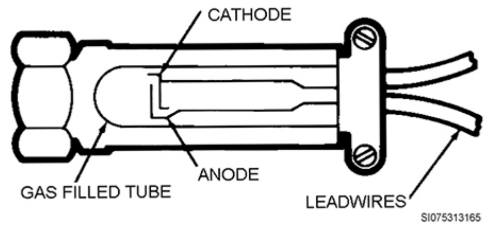


Figure 2–77. UV sensing tube.

When a high enough voltage applies across the electrodes and the tube submits to exposure to the UV source, the cathode emits electrons, which ionize the gas in the tube. When the gas is ionized, the tube becomes conductive and current flows through the tube. You say that the tube "fires" because it glows visibly while it is conducting. The tube's appearance when it fires is a function of the gas that is used. Some tubes fire with a reddish glow; others fire with a blue glow. When the tube fires, the voltage potential between the electrodes drops sharply. When it has dropped far enough, it will no longer emit electrons from the cathode—it is restored to the non-ionized state. During this phase, you say that the tube is "quenched."

Any time the UV tube is exposed to sufficient ultraviolet radiation and sufficient voltage potential applies across its electrodes—from a properly designed electronic network—the tube intermittently fires (becomes conductive) and is quenched (restores itself to the ready condition). UV tubes fire randomly, even if not intentionally exposed to a UV radiation. A background count refers to the firing rate. Observe this random firing by looking at the face of the tube when powered. If it is normal, it will not activate the flame detector relay under usual circumstances.

Application of scanner

Sight the detector at the area of maximum ultraviolet radiation. This happens in the first 30 percent of the length of the flame nearest the burner nozzle. The best angle normally sights along the surface of the flame cone at an angle that lets the detector sight a large part of the flame length within the first third of its overall length. Figure 2–78 shows both good and poor sighting angles.

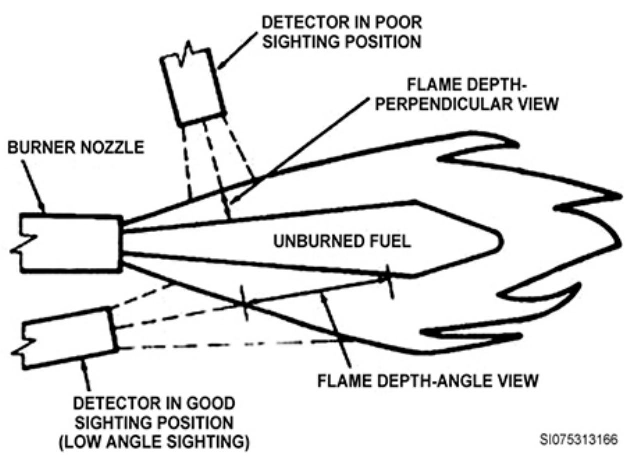


Figure 2–78. UV detector sighting angles.

Ignition spark is the one source of UV other than flame that is commonly present in the combustion chamber. If the UV detector senses ignition spark, a dangerous situation may occur, since the flame relay will pull in whenever the ignition is on regardless of the condition of the pilot or main burner flame. You must make an ignition spark-response check at the time of the detector installation. You simply do this by closing the manual fuel valves and then start the burner, following normal procedures. When ignition starts, the flame relay should not pull in. If you connect a meter to the primary control's test jack, the maximum meter response when ignition starts should be ¼ microampere. UV detectors must not sight either direct or reflected ignition spark.

UV detectors are not as sensitive to high temperatures as the other types. Where the temperature of the surrounding air is above the ambient temperature rating, the whole detector needs cooling. Do this by mounting it in a separate enclosure cooled by compressed air (fig. 2–79) or by wrapping it in a water-cooled coil.

If radiant heat from the burner surface causes overheating, a heat shield between the hot surface and the detector generally gives enough protection. The surrounding temperature cannot be too high. Also, be sure to leave enough airspace to dissipate heat from the shield. A polished surface increases the shield's effectiveness if you can keep it free of dirt. Purging the sighting pipe with clean air is helpful in reducing heat on the sensor face, and it keeps dirt and dust from entering the sighting pipe. A combination of the heat shield and air purge (fig. 2–80) will usually be adequate if the ambient temperature is not too high.

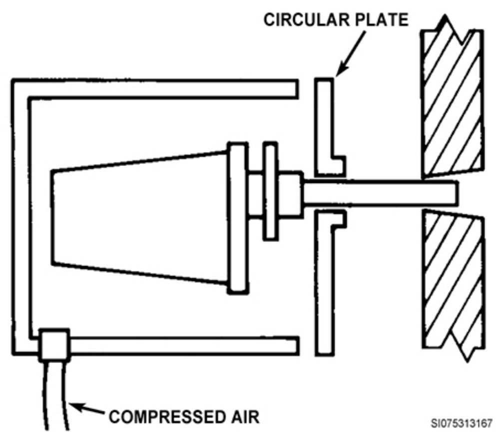


Figure 2–79. Cooling the UV detector with a separate enclosure and compressed air.

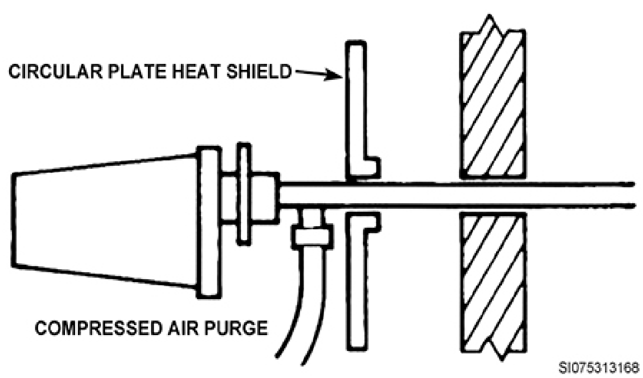


Figure 2–80. Cooling the detector with compressed air purge and heat shield.

As with other types of detectors, the maximum length of the flame detector leads is limited. Primarily use the electrical capacitance between the wires and between the F leads and ground (conduit). Other local conditions, such as line transients or induced currents due to heavy power surges in the area, may also reduce the maximum lead length. The ultimate factor governing lead length must be the flame signal current read on the particular application. If you cannot read a large enough steady flame signal after detector installation, you must take steps to reduce capacitance effects, reduce the effects of other local conditions, or lastly, shorten the flame detector leads.

Flame rod detection systems

The flame rod system depends on the flame's ability to conduct current when an electrical potential applies across it (flame ionization). The flame rod must have a suitable electronic combustion safeguard control to amplify its signal. Use a flame rod only for gas flames because an oil flames' high operating temperatures may damage the system.

The basic principle of a flame rod detection system is flame rectification. This type of system depends on the flame's ability to conduct current when a voltage applies across two electrodes. Heat from the flame makes molecules between the electrodes collide with each other hard enough to knock some electrons out of the atoms, producing ions (flame ionization). Positively charged ions flow to the negatively charged electrode; negatively charged electrons flow to the positively charged electrode.

Figure 2–81 represents AC voltage applied to the electrodes. In a 60-Hz system, it changes polarity 120 times a second; at one instant, electrodes are positive, and $^1/_{120}$ of a second later they are negative. As the voltage changes polarity, the flame current (ion flow) changes direction.

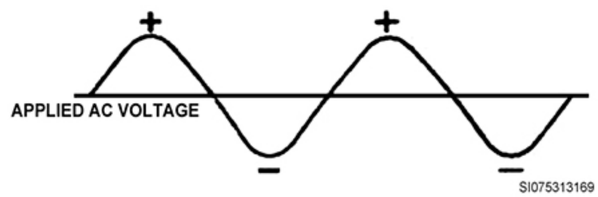


Figure 2–81. AC voltage applied to flame rod electrodes.

The flame rectification system uses two electrodes, the ground electrode is always much larger than the flame electrode (flame rod). For effective operation, the area of the ground electrode must be at least four times that of the flame rod. Usually the ground electrode will be the burner head. Because of the difference in electrode size, more current flows in one direction than in the other. When the flame rod is positive (fig. 2–82), more current flows, but when it is negative, less current flows (fig. 2–83).

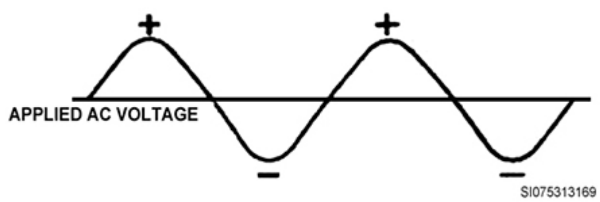


Figure 2–82. Flame rod positive.

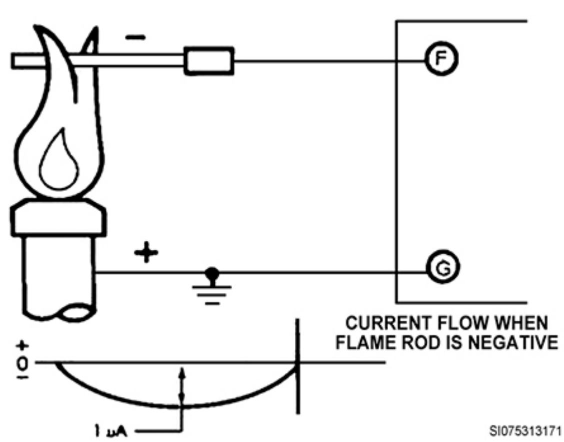


Figure 2–83. Flame rod negative.

With the current in one direction is so much larger than the current in the other direction, the resultant current is, effectively, a pulsating direct current that operates the electronic network. The flame relay pulls in, indicating the presence of a flame and lets the burner sequence continue. In essence, the flame acts like a switch that opens and closes to allow current to flow.

Only the ionized path through a flame and the different sized electrodes can provide the rectified current you need to operate the electronic network in a rectification system. If there is a high-resistance leakage to ground, the flame circuit sends an AC signal into the network, and the system shuts down safely. The rectification system does recognize the difference between a high-resistance leakage to ground and a flame.

Single rod rectification

This type of rectification has one rod that does the sensing and the igniting. During one half cycle of current flow ignition pulses, then for the other half cycle the sensing occurs. One ignition wire runs from the assembly to the ignition control module.

Dual rod rectification

This type has a separate ignition and sensing electrode. There will be two wires running from the assembly to the ignition control module. The requirements for a rectifying flame rod are in the following list below:

- Stable flame.
- Adequate ground area.
- Proper flame circuit.
- Proper location of the flame rod in the flame envelope.

The proved flame must be continuously in contact with the flame grounding area (fig. 2–84).

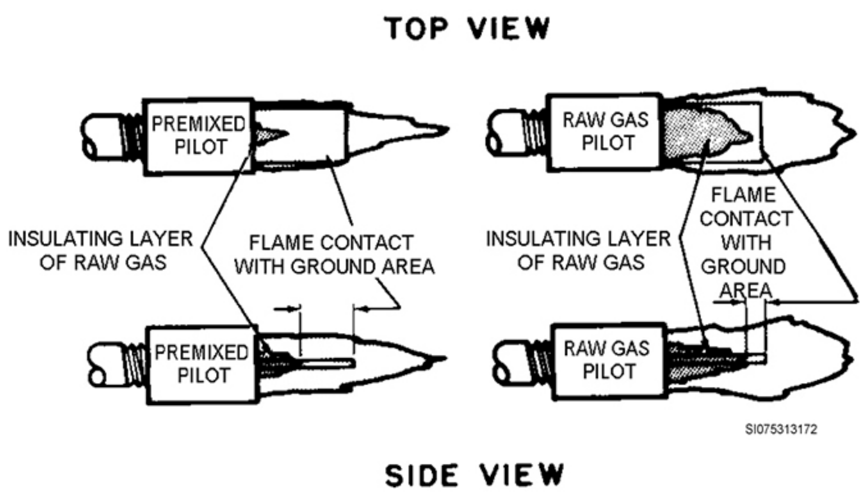


Figure 2–84. Flame contact with ground area—raw-gas pilot versus premixed pilot.

If the pilot flame leaves the flame electrode for a period longer than the flame relay timing, shutdowns are sure to result. Increase the gas pressure to the pilot or enlarge the pilot orifice to provide a stronger flame. Increasing the gas pressure tends to harden and lengthen the pilot flame while increasing its stability under adverse conditions. This stability is especially necessary when the main burner fires with high-pressure gas. Adjust the air mixer to minimize traces of yellow in the pilot.

Figure 2–85 shows a satisfactory pilot installation on an inshot high- or low-pressure venturi-type burner. The pilot is firing in the general direction of the main flame. The pilot is also strong enough to intersect the main flame envelope, and the flame rod location is where it can provide both the pilot and main flames simultaneously. Figure 2–85 is a good example of a pilot in a position to ignite the main burner smoothly.

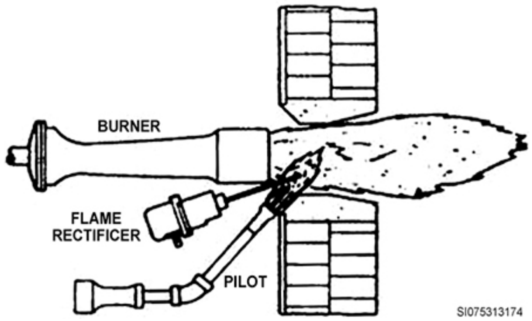


Figure 2–85. Recommended pilot installation on a venturi-type burner.

Figure 2–86 shows an exaggerated poor installation. Here no part of the pilot comes near intersecting the main burner envelope, and the flame rectifier senses a lazy pilot flame (firing at low gas pressure). This installation can cause delayed ignition and rough starts.

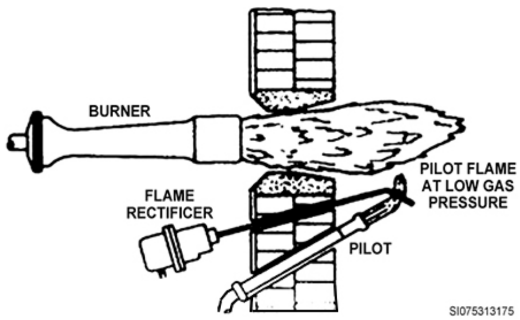


Figure 2–86. Exaggerated poorly positioned pilot and flame rectifier.

On radiant burners, the pilot often mounts alongside the burner or fires through one of the burner openings in the radiant block. In figure 2–87, the pilot fires in the direction of draft and provides a flame that readily intersects with the main burner flame. Position the pilot so that it fires in the general direction of the draft. Never install the pilot burner so that the pilot flame can shift to a position where it will not positively ignite the main burner, but can still make contact with the flame electrode. For example, if the pilot burner installs horizontally or at an incline, the flame electrode must not lie along the top of the pilot burner assembly where a weak or “lazy” pilot flame, inadequate to light the main burner, can curl up around the shank of the flame electrode.

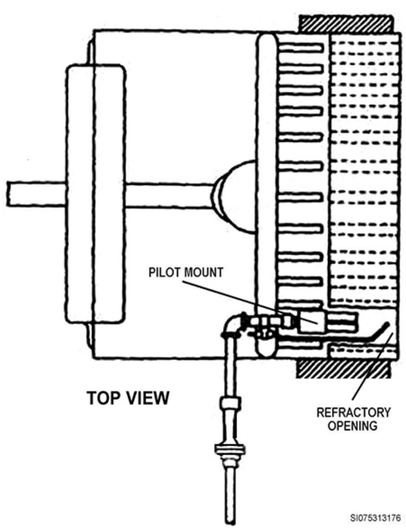


Figure 2–87. Typical mounting of flame rectifier pilot on radiant inshot-type burner.

Adequate ground area

In general you should ensure that the ground area in contact with the flame exceeds the area of the flame rod normally in contact with the flame by at least 4 to 1. This ratio is large enough to prevent ground-area problems regardless of the rod's position in the flame. The best indicator of adequate ground area is a strong, steady flame signal reading of micro DC volts that is read by connecting the meter in series with the F lead. Most controls have a meter jack that automatically places the meter in series with the flame rod. Refer to the instructions packed with the flame safeguard control.

Flame signals can range from 1 to 25 microamps. The reading you get on self-checking systems will be much higher; refer to the control instructions. If the flame signal reading is not right, check the ground area first. If you are in doubt, add more ground area temporarily and recheck the flame signal. If you get a satisfactory reading, add a permanent ground area.

Soot or scale buildup on a flame rod can reduce the ground-to-flame-rod-area ratio to less than the necessary area required. Under "no flame" conditions, soot and scale are nonconductors of electricity but when flame applies, they become conductors. The problem is in the area added to the flame rod by this buildup. More surface area provided by the hills and valleys of the buildup material can easily double or triple the flame rod area. Too much buildup can decrease the flame current below the value required to hold in the flame relay causing burner shutdown. Inspecting and cleaning the flame rod periodically will prevent this.

Proper location of the flame rod in the flame envelope

The location of the flame rod in the flame envelope must provide the required type of flame supervision. The flame rod must always contact the flame. The rod should be placed so that it cannot detect the pilot flame if it gets too small to ignite the main burner flame (pilot providing applications only). The location should prevent changes in the flame rod position or at least eliminate the possibility of any change's causing a dangerous situation.

Proper flame circuit

We have looked at the relationship of the flame, flame rod, and ground area. When a flame immerses the flame rod and the ground area and voltage is applied, a current will flow. To use this current flow, you must provide an unaffected circuit from capacitance, interference from other voltage sources, or leakage resistances to ground. Now let us look at the specific steps that provide this kind of circuit.

The flame rod insulator is normally a nonconductor but when the temperature at the insulator exceeds 500°F, the ceramic material's resistance decreases enough to make it conduct current. This leakage current may be enough to decrease the flame relay and cause burner shutdown. Dirt, soot, and moisture on the insulator can also cause enough leakage to cause shutdown.

For proper operation, you must keep at least a 20-megohm insulating resistance in the flame rod circuit. If the insulating resistance drops below 20 megohms, there is a proportionate drop in flame rectification current, eventually reaching a low point where insufficient output shuts down the system. You should clean the insulator periodically.

Flame lead recommendations are No. 14 wire (rated for 90°C or higher). Actual wire size is not critical; No. 14 is easy to handle and to pull through conduit. The increased resistance of decreased wire size is not significant.

> **EXAMPLE**: 200 feet of No. 30 wire**—**were it practical to use such small wire**—**has a resistance of only 20 ohms. Compare this to the internal impedance of 1500 ohms in the meter you connect in series with the flame rod when you read the flame current.

The type of flame lead insulation is important, because it must prevent leakage to ground; with suitable wire, there will not be any leakage from the wire itself. Use anti-seize tape for high-temperature installation.

The maximum length of the flame lead is limited by the electrical capacitance between the F lead and ground (conduit); in other words, by the amount of current that can flow from the lead to ground. If leads are long enough to let the capacitance exceed 0.02 microfarads, the flame signal is masked and relay operation is uncertain. In practice, the flame lead can be up to 150 feet long, if you use proper wire and if an acceptable flame signal exists at the primary control. The flame lead will run in conduit with other line voltage wiring without fear of stray electromagnetic current pickup. Never run flame lead wires in the same conduit with high-voltage ignition transformer wiring.

Ignition interference is a false signal superimposed on the flame signal. Ignition current feeding through the flame to the flame rod causes it. From the flame rod, it feeds through the F lead to the primary control and back to ground. When the ignition current is small, it will not damage the relay, but it either increases or decreases the flame current. Whether the current increases (positive interference) or decreases (negative interference) depends on the phase relationship of the AC voltage in the F lead and in the ignition electrode. Subtractive differential may be enough to make the relay dropout. Interference will damage the relay if strong enough. When ignition interference damages a relay, you will have to replace the relay.

Self-Test Questions

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

622. Flame detectors

1. When would a flame detector sense a partial flame?

2. What will a flame detector sense if the flame is below the designed threshold?

3. What is the flame detectors safety feature?

4. What characteristics do all flames have?

5. What is a rectifying photocell?

6. What will result if the photocell reacts to glowing refractory light?

7. What effect will excessive heat have on the photocell’s cathode face?

8. What should you do if a photocell fails?

9. What effect does light intensity have on cadmium sulfide’s electrical resistance?

10. What effect does an increase in light intensity have on cadmium sulfide’s resistance?

11. Why does a hot refractory not affect a cad cell?

12. How is cad cell removed for cleaning or replacement?

13. What is bypassed if cad cell terminals F-F are jumped?

14. What type of flame can the infrared detectors be used with?

15. What ability does the ultraviolet flame detection system depend on?

16. What ability does the flame rod detection system depend on?

17. What effect does heat from the flame have on the electrodes of a flame rod detection system?

18. What effect does the current flowing larger in one direction than the other have on the flame relay in a flame rod detection system?

19. In essence, what does the flame act like in a flame rod detection system?

20. How does the flame rectification system recognize the difference between a high resistance leak to ground and a flame?

21. What effect does increasing the gas pressure have on the pilot flame?

22. What effect does soot or scale buildup have on the flame rod?

23. What will happen when a flame immerses the flame rod and the ground area and voltage is applied?

24. What effect can dirt, soot and moisture have on an insulator?

2–5. Primary and Programming Controls

Primary and programming controls are the brains of the heating system. The term primary will be used for oil burners and we will refer to the controls for gas burners as programming controls. These controls are becoming more advanced very quickly. Stay up on the changes in the industry and get a good foundation from this section.

623. Primary controls

Primary controls are used with oil fired burners, they are the brain of the oil heating system. Your knowledge of this lesson is critical to becoming a highly skilled HVAC/R technician. See figure 2–88 for an example of the inputs and outputs of the control.

Purpose

This is a device which operates the entire oil burner. The primary control or primary control unit is the brains of the entire oil burner operation. We will use PCU as an acronym for primary control unit. In figure 2–89, you can see the burner controls and wiring. Look and see how the wires all converge on the PCU. The PCU is the decision maker and controller. It takes inputs from these components and creates outputs that operate the components safely and efficiently.

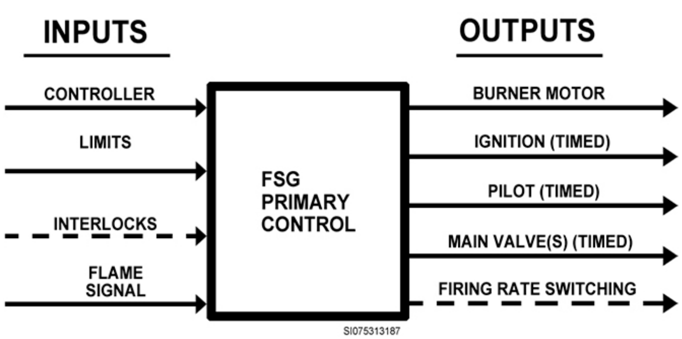


Figure 2–88. Programming control inputs/outputs.

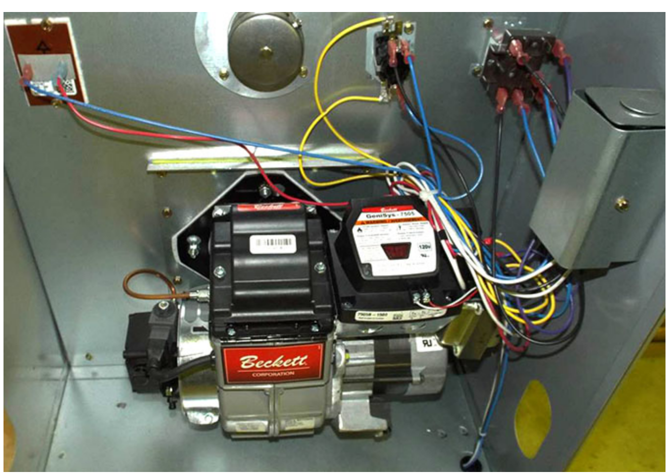


Figure 2–89. Burner controls and wiring.

Here the thermostat will initiate heating by sending a signal to the PCU. The burner motor will energize; this creates air and oil flow. Also, the PCU will send current to the ignition transformer. The ignition transformer creates an electrical arc that should light the flame. As the burner is operating, the PCU relies on different sensing devices for continued safe and efficient operation.

Stack relays

Stack relays may be seen on older units. They operate using a bimetal element that is placed in the stack. If the element doesn't heat within a certain time it will send a signal to the PCU and tell it to shutdown. If it does sense heat from combustion it will continue to operate.

Cad cell relays

Cad cells are flame sensors which decrease their resistance as a flame is sensed. The decrease in resistance allows current to pass and the unit to run. If no flame is sensed it will not allow the PCU to start or continue combustion.

Ignition control

The primary control unit controls the ignition process also. Line voltage is sent from the PCU to the step-up transformer. The transformer then converts 120 volts to approximately 10,000 volts. If heat is not being called for then the PCU will not send line voltage to the transformer. Also, if a safety is open, the decision maker (the PCU) will not send line voltage to the transformer.

Functions of primary control units

Primary control units provide various modes of operation for the safe and efficient use of burners. The various modes are standby, preignition, prepurge, ignition carryover, postpurge, trial for ignition, flame failure response time, recycle time, recycle limit and reset limit. These modes must operate properly for the unit to run as it was designed.

Standby

Standby is when heat is not being called for. The PCU is literally standing by waiting orders from the thermostat.

Preignition

A signal is received from the thermostat for heat. The PCU starts ignition to ensure there is a spark before the burner motor is energized. The reason for this is to ensure there is already an arc when the oil starts to flow.

Prepurge

This can be called a valve on delay. This function is performed to remove any fumes from the combustion chamber and heat exchanger. During prepurge the fuel unit's solenoid valve is held closed so oil doesn't shoot into the combustion chamber. It wouldn't make sense to dump oil in the combustion chamber while you are trying to purge the fumes.

Ignition carryover

The name tells you exactly what this function does. Ignition is carried over even after the flame has been sensed, hence, ignition carryover. This ensures the flame is well established before the electrical arc is taken away from it. This is only used with interrupted ignition because intermittent ignition continues sparking during the entire heating cycle.

Postpurge

This can be called motor off delay or burner off delay. The PCU will close the solenoid valve on the fuel unit, but will allow the burner motor to continue to run. This stops fuel flow and allows the motor to turn the fan and move air through the combustion chamber and heat exchanger. This is the same as a prepurge, except it is after the flame has gone and not before it is lit.

Trial for ignition

This is a limited amounted of time allowed for ignition of the flame to take place. This time will only last for a few seconds. It is also called "lockout time" or "safety lockout time" because the system will lockout after the trial for ignition has passed and ignition was not established.

Flame failure response time (FFRT)

This is the amount of time for the PCU to sense no flame. A FFRT that is too short the PCU would lock out the system. If it is too long, oil can start to fill the combustion chamber.

Recycle time

This can also be called recycle. It is the amount of time the PCU will wait after a failed ignition. For example, there is a call for heat but the flame does not light, the PCU enters a 60 second delay and then repeats the ignition sequence (60 seconds is only used for this example). Other PCU's recycle time will vary.

Recycle limit

Also called limited recycle, this is a limit of the number of times the PCU will try to reset. For example, unit ABC has a recycle limit of 5 times. After the PCU tries to recycle the burner 5 times and fails every time it will lock out the system.

Reset limit

This is the amount of times a PCU can be reset from lockout. This prevents the customer from resetting the unit to many times.

Self-Test Questions

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

623. Primary controls

1. What is the result of the inputs the PCU receives?

2. What does the PCU rely on for safe and efficient operation?

3. How does an open safety effect the PCU's decision to send voltage to the transformer?

4. What does the standby function mean?

5. What occurs when the PCU is in preignition?

6. Why is ignition carryover only used with interrupted ignition?

7. Why does the PCU close the solenoid valve on the fuel unit and allow the burner motor to continue to run during postpurge?

8. How does the reset limit affect the customer?

624. Programming controls

The same thing for the primary controls applies to programming controls. They are used with gas fired burners and they are the brain of the gas heating system. Your knowledge of this lesson is critical to becoming a highly skilled HVAC/R technician.

Non-integrated

This type of control is considered non-integrated. It is can perform simpler task and are seen more on older and less efficient units. These controls are still important because there are many older units in the Air Force still.

Integrated

This type of module uses electronics to provide better control and efficiency than the non-integrated type. These modules can perform self-diagnosis. They are so “smart” they can acquire inputs from various devices, determine what the fault is and then tell the technician via light emitting diodes, also known as LED’s. Look at figure 2–90 for an example of LED’s on a control board. The LED’s are labeled GRN, RED and YEL. For this particular system, the manual states that if both the GRN and RED LED are on, it indicates “normal operation”. If there is a “pressure switch open fault” the GRN LED will flash and the RED LED will be off. Another example is if the YEL LED is continuously flashing it indicates a “low flame sensor signal.

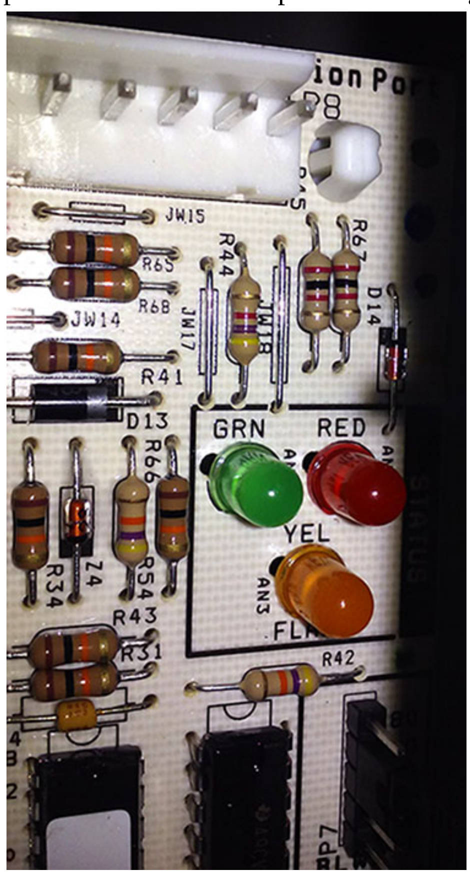


Figure 2–90. LED new burner.

Remember that the meaning of LED’s varies per unit so you must read the manufacturer’s manual to determine what the LED’s are telling you. If you don’t have the manual at the job site you can use a smart phone or wireless device to look up the literature for the model number and brand you are working on.

Prepurge

Just like the PCU, this function is performed to remove any fumes from the combustion chamber and heat exchanger. This is for safety purposes to avoid explosion. During prepurge the combustion blower is turned on to vent fumes. The automatic gas valve will be close at this time because it wouldn’t make sense to put gas in the combustion chamber while you are trying to purge the fumes. Another reason to remove fumes is to help prevent incomplete combustion or misfires.

Inter-purge

If a system has a soft lockout, it will perform a purge before it attempts to relight. The purpose of this purge is the same as any other purge, remove fumes from the combustion chamber and heat exchanger.

Post-purge

This purge occurs after the burner has turned off. It serves the same purpose as the pre and inter-purges. Don’t be confused when the flame is off and you still hear the combustion blower running, it is more than likely in purge mode.

Trial for ignition

This is a limited amounted of time allowed for ignition of the flame to take place. The preset time will only last for a few seconds.

Soft lockout

This lockout occurs if there is trial for ignition that fails. The system lockouts, but only for a period of time. After the preset time has passed, it will try to relight.

Hard lockout

Not all systems have the soft lockout feature. Some will go directly into a hard lockout which requires a technician to respond. Once in a hardlockout, a gas burner will not be relit until a technician comes out to reset it. At this point, the technician should determine why the system went into a hard lockout.

100% shutoff

This feature shuts off the main and pilot gas valves if a flame is not detected. These are not as prevalent as they once were.

Non-100% shutoff

This shutoff will close the main valve, but not the pilot valve when a flame is not detected.

100% shutoff with continuous retry

This feature will shut off the main and pilot valves, but will try to relight a predetermined amount of time has passed. Figure 2–91 shows an example of a continuous retry 100% shutoff controller. You can see the manufacturer is making it no secret what type of control this is, but if you don’t take a look at the device then you may be confused while working on this equipment.

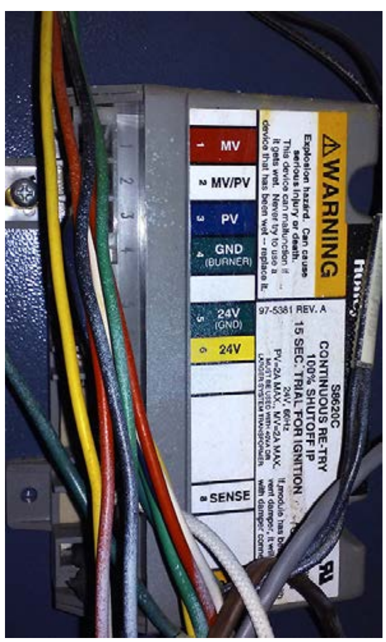


Figure 2–91. Continuous retry.

High limit switch

This switch prevents dangerously hot temperatures in the system. It is usually placed near the heat exchanger to enable it to accurately detect high temperatures. If the temperature gets to high the switch will stop flow to the gas valve.

A common cause of an overheating heat exchanger is the blower not running. If the blower does pass air over the heat exchanger then most of the heat produced will build up in the heat exchanger and trip the high limit switch.

Rollout

A flame could become uncontained and find its way backward and out of the burner. Because of this potential issue, we use rollout switches to stop the unit if this condition occurs. It is placed in a position to sense a flame that is trying to rollout of the burner.

Remember that all of the controls above will "talk" or send information to the control board or module. The board will make decisions based off of its inputs. It is programmed to ensure safe and efficient operation of the equipment.

Self-Test Questions

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

624. Programming controls

1. What advantage does the integrated have over the non-integrated control?

2. Besides safety, what is another reason to remove fumes during prepurge?

3. How long will trial for ignition last?

4. How is a system taken out of a hard lockout?

5. What will the high limit switch do if it senses temperatures that are too high?

6. What does a rollout switch prevent?

Answers to Self-Test Questions

608

1. The hydrogen and carbon of the fuel combine with the oxygen found in atmospheric air.
2. The products of combustion, or fuel gases, have no incomplete oxidized (unburned) fuel and no oxygen.
3. The maximum attainable carbon dioxide under an ideal condition of the particular fuel being burned
4. The percentage of carbon dioxide going up the stack (the products of combustion), is the maximum attainable under an ideal condition of the particular fuel being burned.
5. The nitrogen goes through the combustion process unchanged for all practical purposes.

6. The nitrogen goes through the combustion process unchanged for all practical purposes.
7. Percent for natural gas, 13.9 percent for propane, and 15 to 16.5 percent for fuel oils
8. Oxygen.
9. It burns to form carbon dioxide.
10. Pocalized fuel-rich and fuel-lean zones within the fire.
11. Secondary air.
12. Combustion rate.
13. The firing rate of a burner with a 4 to 1 turndown range will vary from its maximum (100 percent) down to ¼ of its maximum (25 percent).
14. On burner and combustion chamber design.

609

1. Because both the nitrogen and the unburned oxygen become heated, and the heat passes into the flue instead of absorbing into the boiler or furnace.
2. Quality of the combustion equipment.
3. The size and refinement of the combustion equipment, the fuel used, and the adjustment of fuel feed apparatus.
4. Manually or automatically.
5. Excess air loss. Unburned fuel (smoke).Excessive flue-gas temperature.
6. To 3 percent.

610

1. It causes poor burner performance and wastes fuel.
2. Rapid deposit of soot on heat absorbing areas.
3. Vaporization and burning of the oil.
4. Flue draft on the furnace side of the draft regulator is to manufacturer's specification, but over-fire draft is insufficient.
5. It reduces it.
6. It can distort it.
7. It also decreases.
8. Sufficient flame turbulence for smoke-free combustion.
9. After fire smoke.
10. Over firing, wrong oil spray pattern (nozzle), defective or partially clogged nozzle, improperly set electrodes, oil pressure too low, and improperly positioned burner with respect to combustion chamber.
11. May adversely affect chimney draft, may cause a corrosive moisture condensate in the flue or chimney, or, at an extreme, may result in incomplete combustion.

611

1. Carbon in the furnace, soot on the heating surfaces, or smoke from the stack.
2. Too little air.
3. Too much air.
4. Burner air registers.
5. Dampers or fan speed controls.
6. Blue with yellow tips.
7. It causes it to become long, straggling and yellow.
8. Dampers or fan speed controls.
9. Improper combustion.
10. Black smoke.
11. Compare filter paper to other predetermined samples.
12. To get the smoke levels within a reasonable range before performing an analysis with a digital analyze.

13. Decreases their lifespan.
14. Thermocouple.
15. The computer.
16. Prolong its life and usefulness.
17. Get one that will analyze the fuels you have at your base.
18. That carbon dioxide makes up 12% of the total flue gases.
19. Carbon monoxide.
20. Heat energy is used to heat the air that came from the room.
21. Reduce the amount of excess air.

612

1. In both the main and pilot fuel lines.
2. Solenoid valves.
3. A controller such as a thermostat, pressure control, or aquastat closes a circuit to energize a coil.
4. There is a position indicator to let you know if it is open or closed.
5. Relatively constant.
6. Once you are familiar with the system.

613

1. One or more of the burner functions.
2. Gas may be blown into the combustion chamber, pulled in (aspirated) by high velocity air, or permitted to escape into the chamber under its own distribution pressure.
3. Horizontal.
4. Vertical.
5. Increases gas velocity and lowers pressure in the throat of the tube.
6. Creates a slight partial vacuum within the chamber?
7. A short bushy flame.
8. With the main burner at the end of heat demand.
9. Fan or blower blows air into chamber.
10. Fan or blower creates a suction that draws air into chamber.
11. Turndown range of the burner.
12. At minimum firing rates.
13. Low gas pressure, leaking gas valve, lean gas-air mixture, burner ports or pipes too large, excessive temperature of the gas-air mixture, excessive temperature of the burner ports or pipes, insufficient draft, and insufficient combustion space.
14. Location and number of pilots, opening characteristics of the gas valve, manifold charging time, and burner draft conditions combustion chamber temperature, and flame propagation rate.
15. At point of first gas delivery.

614

1. Inside the venturi portion before reaching the burner head.
2. Short, hot flame with high heat release.
3. In the mixture velocity returning to static pressure.
4. Causes them to spin.
5. Rapid mixing.
6. Each cycle of burning leaves a pocket of flame that ignites the next charge of gas-air mixture entering through the flapper valves.
7. Gas ejects into the turbulent air stream from spuds located at the outside of the air stream instead of in the center.
8. Spreads the flame toward the outside wall of the combustion chamber.

615

1. It taps off of the automatic gas valve.
2. The tendency for the small primary air openings to clog with lint and dirt.
3. The flame is less stable.
4. Millivolts.
5. DC voltage.
6. The hot junction.
7. Pipe dope should not be used with electrical connections.
8. Oxidation of the inner element.
9. Continuously.
10. When heat is called for, the ignition control opens the pilot gas valve.
11. The burners will light.
12. Heat.
13. Glow coil.
14. Within 4 to 11 seconds.
15. Creates an electric spark across the gap to the grounded surface of the pilot.
16. If the pilot fails to light.
17. Shut-off.

616

1. Smell.
2. The wiring schematic, local codes, Underwriters' requirements, and National Electrical Code.
3. Open.
4. Turn the switch off.
5. With a soap and water solution.
6. A combustion analysis.
7. About .10 inch of water, negative.
8. Will indicate either an improper primary air or gas pressure adjustment.

617

1. Manufacturer's recommendations.
2. Pilot light.
3. Improper positioning of the thermocouple or thermopile and excessive flue and chimney draft conditions.
4. Long enough to heat the thermocouple or thermopile and ignite the main burner immediately.
5. Draft for proper operation, brush scale or soot off the burner head, clean the interior of mixer or burner parts, and examine gas orifices replacing them if necessary.
6. With a soft material such as a toothpick.

618

1. It will lower its viscosity.
2. To lower its viscosity so that it atomizes easily, and to raise its temperature closer to the ignition point.
3. Vaporized.
4. The reduction of the oil into many tiny droplets that vaporize at a high rate.
5. It ignites it.
6. It produces a scrubbing action.
7. 120 volts, 60 hertz.
8. Only during the initial startup of the burner and then it shuts off.
9. By the primary or programming control.
10. By a three position switch.

619

1. Visual inspection.
2. Explosion.
3. Wipe it up.
4. For proper setting and looseness.
5. Check operating control.
6. Monitor oil pressure, draft flow, stack emission, and the burner firing cycle response to the type of control.

620

1. ¼ inch.
2. Flue gas analysis.
3. You can connect a vacuum gauge to the pump’s optional inlet opening.
4. Turn the pressure screw counterclockwise.
5. Monthly.
6. Never clean the nozzle orifice with anything larger than the orifice size. You can use a toothpick or low-pressure air.

621

1. During start-up period.
2. Decreasing or stopping the fuel feed (which causes loss of ignition) immediately followed by a resumption of the fuel feed without the proper lighting-off cycle.
3. That the conditions for combustion are established and that the burner is ready for starting.
4. It will keep it from starting.

622

1. Never.
2. No flame.
3. Its ability to determine, with absolute certainty, when the flame goes out and to signal the primary control or the programmer accordingly.
4. Production of heat, expansion of gases, production of by-products, emission of light (infrared to ultraviolet), and ionization of the atmosphere in and around the flame.
5. High-vacuum photocell that is practically a perfect rectifier.
6. The flame relay will hold in at the end of the firing cycle, and the burner cannot restart until the flame relay drops out.
7. Cracked, bluish appearance.
8. It is best to replace it with a similar cell mounted in the same place.
9. It increases or decreases its resistance.
10. It drops it.
11. Because the wavelength of the hot refractory is above the cell’s peak response range.
12. By simply unplugging it.
13. Safety switch.
14. Oil or gas.
15. The sensing tube’s ability to respond to ultraviolet radiation and remain insensitive to radiation in the infrared and visible light range.
16. This type of system depends on the flame’s ability to conduct current when a voltage applies across two electrodes.
17. Makes molecules between the electrodes collide with each other hard enough to knock some electrons out of the atoms, producing ions (flame ionization).
18. Effectively, a pulsating direct current that operates the electronic network. The flame relay pulls in, indicating the presence of a flame and lets the burner sequence continue.

19. Like a switch.
20. It doesn't.
21. To harden and lengthen the pilot flame increasing its stability under adverse conditions.
22. Can reduce the ground-to-flame-rod-area ratio to less than the necessary area required.
23. Current will flow.
24. Cause enough leakage to shutdown.

623

1. Creates outputs that operate the components safely and efficiently.
2. Inputs from different sensing devices.
3. The PCU will not send line voltage to the transformer if a safety is open.
4. There is no heat being called for. The PCU is literally standing by waiting orders from the thermostat.
5. The PCU starts ignition to ensure there is a spark before the burner motor is energized.
6. Because intermittent ignition continues sparking during the entire heating cycle.
7. To stop fuel flow and allow the motor to turn the fan and move air through the combustion chamber and heat exchanger.
8. It prevents the customer from resetting the unit to many times.

624

1. Provide better control and efficiency.
2. Prevent incomplete combustion or misfires.
3. The preset time will only last for a few seconds.
4. A technician resets it.
5. Stop flow to the gas valve.
6. A flame could become uncontained and find its way backward and out of the burner.

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).

16. (608) Identify *all* the necessary elements that *must* be present for combustion?
    a. Heat and air.
    b. Air and fuel.
    c. Heat and a spark.
    d. Heat, air, and fuel.

17. (608) How much of the flue gases are made up of nitrogen?
    a. 59%.
    b. 66%.
    c. 79%.
    d. 88%.

18. (608) Why is carbon monoxide undesirable in flue gases, besides the fact that it is dangerous?
    a. Its presence in flue gases represents a waste of fuel.
    b. When it is present there is less than 20% efficiency.
    c. When it is present there is less than 30% efficiency.
    d. Its presence in flue gases means that combustion is not taking place.

19. (608) The turndown of a burner is the ratio of the
    a. maximum firing rate to carbon dioxide.
    b. minimum firing rate to the average firing rate.
    c. carbon monoxide to excess air and pure oxygen.
    d. maximum firing rate to the minimum firing rate.

20. (609) Identify the relationship between excess air and complete combustion.
    a. Excess air will blow the flame out and stop combustion.
    b. It is less than what is needed for theoretical combustion.
    c. Excess air is needed for complete combustion.
    d. Excess air saves heat from leaving the stack.

21. (609) The condition that affects infiltration losses is the volume of
    a. make up air.
    b. inside air that stays indoors.
    c. outside air that escapes outside.
    d. outside air that leaks through cracks and crevices.

22. (610) A pressure-gun burner achieve flame turbulence by
    a. modulating the gas control valve.
    b. fully closing and then opening the fuel valve.
    c. causing straight air flow as it leaves the gun tube.
    d. causing the air to whirl as it leaves the gun tube.

23. (611) The effect too much air has on a flame is that it makes it
    a. short, noisy, and keeps it near the burner.
    b. short, noisy, and tends to pull away from the burner.
    c. short, quiet, and tends to pull away from the burner.
    d. long, noisy, and tends to pull away from the burner.

24. (611) Identify the cause of a *high* CO_2 reading during combustion.
    a. Zero air supplied for combustion.
    b. Insufficient draft and over firing.
    c. Sufficient draft and over firing.
    d. No fuel or gas in the supply line.

25. (612) Where does the signal to open and close a gas valve come from on modern equipment?
    a. Manually operated switches.
    b. Manually operated valves.
    c. Pneumatic devices.
    d. Control board.

26. (613) How does an inspirating burner bring in *primary* air?
    a. Large fans.
    b. Venturi action.
    c. Forced draft action.
    d. Pulse burner principles.

27. (613) The pulse burner introduce gas and air
    a. in operating phases.
    b. every 30 seconds.
    c. in one single phase.
    d. every 45 seconds.

28. (613) Where does gas and *primary* air mix in a premixing burner?
    a. Before they reach the burner port.
    b. After they reach the burner port.
    c. In the combustion chamber.
    d. Inside the burner port.

29. (613) How long will an intermittent pilot stay lit?
    a. During the entire run period.
    b. During ignition sequences.
    c. For 2 to 5 seconds.
    d. Never.

30. (614) The mixture of air is affected by a reduced gas velocity because it allows for
    a. incomplete mixing before it exits the burner ports.
    b. complete mixing before it exits the burner ports.
    c. complete mixing after it exits the burner ports.
    d. partial mixing after it exits the burner ports.

31. (615) What affects the voltage generated by a thermocouple?
    a. Ignition detection.
    b. Temperature sensed by fan controls.
    c. Temperature sensed at the limit control switch.
    d. Temperature difference between hot and cold junctions.

32. (615) The relationship between a sensing thermocouple and a standing pilot is the
    a. pilot ignites the thermocouple.
    b. thermocouple lights the pilot.
    c. thermocouple senses the standing pilot and determines if it is lit correctly.
    d. standing pilot senses the thermocouple and determines if it is lit correctly.

33. (615) Hot-surface ignitors are located in relation to gas flow by a location in which
    a. air will pass over it when the gas valve closes.
    b. gas will pass over it when the gas valve opens.
    c. gas will pass over it when the gas valve closes.
    d. gas will avoid it when the gas valve opens.

34. (615) The way the control module can determine if the glow coil is hot enough to ignite the fuel is due to the resistance of
    a. fan pressure.
    b. limit control.
    c. glow coil or a time delay.
    d. solenoid coil or a time delay.

35. (615) A solid-state device can detect the presence of a flame because the pilot flame conducts the
    a. current to the grounded pilot.
    b. voltage to the grounded pilot.
    c. current to the grounded motor.
    d. current to the grounded bearings.

36. (616) Which type of work is checked for completion during the pre-operational inspection of a gas burner?
    a. Troubleshooting.
    b. Operations Management work.
    c. Operation of the motor and burner.
    d. Installation, repair and cleanup work.

37. (616) Identify what the thermocouple is inspected for during a pre-operational inspection?
    a. Carbon deposits, corrosion or heat damage.
    b. Proper insulation of hot junction.
    c. Ensure flame will not be near it.
    d. Proper output voltage.

38. (616) How long should you wait for gas to clear from the combustion chamber?
    a. 5 minutes.
    b. 15 minutes.
    c. 35 minutes.
    d. 24 hours to be safe.

39. (617) How often should you remove, dismantle, and clean a main burner?
    a. Never.
    b. Every 10 years.
    c. Every 2 months.
    d. At least once a year.

40. (618) A forced draft affect oil burners because it
    a. decreases oil flow.
    b. increases their oil burning capacity.
    c. decreases their oil burning capacity.
    d. forces them to be converted to gas burners.

41. (618) The effect a nozzle has on high pressure oil passing through it is it
    a. will not affect the oil due to high pressures.
    b. creates a star shaped flow.
    c. produces a fine mist.
    d. blocks flow.

42. (618) A gun type burner get its 10,000 volt electric spark from the
   a. fan limit switch once it closes.
   b. step-down transformer.
   c. step-up transformer.
   d. solenoid valve.

43. (618) Where is the high pressure gun type nozzle’s angle of spray located?
   a. On the nozzle’s filter.
   b. Inside the nozzle filter.
   c. On the side of the nozzle.
   d. Near the outlet of the nozzle.

44. (619) What is the combustion chamber inspected for during an oil burner pre-operational inspection?
   a. Cabinet insulation.
   b. Pools of unburned oil.
   c. Proper asbestos insulation.
   d. Proper opening and closing.

45. (619) Which action should be taken if pools of unburned oil have flooded the combustion chamber?
   a. Remove the burn and light the pool of oil.
   b. Light the burner to burn off the flooded oil.
   c. Light the burner and run out of the boiler room.
   d. Soak it up with rags and purge the combustion chamber.

46. (620) How is the spark moved into the path of the oil spray?
   a. Through gas pressure.
   b. Air from the fan will blow the spark into the path.
   c. The solenoid valve will provide a “push” to the spark.
   d. The electrodes automatically move to put spark in pathway.

47. (620) Which action should follow an air or oil pressure adjustment?
   a. Flue gas analysis.
   b. Seasonal shutdown.
   c. Nozzle spray check.
   d. Pre-operational inspection.

48. (621) How do commercial burners vary their firing rate?
   a. Pneumatically only.
   b. Decreasing water supply.
   c. Electrically or electronically according to the load demand.
   d. Electrically or electronically according to the outlet temperatures.

49. (622) Why should you *not* use photocells to detect gas flames?
   a. Liquefied petroleum gas (LPG) is too heavy of a gas and “fogs up” the photocell.
   b. Because a well-adjusted gas flame emits too little visible light.
   c. Gas flames are too dangerous to be used around photocells.
   d. Natural gas corrodes the photocell.

50. (622) How does a cad cell detect light from an oil flame?
   a. Light-sensitive lead.
   b. Light-sensitive cadmium sulfide.
   c. Light-sensitive aluminum.
   d. Light-resistive aluminum sulfide.

51. (622) A factor the flame rod system depend upon is the
    a. fuel oil's viscosity.
    b. solenoids ability to conduct current.
    c. flames ability to conduct current when an electrical potential is applied across it.
    d. flames ability to increase resistance when an electrical potential is applied across it.

52. (623) The purpose of the preignition function is to *ensure*
    a. a spark before prepurge.
    b. there is an arc when the blower starts.
    c. there is an arc when the oil starts to flow.
    d. there is an arc when the oil stops flowing.

53. (624) What is a *common* cause of overheating the heat exchanger on a gas fired burner?
    a. The blower not running.
    b. Thermostat problems.
    c. Low fire conditions.
    d. Proper air flow.

Please read the unit menu for unit 3 and continue ➔

Student Notes

Unit 3. Forced Air and Radiant Heating

3–1. Forced Air Systems 3–1
625. Types and characteristics 3–1
626. Furnace controls 3–12
627. Pre-operational inspection and operational test 3–15
3–2. Radiant Heating Systems 3–18
628. Types and operation of radiant heaters 3–18
629. Pre-operational inspection, operational test for radiant heaters 3–22
3–3. Preventative Maintenance 3–24
630 General forced air preventative maintenance 3–25
631. Preventative maintenance for radiant heaters 3–30

FORCED-AIR AND RADIANT HEATING SYSTEMS are common and fairly simple heating systems. As an HVAC/R systems journeyman, you will work on several types of forced-air heating equipment. In this unit we cover furnaces and radiant heating systems. This discussion will include their types and operating principles, the inspection procedures performed on each unit, and the maintenance of these units.

3–1. Forced Air Systems

So far you have learned about the different types of fuels, fuel distribution, and burners. In this unit, we will learn how those topics are applied to make heat. This section will focus on forced air systems. The discussion will begin with the different lessons covering types and characteristics of forced air systems. Next, the control of furnaces will be covered. Controls are important because they determine when the furnace runs and when it shuts off. After controls, the section will conclude by covering the steps of the pre-operational inspection and the operational test of forced air systems.

625. Types and characteristics

All forced-air furnaces have the following components: heat sources, casing or cabinet, heat exchangers, venting components, blowers and motor and air filters. Although all furnaces have similar components gas and oil furnaces differ somewhat. We explain all of the components in the following paragraphs to include the few mentioned in this paragraph.

Heat sources

The sources of heat for furnaces can be electric, gas or oil fired, or a heat pump.

Casing or cabinet

Manufacturers use steel to form the furnace casing, the steel is usually painted (fig. 3–1). Doors or panels are on the side of the furnace and provide access to sections of the furnace requiring service. Insulation or metal radiant shield lines the inside of the casing adjacent to the heat exchanger to reduce heat losses through the casing and to limit the outside surface temperature of the furnace. On some furnaces, the inside of the blower compartment has insulation to provide acoustical dampening of the blower noise. In other words, to make it quieter.

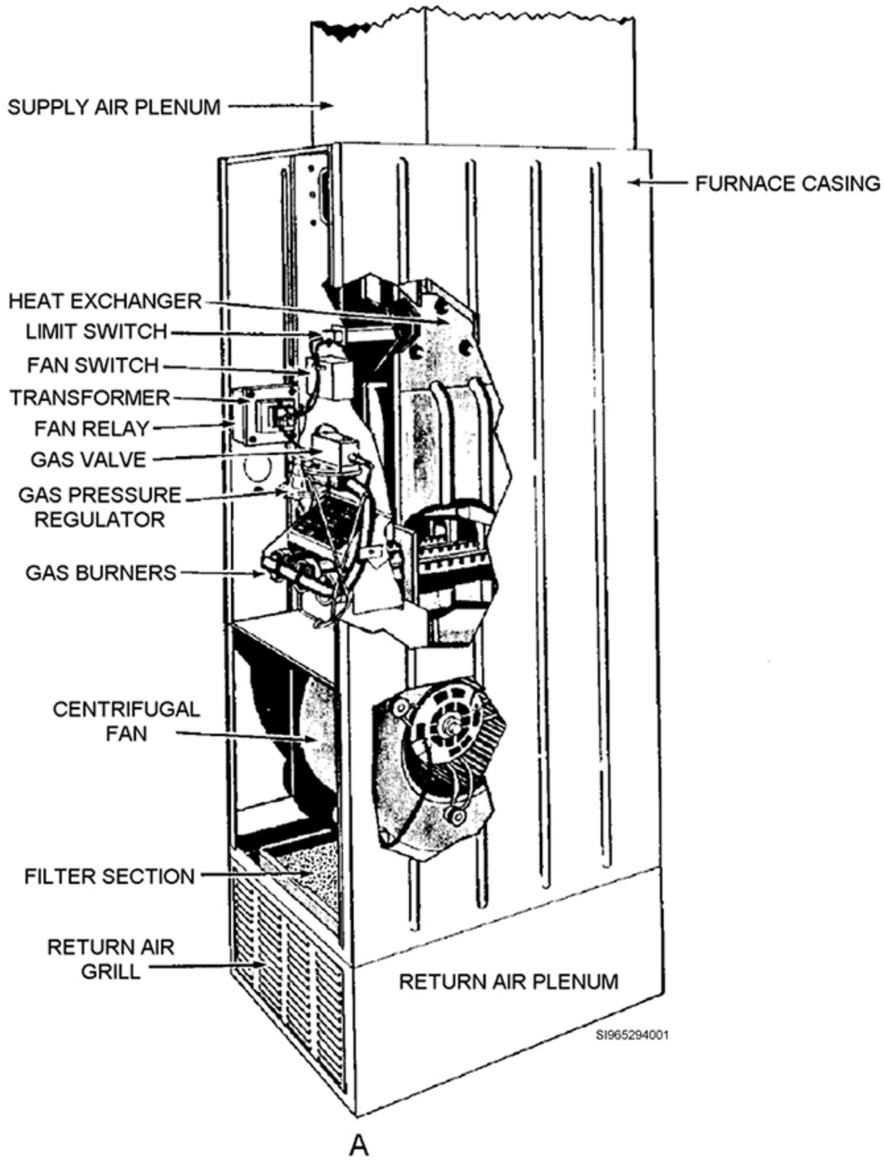


Figure 3–1. Gas fired forced air furnace.

Heat exchangers

Most furnaces have a steel heat exchanger. Each manufacturer has its own designs for gas-fired and oil-fired furnaces, but all heat exchangers serve two purposes. The heat exchanger of a furnace is the component that contains the flame and the combustion gases, this component also heats the cool air surrounding the heat exchanger, which then warms the building. The inner part of the heat exchanger (known as the combustion chamber) is where the fuel is burned. Metal surrounding the combustion chamber absorbs the heat from the combustion gases by conduction. Then, radiation and convection heat air that flows over the outside of the metal. This warm air is supplied to the area that needs to be heated. Figure 3–2 shows the application of a heat exchanger.

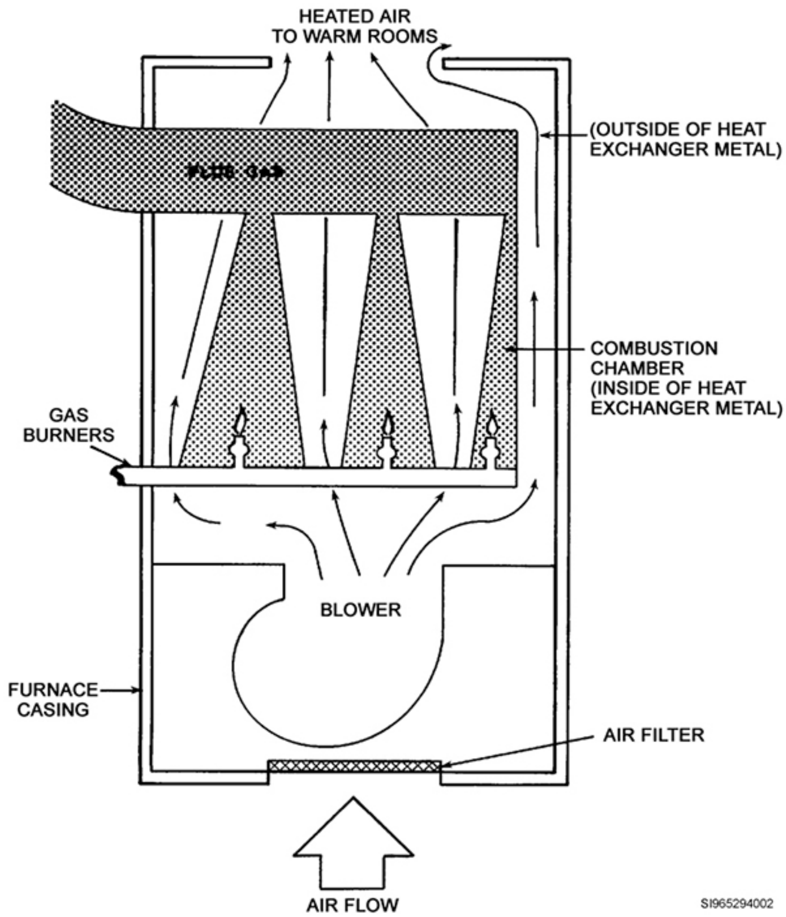


Figure 3–2. Heat exchanger application.

If the furnace circulates clean air and the heat exchanger remains dry, this material has a long life and does not easily corrode. Some heat exchanger corrosion and failure problems are the result of exposure to halogens in the flue gas. These problems come from combustion air that has materials such as laundry bleach, cleaning solvents, and fluorinated hydrocarbon refrigerants. Many deluxe furnace models use a coated heat exchanger to provide extra protection against corrosion. The commonly used coating materials include aluminized steel, ceramic-coated steel, and stainless steel. We use corrosion-resistant heat exchangers in a furnace that is certified for use downstream of a cooling coil.

High efficiency heat exchangers are commonly used in many gas-fired furnaces. It consists of two heat exchangers, a primary heat exchanger as mentioned before and an additional heat exchanger known as a condensing heat exchanger. Figure 3–3 shows one manufacturer’s type.

This condensing heat exchanger consumes more heat before releasing it out the flue. It does this by using primary and secondary heat exchangers to extract additional heat from combustion. The cool return air passes over the secondary heat exchanger first and this warms the air up before it passes over the primary heat exchanger. The initial warming of the air increases the efficiency and performance of the furnace to higher 90 percent. Figure 3–4 shows differences in flue gas temperature. As you can see, the temperatures of the older style are significantly higher than the new style.

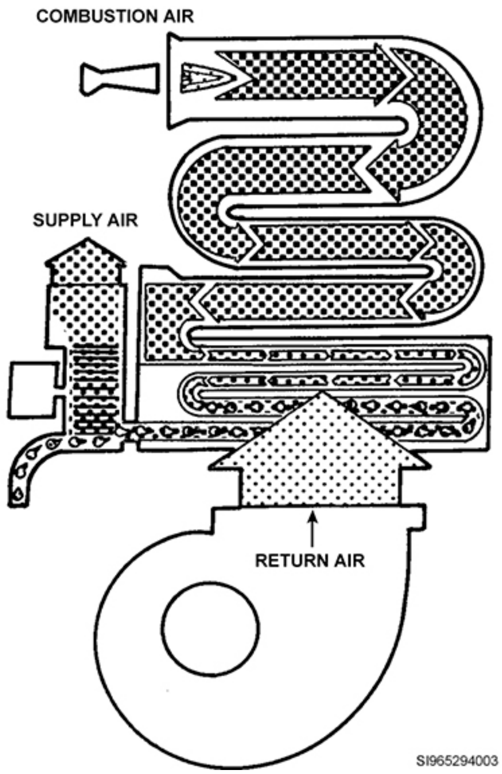


Figure 3–3. Heat exchanger with condensing heat exchanger.

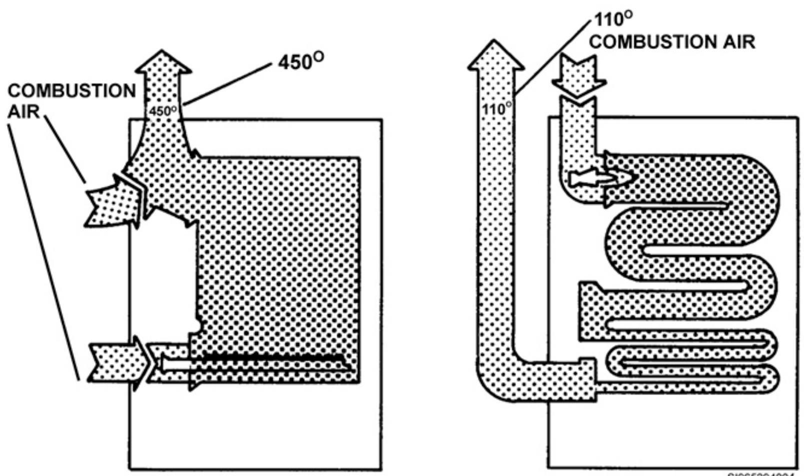


Figure 3–4. Temperature difference of heat exchanger.

Venting components

Once most of the heat is removed from the combustion gases, those gases are released to the vent connection. These connections also differ on oil- and gas-fired units.

Atmospheric vented, indoor gas-fired furnaces are equipped with a draft hood or draft diverter, which connects the heat exchanger flue gas exit to the vent pipe or chimney. The draft hood or draft diverter has a relief air opening large enough to ensure that the exit of the heat exchanger is always at atmospheric pressure. One purpose of the draft hood is to make certain that the natural-draft furnace continues to operate safely without generating carbon monoxide if the chimney has a blockage, if there is a downdraft, or if there is excessive updraft for any reason. Another purpose is to maintain constant head on the combustion system. Direct-vent furnaces do not use a draft hood of this type; instead, they use a control system that shuts the furnace down if the chimney becomes blocked.

Power-vent furnaces use a blower to force or induce the flue products through the furnace. These furnaces may or may not have a relief air opening; in either case, they meet the same safety requirements.

Install an automatic damper on oil-fired furnaces in the first joint of the stack where the pipe leaves the furnace. This damper uses a weighted butterfly damper that maintains a constant draft, regardless of wind and temperature. For this reason, we call it a *draft regulator* instead of a damper. Figure 3–5 illustrates a draft regulator.

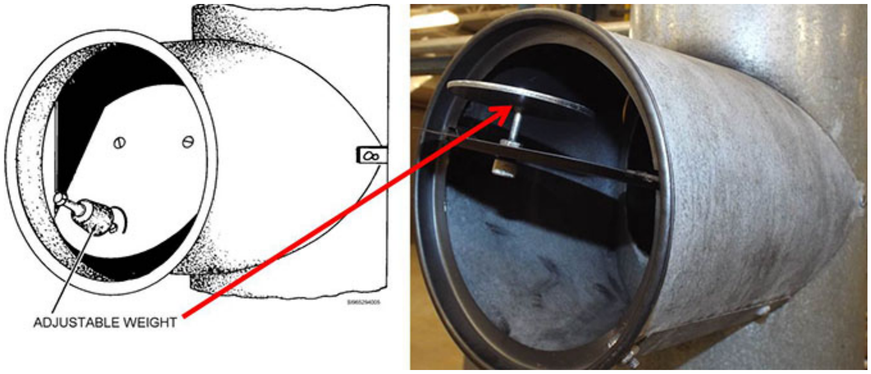


Figure 3–5. Draft regulator.

Automatic and proper operation of a draft regulator depends upon correct installation because it must balance correctly and be free to move at the slightest change in draft pressure. Regardless of whether the regulator installs in a vertical, horizontal, or angled smokestack, the top of the damper must be at the true top position—make sure to plumb the face (straight up and down). When we use the regulator in a horizontal or nearly horizontal pipe, we do not use the counterweight.

Combustion gases for condensing furnaces are considerably lower than non-condensing furnaces. Therefore, CPVC pipe is used instead of metal. Also, the condensate these furnaces create can be corrosive so the secondary heat exchanger will be stainless steel and may include a condensate pump that will remove any condensate build up.

Blowers and motors

Forced-air furnaces use centrifugal blowers with forward-curved blades of the double-inlet type almost exclusively. These blowers overcome the resistance of the furnace air passageways, filters, and ductwork. As technicians, we should always attempt to view the rotation and discharge of a fan from the drive side. The blower is the component that pulls air from the conditioned space and blows it over the hot heat exchanger. If the blower is not running then there will be no heat transfer.

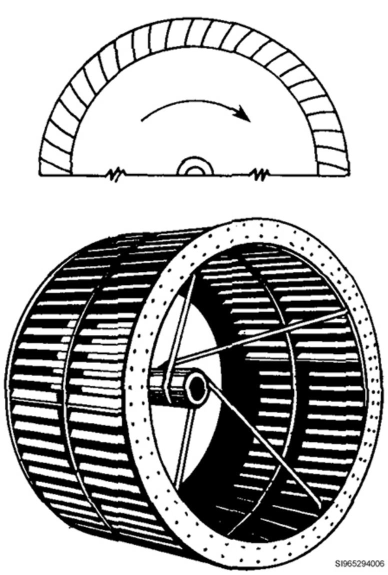


Figure 3–6. Forward curved centrifugal wheel.

The blades of a forward-curve wheel are narrow and curved like a crescent. The inside of the curve faces and is slightly inclined in the direction of airflow (fig. 3–6). The wheel accelerates the air and discharges it at a higher speed than that at which the fan is rotating. Forward-curved blades move large masses of air at low revolutions per minute (rpm) quietly and require less space. Manufacturers usually use forward curved blade fans in residential and light commercial applications, where maximum air delivery and low noise levels are required. Do not use them where dust fumes can adhere to the blades.

Designers will use specific purpose, electric motors for a furnace. The blower may be a direct-drive type with the blower wheel attached directly to the motor shaft (fig. 3–7), it may be a belt-driven blower wheel. Figures 3–8 and 3–9 show drive configurations.

We can obtain speed variations of direct drive motors by changing the wiring configuration in accordance with manufactures recommendation, typically found on the motor. We vary the speed of belt-drive blowers by adjusting a variable-pitch drive pulley.

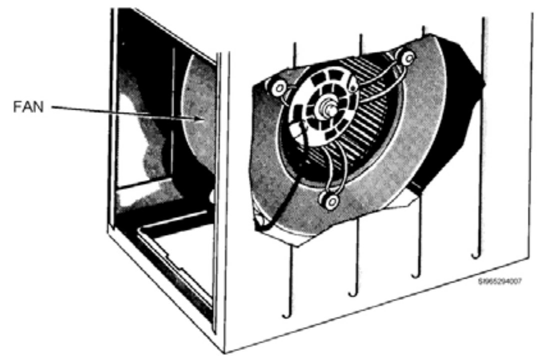


Figure 3–7. Direct drive blower assembly.

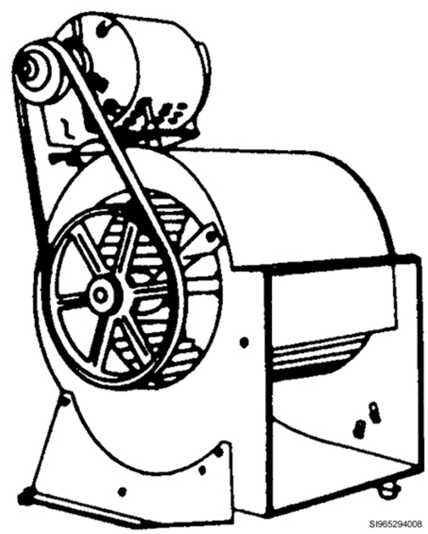


Figure 3–8. Belt driven blower assembly with motor mounted on top.

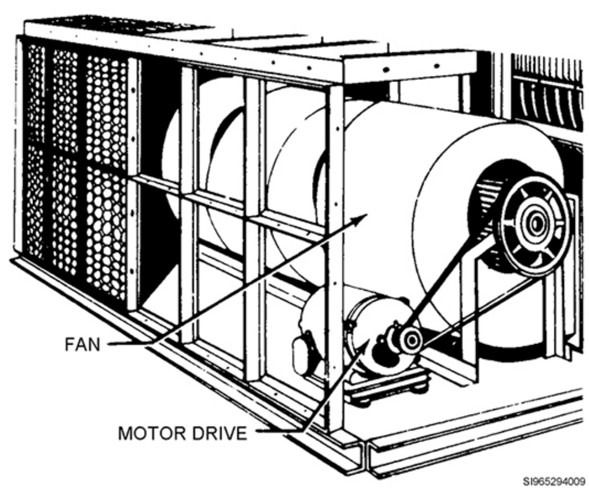


Figure 3–9. Belt driven blower assembly with motor mounted on floor.

Combustion blowers and motors

These blowers bring fresh air into the combustion chamber and push or pull the combustion gases out of the chamber. There are induced draft blowers which are located downstream of the heat exchanger and pull the gases out of the combustion chamber. There are also forced draft blowers that are before the heat exchanger and push the air through the combustion chamber.

Bearings

There are three common types of bearings used on force-air furnace blower assemblies. They are anti-friction bearings, sleeve bearings, and thrust bearings. Figure 3–10 shows an example of thrust bearings.

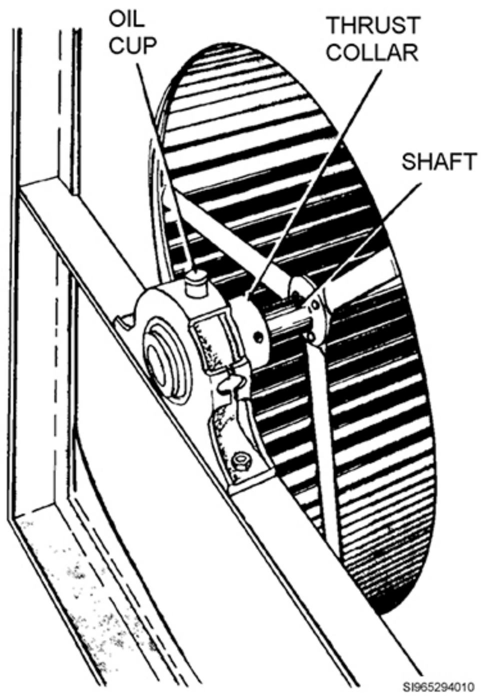


Figure 3–10. Thrust bearings.

Pulleys

A pulley is a wheel used to transmit power by means of a drive belt or V-belt. Figures 3–8 and 3–9 illustrate the two most common types of pulleys. The larger pulley attaches to the fan shaft. These pulleys come in various sizes and are usually selected based on speed and local applications. The smaller pulley connects to the motor shaft. Many of these pulleys are adjustable.

Drive belts

You might use a drive belt when it is necessary to maintain exact speed ratios. They also help cushion the equipment against shock and impacts. The V-belt is widely used for all types of machinery.

Air filters

Filters supplied with a forced-air furnace are either the reusable or washable type. The filter is always located in the circulating air stream ahead of the blower and heat exchanger. Filters are normally marked with an arrow to show proper airflow direction and installation.

Types of airflow variations

The preceding paragraphs described the major components of a forced-air furnace. Manufacturers and installers arrange these components in a variety of configurations to suit residential heating systems. We explain the relative positions of the components in the different types of furnaces in the following paragraphs.

Upflow or high-boy furnace

This furnace's design has the blower beneath the heat exchanger and discharges supply air vertically upward (fig. 3–11). Return air enters through the bottom or the side of the blower compartment and supply air leaves at the top. This furnace will be in closets and utility rooms on the first floor or in basements with the return air ducted to the blower compartment entrance.

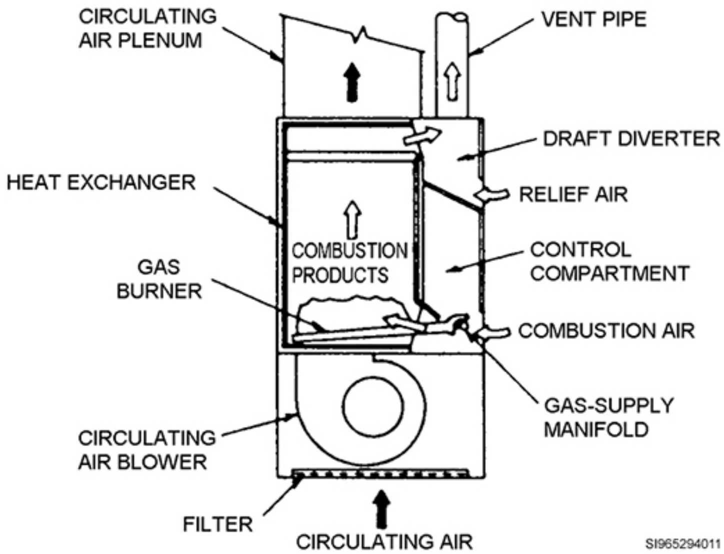


Figure 3–11. Upflow forced air furnace.

Downflow furnace

The downflow furnace has the blower located above the heat exchanger and discharges supply air downward (fig. 3–12). Return air enters at the top and supply air discharges vertically at the bottom. This furnace works in partnership with a perimeter heating system in a house without a basement. It can be in upstairs furnace closets and utility rooms supplying conditioned air to both levels of a two-story house.

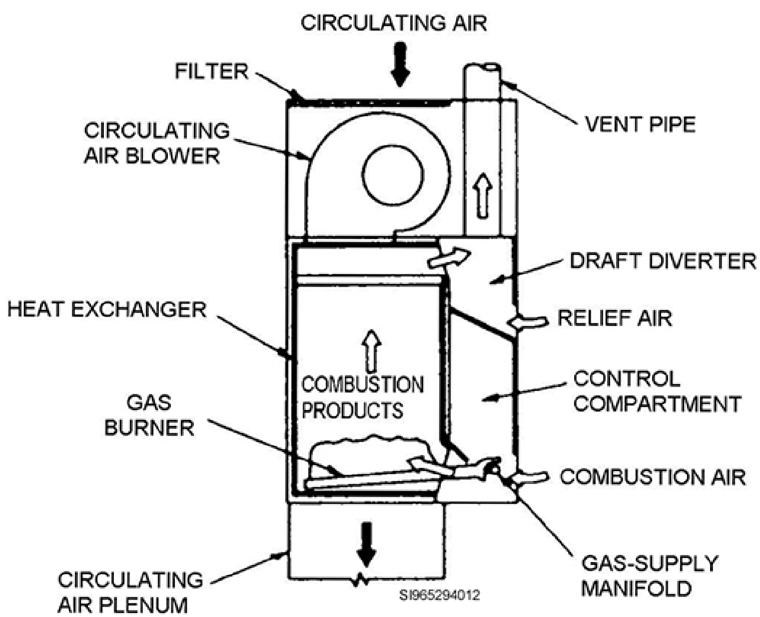


Figure 3–12. Downflow (counterflow) forced air furnace.

Horizontal furnace

The horizontal furnace has the blower located beside the heat exchanger (fig. 3–13). The return air enters at one end, and then travels horizontally through the blower and over the heat exchanger. Supply air discharges at the opposite end. Use this furnace for locations with limited headroom, such as in attics, crawl spaces, or suspended under the ceiling. These units are often designed so that the components are arranged to allow installation for airflow from left to right or from right to left.

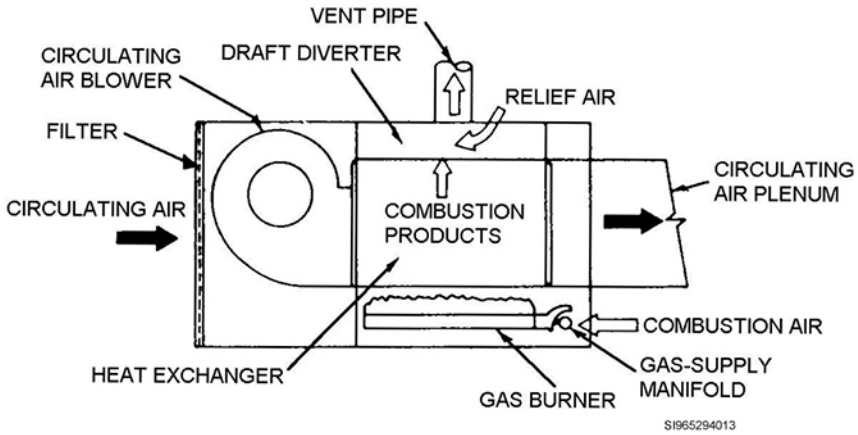


Figure 3–13. Horizontal forced air furnace.

Basement or low-boy furnace

The basement or low-boy furnace is a variation of the upflow furnace and requires less head room (fig. 3–14).The blower is located beside the heat exchanger at the bottom. Return air enters the top of the cabinet, is then drawn through the blower, discharged over the heat exchanger, and finally supply air leaves vertically at the top.

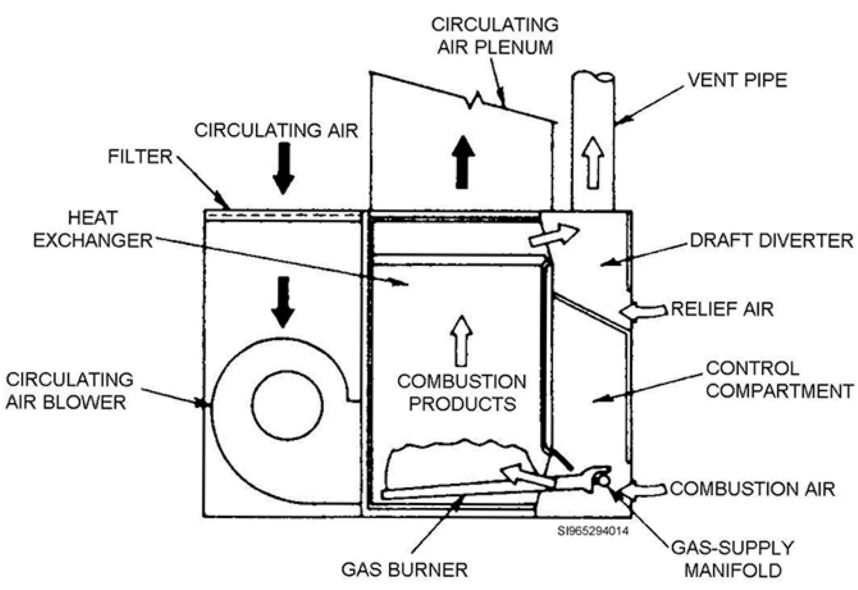


Figure 3–14. Basement (low-boy) forced air furnace.

Indoor-outdoor furnaces

Certified designs for central system residential units include either indoor or outdoor use. Indoor furnaces come in upflow, downflow, or horizontal arrangements. Outdoor furnaces normally are horizontal flow and are available in two basic styles.

One style is the heating-only outdoor furnace. This furnace is similar to the indoor horizontal furnace. It uses the same components in a similar design arrangement. Seals are the primary differences of outdoor furnace motors, they also provide controls to prevent weather from adversely affecting them. The exposed components contain corrosion-resistant materials such as galvanized or aluminized steel.

Another style outdoor furnace is the combination package unit. This unit is a combination of an air-conditioner and gas furnace in a single casing. Designs vary; however, the most common type of combination package consists of an electric air-conditioner with a horizontal gas furnace. An advantage is that much of the interconnecting piping and wiring is included in the unit.

Air: before and after the furnace

The air that is drawn into the furnace comes from everywhere in the conditioned space. For example, in a house the air is drawn from the bedrooms, bathrooms, kitchen, closets, living rooms, etc. Once it is taken into the furnace it is warmed and discharged from the system. The warm air travels through ductwork to reach all of the previously mentioned areas of the house. The cycle continues and won't stop until the heat is turned off by the thermostat or other control.

Make up air units

In a well-sealed building a forced draft heating system can create a negative pressure. To correct this negative pressure a make-up air unit is installed. These units control the intake of fresh air into a facility.

The make up air is drawn into the return duct when the blower turns on. This happens because the blower creates a negative pressure on the return side. The make up air is drawn into the return side so it can be filtered and conditioned.

Make up air units can also be installed to draw air into the room where the furnace is located.

Two stage furnaces

This furnace varies from conventional furnaces because it can vary its output. The flame can vary between low and high, low is the first stage and high is the second stage. If the conditioned space requires less heat, stage one will run the flame low and conserve energy.

Variable speed motors can be used on the blower to adjust the speed automatically via the thermostat. This is newer technology and allows the blower to run at exactly the speed the conditioned space requires.

Unit heaters

This is another type of forced air unit. It will often have hot water flowing through finned tubes and a fan that pushes the air over the tubes. It is used to heat large areas or areas near large doors.

Self-Test Questions

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

625. Types and characteristics

1. Besides reducing heat loss, why do some furnaces have insulation on the inside of the blower compartment?

2. What affect does the heat exchanger have on the cool air that surrounds it?

3. How does the metal surrounding the combustion chamber absorb the heat from the combustion gases?

4. What is the additional heat exchanger called in newer high efficiency furnaces?

5. How does a condensing heat exchanger consume more heat than a traditional heat exchanger?

6. Why is a draft regulator not called a damper?

7. What effect will correct installation of a draft regulator have on its operation?

8. Why must the secondary heat exchanger be made of stainless steel?

9. What are the three types of bearings used in force air furnace blower assemblies?

10. What is a pulley?

11. What does the arrow on a filter mean?

12. Where will high boy furnaces be located?

13. Where will you find a downflow furnace?

14. What is the most common type of indoor-outdoor combination package unit?

15. How does the warm air from the furnace all of the areas in a building?

16. Why is make up air drawn into the return side of the unit and not the supply side?

626. Furnace controls

Furnace controls are the components that tell the unit when and how to run and when to shut off. To be an effective HVAC/R technician you must have a firm grasp of these controls. The main elements of a heating control system are the thermostat, primary control, limit control, and the auxiliary controls.

Automatic furnace controls

Automatic controls on heating systems accomplish one or more of the following conditions:

- Ensure required conditions of temperature, pressure, or humidity.
- Provide safety protection by preventing operation of mechanical equipment when such operation would be harmful or hazardous.
- Ensure efficient operation by providing steady conditions and preventing excessive operation of the system.
- Eliminate human error in operation of heating equipment.

Thermostats

The thermostat is the "nerve center" for a heating system. It is a temperature-sensing device that responds to changes in ambient temperature to start and stop the system. The space between startup and shutdown is the differential with the differential normally being adjustable. Some thermostats have a fixed differential.

Thermostats use many different kinds of sensing elements. Mercury switches and bimetallic elements were common sensing elements in the past. Today, digital thermostats use thermistors.

Control boards

Control boards are extremely common on furnaces (fig. 3–15). You probably won't find a furnace without one. Let's take a quick look at a control board. Keep in mind that this is only one type of board. The yellow circle shows where the thermostat wires are connected to the board. The red circle shows a fuse. The green circle gives a visual of the heating, cooling and fan switches and the blue circle shows the LED's that were discussed in the last unit.

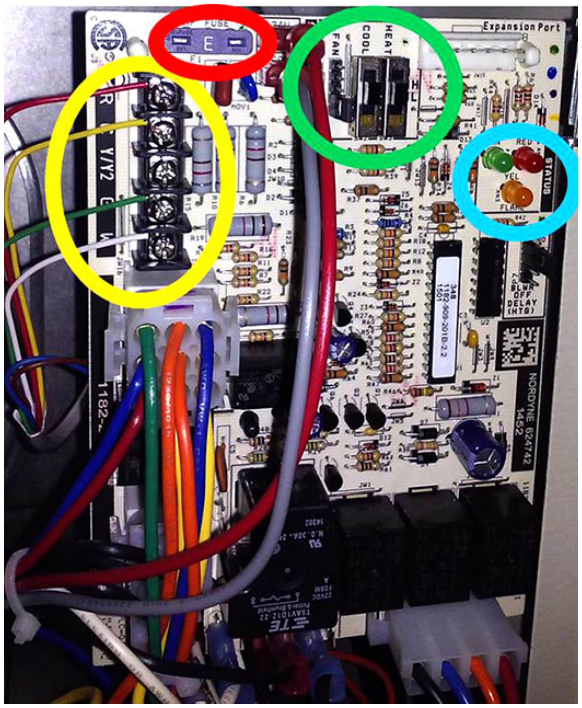


Figure 3–15. Furnace control board.

Gas burner primary controls

The primary control for a gas burner is the automatic gas valve that opens or closes in response to the thermostat signals. Also included in gas burner control systems are limit controls, fan controls, combination fan and limit controls, and accessory controls.

Limit controls

Limit controls are necessary on heating equipment as a built-in safety feature to prevent the temperature from exceeding a safe operating limit. This function is distinctly for safety control. This control responds to temperature changes through a bimetal element. See figure 3–16 to discover where the limit control will be located. If the temperature reaches a dangerous temperature, the sensing element operates a set of normally closed (NC) contacts and opens the circuit to the burner. Figure 3–17 shows two of the ways in which this control connects in series with the burner circuit. The main point to remember is that the control has to shut the firing equipment off at the set temperature. These controls can be pre-set or adjustable. The maximum setting for these controls is usually 200° F.

Figure 3–16. Limit controls.

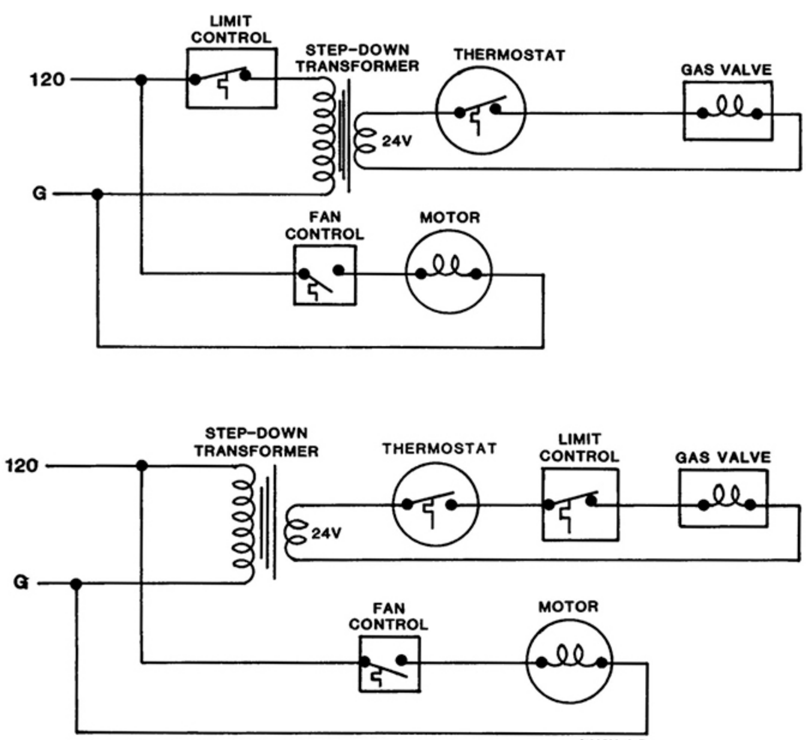


Figure 3–17. Wiring circuits for limit and fan control.

Always check the manufacturer's instructions for the required setting for the equipment on which you are working. Make sure the wiring conforms to local electrical ordinances. Use no lubricating oil on the internal mechanism and make sure the cover is in position at all times.

Fan control

The fan control, shown in figure 3–18, controls the operation of the blower in a forced forced-air furnace. The fan control is similar in construction to the limit switch but operates in a directly opposite manner. The limit control stops the operation of a heating system because of excessive heat in the system, but the fan control starts the fan when the air in the furnace plenum rises to a predetermined temperature. The fan control element is in the plenum of the furnace. The fan control also connects in series with the blower motor. It is not in series with the burner circuit. It operates on line voltage. The image shown is from a schoolhouse trainer and is not an actual design of a furnace.

Combination control

The combination fan and limit control (fig. 3–18) combines the fan control and limit control in one unit. Both controls operate from one bimetal element and the element is installed in the plenum. This control is the most popular type of small furnace control because of its simplicity and economical installation. It does not have to be in a critical level position since it uses mechanical switches. The fan can be turned on or off manually at the switch. Sliding tabs provide for setting the ON and OFF positions of the fan and the high limit control (fig. 3–19). The yellow arrow points to the fan Off tab, the orange arrow points to the fan On tab and the red arrow points to the High Limit tab.

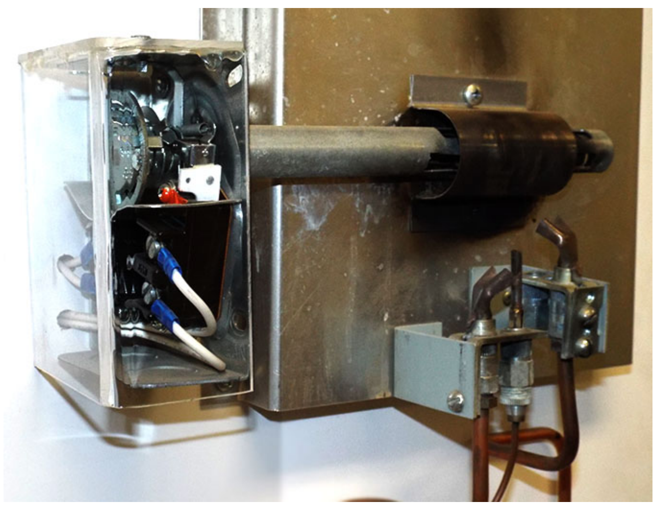


Figure 3–18. Combination fan-limit control.

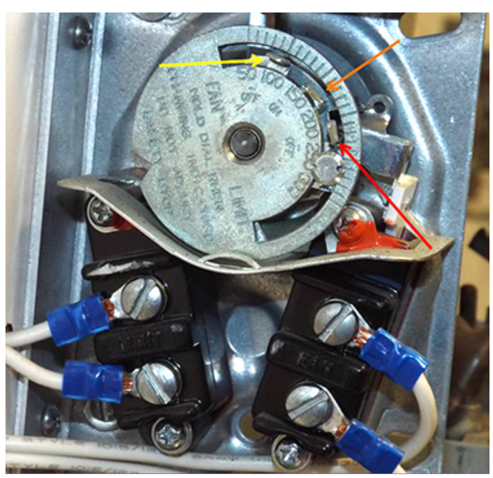


Figure 3–19. Combination fan-limit control settings.

Humidistat

A humidistat senses the relative humidity of the air in a space or system. Wood, hair, or animal membrane makes up the sensing element. Newer electronic humidistats use solid state sensors instead of these elements. The resistance of the sensor changes as the amount of moisture in the air changes. The humidistat “sees” the changes in resistance and sends the proper output signal. Therefore the output of the humidistat varies depending on the resistance that changed because of the humidity. Humidistats operate humidifiers or dehumidifiers.

For example, when the system uses a humidifying device with a spray nozzle, a solenoid valve is controlled. The humidistat in the conditioned space automatically energizes the solenoid when the relative humidity drops below the humidistat setting. As soon as the humidity in the conditioned space elevates to the amount needed to satisfy the humidistat, the circuit opens and the solenoid valve shuts off automatically. Choose a location where there is a good circulation of air around its sensing element.

Oil furnace controls

Oil-fired forced-air furnaces use the same type of thermostats, fan switches, limit switches, and humidifiers as the gas-fired furnaces we just discussed. The only major difference is the primary control.

Self-Test Questions

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

626. Furnace controls

1. What is a thermostat?

2. What is circled in red on the control board?

3. Where is the combination fan and limit control installed?

4. How are the on-off positions set on the combination fan and limit control?

5. What does the humidistat do when it “sees” a change in resistance?

627. Pre-operational inspection and operational test

Before you place a new, reconditioned, or inactive forced-air furnace into service, carefully do a pre-operational inspection. Always do the inspection according to the manufacturer’s recommendation, pertinent Air Force Instructions, and any local base directives. This will ensure you are incompliance with mandatory requirements and have obtained a safe and efficient operation of the equipment.

After you perform the pre-operational inspection; perform the operational test. This lesson will cover the general procedures, but nothing will replace on-the-job training and your reading of the manufacturer’s manuals for the equipment you are working on.

Pre-operational inspection

Remember that you must do a pre-operational inspection of the burners at this time. Those instructions were covered earlier in this unit. Now you must thoroughly inspect the remaining areas of the unit before operation. Let's start with gas-fired furnaces.

Gas-fired furnaces

The gas-fired furnace has several inspection areas that must be examined. The following table provides a list of items that are required for inspection:

Gas Fired Furnace Inspection Areas	
Mechanical room	Inspect the furnace room for cleanliness and remove any combustible material, such as paper or boxes. Occupants will not store any items in the furnace room whatsoever. To do so is a violation of Air Force Instructions.
Gas leaks	First and most important, inspect for gas leaks. Turn off the power to the unit so that the burner will not ignite during your inspection. To turn the unit off, simply turn the thermostat to the OFF position. Also, turn off the furnace circuit breaker and tag it so that no one will turn it back on. Some furnaces have a standard plug that you can unplug. Some have a red switch like the one seen in figure 3–20. Turn this switch off. Use a soap and water solution to check for leaks. (**NOTE**: At this point gas will only go up to but not beyond the gas valve. Gas only goes beyond the gas valve when the valve energizes and is open.)
Heat exchanger	When inspecting the furnace itself, always inspect the heat exchanger for cracks, corrosion, excessively heated sections (deformed or warped metal), soot deposits, blockages, and cleanliness. If you are unsure of your findings and what action you should take, ask your supervisor. **NOTE**: A cracked heat exchanger could allow gases such as carbon monoxide to get into the rooms and cause serious sickness or even death.
Vent components	Ensure that all air and gas ducts and passages are tight and free from obstructions.
Accessories	Make sure that the air filter is clean and that the humidifier fills with water and ready for operation.
Electrical	Also, inspect the wiring of controls and ensure all controls are set properly.
Blower section	Check the air blower and motor for alignment, cleanliness, proper lubrication, rotation, and speed.
Gas regulator	Check the supply gas pressure to the gas pressure regulator with a manometer and ensure that the pressure is set to the manufacturer's recommendations.

Figure 3–20. Gas burner emergency switch.

Oil-fired furnaces

Oil-fired furnaces require the same type of inspections as the gas-fired units do. The main difference is in checking the fuel piping system and the oil burner itself.

Operational test

After you do a pre-operational inspection, also run the equipment through a complete cycle to see if you need to make any adjustments. On gas-fired furnaces, you first light the pilot light and ensure it is in the proper position to ignite the main burners. Turn the power back ON and turn the thermostat up so that it calls for heat. Observe the ignition and ensure it is smooth. Once the blower system comes on, turn the thermostat back down so that the burners shut off. Observe the operation of the furnace through this cycle and make adjustments as necessary.

You must also ensure that the safety limit control is operating properly. To perform this test, first turn the power back OFF and disconnect the blower circuit. Turn the system back ON, adjust the thermostat to call for heat, and observe the burners. The burners should light and continue burning until the air in the plenum reaches the setting of the limit (maximum 200° F). When the air temperature reaches this setting, the system must then shut off.

One method of seeing if the limit is operating at the proper temperature is to drill a small hole near the bimetallic element of the control. Insert an ordinary stack thermometer into the hole, watch the temperature rise, and note at what temperature the control opens the circuit. The use of the stack thermometer in this fashion serves as a check upon the calibration of the limit control and its rapidity in responding to the air temperature changes in the plenum. The control should operate close to the setting prescribed by the manufacturer. After you observe the operation of this control several times, remove the stack thermometer and seal the small hole in the duct with a sheet-metal screw.

The last checks to make are the combustion analysis and smoke tests. For these, follow the procedures that we explained earlier. Once you make all tests and are satisfied with the results, place the thermostat in the OFF position and notify the facility manager that the unit is ready to perform its job.

Self-Test Questions

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

627. Pre-operational inspection and operational test

1. What must be done before you place a new, reconditioned, or inactive forced-air furnace into service?

2. What is the furnace room inspected for?

3. What should be done to the circuit breaker after it is turned off?

4. What should you inspect the heat exchanger for?

5. How should the air filter and humidifier be inspected?

6. What is the main difference between the gas-fired and oil-fired furnace's pre-op inspection?

7. On gas-fired furnaces, what should be lit first?

8. How is the calibration of the limit control checked?

9. What is done after you are satisfied with all test results?

3–2. Radiant Heating Systems

Radiant heaters, also known as infrared heaters, are compact, self-contained, direct-heating devices used in hangars, warehouses, gymnasiums, and for areas such as loading docks. Radiant heating units may be electric, gas-fired, or oil fired. We only cover the gas and oil types, controls used on these heaters, the pre-operational inspection, and operation test of these units in this section.

628. Types and operation of radiant heaters

Radiant heaters are simple and efficient systems. This lesson is about the types of radiant heaters, operation of radiant heaters and lastly will cover a brief discussion about radiant heater controls.

Operational principles

Radiant heating units are effective for spot heating. However, because they use less energy than conventional space-heating systems, a primary application is for total heating of large areas and entire buildings. Radiant heaters use electromagnetic waves to transfer energy directly to solid objects. Little energy is lost during the transmission because air is a poor absorber of infrared energy. Since there is no need for an intermediate transfer medium (such as air or water), fans, or pumps are not required.

As floors and objects warm up by the infrared energy, they heat to the air by convection. An energy saving advantage of radiant heat is that we can turn it off when there is no need; when we turn it on again, it is effective in minutes.

Radiant heaters

There are three types of heaters—gas, oil, and electric. We only discuss the gas-fired units in this lesson.

Modern gas-fired radiant heaters burn gas to heat a specific radiating surface. The surface will heat up by direct flame contact or with combustion gases. The specific radiating surface of a properly designed unit increases radiant releasing efficiency and directs radiation toward the load. The types of radiant gas heaters we cover are tube-heater and ceramic heaters.

Tube heaters

Some types of radiant heaters fire internally. They have the radiating surface between the hot gases and load. Combustion takes place within the radiating elements, which operate with surface temperatures up to 1200° F. The elements are usually made of tubes. Tube type radiant heaters vent to the outside. See figure 3–21 for an example of a tube type heater. Notice the aluminum reflectors. The reflectors assist the radiation to reach its desired location.

Figure 3–21. Radiant tube heater.

Ceramic radiant heaters

This type of heater has a refractory material, which may be porous ceramic, drilled port ceramic, stainless steel, or a metallic screen. See figure 3–22 for an example of a porous ceramic type heater. These units are enclosed, except for the major surface facing the load. A combustible gas-air mixture enters the enclosure, flows through the refractory material to the exposed face, and distributes evenly by the porous character of the refractory (fig. 3–23). Combustion occurs evenly on the exposed surface. The flame recedes into the matrix, which adds radiant energy to the flame. If the refractory porosity is suitable, the system can use an atmospheric burner. This results in a surface temperature that approaches 1650° F. Power burner operation may be required if refractory density is high. However, the resulting surface temperature may also be higher than 1800° F.

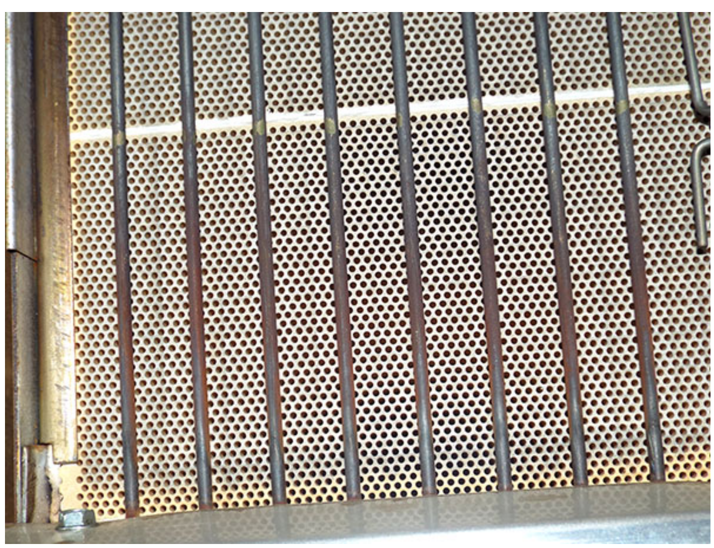


Figure 3–22. Porous ceramic.

Figure 3–23. Gas lit and distributed evenly over material.

Controls

Normally, gas and oil fired radiant heaters have all controls (except the thermostat) on them (fig. 3–24). In figure 3–24 you can see that the gas valve, burner, ignition control and other controls are all in the box. The only control that is outside of the unit is the thermostat. Because of the effects of direct radiation, higher mean radiant temperature (MRT) and decreased ambient temperature compared to forced air systems, radiant heating requires careful selection and location of the thermostat sensor. Some installers recommend placing the thermostat or sensor in the radiation pattern, while others do not recommend it. Factors for thermostat placement include the nature of the system, the type of radiant heating units used, and the nature of the thermostat or sensor. Furthermore, no single location appears to be equally effective during the periods after a cold start and after substantial operation.

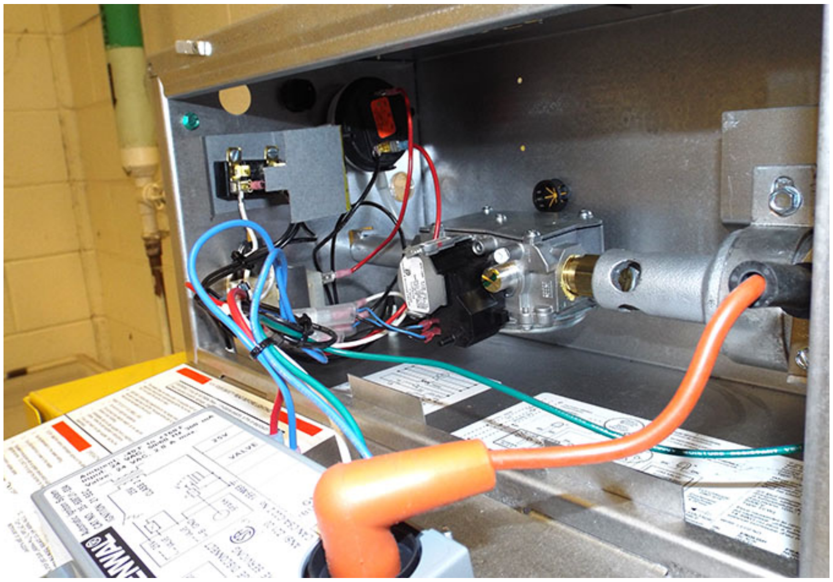


Figure 3–24. Radiant tube heater controls in control box. (Notice absence of thermostat)

We can use a radiant heating system controlled by low-limit thermostats for freeze protection. A thermostat usually controls an automatic valve on gas-fired radiant units to provide *on-off* control of gas flow to all burners. If a unit has a pilot flame, a sensing element prevents the flow of gas to burners only or both burners and pilot, when the pilot extinguishes. The system can use electrical ignition with provision for manual or automatic re-ignition of the pilot if it goes out. It can also use electric spark ignition. See figure 3–25 and figure 3–26. In figure 3–26, ignition starts at the orange plug and travels to the electrodes.

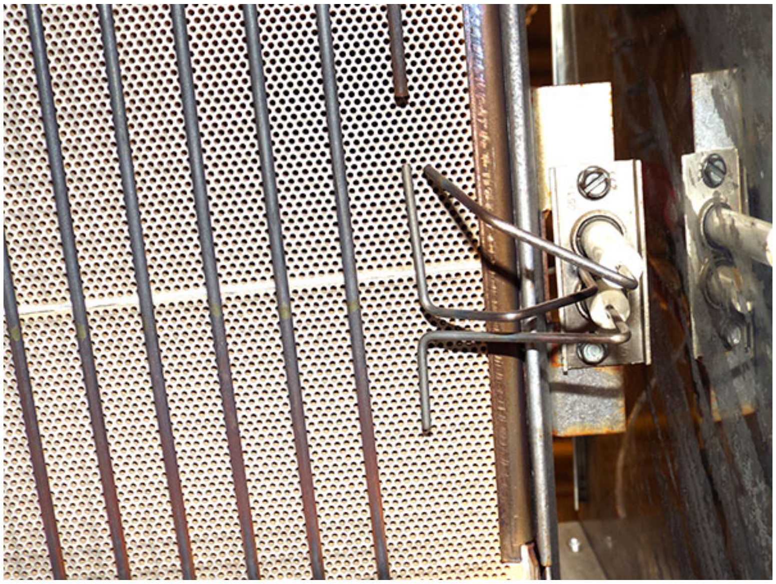


Figure 3–25. Spark ignition on ceramic radiant heater.

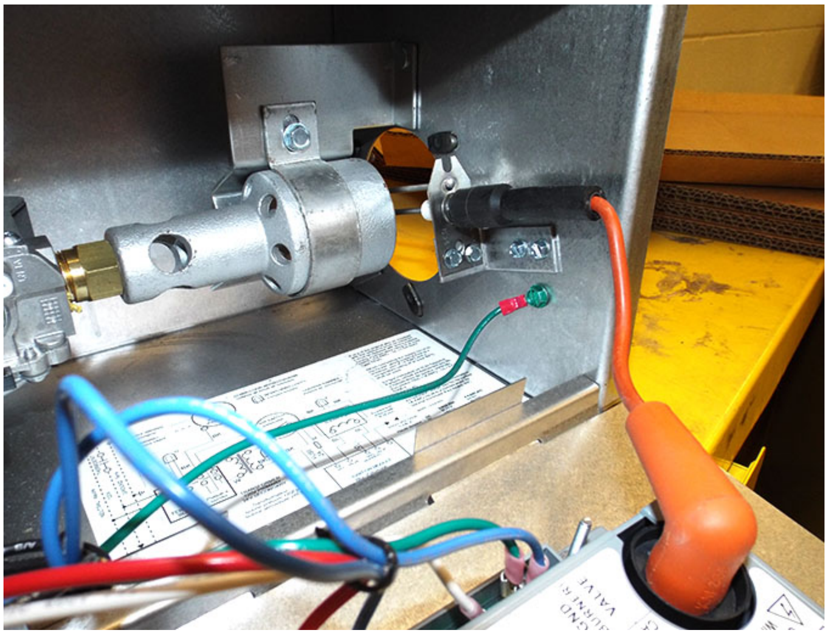


Figure 3–26. Spark ignition on tube-type radiant heater.

Gas radiant systems for full buildings may have a zone thermostatic control system in which a thermostat representative of one outside exposure operates heaters along that outside wall. Two or more zone thermostats may be required for extremely long wall exposures. Heaters for an internal zone group around a thermostat is representative of that zone. Use manual switches or input controllers for spot or area heating.

Self-Test Questions

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

628. Types and operation of radiant heaters

1. How do radiant heaters transfer energy directly to solid objects?

2. How does a surface heat up from infrared heaters?

3. How do reflectors effect radiant heat flow?

4. What effect does the porous refractory of a ceramic radiant heater have on gas flow?

5. Why does radiant heating require careful selection and location of the thermostat sensor?

629. Pre-operational inspection, operational test for radiant heaters

Now we will cover the pre-operational inspection and operational test for radiant heaters. Just as in any other devices and their uses, there are precautions we must follow in the inspection of radiant heaters. Following these precautions may avoid injuries and even death.

Pre-operational inspection

Always follow the manufacturer's recommendation regarding the inspection of radiant heaters. Most of the pre-operational inspection will be a safety check. The following 16 areas will be checked:

1. All infrared heaters covered in this lesson have high surface temperatures when they are operating and should not be used when the atmosphere contains ignitable dust, gases, or vapors in hazardous concentrations.
2. Follow the manufacturer's recommendations for clearance between a fixture and combustible material. Post warning notices defining proper clearances near the fixture.
3. Follow manufacturer's recommendations for clearance between a fixture and personnel areas to prevent personnel stress from local overheating.
4. Do not use radiant fixtures if the atmosphere contains gases, vapors, or dusts that decompose to hazardous or toxic materials in the presence of high temperature and air.
5. Humidity must be controlled in areas with unvented gas-fired radiant units because water formed by combustion increases humidity. Sufficient ventilation, direct venting, or insulation on cold surfaces helps control the moisture problems.
6. Provide adequate makeup air to replace the air used by combustion-type heaters, regardless of whether units are direct-vented or not.
7. If unvented combustion-type radiant heaters are used, the area must have adequate ventilation to ensure that products of combustion in the air do not exceed an acceptable level.
8. Protect personnel, kept comfortable with radiant heating equipment, from substantial wind or drafts. Suitable wind shields seem to be more effective than increased radiation density.

9. Inspect all electrical connections to ensure they are tight, the proper size and in good condition. Also, ensure all wiring conforms to the latest edition of the National Electric Code.
10. Inspect all gas lines for leaks and to ensure proper installation according the manufacturer's manuals.
11. Inspect the mounting of the heater. If it is suspended by chains or a thread rod ensure they are secure. You wouldn't want a loose heater falling on a multi-million dollar aircraft in hangar.
12. Inspect reflectors (if installed) for looseness. In buildings that are exposed to winds, such as hangars, these reflectors can bend and sometimes break and fall on aircraft or equipment.
13. Ensure fuel on heater data plate matches the fuel being supplied to the heater.
14. Ohm out all fuses to ensure they are good.
15. Check the supply pressure. Ensure it falls within the minimum and maximum pressures that the manufacturer provides. For example, a minimum of 5" water column and a maximum of 14" water column. If you had a pressure of 7" water column this would work.
16. Ensure all hangar or doors are closed. If it is 30 degrees outside and a hangar door is open you will never satisfy the conditioned space.

Operational test

After the pre-operational inspection, perform an operational test. First let's take a look at the following lighting instructions are for a tube type heater.

1. Turn on the gas and electrical supply. Rotate the gas valve knob to the "ON" position.
2. Set the thermostat to call for heat. The blower motor will energize.
3. Ignition should occur after a predetermined air pre-purge.
4. If ignition fails, the unit will spark for approximately 21 seconds and go into safety lockout. Turn the thermostat (power) off for 60 seconds to take the system out of lockout.
5. If the heater does not light, manually reset the thermostat or shut off power completely for 5 minutes before attempting to relight.
6. To permanently shut down the heater, rotate the gas valve knob to the "OFF" position and turn off the gas and electrical supply.

Now that the unit is running observe the following steps in the operation:

1. Check for proper voltages. Check incoming power at the breaker, power at the box and then the control power.
2. Observe the system sequence of operations by following the manual for the system you are working on.
3. Listen for awkward noises.
4. Adjust as necessary the gas valve outlet gas pressure.
5. Perform an air switch check. (general procedures)
    a. Open hinged access panel.
    b. Add tubing to connect the air switch with the connector tee and the existing tubing.
    c. Connect plastic tubing of a digital or inclined water manometer. Check manual for the required manometer scale size.

   d. Turn heater on and wait until blower motor is activated.
   e. Observe air pressure from manometer. This should be higher than the set point inches WC for correct operation.
6. Let the system cycle off and back on to ensure proper operation.

Self-Test Questions

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

629. Pre-operational inspection, operational test for radiant heaters

1. What is done to notify personnel of radiant heater clearances?

2. Where should you not use radiant heaters?

3. What must be done to humidity if unvented gas-fired radiant unit is used?

4. What should electrical connections be inspected for?

5. How is the mounting of the heater inspected?

6. In regards to fuel, how should the unit data plate be inspected?

7. What is the first step of the operational test?

8. What is the second step of the operational test?

9. How is the heater permanently shut down?

10. Where should voltage be checked?

3–3. Preventative Maintenance

Preventative maintenance is vital to the efficient and safe operation of forced air and radiant heating systems. The Air Force has heavily shifted its focus to a stronger preventative maintenance (PM) program. The lessons in this section provide the procedures to perform PM on both forced air and radiant heating systems.

630 General forced air preventative maintenance

This lesson covers PM for forced air systems. Some items, such as burners and thermostats apply to radiant heating systems also. Preventative maintenance for components specific to the radiant heater is covered in the next lesson. This lesson deals with lubrication, adjustments and cleaning that is required for the heating systems we have discussed.

Lubricating

Lubricate blower motors and bearings about every 6 months. Use five to six drops of a good grade of SAE oil—do not over-lubricate. Most direct-drive blower motors do not require oiling, but check the manufacturer's instructions so you don't accidentally try to oil a motor that doesn't require it.

Anti-friction bearings have races, balls, or rollers that are very hard and consist of highly polished surfaces. Lubricate these bearings with good grade of grease or oil. Also lubricate sleeve bearings with oil or grease. You can oil lubricated bearings in one of several methods, such as force-feed, ring-feed, drip feed, or saturated wick. You can also lubricate thrust bearings in the same manner as other bearings.

Adjusting

We can make many adjustments to forced-air heating equipment and its components. We cover some of these adjustments in the following paragraphs.

Burner

We covered burner adjustments earlier. Therefore, we do not cover them in detail at this time. However, one adjustment not discussed earlier is stack draft.

Draft is established when air is heated by the burner flame, becomes lighter, and rises. The higher the temperature, the faster it rises. The draft that goes up the stack or chimney is *negative draft* or *updraft*. Cold air that enters a chimney is a *positive draft* or *downdraft*. Figure 3–27 shows two possible sources of downdraft conditions. Use downdraft hoods similar to the one shown in figure 3–28 to eliminate a downdraft condition in a chimney. Such a hood mounts on the top of the stack or chimney. A draft blowing down through one side or the other cannot be allowed to go down into the chimney or stack, thus preventing a downdraft condition.

Figure 3–27. Causes of downdraft.

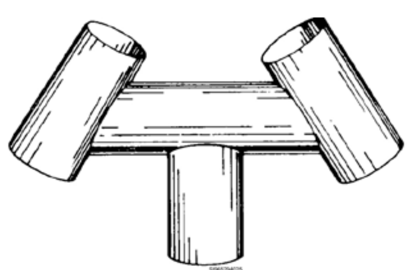


Figure 3–28. H-type downdraft hood.

Measure draft in inches of water column or, in the case of small domestic furnaces, a draft is measured in hundredths of inches of water column. Measure draft with a manometer, digital or analog. A technician can insert a probe in two places, in the breaching (or stack) on the burner side before the draft regulator (fig. 3–29) or over the fire, through a small hole above the flame. Always adjust the draft in accordance with the manufacturer's instructions.

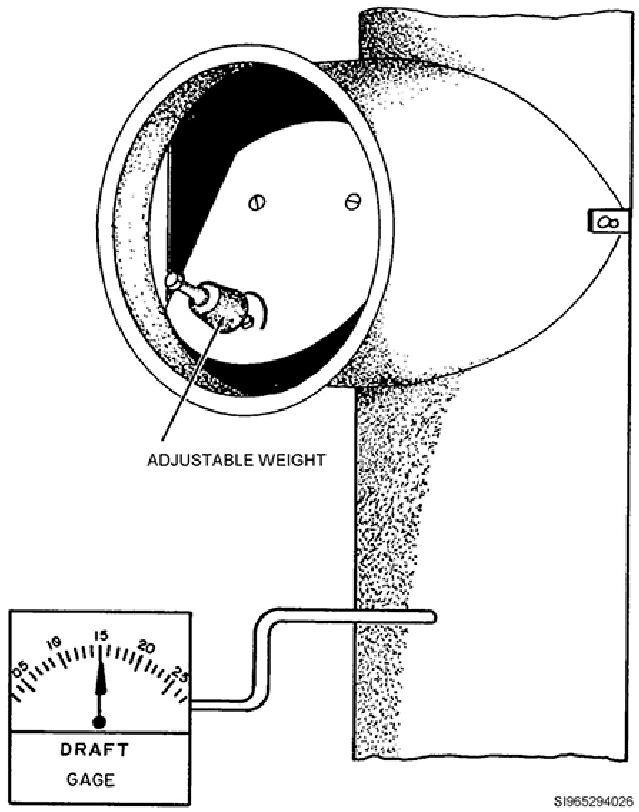


Figure 3–29. Draft regulator with draft gauge.

Thermostats

Because of the many types and manufacturers' designs, it would be impossible to cover the adjustments of thermostats. The location of the thermostat can affect the operation of the heating system. Before you make any adjustments, first ensure there is no exposure from heat or cold from any windows, doors, drafts, etc. Install the thermostat where it will register, as closely as possible the average ambient temperature to be controlled. An inner wall is an ideal place. Mount the thermostat about four to five feet above the floor.

Limit control

Always set the limit control to the manufacturer's recommended setting. Usually this is from 175 to 200° F.

Fan control

The fan control has two settings, the fan ON, and the fan OFF. The fan OFF temperature is generally set at 5 to 10° F above the desired room temperature. This turns the fan off before the air entering the room becomes too cool to heat the room effectively and actually feels like a draft. The fan ON temperature is set approximately 20° F higher than the fan OFF temperature so that the fan will not start before the temperature of the air leaving the unit is warm enough. For example, if the desired room temperature is 70° F, the fan OFF setting would be from 75 to 80° F and the fan ON setting would be 95 to 100° F. Again, follow the manufacturer's instructions when you adjust the fan control.

Combination control

The combination control combines a limit control and a fan control. Therefore, there are three adjustments. The limit adjustment procedures are the same as those we mentioned earlier—approximately 175 to 200° F. Make the fan switch ON/OFF adjustments as we stated previously.

Bearings

Some belt-driven blowers have self-aligning bearings. Others have bearings that stay in place by bolts that stabilize the bearings to the blower housing. If the bearings are binding, loosen the bolts and let the bearings come into alignment before you tighten them.

The thrust collars lock to the shaft on the lock side of the bearings. A leather washer is located between these and the end of the bearings. The collars keep the shaft from sliding out of the bearings and, when properly adjusted, prevent endplay. If you hear a thumping noise in the blower, it is the result of too much endplay. Adjust the collars and the noise will disappear. Make sure you adjust the collars as close to the sides of the bearing as possible without binding against the bearing. After every adjustment, remove the blower belt and spin the blower by hand in order to make sure it rolls freely.

Blower speed

Centrifugal fan units operate under a wide range of speeds. The exact speed of a specific fan unit depends on the design of the system. The technician obtains the proper speed ratio between the blower and the motor by using pulleys with different diameters on the blower and the motor. To permit minor speed ratio changes, the motor pulley is usually adjustable. Figure 3–30 shows a typical single-groove, variable-pitch motor pulley.

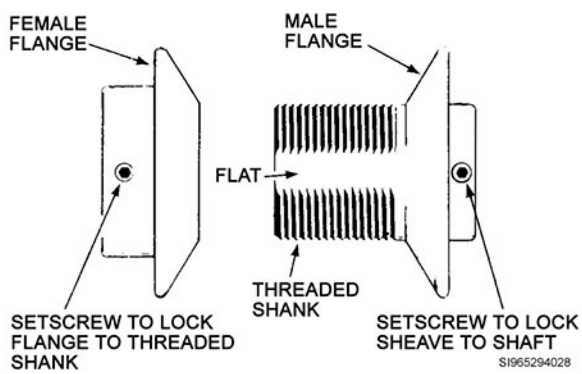


Figure 3–30. A variable-pitch pulley.

Before you change the drive ratio, first determine that the motor is not overloaded. That is, before you bring the pulley flanges closer together to make the pulley pitch diameter large, take an ammeter reading with the motor under full-load operating conditions. Then, compare this ammeter reading with the full-load amperage stamped on the data plate. When you make a pulley change, do not bring the flanges so close together that the belt rides above the flanges. Also, do not separate them so widely that the belt rides below the "V" of the flanges. Either condition causes rapid wear of the belt.

To adjust a variable-pitch pulley, first loosen the setscrew on the movable flange then, screw the flange in or out as desired. After you make the proper adjustment, position the movable flange so that the setscrew rests on the flat side of the hub and tighten the setscrew. Lastly, realign the pulleys on the motor and the blower and check the belt tension.

Belt replacement and adjustment

Since a new belt is somewhat shorter in length than an old stretched belt, you must not force it on the pulleys. To make sure you do not force it, loosen the motor on its base, and shift it closer to the blower. Then place the belt on the motor and blower pulleys, readjust the motor, and tighten it to its base. The belt must fit completely in the “V” of both pulleys; otherwise, you will have rapid wear, noise, and slipping.

A good method for checking proper tension is to strike the belt with your hand. A correctly adjusted belt will vibrate; a slack belt will feel dead and will not vibrate. Be careful that you tighten belts no more than necessary to prevent slippage. A belt that is too tight causes an extra load on the motor and may damage the motor and blower bearings. Figure 3–31 shows the proper belt tension for domestic blower units. The belt tension shown is a rule of thumb. If you install new belts, recheck the belt tension after you operate the motor for 24 to 48 hours.

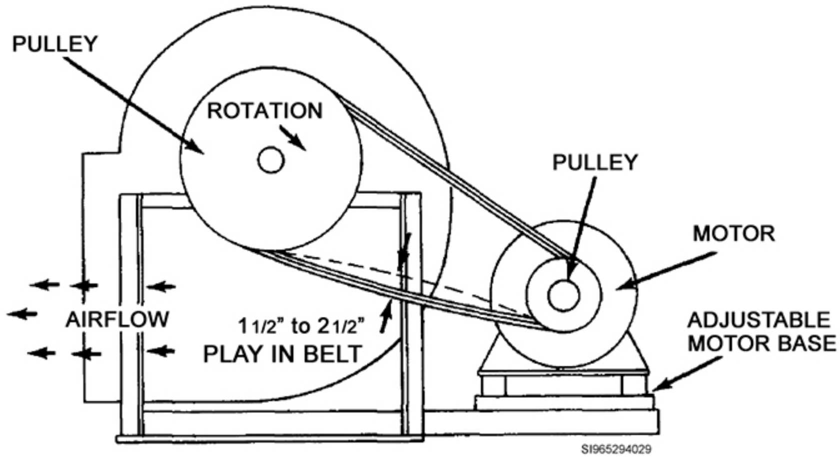


Figure 3–31. Blower belt adjustment.

Pulley alignment

Check the motor and blower pulley alignment each time you replace a belt, adjust pulleys, or loosen the motor on its mount. You can check pulley alignment by using a straightedge or a tight line (fig. 3–32). The motor shaft is usually long enough so that you can adjust the pulley to line up with the blower pulley. However, if you cannot make the alignment by this method, you must readjust the motor on its mount. Improper alignment of pulleys shortens the life of belts and causes excessive wear on the faces of the pulley flanges.

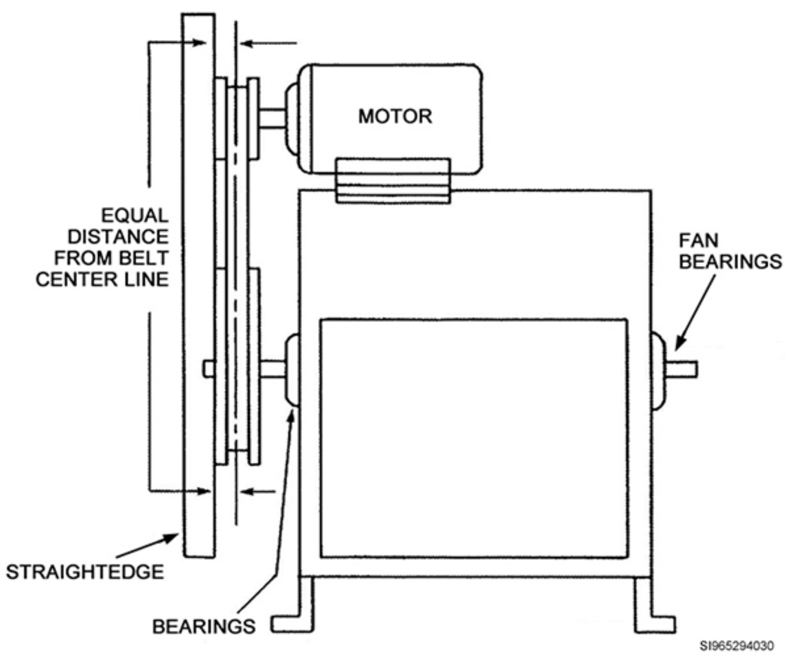


Figure 3–32. Checking pulley alignment.

Cleaning

Just as there are components on forced-air systems to lubricate and adjust, there are components to clean. We cover the cleaning of these components in the following paragraphs.

Controls

Keep all controls used on forced-air systems dry, dust free, and lint free at all times. Accumulation of foreign material inside the control housing causes improper operation. Clean contacts of all controls with contact-spray cleaner if it is available. If not, you can clean the contacts with a soft brush or by passing a piece of hard-finished paper between them as you hold the contacts lightly closed with your fingers. Never attempt to clean contacts with emery cloth (sandpaper) or other abrasive materials.

Heat exchanger

Clean the heat exchangers annually. When you clean the heat exchanger, use a wire brush to remove soot and corrosion deposits. Then use a vacuum cleaner to remove any deposits that remain.

Blower assembly

Clean the blower assembly at least annually. The blower fan requires some special attention. Begin by using a dry rag to remove any dust or lint accumulation from the blades and then vacuum them clean. When you clean the fan, be very careful not to move any balancing weights that may be on the fan blades. To move them or to loosen them, unbalances the fan and causes damage to the fan bearings in a short period. Also, take care not to bend any blades. If the blades become bent, the blower efficiency reduces and bearings eventually destruct.

Clean the fan housing with a dry rag and a vacuum cleaner. Clean the air intake to the blower motor. Never use water to clean blower assemblies because of the possibility of starting corrosion. Most furnaces now have blower assemblies that you can remove for ease of cleaning.

Burner

We covered the procedures for cleaning burners earlier. Therefore, we will not cover these procedures here, although it's important for you to know that it is an item required to be clean. You may want to review that area, unit 2 of this volume at this time to refresh your memory.

Room

To clean the room where the unit is located, completely dust the walls and the units casing. Vacuum any dust, dirt, soot, corrosion, or lint accumulations from the floor. Also, clean any fuel oil from the floor.

Self-Test Questions

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

630. General forced air preventative maintenance

1. Why should you check the manufacturer's instructions to see if a motor needs lubricated?

2. When is draft established?

3. What is the draft that goes up the stack called?

4. What is the cold air that enters a stack called?

5. Where can a probe be inserted to measure draft?

6. What should be done before you change the drive ratio?

7. When taking an amperage reading under full load operating conditions, what do you compare your reading too?

8. What must be avoided while you are adjusting pulleys?

9. How should the controls of a forced-air heating system be maintained?

10. How often should heat exchangers be cleaned?

631. Preventative maintenance for radiant heaters

As stated previously, PM is extremely important. It saves the Air Force money and it saves the technician time. A solid radiant heater PM program can decrease the amount of service calls received which means less time spend fixing broke equipment. Also, if the radiant heaters are serviced properly then their life expectancy increases, this saves the Air Force money.

Since radiant heaters are usually out of arms reach their maintenance is often be neglected. PM for a radiant heater commonly requires a lift that allows the technician to reach the equipment. This deters some people from wanting to work on radiant heaters. Before you fall in line with this bad habit consider the people and the multi-million dollars' worth of equipment that rely on the heat provided by radiant heaters. We don't want a crew chief to feel freezing cold while working on an expensive jet so make sure you do your PM on radiant heaters!

General maintenance

Gas-fired and oil-fired radiant heaters require periodic cleaning to remove dust, dirt, and soot. You must keep reflecting surfaces clean so they remain efficient. An annual cleaning of heat exchangers, radiating surfaces, burners, and reflectors with low pressure compressed air is usually sufficient. Use the manufacturer's instructions for exact air pressures. Any chemical cleaners used should not leave a film on aluminum surfaces. Dirty reflectors reduce heat output.

Keep both main and pilot air ports of gas-fired units free of lint and dust. The nozzle, draft tube, and nose cone of burners of oil-fired units operate with a particular combustion chamber design, so you must replace them carefully.

Suspension system

Check that the suspension system is holding the heater level. Ensure that the heater is hanging securely, look for any evidence where the heater may have been hit accidentally and tighten any loose hanging points. Check that S hooks are closed. Check that there is no evidence of wear on the chain at the connection to the heater and at the ceiling.

Venting system

Disconnect vent pipe and inspect internally using a flashlight to make sure no foreign material has collected in the pipes. Check the external vent cap and make sure that there is no obstruction around the exhaust openings. Clean any foreign materials. Inspect any joints to make sure they are completely sealed.

Combustion air intake

Disconnect combustion air intake from the control box and inspect internally using a flashlight to make sure no foreign material has collected in the tubes and that there is no obstruction around the air intake openings. Clean any foreign materials. Inspect any joints to make sure they are completely sealed.

Heat exchanger tubes

Inspect the heat exchanger tubes to make sure they are not cracked, sagging or showing signs of fatigue.

Gas lines

Make sure that the gas lines are not leaking. Check the gas connection to the heater for any signs of damage, fatigue or corrosion. If there is any damage or leaks to the gas connection or piping immediately stop using the heater. Fix the damage or leak and then resume operations. Check that the gas lines are not bearing the weight of the heater.

Self-Test Questions

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

631. Preventative maintenance for radiant heaters

1. How are heat exchangers, radiating surfaces, burners and reflectors cleaned?

2. How is the radiant heater suspension system inspected?

3. How is the external vent cap inspected?

4. How is the heat exchanger inspected?

Answers to Self-Test Questions

625

1. To provide acoustical dampening of the blower noise.
2. It heats it.
3. Conduction.
4. Condensing heat exchanger.
5. It does this by using primary and secondary heat exchangers to extract additional heat from combustion.
6. This damper uses a weighted butterfly damper that maintains a constant draft, regardless of wind and temperature.
7. It will balance correctly and be free to move at the slightest change in draft pressure.

8. Because the condensate created can be corrosive.
9. Friction bearings, sleeve bearings, and thrust bearings.
10. Wheel used to transmit power by means of a drive belt or V-belt.
11. Shows the proper direction of airflow.
12. In closets and utility rooms on the first floor or in basements with the return air ducted to the blower compartment entrance.
13. It can be in upstairs furnace closets and utility rooms supplying conditioned air to both levels of a two-story house.
14. One with an electric air-conditioner with a horizontal gas furnace.
15. Ductwork.
16. So it can be filtered and conditioned.

626

1. A temperature-sensing device that responds to changes in ambient temperature to start and stop the system.
2. The thermostat wires connected to the board.
3. In the plenum.
4. Sliding tabs.
5. It sends a proper output signal.

627

1. Pre-operational inspection.
2. Cleanliness and remove any combustible material, such as paper or boxes.
3. Tag it so that no one will turn it back on.
4. Cracks, corrosion, excessively heated sections (deformed or warped metal), soot deposits, blockages, and cleanliness.
5. Make sure that the air filter is clean and that the humidifier fills with water and ready for operation.
6. The main difference is in checking the fuel piping system and the oil burner itself.
7. The pilot light.
8. Insert an ordinary stack thermometer into the hole, watch the temperature rise, and note at what temperature the control opens the circuit. The use of the stack thermometer in this fashion serves as a check upon the calibration of the limit control and its rapidity in responding to the air temperature changes in the plenum.
9. Place the thermostat in the OFF position, and notify the facility manager that the unit is ready to perform its job.

628

1. Infrared energy.
2. Direct flame contact or with combustion gases.
3. Assist radiation to reach desired location.
4. Gas flow flows through the refractory material to the exposed face, and distributes evenly.
5. Because of the effects of direct radiation, higher mean radiant temperature (MRT) and decreased ambient temperature compared to forced air systems.

629

1. Post warning notices near the fixture that define proper clearances.
2. If the atmosphere contains gases, vapors, or dusts that decompose to hazardous or toxic materials in the presence of high temperature and air.
3. It must be controlled.
4. Inspect all electrical connections to ensure they are tight, the proper size and in good condition. Also, ensure all wiring conforms to the latest edition of the National Electric Code.
5. If it is suspended by chains or a thread rod ensure they are secure.
6. Ensure fuel on heater data plate matches the fuel being supplied to the heater.

7. Turn on the gas and electrical supply. Rotate the gas valve knob to the “ON” position.
8. Set the thermostat to call for heat. The blower motor will energize.
9. Rotate the gas valve knob to the “OFF” position and turn off the gas and electrical supply.
10. Check incoming power at the breaker, power at the box and then the control power.

630

1. So you don’t accidentally try to oil a motor that doesn’t require it.
2. When air is heated by the burner flame, becomes lighter, and rises.
3. Negative draft or updraft.
4. Positive draft or downdraft.
5. A technician can insert a probe in two places, in the breaching (or stack) on the burner side before the draft regulator (figure 3–29) or over the fire, through a small hole above the flame.
6. Determine that the motor is not overloaded. Take an ammeter reading with the motor under full-load operating conditions.
7. Full-load amperage stamped on the data plate.
8. Do not bring the flanges so close together that the belt rides above the flanges. Also, do not separate them so widely that the belt rides below the “V” of the flanges.
9. Keep all controls used on forced-air systems dry, dust free, and lint free at all times.
10. Annually.

631

1. With low pressure air.
2. Ensure it is holder the heater level.
3. Check the external vent cap and make sure that there is no obstruction around the exhaust openings.
4. Inspect the heat exchanger tubes to make sure they are not cracked, sagging or showing signs of fatigue.

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).

54. (625) Identify the purpose of the draft hood.
    a. Make up for force of air the blower cannot create.
    b. Maintain constant head on the combustion system.
    c. Prevent a constant head on the combustion system.
    d. Maintain fluctuating head on the combustion system.

55. (625) Which device(s) creates the resistance that blowers *must* overcome?
    a. Pilot piping.
    b. Solenoid valves.
    c. Combination gas valves.
    d. Furnace air passageways, filters, and ductwork.

56. (625) Where does return air enter on an upflow furnace?
    a. Inside the combustion chamber.
    b. Through the top of the blower compartment.
    c. Through the top or side of the blower compartment.
    d. Through the bottom or side of the blower compartment.

57. (625) Negative pressure is corrected in a well-sealed building by installing
    a. another combustion fan.
    b. a negative pressure kit.
    c. an additional blower.
    d. a make-up air unit.

58. (626) How is the furnace fan control connected with the blower motor?
    a. Induction.
    b. In series.
    c. In parallel.
    d. Magnetic field.

59. (627) When the thermostat is turned down past the ambient temperatures the burner should
    a. enter ignition carryover.
    b. start trial for ignition.
    c. turn on.
    d. shut off.

60. (627) Which action is the *first* step in checking the safety limit control?
    a. Turn power OFF and disconnect the blower circuit.
    b. Turn power OFF and connect the blower circuit.
    c. Turn power ON and connect the blower circuit.
    d. Turn power ON and disconnect the blower circuit.

61. (628) Which type of control is *not* usually located on the radiant heater?
    a. Air pressure switch.
    b. Ignition control.
    c. Transformer.
    d. Thermostat.

62. (629) Which inspection process is performed after the radiant heater pre-operational inspection?
    a. Safety check.
    b. Gas line check.
    c. Gases in the air.
    d. Operational test.

63. (629) How many seconds should the thermostat be turned off to take the system out of lockout?
    a. 20.
    b. 60.
    c. 80.
    d. 90.

64. (630) What should be done before making *any* thermostat adjustments for a forced air furnace?
    a. Ensure the blower functions properly.
    b. Ensure bearings are not overheating.
    c. Ensure no exposure from heat or too cold from windows, doors or drafts.
    d. Ensure there is a lot of exposure from heat or too cold from windows, doors or drafts.

65. (630) The fan's OFF temperature setting is generally set for how many degrees above the desired room temperature
    a. 0 to 5° F.
    b. 3 to 5° F.
    c. 5 to 10° F.
    d. 15 to 20° F above.

66. (630) If you need to remove soot from the heat exchanger, what would you use?
    a. Your hands.
    b. Garden hose.
    c. Vacuum cleaner.
    d. Pressure washer.

67. (631) How is a radiant heater's combustion air intake inspected?
    a. Disconnect air intake and inspect internally using a flashlight.
    b. Connect vent pipe and inspect externally using a flashlight.
    c. Disconnect air intake and inspect externally for weight.
    d. Connect air intake and inspect internally using a level.

Please read the unit menu for unit 4 and continue ➔

Student Notes

Unit 4. Boilers

4–1. Properties of Steam Generation 4–1
632. Properties of steam 4–1
633. Internal boiler parts 4–3
4–2. Steam Boilers and Auxiliary Equipment 4–8
634. Steam boilers and draft systems 4–8
635. Boiler accessories 4–10
636. Boiler feed-water equipment 4–17
4–3. Steam Distribution 4–19
637. Steam systems and piping 4–19
638. Steam system components 4–22
4–4. Hot Water Boilers and Auxiliary Equipment 4–24
639. Classifications of boilers 4–24
640. Makeup water supply line 4–29
641. Boiler support equipment 4–31
642. Safety devices and expansion tanks 4–35
4–5. Hot Water Boiler Operation and Maintenance 4–40
643. Pre-operational inspection 4–40
644. Operational test 4–41
645. Preventative maintenance of hot-water heating systems 4–44

A BOILER IS A PRESSURE VESSEL designed to transfer heat to a fluid. In the last unit, we talked about furnaces that heat the fluid, air. For boilers, we are interested in systems where the fluid is usually water, in the form of liquid or steam. This unit will cover both steam and hot water boilers and their associated equipment.

4–1. Properties of Steam Generation

In this section, we cover the fundamentals of steam generation and boiler parts. We begin our discussion by studying the properties of steam. In this discussion we will cover the internal boiler parts that are required to make each type of steam boiler operate.

632. Properties of steam

Let us suppose that you set an open pan of water on the stove and turn on the heat. When the water reaches the boiling point (212°F or 100°C at sea level), there is a physical change—the water starts vaporizing. If you hold the temperature at the boiling point long enough, the water continues to vaporize until the pan is dry. A point to remember is *the temperature of water will not increase beyond the boiling point.* Even if you add more heat after the water starts to boil, the water will not get any hotter, as long as it remains at the same pressure. See figure 4–1 for an example of a steam boiler.

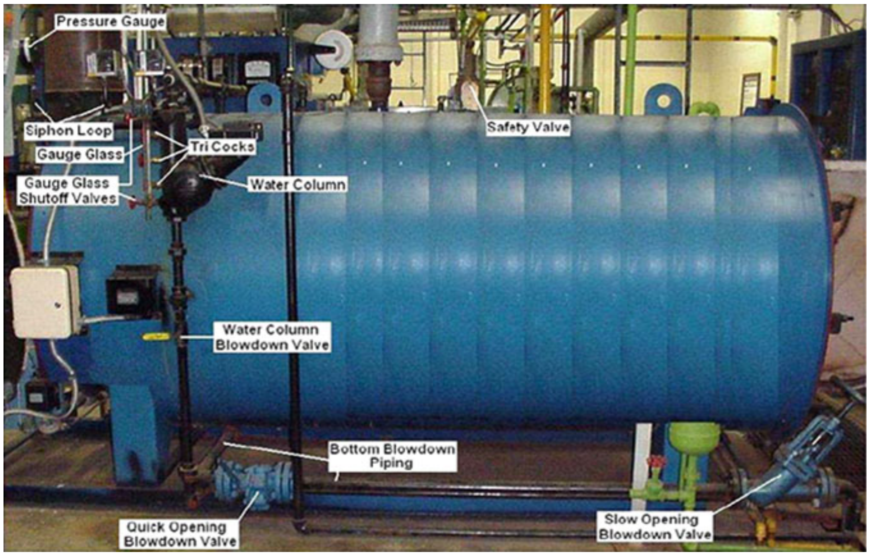


Figure 4–1. Boiler.

Properties of steam

Steam has particular characteristics related to specific volume, temperature, pressure, and heat content. Figure 4–1 is a condensed version of these properties. Note that the conditions indicated are for saturated steam. This means that the steam at any given temperature and pressure begins to condense if the temperature is slightly lowered and becomes superheated if the temperature is slightly increased. Superheating steam in a system has little value. The cost necessary to produce the superheated steam outweighs the benefits gained.

Once the condensate is formed, it normally cools below the condensing temperature before it returns to the boiler. The reduction in temperature is referred to as "subcooling."

Also note in figure 4–2 that there are three enthalpy figures given ("Sensible," "Latent," and "Total"). The enthalpy of saturated liquid is the heat content of the water just before evaporation; the enthalpy of saturated vapor is the heat content of the gas just after evaporation. The enthalpy of evaporation is the difference between the two or the amount of heat in Btu/lb required to change from a liquid to gas at saturation.

PROPERTIES OF SATURATED STEAM					
Gage Pressure (PSI)	Temp. °F	Heat in Btu's per lb.			Volume Dry Sat. Cu. Ft./lb.
		Sensible	Latent	Total	
15" wg.	179	147	991	1138	51.41
0	212	180	971	1151	26.8
5	227	196	961	1156	20.1
13	246	214	949	1163	15.1
15	250	218	946	1164	13.9
25	267	236	935	1170	10.6
51	299	268	912	1180	6.6
75	320	290	896	1186	4.91
100	338	309	882	1190	3.89
125	353	325	869	1194	3.23
150	366	339	858	1197	2.76
175	377	351	848	1199	2.41
200	388	362	838	1200	2.14
225	397	372	830	1202	1.92
255	408	383	819	1203	1.71
275	414	391	813	1204	1.6
305	423	400	804	1204	1.45
325	429	407	798	1205	1.36
355	437	416	790	1205	1.26
375	442	421	784	1205	1.19

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Figure 4–2. Properties of saturated steam.

Temperature/pressure relationship

Suppose you place a close-fitting lid on the pan of boiling water. The lid keeps the steam from leaving the container. If you make an opening in the lid, steam escapes at the same rate as it generates. As long as any water remains in the pan and as long as the pressure remains constant, the temperature of the water and steam remains constant and equal.

The steam boiler operates on the same basic principle as a closed container of boiling water. We can increase the temperature and the pressure at the same time by increasing the amount of time we supply heat. Bear in mind that an *increase* in pressure means an *increase* in the boiling point.

To find the temperature of the water in a steam boiler, you must know the steam pressure. Take the square root of the steam pressure, multiply this by 14, and add the constant number of 198. For example, when the steam pressure is 100 psig, the square root is 10. When we apply 10 to the formula, the water temperature is 338°F. ($10 \times 14 + 198 = 338$). We can express this with the formula: square root of the psi × 14 + 198 = boiler water/steam temperature.

Self-Test Questions

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

632. Properties of steam

1. What is saturated steam?

2. Why does superheated steam have little value in HVAC?

3. What normal happens to the condensate before it returns to the boiler?

4. How is steam's temperature and pressure increased at the same time?

633. Internal boiler parts

The boiler is the main unit of a steam heating system. Every other piece of equipment supports the boiler in its function of boiling water. A boiler is composed, essentially, of two main sections: (1) the furnace, in which fuel combustion takes place and (2) the pressure parts, which contain water and/or steam.

Furnace

Combustion takes place within a combustion chamber. Circulating air passes over the outside surfaces of the heat exchanger so that it does not contact the fuel or the products of combustion. The products of combustion are passed to the outside atmosphere through a vent.

A boiler furnace can consist of a rectangular or barrel-shaped steel casing, which has a lined floor, front wall, side walls, and rear wall with refractory material. The refractory lining serves to protect the furnace casing and to prevent loss of heat from the furnace. Refractory retains heat for a relatively long time and thus help to maintain the high furnace temperatures required for complete and efficient combustion of the fuel. Refractory can form baffles, which direct the flow of combustion gases and protect drums, headers, and tubes from flame and excessive heat.

There are many different kinds of refractory materials. The particular use of each type is determined by the chemical and physical characteristics of the material in relation to the required conditions of service.

Pressure parts

These totally enclosed, metallic, air, water, and steam tight sections, compartments, or tubes contain steam or water. They must be strong enough to withstand the maximum pressure and temperature for the boiler designed. These parts include the drums, headers, water legs, tubes, and water walls.

Drums and tubes are the principal pressure parts largely because of their ease of manufacture and the characteristic of a cylinder as such that it has maximum strength for minimum material thickness. Tubes can be bent readily and arranged in groups, which give effective heat absorption and minimum cost.

Drums

Boiler drums divide into two types: steam drums and mud drums (fig. 4–2). This type of drum can be found on water-tube boilers.

The steam drum (fig. 4–3) is always located at the top of the boiler. It consists of two bent or rolled steel sheets (plates) welded together to form a cylinder, as shown in figure 4–4. The thickness of the plates depends on the pressure that the drum must withstand.

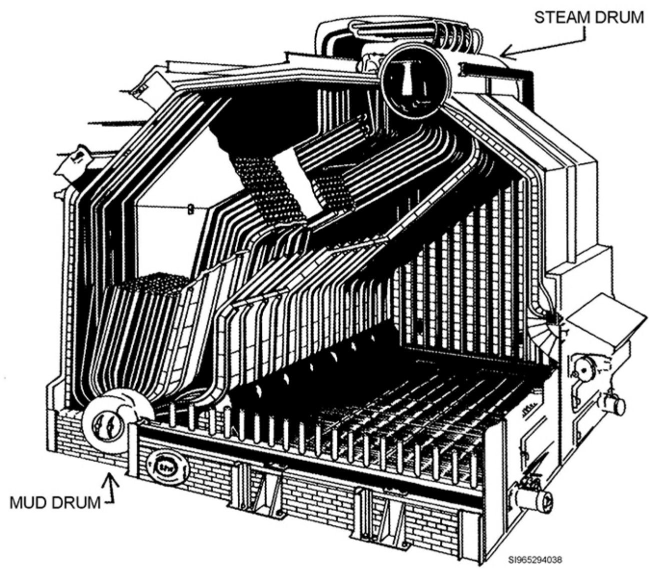

Figure 4–3. Location of steam and mud drums.

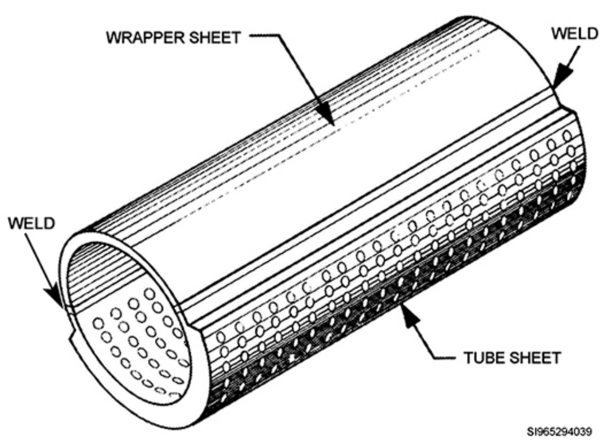

Figure 4–4. Boiler steam drum construction.

Steam drums are rated according to the pressure they can carry. Exceeding the rated pressure weakens the metal and damages the drum. The steam drum provides a space for the accumulation of steam generated in the tubes and the separation of moisture from the steam. It also serves as a storage space for boiler water; water distributes from the steam drum to the downcomer tubes. (In normal operation, the steam drum is about half-full of water.) In addition to these basic functions, the steam drum either contains or connects too many of the important controls and fittings required for the operation of the boiler.

The mud drum (fig. 4–3) equalizes the distribution of water to the generating tubes and provides a place for the collection of loose scale and other solid matter in the water. This sediment exits from the mud drums by periodic operation of the bottom blowdown valves.

Tubes

The tubes of a steam boiler are fire-tube or water-tube. Specific information on tubes is explained when we discuss the different types of these boilers later. The material, size, thickness, and method of connection must conform with American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section I Power Boilers; areas PFT for fire-tube boilers and PWT for water-tube boilers.

Other major components

The two main parts of the boiler are furnace and pressure parts, but there are some other components within these parts to discuss.

Internal feed pipe

The internal feed pipe runs the full length of the steam drum. It is in the water space near, but not touching, the bottom of the drum. One end of the internal feed pipe connects to the boiler feed line; the other end is sealed. It enters through either the front or the rear of the drum. The feed water flows from the feed water heater into the feed water pipe and distributes evenly throughout the drum through holes in the feed pipe. These holes follow along the entire length of the feed pipe so that the feed water discharges upward rather than downward. This arrangement has the following two main advantages:

- The incoming feed water causes the least possible interference with the natural circulation of water in the boiler when it discharges upward.
- The relatively cool incoming water enters away from the hot drum metal to reduce the possibility of thermal shock.

Surface blow line

The surface blow line is also a perforated pipe that extends the full length of the steam drum about half an inch below the normal water level, with holes along the upper side only. It removes grease, scum, and light solids from the boiler water. One end of the line is sealed; the other end connects through the drum to the surface blow valve.

Dry pipe

The dry pipe is a steel pipe about 5 or 6 inches in diameter. It runs almost the whole length of the steam drum's centerline. Both ends are closed; steam enters through holes or slits cut along the length of the upper surface so that the steam must make a sudden change of direction to enter the pipe.Some moisture is lost when the steam changes direction; the dry pipe is, in effect, a steam separator. The steam leaves the dry pipe through the main steam outlet.

Baffles and swash plates

Various kinds of baffles in the steam drum direct the flow of steam or water, ensure adequate circulation throughout the drum, and prevent violent agitation of the water. Most steam and water baffles are removable.

Steam baffles may consist of steel plate deflectors, perforated steel plates, or a labyrinth of steel screens. Perforated steel plate baffles are installed horizontally (or almost horizontally) just below the surface of the water. Labyrinth steel screen baffles have several sinuous steel plates that are quite close together and placed so that the steam must follow the labyrinths between the plates. Water baffles may be in the steam drum to guide the relatively cool feed water to the downcomers after it discharges from the internal feed pipe.

Swash plates are in some types of boilers to prevent excessive surging of the water from one end of the drum to the other. Swash plates lay vertically, across the lower half of the drum. A space is between the swash plate and the drum so that the water can flow past the plate at a restricted rate.

Stays

Braces or stays hold the flat surfaces of a boiler. The most important types are the gusset, diagonal, through, sling, and staybolts.

Gas baffles

Gas baffles are thin walls or partitions that direct the combustion gases over the heating surfaces with minimum draft loss and maximum heat absorption. Baffles design and installation does not conform to the reduction in gas volume that results when heat absorption lowers the gas temperature. When this is true, we get constant gas flow velocities with minimum draft loss. Baffles material is either refractory material or metal. Steel baffles are in low-temperature zones whereas refractory baffles are in high-temperature zones.

Fusible plug

Fusible plugs are in some fire-tube boilers to provide protection against low water and the resulting damage to the boiler. They are hollow bronze or brass plugs filled with an alloy (mostly tin) that has a low-melting point (usually 445° to 450°F.) Fusible plugs that use a filler metal other than tin and a melting temperature higher than 450°F are available.

The two types of fusible plugs are designated “waterside” or “fireside” according to location. Waterside plugs are fusible plugs that insert from the waterside of the plate, flue, or tube to which they attach. Fireside plugs are fusible plugs that insert from the fireside of the plate, flue, or tube to which they attach.

These plugs are located at the lowest permissible water level (as determined by the manufacturer) of the boiler. The plug will hold as water cools it. When the water level drops below the plug, the tin melts and blows out. The boiler than has to be taken out of operation to determine what causes the low-water level and to replace the fusible plug.

Soot blowers

Soot blowers are on large steam boilers to remove soot from the firesides of steaming boilers. They must be used often to prevent a soot buildup (at least once per day). An endless chain operates one type of soot blower; when you pull the chain, an element (consisting of a long pipe with nozzle outlets) rotates. Steam travels through a steam valve and discharged from the nozzles in the elements at a high velocity. The nozzles direct the jets of steam so that they sweep over the tubes and loosen the soot so it exits from the boiler. Most soot blowers can be rotated a full 360°.

Always use soot blowers in the proper sequence so that the soot is swept progressively toward the uptakes. Normally, use the uppermost soot blowers at the beginning and again at the end of the blowing sequence.

Self-Test Questions

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

633. Internal boiler parts

1. What are the two main sections of the boiler?

2. What does heat retained in the refractory assist with?

3. Where is the steam drum located?

4. How does exceeding the rated pressure affect a steam drum?

5. How does sediment exit the mud drums?

6. Why do holes follow along the entire length of the feed pipe?

7. What are the two main advantages of feed water discharging upward rather than downward?

8. Why are holes cut along the length of the upper surface of the dry pipe?

9. What is the relationship between baffles and the steam?

10. How do swash plates affect water in the drum?

11. What is the relationship between gas baffles and combustion gases?

12. Where are fusible plugs located?

13. What must occur after a fusible plug blows out?

4–2. Steam Boilers and Auxiliary Equipment

Now our discussion turns towards steam boilers and their accessories. First we will discuss the steam boiler and its different types of draft systems. Then we will cover steam boiler accessories and finalize the section with a discussion of boiler feed water equipment. Let's get started with the steam boiler.

634. Steam boilers and draft systems

In this lesson boilers and draft systems are covered. Pay attention because draft systems are crucial to boiler operations.

Boilers

Steam boilers and heating systems are a type of hydronic system. The water in these systems is converted into steam. The steam is then sent to terminal units such as radiators for the heat to be transferred to the conditioned space. As the steam travels through the radiator it condenses back to a water and returns to the boiler.

Mechanical draft systems

The main advantages of mechanical draft systems are greater flexibility, operation that is independent of weather conditions and flue gas temperature, and greater salvage value. In many large steam plants, the stack is only a convenient fume removal funnel; mechanical draft systems help overcome all draft losses.

Mechanical draft systems classify as forced draft, induced draft, and balanced draft. In the *forced draft system* (fig. 4–5), combustion air pushes through the air ducts, air preheater, wind box, burners or fuel bed, and any other resistance between the fan discharge and the furnace. There must be enough pressure left to push the combustion gases through the boiler, economizer, air preheater, and duct collector (if used) up to the stack. *Induced draft systems* (fig. 4–6) must develop enough draft to draw the required quantity of combustion air through all of the resistances just listed.

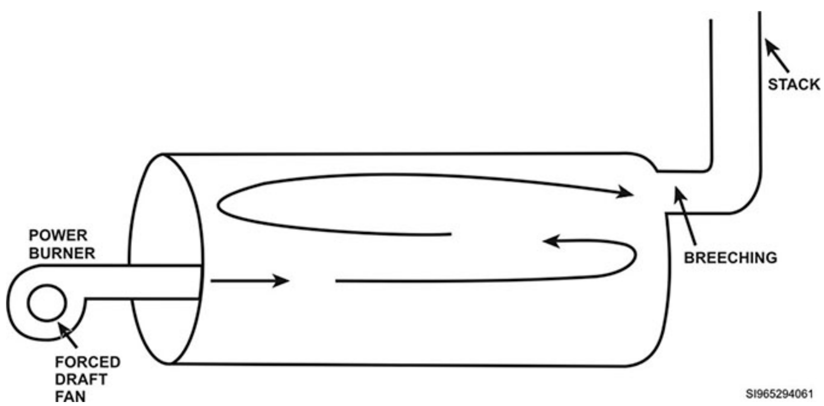

Figure 4–5. Boiler with forced draft.

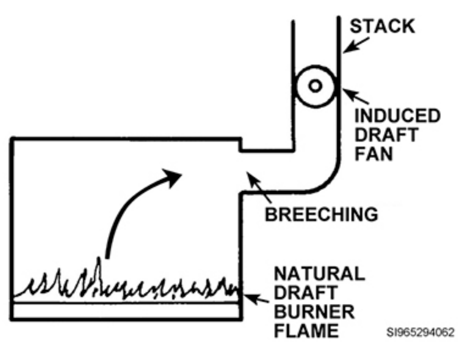

Figure 4–6. Boiler with induced draft.

The *balanced draft system* (fig. 4–7) is a combination of the other two systems. Forced draft fans force air through the fuel bed or burners into the furnace. Induced draft fans draw the flue gas through the complete steam generator unit, breeching, and stack. The outputs of both kinds of fans regulate to keep a balanced draft in the furnace at all times. The balanced draft system takes more equipment and costs more initially, but it is more flexible.

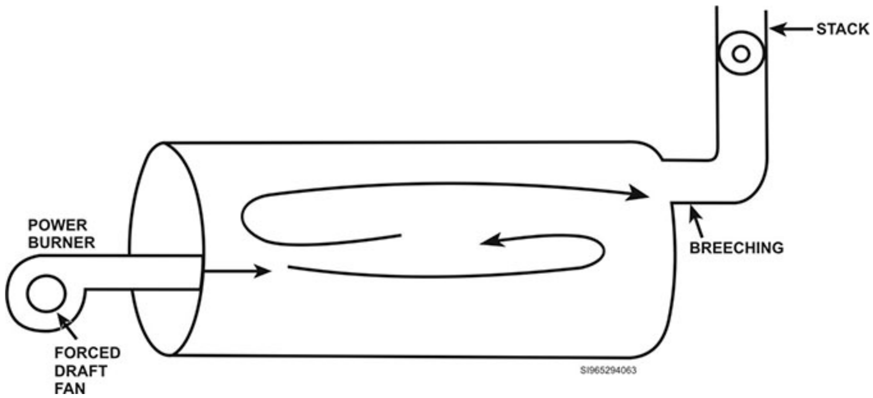

Figure 4–7. Boiler with balanced draft.

Forced draft fans

Centrifugal fans are used in forced draft systems. *Reliability* is essential to continuous operation. The blades shape prevents any collection of dirt that could disturb fan balance. Generally, centrifugal fans with backward-curved blades are best for this purpose.

Induced draft fans

Induced draft fans operate under more severe conditions than forced draft fans do. They must handle a larger volume of hot, dirty, and often erosive and corrosive gas. The system may use flat, forward-curved, or backward-curved blades, but the modified curvature reduces dirt deposits and decreases the wear from ash particles.

Fan drives

Since electric motors are less expensive and more efficient than other drives, they are the typical fan drives used.

Fan output control

There are several common ways to control the output of a fan. A damper at the fan discharge allows for fan control. Its initial cost is low, its arrangement is simple and well adapted to automatic control, and regulation is continuous. Inlet vane controls are in forced draft fans. It is more efficient than the outlet damper control, but its initial cost is higher. Considering power consumption, variable speed is the most efficient way to control fan output.

Self-Test Questions

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

634. Steam boilers and draft systems

1. What happens to water in a steam boiler?

2. What happens to the steam once it is created in the boiler?

3. What are the main advantages of a mechanical draft system?

4. What is a positive result of the higher initial cost of a balanced draft system?

5. What type of fan is best for forced draft systems?

635. Boiler accessories

In this lesson boiler accessories are covered. They vary from blowdown valves, water columns, alarms, tanks, safety features and low water cut-offs. Each part plays its role in the operation of our steam boiler systems.

Blowdown valves

The first auxiliary components discussed are blowdown valves. They are mentioned along with boilers because of their importance. Blowdown valves are used to discharge sludge from a boiler, lower the water level rapidly, and reduce the total concentration of dissolved and suspended solids in the boiler water.

Normally, the blowdown connections are at the lowest water space of the boiler, such as at the bottoms of mud drums and headers. Since sediment tends to collect in the blowdown line where there is no normal water circulation; the pipe may become overheated and burn out.

Valve applications

Where several blowoff lines from more than one boiler connect to a common header, a guard valve prevents workers from scalding hazards in boilers that are down for repairs. Blowoff valves are constructed to pass sludge and sediments. Never use valves with dams or pockets in which sediment will settle.

Figure 4–8 shows a tandem installation consisting of a quick opening, swing-gate blow valve (blue valve) connected in series with a seatless, slow-opening valve.

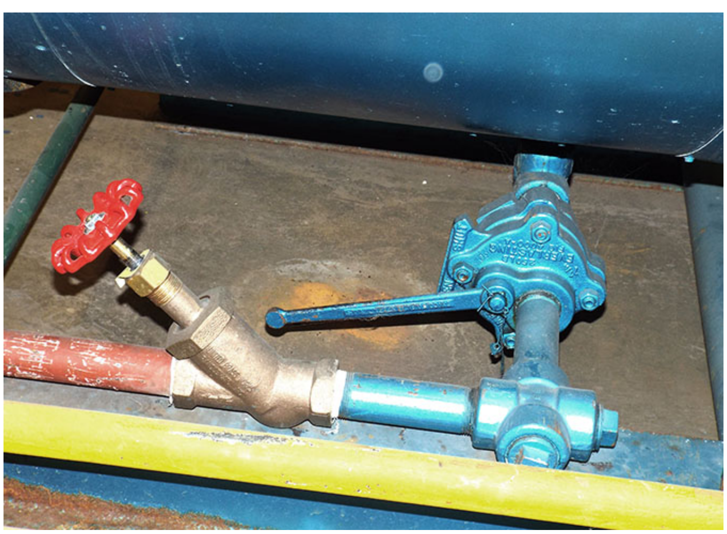

Figure 4–8. Tandem blowdown valve.

Water columns

A water column is a hollow chamber made of cast iron, ductile iron (malleable), or steel. A water column has suitable connections for the boiler, water column drain, gauge cocks, and a water gauge glass. Figure 4–9 illustrates typical water columns.

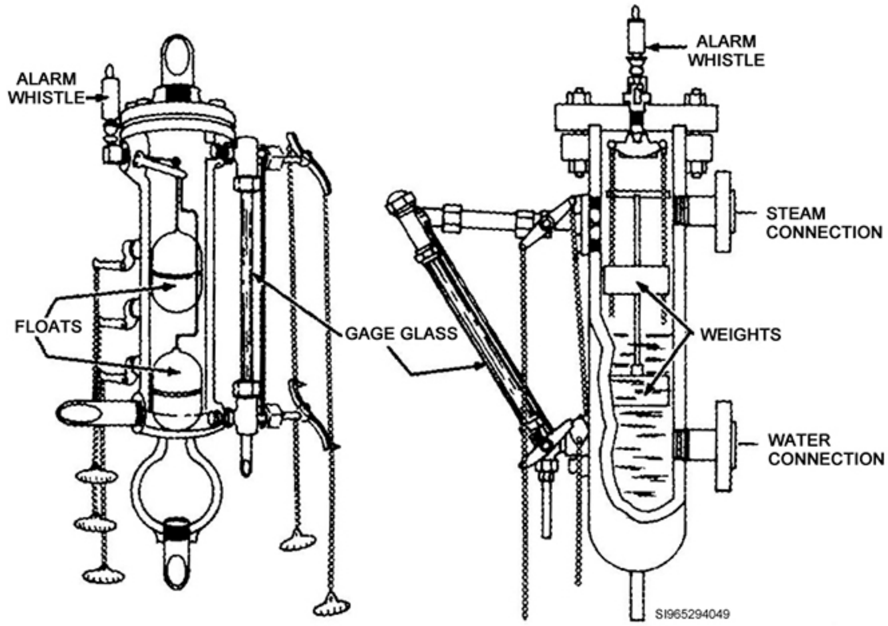

Figure 4–9. Typical water columns.

Water column drain

This drain valve permits the blowdown of the water column to clear any mud or sediment from the pipe and for testing purposes. Discharge the ends of blowdown lines to a safe point.

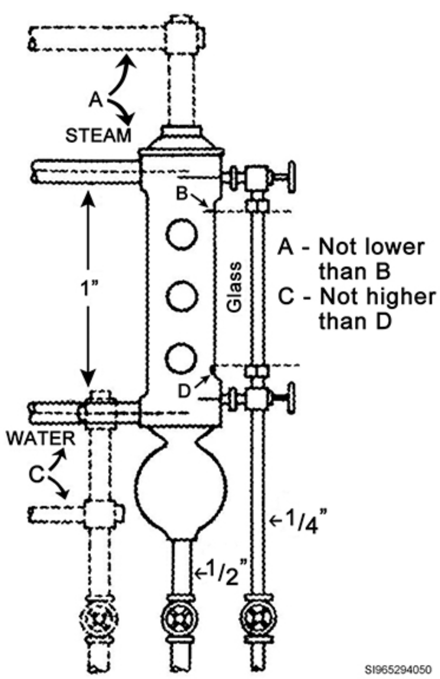

Figure 4–10. Water column and gauge-glass connections.

Gauge cocks

The number of gauge cocks depends on the size of the boiler. Gauge cocks operate by hand wheel, chain wheel, or lever.

Gauge glass (sight glass)

The gauge glass lets you tell, by sight, the water level in the boiler, when the boiler operating pressure exceeds 100 psi (fig. 4–10).

Use the water gauge glasses shown in figure 4–11 with boilers operating at low and medium pressures. Each consists of a strong glass tube connected to the boiler or water column by two special fittings.

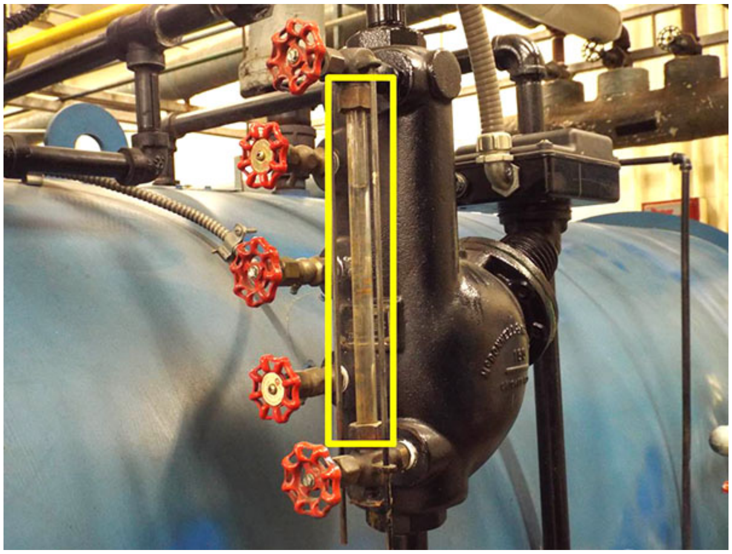

Figure 4–11. Water column and gauge-glass connections.

High and low water alarms

Water columns usually have alarms that indicate abnormally high or low water levels in the boiler. One type of alarm has floats that follow the water level variations—floats which operate an alarm at low or high water levels.

Surge tanks

It is not possible to keep condensate coming back to a boiler plant at the same rate that steam is going out. Sometimes the demand for steam from a boiler exceeds the rate at which condensate returns from the system; the reverse is also true.

Surge tanks compensate for uneven flows and regulate differences between the demand and supply of water at a given time. Water is stored in the tank when the supply exceeds the demand. It supplements the feed water when the demand is higher than the supply. Since the condensate is stored for later use, the dependence on cold feed water is reduced. Surge tanks stand above the feed water heater and supply water to the heater by gravity flow. Those that sit at a low level deliver water by a pump. Tanks can be equipped with have water gauges, low water alarms, control panels, overflows, drains, vents, and other components according to the type of installation.

Flash tanks

Water stores a definite amount of heat energy for each saturation pressure and temperature. When pressure reduces, the heat energy not needed under the new condition evaporates part of the water. Because this reaction is instantaneous and violent, it is *explosive boiling.*

The amount of water flashed into steam by explosive boiling depends on the initial pressure and temperature and the final pressure of the water.

We can avoid water hammer and other disturbances in the piping system by using flash tanks to separate the steam from the water. These tanks are usually small and are located close to the traps where the pressure release occurs. Sometimes, a plant can use the steam formed in a low-pressure steam system. Normally, the flash tank vents to the atmosphere to keep the trap from discharging against a back pressure. Flash tanks are components of boiler blowdown systems. In this type of installation, boiler water with relatively high temperature and pressure discharges to the flash tank. Part of the water flashes into steam and is used for heating. The rest of the water discharges to the sewer, directly or after it has passed through heat exchangers to heat the boiler feed water.The flash tank has now recovered and reused valuable heat from the system as opposed wasting it down a drain.

Boiler safety and safety relief valve requirements

Safety valves and safety relief valves relieve excessive pressures in steam boiler systems. ASME boiler codes rigidly prescribe their construction, performance, and installation standards.

Several different types of pressure releasing valves are used for steam boilers, but all are designed to open completely (pop) when a specific pressure is reached. They remain open until a specified pressure drop occurs.

Safety valves

A safety valve is one that opens automatically when the pressure in the boiler or vessel exceeds a set value. It discharges steam into the atmosphere to prevent the boiler from operating at unsafe pressures.

Safety relief valves

A safety relief valve is an automatic, pressure-actuated, relieving device suitable for use on steam (gases) or water service, depending on the application. Safety relief valves should be installed at any point at which pressures can be expected to exceed the safe limits of the system components. The following are some causes of excessive pressures:

- Over pressurization from fill system.
- Pressure increases due to thermal expansion.
- Surges caused by momentum changes (shock or waterhammer).

Safety relief should be provided to protect boilers, heat exchangers, cooling coils, chillers, and the entire system when the expansion tank is isolated for air charging or other service. As a minimum, the ASME Boiler Code requires that a dedicated safety relief valve be installed on each boiler and that isolating or service valves be provided on the supply and return connections to each boiler.

Boiler stop valves

The steam outlet line from a boiler must have a stop valve to secure the boiler when the need occurs. These valves are not for regulating purposes; they must be either completely open or closed. The stem position indicates whether the valve is open or closed.

Low water cutoff

Steam boilers have water level control devices to shut off the automatic fuel burning equipment when the boiler's water level is too low for safe operation. The two types of low water cutoffs are the float-type (fig. 4–12) and the probe-type (fig. 4–13). The float-type uses a float in the boiler water (fig. 4–12, #5) or in a float chamber connected to the boiler. The float connects through a linkage to a switch (fig. 4–12, #19) that controls the automatic fuel burning equipment. As the water level falls, the float drops until it reaches the point at which it activates the switch to shut off the automatic fuel burning equipment.

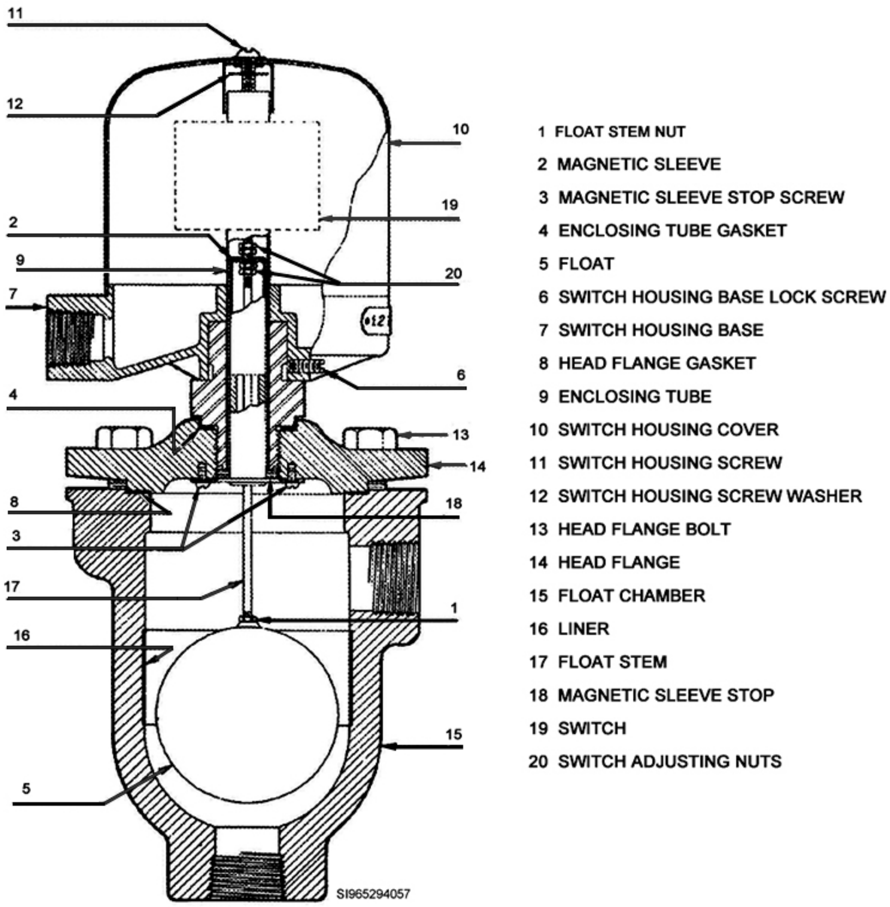

Figure 4–12. Float-type low-water cutoff.

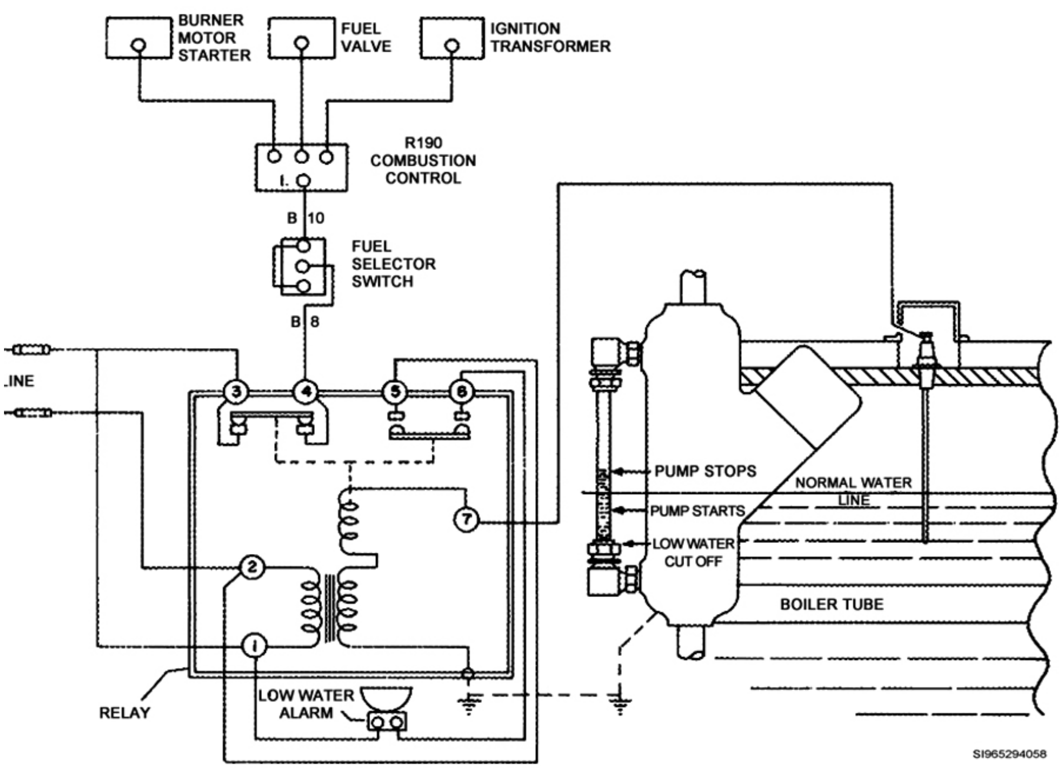

Figure 4–13. Probe-type low-water cutoff.

Some boilers have a float-operated feed water and low water control like the one in figure 4–14. This control attaches to the water column to keep the boiler from operating with a low water level. It uses a float, arm, and set of electrical contacts. As a low water cutoff, the float (fig. 4–14) rises or lowers with the water level in an enclosed chamber. The chamber connects to the boiler by two lines (fig. 4–14) that let the water and steam keep the same level in the float chamber and the boiler. An arm and linkage connects the float to a set of electrical contacts (fig. 4–14) that operate the feed water pump when the water level drops. If the water supply fails or the pump stops and lets the water level continue to drop, another set of contacts operates an alarm bell and shuts off the fuel supply to the boiler.

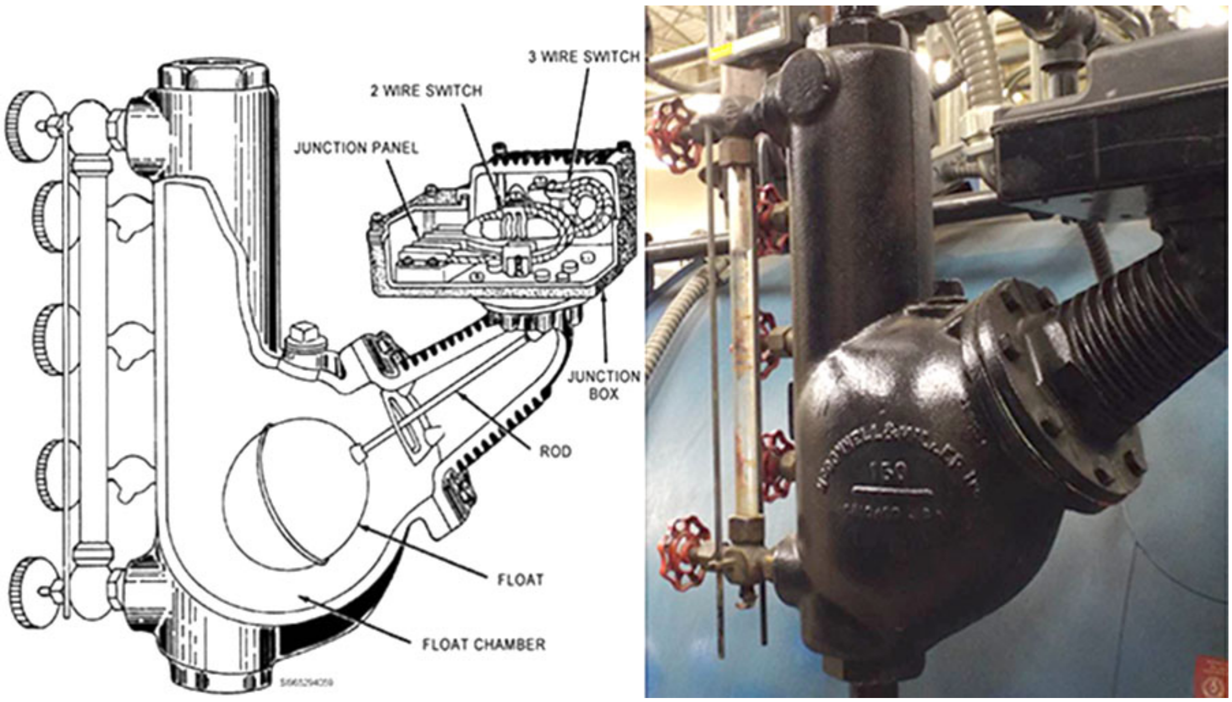

Figure 4–14. Float-type feed water and low-water cutoff.

On some small boilers, the low water cutoff combines with a water feeder to add water to the boiler when the water level falls below the safe operating limit. The boilers are available with either single or dual switch assemblies.

The probe-type low water cutoff device (fig. 4–15) depends on the flow of a low electrical current to control the operation of the automatic fuel burning equipment. The electrical current flows from the probe through the water to energize the relay. As long as the water remains in direct contact with the probe, the relay stays energized and keeps contacts 3 and 4 closed and contacts 5 and 6 open. When the water level drops, it breaks direct contact with the probe, thus opening the probe circuit. This, in turn, de-energizes the relay, causing contacts 3 and 4 to shut off the fuel burning equipment and closes contacts 5 and 6 to energize the low water alarm.

The probe design is also a feed water control. In figure 4–16, the relay energizes when the upper electrode touches water, opening electrical contacts 3 and 4, and closing contacts 5 and 6. The relay remains energized until the water recedes from the lower electrode, which, in turn, opens the probe circuit, which de-energizes the relay. When the relay is de-energized, it closes contacts 3 and 4 and starts the feed water pump. The pump continues to run until it raises the water level to the upper electrode. This closes the probe circuit and energizes the relay to shut the pump off by opening contacts 3 and 4.

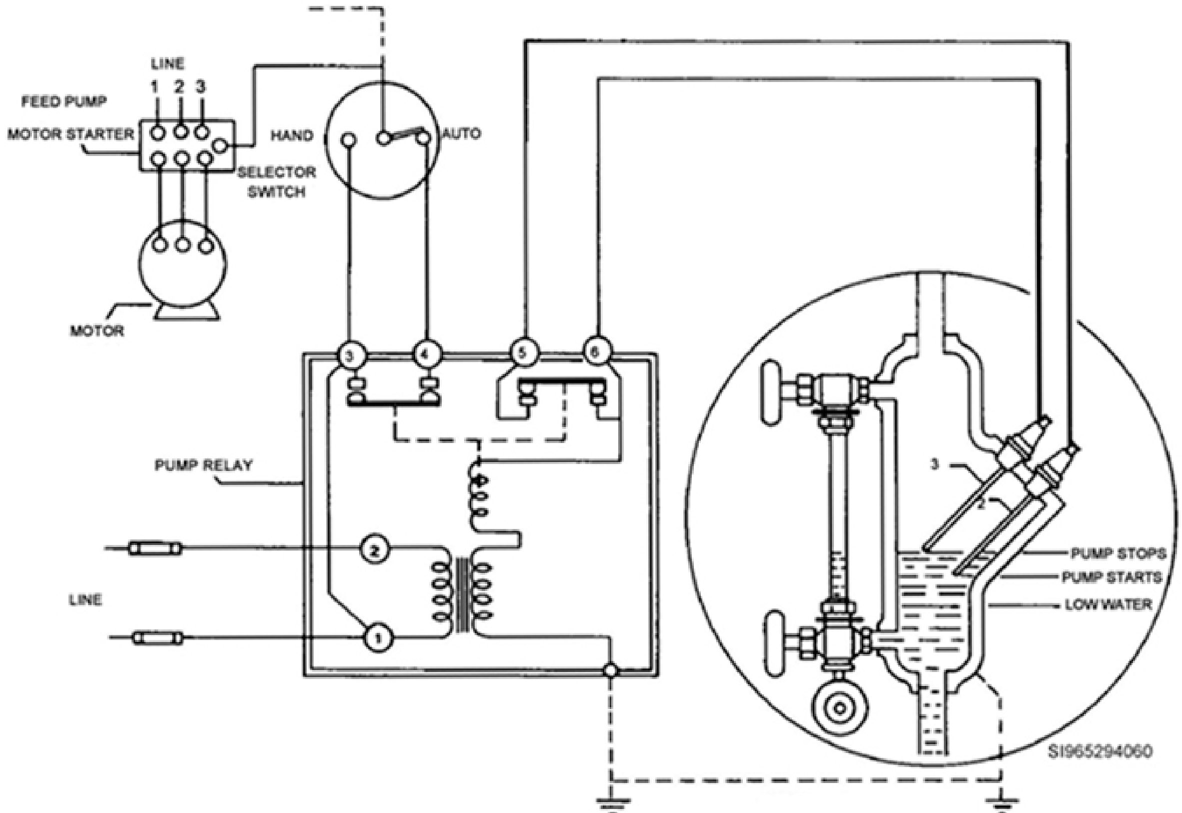

Figure 4–15. Probe type feed water and low water cutoff.

Self-Test Questions

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

635. Boiler accessories

1. What are blowdown valves used for?

2. Where are blowdown connections located?

3. What does a guard valve prevent?

4. What is the relationship of the water column drain and mud or sediment?

5. What is relationship between surge tanks and uneven flows of water?

6. Where are flash tanks usually located?

7. What can water in the flash tank be used for before it is flushed down the drain?

8. What position must boiler stop valves be in?

9. What is the relationship between the boiler stop valve’s stem and its position?

10. What effect would a low water cutoff have on the burner if a low water condition exists?

11. How does probe conduct electricity?

636. Boiler feed-water equipment

For continuous boiler operation, we must replace the water converted to steam. Replacement water injects intermittently or continuously. Small boilers generally use the intermittent method since it allows a variation in boiler water level. Moderately sized and large boilers normally use the continuous feed method. With automatic feed water regulators, this method lets us hold a constant water level, irrespective of load variations.

Feed water requirements

The feed water injects directly into any zone subjected to radiant heat or close to riveted points of shell or furnace sheets. In fire tube boilers, the feed pipe generally enters the boiler at the top of the shell, near the front end, and extends about half the length of the boiler. Its end attaches so to discharge the makeup below the boiler water line without disturbing normal water circulation. In water-tube boilers, the feed water generally enters through an internal feed pipe that runs the full length of the steam drum.

Feed water valves

The feed line will have a check valve (gold colored valve) near the boiler and a stop valve (gate valve) between the check valve and the boiler. See figure 4–16 for an example.

Figure 4–16. Check valve and stop valve.

Feed water regulators

To keep a constant water level regardless of load fluctuations, feed water goes into the boiler at the same rate that steam draws off. The water usually enters automatically with a feed water regulator. Automatic-throttling feed water regulators will have stop valves on the inlet and outlet sides and a throttling bypass valve for manual operation.

Bypass line

Figure 4–17 illustrates a bypass line, usually installed with all feed-water regulators to allow you to bypass the feed-water regulator and manually, and more quickly, feed water into the boiler during repair or replacement of the regulator. To bypass the regulator (fig. 4–17 red circle), simply close the two supply valves (fig. 4–17 yellow circles) and open the hand bypass valve (fig. 4–17 green circle). When the bypass valve is open, *always* monitor the amount of feed-water entering the boiler by observing the gauge glass. You will have to manually open and close the bypass valve and observe the water level in the gauge glass to control the amount of water entering the boiler and maintain the proper water level.

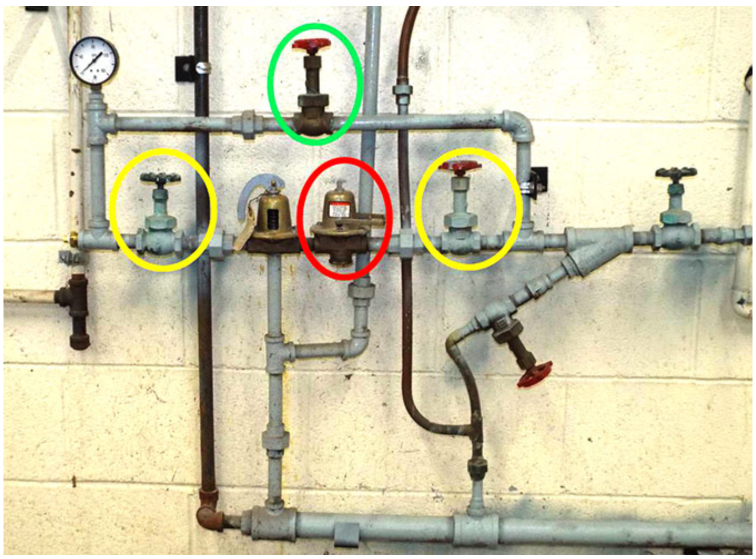

Figure 4–17. Location of regulator with a bypass line.

Self-Test Questions

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

636. Boiler feed-water equipment

1. Where does feed water typically enter a fire tube boiler?

2. Where does the water generally enter a water tube boiler?

3. What is installed between the check valve and boiler in a feed water line?

4. What is installed at the inlet and outlet of the feed water regulator?

4–3. Steam Distribution

We cannot just create steam and call our jobs complete. We must ensure the steam gets to places where it can do work, in this case, heat buildings. This lesson covers steams systems, piping and various components such as steam traps. We will start by covering steam systems and piping.

637. Steam systems and piping

A steam heating system uses the vapor phase of water to supply heat to a conditioned space or process. This is done by connecting a source of steam through piping with suitable terminal heat transfer units located at the space or process. Steam heating systems are referred to by the source of the steam, such as from boilers (central systems) and from district or remote heating systems. The temperatures and heating effects of steam systems vary over wide ranges. They may vary based on the space temperatures required or on specific heating processes unrelated to climate control.

Types of systems

A steam heating system is known as a one-pipe system when a single main serves the

- supply steam to the heating unit, and
- convey condensate from it the heating unit.

Each transferring device usually has only one connection that must serve as both the supply and the return, although separate supply and return connections may be used. A steam heating system is known as a two-pipe system when each transferring device is provided with two piping connections and when steam and condensate flow in separate mains and branches.

Remember, the condensate is a result of the steam’s heat being used up. Some of the steam converts back to water and this is why we have condensate returns.

In gravity systems (fig. 4–18) the condensate returns to the boiler solely by gravity, but the steam flows by the effect of the steam pressure. When the condensate cannot be returned to the boiler by action of gravity, the system must employ either traps or pumps. These systems are known as mechanical return systems (fig. 4–19) and are either open return systems or vacuum (closed) systems. In these systems, the condensate flows to the mechanical condensate-returning device by gravity, and the steam pressure assists in moving the condensate back to the boiler.

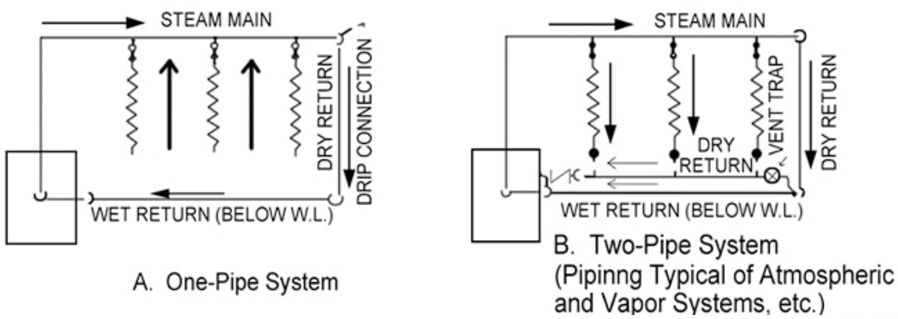

Figure 4–18. Basic piping circuits for gravity flow of condensate to point of return.

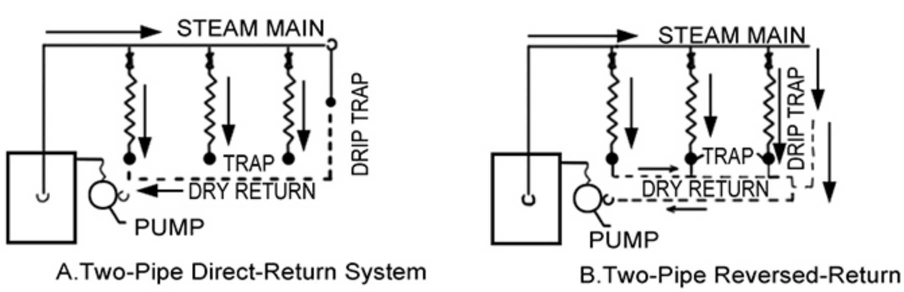

Figure 4–19. Basic circuits for mechanical return systems.

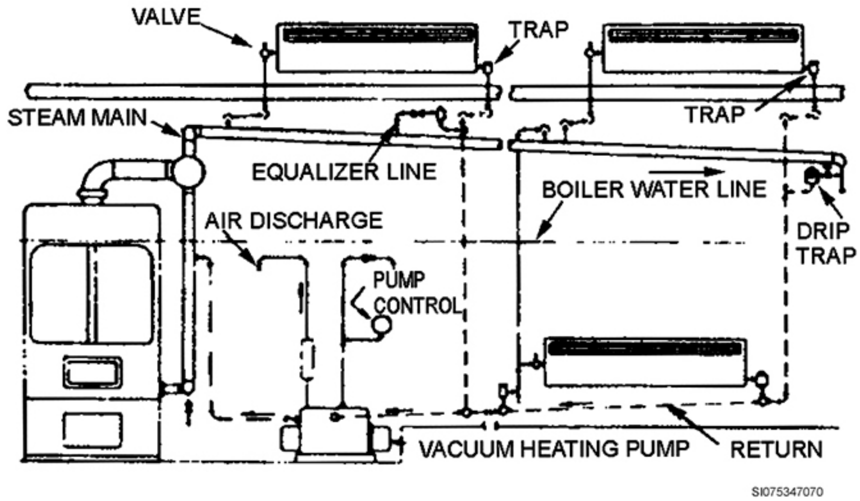

Figure 4–20. Typical two-pipe vacuum system.

There are three basic functions of steam piping systems. The two most common are distribution of steam and return of the condensate. In systems where no local air vents are provided, the removal of the air is also a function of the piping system (fig. 4–20).

Steam piping systems

The distribution of the steam should be rapid, uniform, and noiseless, with the release of air at a rate equal to or greater than the intended steam distribution. An air-bound system will not produce heat properly. It is desirable to maintain equivalent resistances through the supply piping to, and the return piping from, each terminal unit or heat exchanger.

You must drain the condensate collecting in steam piping and terminal units to prevent interference with the steady flow of steam and air.

It is important that steam piping systems distribute steam not only at full design load but also during excess and partial loads. Usually, the average winter steam demand is less than half the demand at the design outdoor temperature. Moreover, when rapidly warming up a system, even in moderate weather, the load on the steam main and returns momentarily may exceed the maximum operating load for severe weather due to the necessity of raising the temperature of metal in the system to the steam temperature and raising the building to design indoor temperatures.

Safety

When you work around steam and hot-water systems, you must be aware of several safety aspects. Steam systems generate intense heat that is radiated or conducted through the metal walls of the materials used to transport or consume its energy. The actual steam itself poses a threat to life and limb when you do not treat it with respect. Finally, steam systems are invariably installed in small, tight spaces crowded with hot pipes and full of overhead and tripping hazards.

In many cases, insulation is used to put a physical barrier between the piping, and so forth, and the personnel working on or around the equipment. When insulation is not available or practical, railings or other physical barriers may be installed to prevent personnel from coming in contact with hot pipes, valves, or terminal units.

As an individual, you can protect yourself by using personal protective gear. When you work on steam equipment, keep your shirt on with the sleeves rolled down.The thin layer of material may not seem like much, but it provides sufficient insulation to protect you from a burn if you accidentally contact a hot surface.

Leather gloves also provide protection while you work on steam. When selecting your gloves, be aware that when they get hot, you must be able to remove them in a hurry. Select gloves that are somewhat oversized so they are easy to remove. Wearing gloves may take some getting used to, but the gloves are a safety tool, not a fashion statement.

When working on a steam system, protecting yourself from hot pipes is not your only concern; you must also be aware of the high-pressure steam contained in them. Before removing any component of the system, determine if there is any pressure in the system. To do this, locate and read the pressure gauges. If no gauges are available, you should be able to feel *(at a distance)* heat being radiated from equipment that contains steam.

Always isolate the portion of the system on which you intend to work. Once you have it isolated, if time allows, let the system cool before you work on it. If you must work on it immediately, remember your personal protective gear—safety goggles or other means of eye protection, long sleeves, and gloves. Don these items before you begin to work. Be aware that gate valves have a tendency to leak, so be prepared for some steam to be present as you work, even though you have the area isolated. Before "cracking" a union open, try to locate a spot to open a valve to the atmosphere so any steam can escape. When this is not possible, *slowly* open the system while protecting yourself at all times.

The last consideration is the environment in which you'll work. For the most part, it's going to be hot, so be aware that heat stress or heat stroke is a real threat. Remember the signs for each and be looking for them. Take the proper precautions to protect yourself from their dangers.

The environment also poses overhead and tripping hazards. Wearing a hard hat in a mechanical room or a pipe chase is highly recommended. Tripping hazards, when you are aware of them, pose less of a threat. Paint them with colors that make them stand out. Brief all personnel on their location.

Steam safety is a state of mind and a way of interacting with your workplace with a safe attitude. Practice all the precautions mentioned here until they become as natural as tying your shoes. When you think you have done everything possible to be as safe as possible, you are on your way to completing your task without injury to yourself or a coworker or damage to the equipment.

Self-Test Questions

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

637. Steam systems and piping

1. What must be used if gravity cannot return condensate to the boiler?

2. What is a system called that uses pumps to return condensate?

3. How does the absence of local air vents affect the function of the piping system?

4. What effect does rapidly warming up a steam system have on load on the steam main and returns?

5. What can be installed to prevent personnel from contacting hot pipes if insulation is not available?

6. How should sleeves be worn when working on steam equipment?

7. How should gloves be selected if you are working on steam equipment?

638. Steam system components

This section will cover steam traps and safety devices. As you will learn, steam traps play an important role in our systems. Also, safety devices are critical because steam systems can be very dangerous.

Steam traps and strainers

Steam traps are important components of most steam heating systems. These devices allow steam systems to properly distribute the heating medium and operate to perform two different functions: (1) holding steam in the radiation heating coils and heat exchangers until its latent heat is given up and (2) while, at the same time, releasing noncondensables and condensate from the steam trap and steam supply mains into the condensate return line. Steam traps are usually regarded as drainage devices that release liquids and gases from a higher to a lower pressure.

In general, steam traps consist of an inlet connection that opens into a chamber or passage into which condensate and noncondensable gases flow. As well as an orifice through which the condensate and fixed gases are discharged, a valve that regulates or throttles the flow through the orifice port, and an outlet connection.

Without a trap as the means of confining the steam to heat transfer equipment, proper distribution and heat transfer related to the load cannot take place since the pressure obtained in each unit is virtually unaffected by the pressure in the return piping.

Thermostatic traps

Thermostatic traps react to a difference in temperature between steam and condensate (fig. 4–21). A bellows or bimetallic element operates a valve that opens in the presence of condensate and closes in the presence of steam. Because condensate is initially at the same temperature as the steam from which it was condensed, the thermostatic element must be designed and calibrated to open at a temperature below the steam temperature; otherwise, the trap would blow live steam continuously.Therefore, the condensate must be subcooled by allowing it to back up in the trap and a portion of the upstream drip leg piping, both of which are left uninsulated.

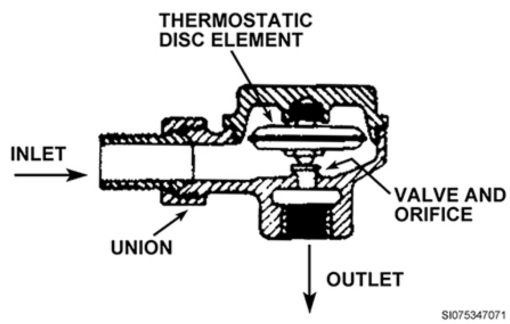

Figure 4–21. Thermostatic trap.

Some thermostatic traps operate with a continuous water leg behind the trap so there is no steam loss. However, this prohibits the discharge of air and noncondensable gases and can cause excessive condensate to back up into the mains or terminal equipment and cause operating problems. Devices that operate without significant backup can lose steam before the trap closes.

Mechanical traps

Mechanical traps are buoyancy operated, depending on the difference in density between the steam and condensate. See figure 4–22 for an example of a float and thermostatic trap.

Figure 4–22. F&T trap.

Leaking steam traps are a common maintenance problem on all steam systems. A critical problem in HVAC steam systems is the flow of condensate from coils, especially those used for 100 percent outside air. Proper operation means that there must be even steam flow and distribution in the coil. Condensate trapped in the coil prevents even steam distribution. Should the temperature fall low enough, freeze-up might occur. Air must be allowed to enter the atmospheric system coil to prevent tubing collapse during the fall of pressure during initial heating, but it must then be immediately vented to prevent holding condensate in the coil. Further, the coil must be rapidly drained of condensate to reduce the chance of freezing. Even under the best operating conditions, a “nonfreeze” coil (tube-in-tube) can freeze. It is imperative that you do not allow improper venting and condensate removal to aggravate the problem.

Reducing/regulating and safety relief valves

Where steam is supplied at pressures higher than required, one or more pressure-reducing valves (pressure regulators) are required. The pressure-reducing valve reduces pressure to a safe point and regulates pressure to that required by the equipment. The heating industry refers to valves according to their functional use. There are two classes of service provide in the following list:

1. Where the steam must be shut off completely (dead-end valves) to prevent buildup of pressure on the low-pressure side during no load, use single-seated valves.
2. Where the low-pressure lines condense enough steam to prevent buildup of pressure from valve leakage, use double-seated valves.

Do not pipe the outlet from relief valves to a location where discharge can injure people or property.

Self-Test Questions

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

638. Steam system components

1. What two functions do steam traps allow?

2. What are steam traps usually regarded as when referring to drainage?

3. What do steam traps generally consist of?

4. What effect does steam have on the bimetallic element in a thermostatic trap?

5. What would happen if thermostatic traps weren't calibrated and designed to open at a temperature below the steam temperature?

6. What is a critical problem in steam systems?

7. Why must steam coils be rapidly drained?

4–4. Hot Water Boilers and Auxiliary Equipment

Before we cover each individual system, we discuss general boiler construction and the different boiler classifications. These boilers generate either steam or hot water, depending on the type of controls installed on them and the attached distribution system design. We have already covered steam boilers and its components so this section will only discuss their classification.

639. Classifications of boilers

It is important to know the classifications of boilers. It is important because the cost of the different boilers and the space requirements will affect which boiler you choose to purchase.

Classifying boilers

We can group boilers into classes based on working pressure and temperature, fuel used, materials of construction, shape and size, application (such as heating or process), condensing or non-condensing and many other ways. Excluding specially designed boilers; significant class descriptions are in boiler catalogs or are available from the boiler manufacturer. We look at some common groups of boilers that we use for heating water.

Some water boilers may be equipped with either internal or external heat exchangers to supply domestic (service) hot water. Every steam or water boiler is rated at the maximum working pressure determined by the

ASME *Boiler Code Section* (or other code) under which it is constructed and tested. When installed, it must also be equipped with safety controls and pressure relief devices mandated by such code provisions.

By working temperature/pressure

With a few exceptions, construction of all boilers meets the American Society of Mechanical Engineers' (ASME) codes. The ASME *Boiler and Pressure Vessel Code, Section IV, Heating Boilers*, applies to low-pressure boilers, and the ASME *Codes, Section I, Power Boilers*, applies to high-pressure boilers.

Steam boilers are available in standard sizes of up to100,000 lb steam/h (60,000 to 100,000,000 Btu/h or 17 to 30,000 kW), many of which, are used for space heating in both new and existing systems. On larger installations, they may also provide steam for auxiliary uses, such as hot-water heat exchangers, absorption cooling, laundry, sterilizers, and the like.

Residential heating will normally use low pressure, water boilers. Some water boilers are equipped with either internal or external heat exchangers, which are used to heat domestic hot water for cooking and bathing.

Every steam or water boiler is rated at the maximum working pressure determined by the ASME Boiler Code Section (or other codes) under which it is constructed and tested. It must be equipped, when installed, with safety controls and pressure-relief devices mandated by such code provisions.

Boiler Classifications		
Steam operating pressures	**Hot water operating pressures**	**Hot water operating temperatures**
Low pressure boilers—15 psig steam.	Low pressure boilers—up to 160 psig.	Low temperature hot water—up to 250° F
High pressure boilers—over 15 psig steam	High pressure boilers—over 160 psig water.	High temperature hot water—over 250° F

By fuel used

In the Air Force, we typically use either fuel oil or gaseous fuels as a primary fuel. Several designs allow firing with oil or gas by burner conversion or by using a dual (combination) burner.

Boilers may be designed to burn coal, wood, various grades of fuel oil, various types of fuel gas, or to operate as electric boilers. A boiler designed for one specific fuel type may not be convertible to another type of fuel. Some boiler designs can be adapted to burn coal, oil, or gas.

By materials of construction

Most boilers are made of cast iron, steel, copper, stainless steel, and aluminum. Some smaller sized boilers are made of copper or copper-clad steel.

By size

Water boilers are available in standard sizes of up to 100,000,000 Btu/h (30 MW) from 50,000 Btu/h (15 kW), many of which are in the low-pressure class and are used for space heating in both new and existing systems.

Cast-iron boilers

Cast-iron boilers (fig. 4–23) have individually cast sections. They assemble into blocks (assemblies) of sections using push or screw nipples (fig. 4–24), gaskets, or an external header to join sections pressure tight and to provide passages for the water and the products of combustion separately. The number of sections assembled determines the boiler size and energy rating. A distinct advantage to sectional boilers is that installers can move the sections through regular sized doors. Assembly happens inside the boiler room for new installation or when replacing broken sections. Sections may be vertical or horizontal. The vertical is the most common. The boiler may be dry-base (the firebox is beneath the fluid-backed sections), wet-leg (the firebox top and sides are enclosed by fluid-backed sections), or wet-base (the firebox is surrounded by fluid-backed sections, except for the necessary openings).

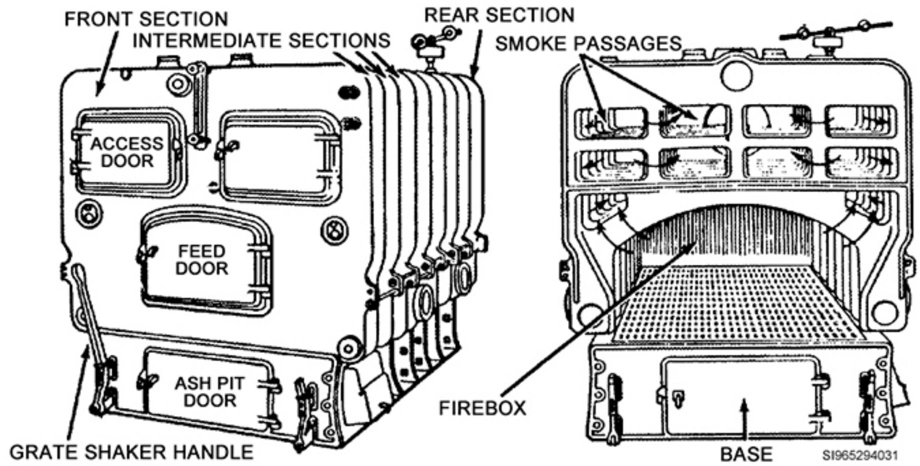

Figure 4–23. Cast-iron boiler.

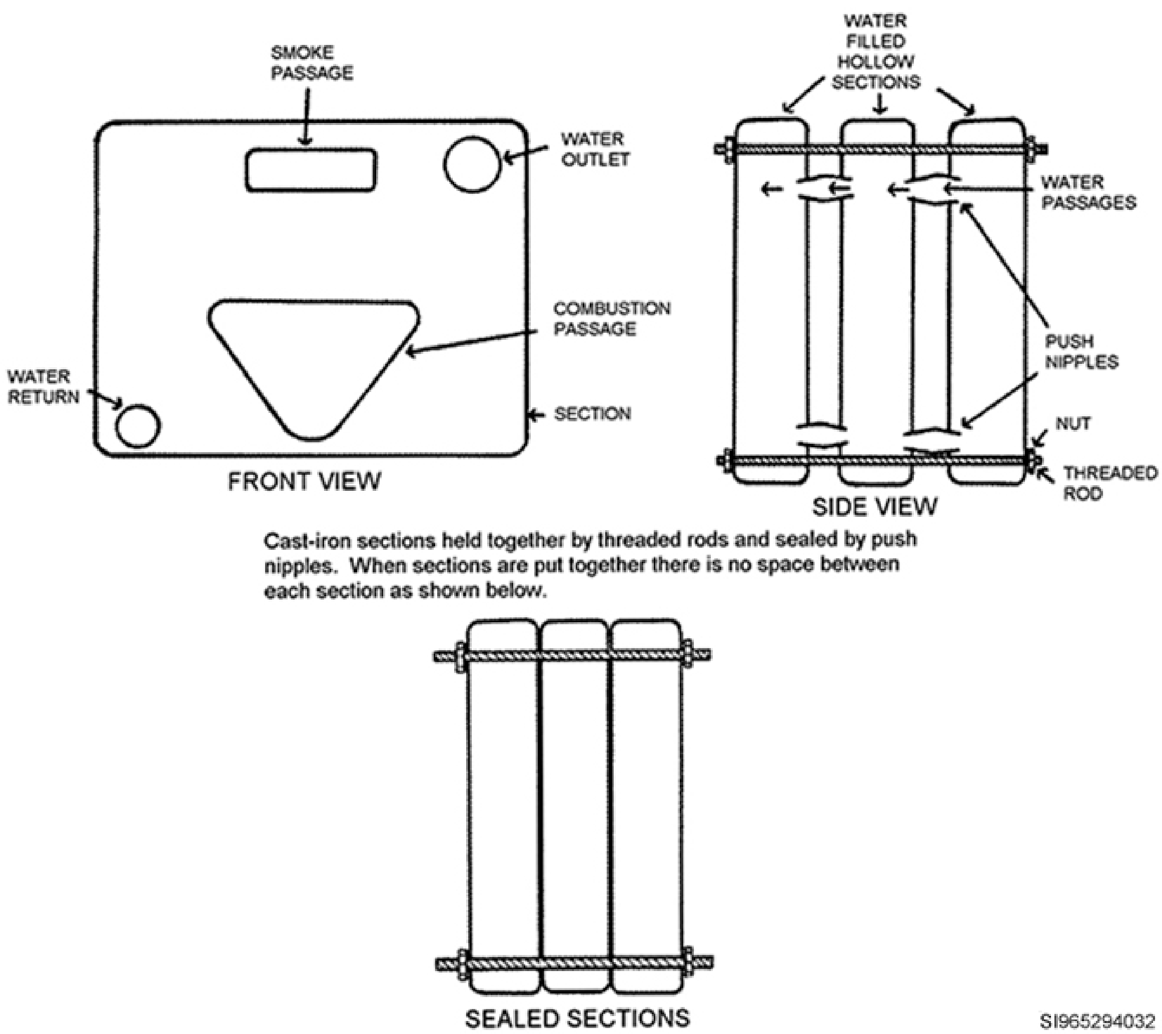

Figure 4–24. Cast-iron sections.

Steel boilers

Steel boilers are fabricated into one assembly of a given size and rating, usually by welding. The heat-exchange surface past the firebox is usually an assembly of vertical, horizontal, or slanted tubes. The tubes may be *firetube* (fig. 4–25), in which the hot-flue gases are inside the tubes and the water heated is outside of the tubes or *watertube* (fig. 4–26), in which the water inside the tubes and the hot-flue gases are outside of the tubes. As with cast-iron boilers, dry-base, wet-leg, or wet-base designs are used.

Most small heating boilers are of the dry-base vertical design. Larger boilers usually have horizontal or slanted tubes and both watertube and firetube designs are used. A popular design for medium and large steel boilers is the *Scotch*, or *Scotch Marine* (fig. 4–27), which are characterized by a central fluid-backed cylindrical firebox surrounded by firetubes in one or more passes, all within the outer shell.

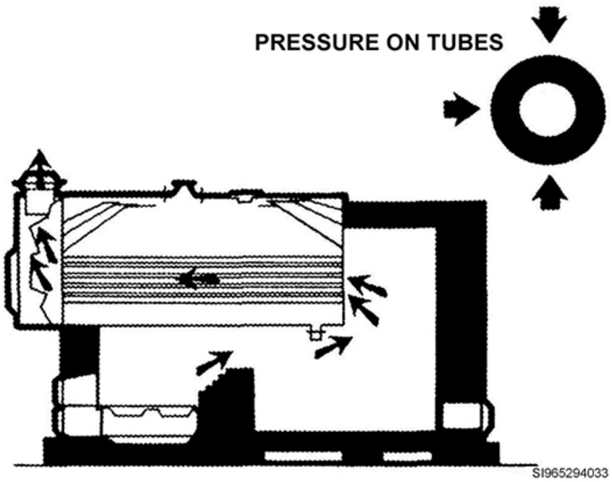

Figure 4–25. Typical fire-tube boiler.

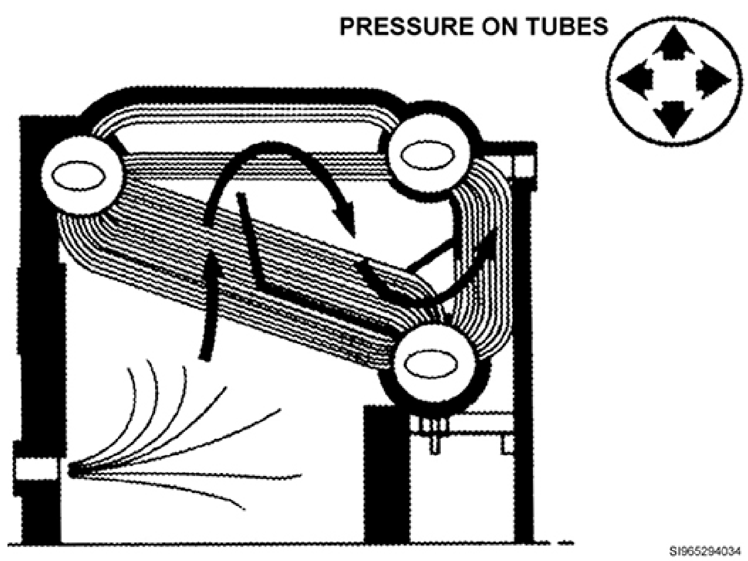

Figure 4–26. Typical water-tube boiler.

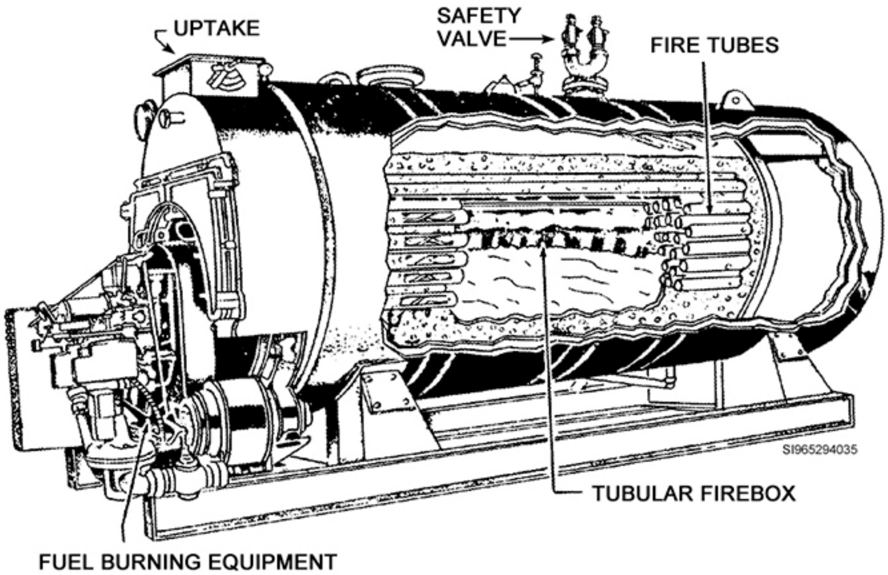

Figure 4–27. A typical scotch boiler.

Copper boilers

These boilers are usually some variation of the water-tube boiler. Some of these boilers are wall-hung residential boilers. Natural gas is often used for copper boilers.

Stainless steel boilers

Usually are designed to operate with condensing flue gases. Most are single-pass, fire-tube design and are generally resistant to thermal shock.

Aluminum boilers

Aluminum boilers are usually designed to operate with condensing flue gases. Typical designs incorporate either cast aluminum boiler sections or integrally finned aluminum tubing.

Condensing and non-condensing boilers

In a condensing boiler the flue gases condense to water and are drained away. These boilers are designed for a low return water temperature. Condensing boilers can be up to 98% efficient and are becoming very popular in the Air Force. The condensation can be corrosive so the internal parts and stack are constructed with corrosion resistant material. The stacks are often made with CPVC.

Non condensing boilers cannot reach these efficiencies. If they did the condensate would corrode the components.

Self-Test Questions

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

639. Classifications of boilers

1. How can boilers be grouped?

2. What are some auxiliary uses of steam boilers?

3. What is the psig rating of low pressure hot water boilers?

4. What is a distinct advantage of sectional boilers?

5. What are condensing boilers stacks usually made from?

640. Makeup water supply line

Each low-pressure water boiler has various fittings and accessories that are common on the makeup water supply line. We cover these items first. We discuss the distribution system the boiler serves later. A water boiler may or may not have all of these components. We begin our discussion with the makeup water supply line.

Makeup water supply line

This line supplies the boiler and the distribution system with city water. The water may be supplied either manually (open tank system) or automatically (closed tank system). Figure 4–28 shows the makeup water supply line and components that we cover. Refer to this figure as you read the following paragraphs.

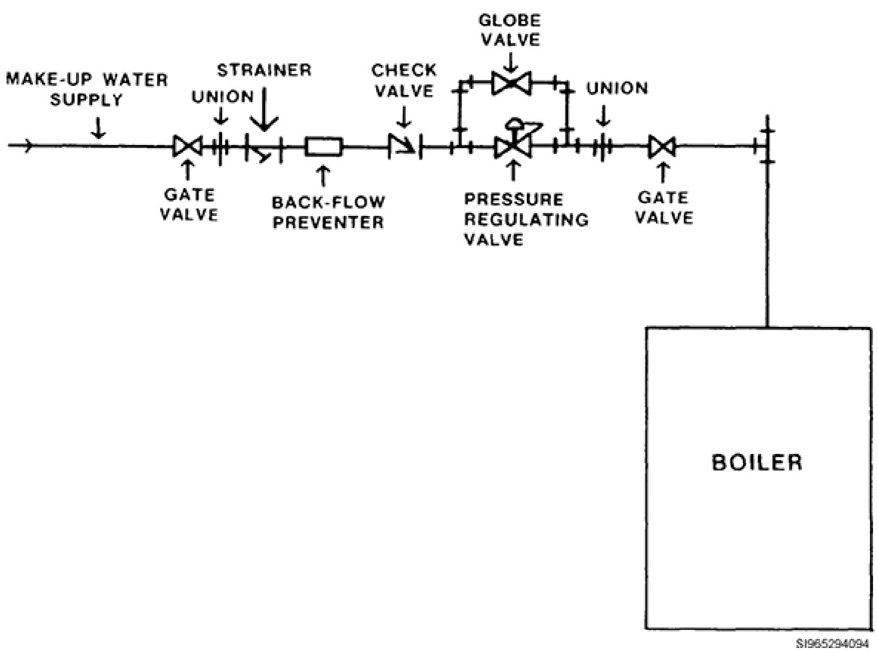

Figure 4–28. Makeup water supply line.

Gate valves

Gate valves install in the makeup water supply line to isolate the boiler from the city/base water supply for maintenance and repair of the boiler and system. Never use these valves for throttling the water flow to the system. Always have these valves in either the fully open position or fully closed position.

Strainers

Strainers install in the makeup waterline to filter the incoming water. Makeup water may contain sediment or dirt, which may damage expensive equipment and components located downstream.

Back-flow preventer

A back-flow preventer prevents backflow of antifreeze solutions or chemical treatments from the boiler water from entering the makeup water supply and contaminating it.

Check valve

A check valve is installed in the makeup waterline to prevent boiler water from entering the city/base water and contaminating it. This back-flow drainage of boiler water could happen if the supply water pressure fell below the boiler pressure.

Pressure regulating valve

This valve is *only* on closed tank systems, not open tank systems. Because the water circulates in a closed system, the makeup requirements of the hot-water system are low. A pressure regulating (reducing) valve usually installs in the makeup or cold waterline to the boiler. This valve automatically keeps the closed system supplied with water at a predetermined safe pressure.

The valve consists of an inlet and outlet, strainer, diaphragm, spring, adjustment stem, and locknut. The spring tension determines the amount of water that passes through the valve. To increase the discharge pressure, loosen the locknut and turn the adjustment stem clockwise. To decrease the discharge pressure, turn the adjustment stem counterclockwise.

Pressure regulating valves have either inlet or outlet markings or directional arrows to indicate the proper flow direction. Depending on the type of boiler, distribution system, and manufacturer’s recommendations, installation of this valve varies.

Bypass line

A bypass line with a globe valve might install in the makeup waterline. When used, it can bypass the pressure regulating valve. When you open the bypass line valve, you can fill an empty boiler with water much faster than with the pressure-regulating valve. Do not keep bypass valves in the open position. They are for temporary use only (mainly when working on the pressure regulating valve) and must be closed when they are not in use.

Self-Test Questions

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

640. Makeup water supply line

1. Why are gate valves installed in the makeup water supply line?

2. Where is a pressure regulating valve usually installed?

3. What is the relationship between the pressure regulating valve and the supply water to boiler?

4. How is the discharge pressure of a pressure regulator increased?

641. Boiler support equipment

There are many attachments available for use with boilers. Let us take a quick look at some of them.

Boiler accessories and connections

All boilers have certain accessories and connections for safety and ease of operation. The various accessories used on low-temperature water boilers may include easy viewing displays and controls, the tridicator, safety relief valve, boiler drain valve, aquastat, weather control, inlet and outlet connections, dip tube, and an indirect water heater. Figure 4–29 shows components in the following text.

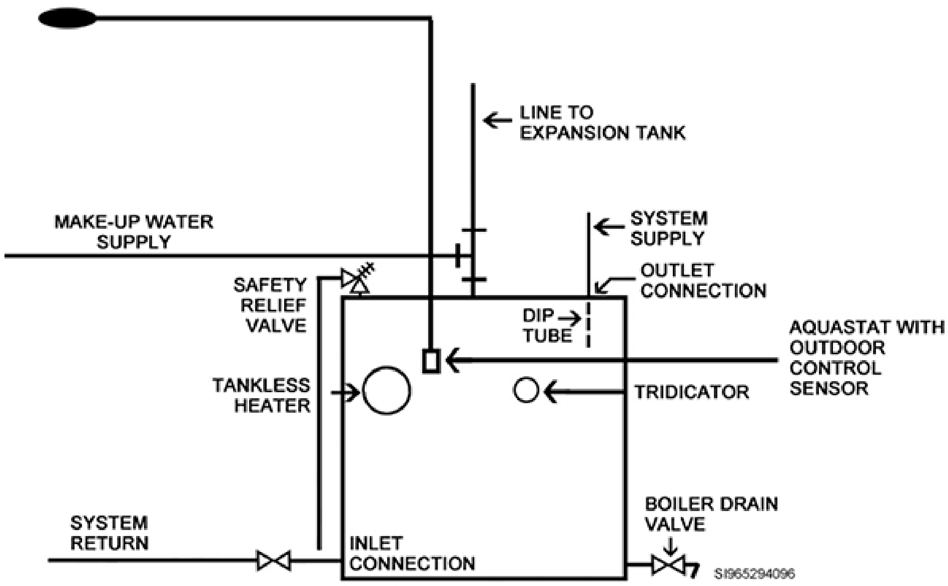

Figure 4–29. Boiler accessories.

Boiler displays and controls

Displays and buttons like the one shown in figure 4–30 are very common. The electronic display is used to configure boiler settings and monitor boiler operation. There are gauges that show the pressure and temperature. The buttons are for changing the display mode, entering values for settings, and resetting after lockout. There are numerous configurations of displays and buttons on boilers. Use the manual supplied by the manufacturer for the boiler you are working on.

Figure 4–30. Boiler displays and buttons. (Reprinted by permission.)

Tridicator

This gauge combines a pressure gauge, water temperature gauge, and an altitude setting (fig. 4–31). The purpose of this gauge is to show the level of water proper for, and actually present in, the system. This gauge has three needles, one red, and two black. One of the black needles is for the temperature gauge. The other black needle is for the water pressure that is required for the highest heat consumer in the building. The red needle is for altitude and is set manually at the time of installation to indicate the "altitude" of the highest consumer in the system. When the setting of the black needle matches the setting of the red one, the system is full.

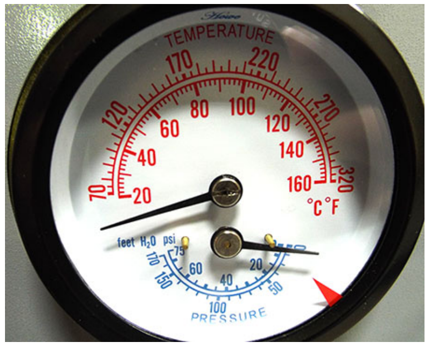

Figure 4–31. Tridicator.

By reading the tridicator, you can tell whether the valve is operating correctly. For example, if the boiler is serving a two-story building, the altitude is set for approximately 20 feet. The altitude gauge is essential for operating a hot-water heating system. One pound of water pressure is equal to 2.31 feet. In other words, if a system is 45 feet high, you can determine the necessary pressure by dividing 45 by 2.31 = 19.48 psig. Therefore, to assure water at the highest point of the system, a boiler pressure of 19.5 psig is necessary.

Safety relief valve

Boilers will have at least one officially rated pressure relief valve set to relieve at or below the maximum allowable working pressure of the boiler. The safety relief valve (fig. 4–32) connects to the top of the boiler. It is necessary to prevent the operating pressure of the boiler from exceeding the maximum permissible pressure. Safety relief valves are spring loaded. The valve is also factory set; do *not* change the spring tension. If you require a different spring pressure, replace the valve.

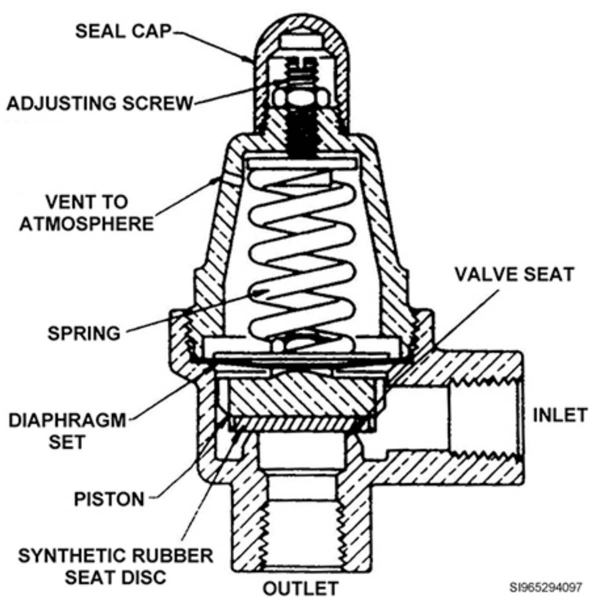

Figure 4–32. Safety relief valve.

If the pressure in the boiler and system is above the set pressure of the safety relief valve, this pressure causes the valve to open and relieve the excess pressure. Never reduce the discharge side (outlet) of the valve. Instead, the discharge piping must be in such a way as not to burn anyone if the valve opens.

Drain valve

Place a drain valve in the tapping provided by the boiler manufacturer. The drain valve installs at the bottom of the boiler to allow you to drain the boiler and the system if desired. It should be piped so that it discharges to the floor drain.

Aquastats

Aquastats are water temperature controls used on hot-water boilers to start and stop the fire burning equipment at predetermined settings and as a limit control. As a limit control, they serve the same purpose as a high limit on a forced-air furnace, but in a water system. They are a safety feature to stop the firing equipment if the temperature goes beyond the operating temperature. An example of this would be the operating temperature of 160° F on and 180° F off. If exceeding the temperature of 180° F, then the high-limit setting (such as 200° F) stops the burner.

There are many types of aquastats available. One model is to limit the boiler water temperature only. Another combines a high limit with a differential adjustment. The differential may be fixed (factory set) or adjustable. Adjustable differentials may adjust over a wide range (2° to 45° F in some cases) by turning a knob or a slotted screw. The differential determines the temperature lag of the firing equipment between stop and start. To determine the point at which a burner restarts, subtract the differential setting from the range setting.

A third type of aquastat is a combination aquastat. This aquastat combines a limit control with an outdoor weather control that is an outdoor reset. In the combination aquastat, the limit control still limits the boiler operating temperature and the outdoor weather control overrides the operating limit if the outdoor temperature reaches a predetermined setting. For example, if the outdoor weather control is set at 65° F and the outdoor temperature is 65° F or above, the contacts open and cause the burner to shut off. This cuts down on fuel consumption on relatively warm days.

The sensing element (a remote-bulb device) is outside the building out of direct sunlight. Still another type of aquastat combines a limit control with a differential for an operating limit and a second dial for a circulating pump control. This second dial allows the pump to operate only when the boiler water temperature reaches the set point of the dial. For example, if the pump control set point is set at 120° F, the pump will not start until the boiler water temperature reaches 120° F. This prevents the circulation of relatively cool water and saves energy.

Most aquastats a snap action switch with a remote-bulb device sensing element (newer models) inserted into an immersion well. An immersion well is a hollow tube that screws into the boiler. The temperature-sensing element is inside the immersion well and is not in contact with the boiler water. The water temperature transfers by conduction and convection to the sensing element. This prevents damage to the sensing element and allows you to remove the control without draining the boiler.

Inlet connection

The inlet connection is where the water that returns from the distribution system enters the bottom of the boiler. When properly used, the inlet connection prevents thermal shock. Thermal shock is the difference of water temperature between the cooler return water from the distribution system and the hot water inside the boiler.

Outlet connection

The outlet connection is where the heated water leaves the boiler to supply the distribution system. Make sure the outlet piping is as large as the boiler outlet, connection tap.

Dip tube

Most water heating boiler manufacturers install a dip tube. This connection (fig. 4–33) prevents the air and gases that's released from the heated water in the boiler from entering the distribution system. This is done by extending the boiler discharge pipe into the boiler so only water enters the line. The air and gases rise to the top of the boiler where a small line vents it to the expansion tank. A number of manufacturers have designed an external boiler fitting that does the same thing as the dip tube and vent line.

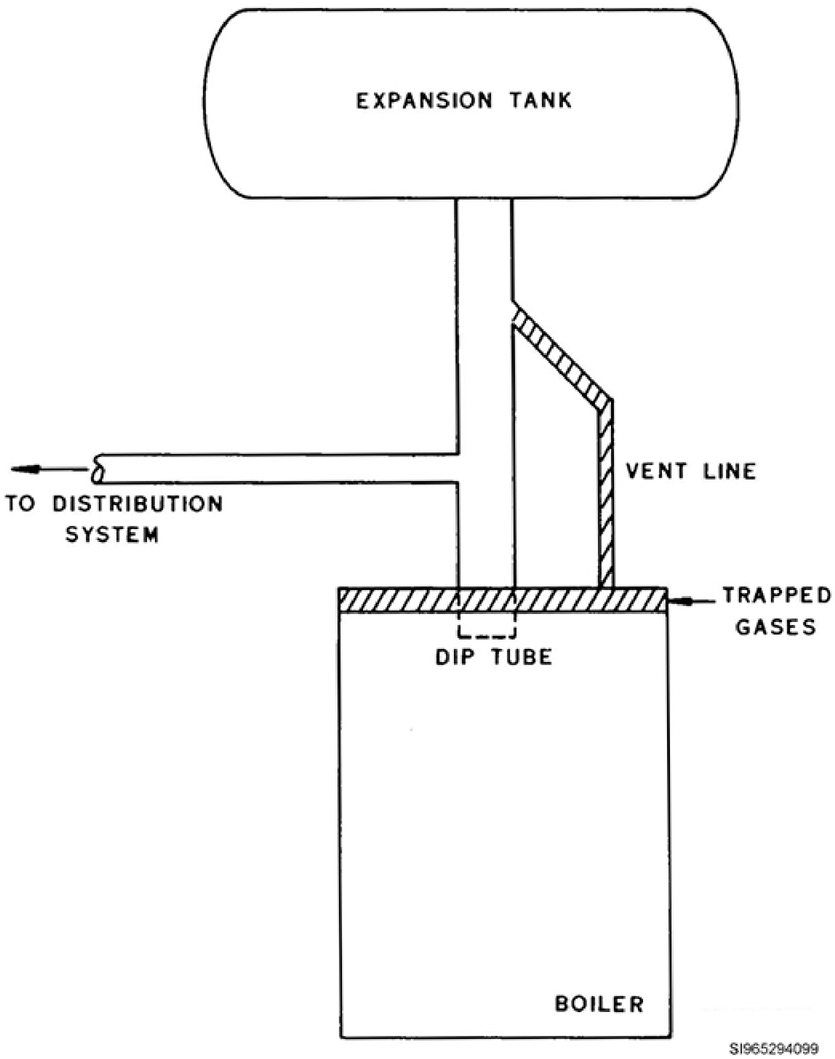

Figure 4–33. Dip tube and vent line.

Indirect water heater

Indirect water heaters, sometimes called tankless heaters or instantaneous heaters, install directly inside the boiler. This heater has long coils of tubing and usually has fins attached to the coils. The boiler water that surrounds the coil heats these units. Domestic water for bathing and so forth passes through the coils, making only one pass. A three-way mixing valve mixes cold water with existing hot water from the heater. This is to maintain a uniform temperature of the domestic hot water and to prevent scalding of the water users.

Self-Test Questions

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

641. Boiler support equipment

1. What is the purpose of the tridicator?

2. What do the black needles on the tridicator indicate?

3. What do the red needles on the tridicator indicate?

4. What is the necessary pressure of a system if the highest point in the system is 50 feet high?

5. What should be done if a different spring pressure is needed on a safety relief valve?

6. Where is the drain valve discharge into?

7. What will happen to the burner if an outdoor weather control is set at 70 degrees and the outdoor temperature rises above 70 degrees?

8. When will the pump start if the pump control set point is 120 degrees?

9. How does temperature reach the sensing element in a conversion well?

642. Safety devices and expansion tanks

All hot-water systems have certain accessories and connections for safety and ease of operation that are on the boiler and included in and on the expansion tank. Various accessories that we look at include low-water cutoff and the air vent valve. Figure 4–34 shows these items, as you read the following paragraphs, refer to this figure as needed.

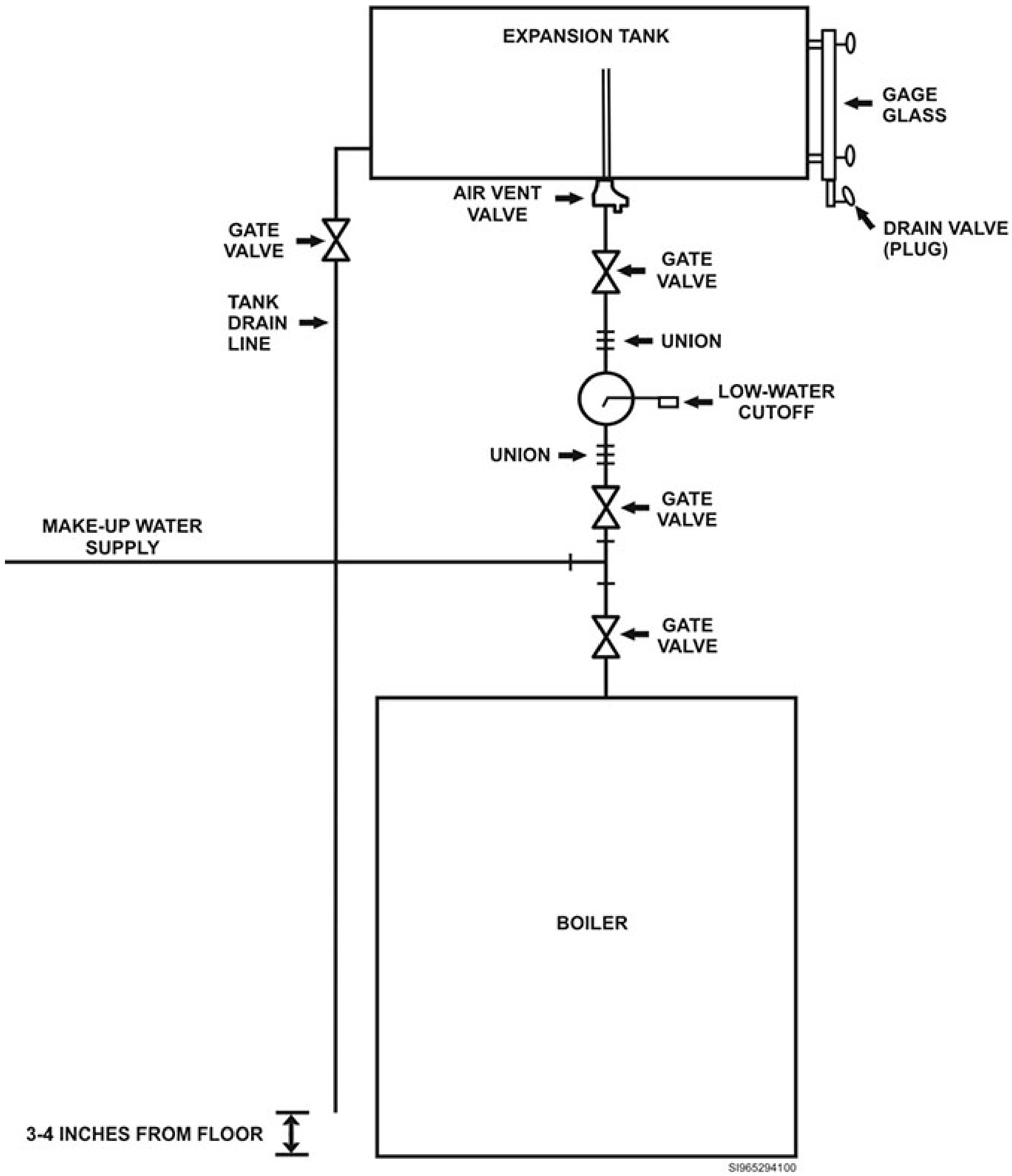

Figure 4–34. Components from boiler to the expansion tank.

Low-water cutoff

A float type low water cutoff is often used on boilers. The float operates a switch that interrupts the power to the main burner if the water level drops to a predetermined level.

Air vent valve

An air vent valve is a device that installs into the bottom of an expansion tank on a closed tank system. The air vent valve normally has a hollow tube that extends into the expansion tank as in figure 4–35. In addition, it has a hollow needlepoint plug that, when loosened, allows air to enter the tank when the tank is empty or exit the tank when the tank is pressurized. The purpose of the air vent valve is to adjust the amount of air and water inside the expansion tank. See figure 4–36 for an example of an air vent valve that is connected to the bottom of the boiler.

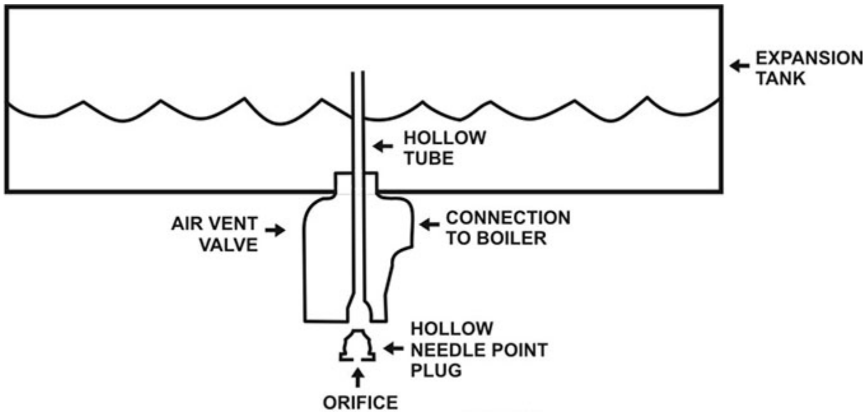

Figure 4–35. Air vent valve installed in tank.

Figure 4–36. Air vent valve.

Gauge glass

A gauge glass sometimes will mount on the side of an expansion tank to allow you to see the amount of water in the tank. Gauge glasses consist of a strong glass tube that connects to the tank by two special fittings. The glass must be visible at all times.

Tank drain

Expansion tanks usually have a tank drain and valve. The purpose of the tank drain is to allow you to drain the expansion tank while the system is still in operation. Place the drain line opening within 3 to 4 inches of the floor to prevent burns during draining of the expansion tank.

Expansion tanks

Every water heating system should have an expansion tank to handle the expansion and contraction of water that occurs as its temperature changes (fig. 4–37). The expansion tank should be large enough to permit the water volume to change without causing undue strain on the equipment.

Figure 4–37. Expansion Tank.

Open-tank system

In open-tank systems, the expansion tank vents freely to the atmosphere (fig. 4–38). Normally, these systems are limited to installations with operating temperatures of 180° F or less. Operation at higher temperatures, which would be near the boiling point of water at atmospheric pressure (212° F), could be troublesome. One drawback to open-tank systems is that water is in contact with the atmosphere at all times, this can cause corrosion.

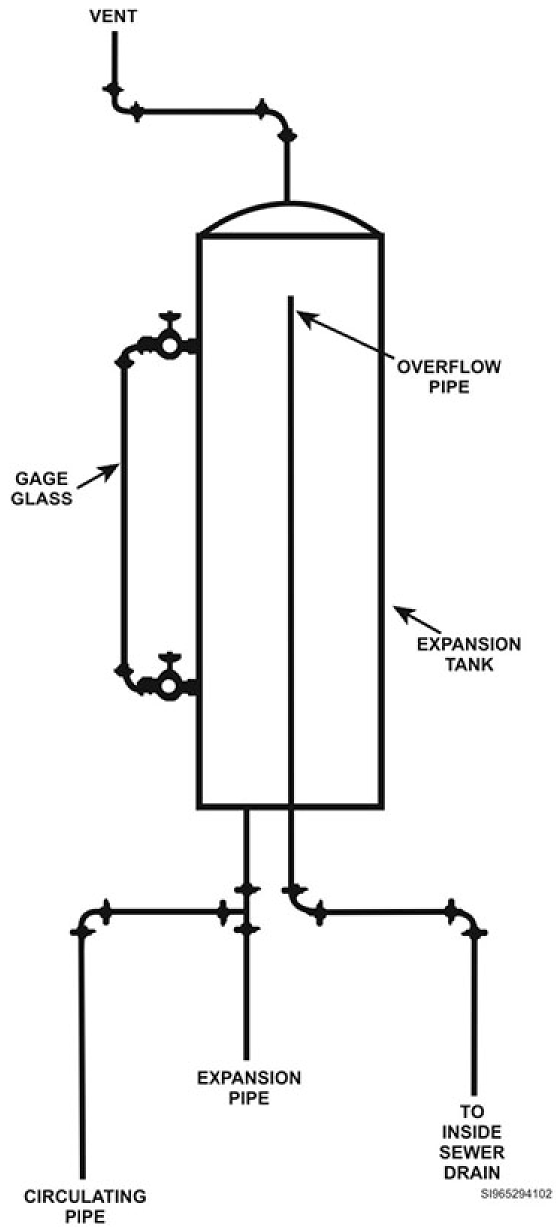

Figure 4–38. Open expansion tank.

Closed-tank system

This system uses an airtight tank that prevents free venting to the atmosphere. Therefore, heating systems using it will pressurize and operate over a wide range of temperatures and pressures. When the saturation pressure rises to correspond to the desired temperature, the system will operate above 212° F. In operation, as heated water expands, the excess water moves into the tank and compresses the entrapped air, thereby increasing the pressure on the system. When the water temperature lowers, the water contracts, air in the tank expands, the excess water returns to the system, and the pressure drops. A closed expansion tank must be large enough to keep a reservoir of compressed air above the water level to cushion the excess water that enters. Thus, the tank must provide space for changes in both water and air volume. In closed tank systems, a gauge glass and air vent valve, water inlet, and drain and relief valves permit the operator to observe and adjust the proportion of air in the tank.

If the tank is too small or if it does not contain enough air, two undesirable conditions can occur. First, as temperature increases, the water expands and the system pressure may increase above the permissible level. This causes the relief valve to open and waste water. Second, as temperature drops, the water contracts, and the pressure may drop below the permissible minimum. As the water losses volume, air can draw in through imperfections in piping (leaks) or if the system high points contain automatic air vents. This usually causes air locks or circulating problems. If the tank is too large, it will cost more and require more space.

Size of expansion tanks

The capacity of the tank depends on the amount of water in the system and the operating temperature range. Follow the manufacturer’s recommendations and ASME when sizing expansion tanks. The excess water is stored in the expansion tank until the water temperature becomes lower. It then returns to the system.

Location of expansion tanks

Check manufacturers manuals for expansion tank location. Open tanks are usually located higher than the highest point of the system and connected to the suction side of the pump to prevent sub-atmospheric system pressures caused by pump operation. This system should have an internal overflow drain. As required by the ASME *Boiler and Pressure Vessel Code*, water must not freeze in the tank, the tank vent, and the pipe leading to the tank.

Self-Test Questions

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

642. Safety devices and expansion tanks

1. Where is the air vent valve installed on the expansion tank?

2. What is the relationship between the air vent valve and the air and water in the expansion tank?

3. When should the gauge glass be visible?

4. What temperatures could cause problems in open tank systems?

5. What happens if the water in the expansion tank increases above permissible levels?

4–5. Hot Water Boiler Operation and Maintenance

Hot-water system operation is, for the most part, automatic. Although, to keep a hot-water system operational, you, as a HVAC/R Journeyman, need to have a basic understanding of how to perform preoperational inspections, operational tests and preventative maintenance. This section assists you in improving your knowledge of these areas and job accomplishment.

643. Pre-operational inspection

All hot-water systems of the same type (one-pipe, two-pipe, or series-loop systems) have similar designs and operating principles. However, installation details (i.e., location of the expansion tank, circulators, vents, valves, etc.) may vary considerably. Before you attempt to operate a system, check its installation carefully. An adequate understanding of the location and purpose of the equipment and its controls prevents unnecessary outages and equipment failure.

Preoperational inspection

Before you start any system, always perform a preoperational inspection. This step should include inspecting the boiler unit, water-gauge glasses, auxiliary equipment, meters, instruments, gauges, and controls. During your inspections, make sure that all installation, repair, maintenance work, and cleanup work has been completed. Check all piping for leaks, adequate support, and insulation where required.

Boiler unit

See that the boiler access and observation doors are closed. Check all air and gas ducts and passages of the boiler for tightness and freedom from obstructions. Make certain that blow-down lines are properly installed and fastened and that drain valves are closed. Check the supply and return header valves to see that they are in good operating condition.

Water-gauge glasses

Make sure that the water-gauge glass valves on the expansion tank are open. Check for clear visibility of the gauge glasses from the operating floor and see that any lamps (lights) that are present are in good working condition.

Auxiliary equipment

Inspect all required auxiliary equipment (such as fuel-burning, draft, feedwater, and combustion-control systems) for proper installation and for readiness for operation. Lubricate pumps in accordance with the manufacturer’s specifications and that test their rotation. Ensure that all installation, repair, and cleanup work on balancing devices, heat transmitters, etc. is completed and that units are ready for operation.

Meters, instruments, and gauges

Inspect all meters, instruments, and gauges for proper installation and readiness for operation. If any of these devices are broken, replace them before the operational test. Check the pressure relief valves, limit controls for the proper setting, and make certain that they are in good operating condition.

Controls

Check the thermostats, primary controls, limit controls, and auxiliary controls for proper calibration. Preset the controls, if necessary, so they operate within the approved limits.

Just as in everything else, there are proper ways of starting up a boiler. Familiarize yourself with the steps involved and be sure you do the startup properly.

Self-Test Questions

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

643. Pre-operational inspection

1. What position should the boiler access and observation doors be in during the pre-operational inspection?

2. Why are the air and gas ducts inspected?

3. What position should the water gauge glass valves be in?

4. Why should all meters, instruments and gauges be inspected?

644. Operational test

An operational test is absolutely critical for boiler systems. Boilers can become very dangerous if their operation is not checked properly. This lesson will give you guidance on how to fill a system and then how to run an operational test. As always, these are just general guidelines because each boiler has its own specifications and needs.

Filling the system

First you must know how to fill a boiler system. For this process, pay *very* close attention at the position of the valves. To fill up a boiler

- close all manual air vents,
- open the boiler supply main valve and the return header valves,
- open the inlet and outlet valves of the circulators (if you don’t, you could damage the circulators),
- open all valves to heat terminals, and
- open the manual feed-water valves until the expansion tank is approximately one-half full.

Now that you have the valves in the proper position you can continue the following process:

- Energize the circulators and establish a definite water circulation in the system. Check the operation of the circulators for noise, vibration, abnormal temperature, and other factors.
- Begin venting the lowest heat terminal or other space heating equipment.
- Open the vent valves (if manually operated) until all air exits and water starts to flow. Vent the rest of the units progressively. If necessary, add water to the system to complete venting of all units.

NOTE: Drain and refill the system several times to remove all grease, core sand, and other foreign material before you start the burner for *initial* operation.

Initial operation

An initial operation means to operate a boiler for the very first time. It does *not* mean the first time that year. To conduct an initial operation, light the boiler and slowly heat the system water and furnace refractory. The length of time that is involved in bringing a system up to operational readiness depends a great deal on the size and type of the system; therefore, when you operate a newly filled system for the first time, heat it to a higher temperature than the temperature anticipated for normal operations, but not above the safe limits. This procedure expels entrained air from the system water and helps to vent the system.

Following a cold start, condensation may occur in a gas-fired boiler to such an extent that it appears as if the boiler is leaking. This condensation will stop after the boiler is hot.

After the system has been in operation for 2 days, open the boiler drains to eliminate heavy core sand and similar materials which tend to flow to this low part of the system. When you open drain valves or when you feed makeup water to a hot-water heating system, keep the water flowing slowly to prevent excessively rapid temperature changes that cause stresses in the boiler. After the system has operated for about 10 days, reopen the air vents (manually) and release all air from the system. Afterwards, check the system periodically for venting requirements.

When you start a panel heating installation for the first time, you should supply water to the panels at a temperature that is not more than 20° F above room temperature or that does not exceed 90° F. Maintain this temperature for 2 days; then, progressively increase it by about 5° F a day to the normal operating temperature, but do not let it exceed 140° F. After you flush and vent the system, do not drain it unless an emergency makes this necessary.

Water level

In operating a hot-water system, it is very important to maintain the proper water level in the expansion tank. When the system is cold, the water level should be low enough (less than 50 percent of tank capacity) to allow the heated water to expand. Blow down the water to this level if necessary. After the water reaches normal operating temperature and pressure, close the manual feed valve and use only the pressure-regulating valve. The regulating valve automatically maintains the system water level. Inspect the waterline in the expansion tank frequently.

Pressure

Observe the system pressure frequently. This pressure gives information about unfavorable conditions, such as low water, which shows by below normal pressure, and system stoppages, which can indicate by abnormally high pressures. System stoppages may result from freezing or other factors. A rise in water pressure in a closed system may indicate, among other things, a completely filled expansion tank, or a volume of air in the tank that is inadequate for the necessary expansion. When the system pressure rises above normal, the pressure relief valve should operate. However, if the pressure relief valve fails to operate when the system pressure rises above the determined setting, shut down the boiler immediately. If the high pressure results from an excessive fuel-burning rate, the water temperature will exceed the limit control setting, thereby shutting down the boiler and starting the circulators.

Combustion equipment

Observe the operation of the burners. Only after you perform combustion analysis do you make any required air/fuel adjustments. Ensure that the burner motors are not vibrating excessively or making abnormal noises. Make sure any linkages, if used, are properly connected, aligned, and free moving; if not, correct the condition.

Control systems

Safe and correct operation of a hot-water system depends on the proper functioning of control equipment. Periodically, check the operation of thermostats; primary, limit, and auxiliary controls; and calibration and setting.

Circulating pumps

Circulating pumps that are in hot-water systems are very simple. Check them carefully for abnormal noise, vibration, or excessive operating temperature. Be sure that they rotate freely and properly. When the system uses stuffing boxes, be sure they are not so tight that they score the shaft.

Heat terminals

Set valves for the maximum opening that is compatible with equipment size and system temperature balance. Open manual air vents periodically to free the equipment of air. Some hot-water systems have radiator valves for closing off circulation through the radiators. Sometimes these valves have weep holes that allow enough water circulation, even when the valve is closed, to prevent the radiator water from freezing.

Normal operation

Well-designed hot-water heating systems rarely present operating difficulties at normal temperatures and pressures. If rapid fluctuation or pulsation pressures should occur, check for system leaks, stoppages, and correct pressure relief, valve operation. The indicated pressure of a closed system may increase slightly when the water temperature increases. Each system has its own definite increase characteristic that is determined by the water capacity of the system and the size of the expansion tank. Observe and record this characteristic when the system is in perfect operating condition. Any later deviations from the established pressure may indicate that the water level is low (if pressure decreases) or that the system is clogged or plugged (if the pressure is above normal). Watch the water level in the expansion tank.

Self-Test Questions

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

644. Operational test

1. What should be done to the air vents when filling up a boiler?

2. What could happen if you don’t open the inlet and outlet valves of the circulators?

3. What should be done to the valves of the heat terminals when filling up a boiler?

4. How should the system be heated when operating it for the first time?

5. What should be done after a new system has been in operation for two days?

6. What must be accomplished to prevent excessive rapid temperature changes while draining the boiler?

7. What is done after the system has been operating for 10 days?

8. What should the pumps be checked for during operation?

645. Preventative maintenance of hot-water heating systems

Even a system that operates perfectly requires periodic servicing and overhauling to keep it operating that way. In this section, we discuss the servicing of hot-water heating systems, including lubricating, adjusting, and cleaning. We also discuss the seasonal overhaul of hot-water boilers and systems. Accomplish preventative maintenance at daily, weekly, and monthly periods as determined by your squadron based off of manufacturer’s manuals.

Service

When you service a hot-water heating system, you are lubricating, adjusting, and cleaning various boiler, burner, and system components.

Lubricate

When you lubricate a centrifugal pump and motor, *always* follow the manufacturer’s instructions. Only use the manufacturers approved oil or grease in the recommended amounts for that particular pump and motor.

Motors and pumps

To lubricate small centrifugal pump motors, usually you need to add 5 to 6 drops of oil to the motor about twice per year. Many larger pump motors have oil cups or grease zerks. If they are lubricated by grease, make sure that you remove the grease plug, which is normally located on the opposite side of the grease fitting. Failure to remove the grease plug may cause the motor bearings to overheat, which may damage the pump motor. Use only oil or grease approved by the manufacturer and add only the amount that they recommend.

Many small centrifugal pumps have stuffing boxes that contain an oil-saturated wick, which opens above the pump shaft and bearings. Saturate the wick with oil at all times to lubricate the shaft bearings.

Larger centrifugal pumps may have bearings that lubricate with oil, grease, water, or any combination of the three. When you oil or grease larger pumps, you can follow the same procedures we gave earlier for pump motors that are oiled or greased. Water-cooled bearings leak for cooling purposes and, in some designs, for lubrication. Leakage usually pipes to a floor drain. Tighten stuffing box packing evenly and allow a trickle of water leakage to cool the lubricant.

When oil rings lubricate pumps, maintain the proper oil level, and see that the rings are turning. Drain the oil periodically and add only the type and amount of oil recommended by the manufacturer.

Valves

Some of the valves installed in a hot-water heating system require lubricating. You can lubricate small valves by using graphite; larger valves usually have grease fittings. Follow the manufacturer’s recommendations when you lubricate valves. Use grease to lubricate valve linkages.

Burner motors

We covered the lubrication of burner motors and burner linkage earlier. You may wish to review that area at this time in volume 4, unit 2, LOs 617 and 620.

Adjust

Some of the components that you adjust on hot-water heating systems are water pressure regulating valves, tridicators, aquastats, outdoor resets, water level in expansion tanks, burners, and system balancing devices. We begin with the water pressure-regulating valve.

Pressure regulating valve

As you may recall, pressure-regulating valves automatically keep a closed system supplied with water at a predetermined safe pressure. Before you adjust the system pressure, you must first observe the pressure by looking at the pressure gauge and determining the pressure requirement of the system. If the system pressure needs to be increased, loosen the locknut that is located at the top of the valve. Next, turn the adjusting screw clockwise. To decrease the system pressure, turn the adjusting screw counterclockwise. Drain a small amount of water from the boiler drain valve while you check the pressure gauge to ensure that you made your adjustment properly.

Tridicator

You can adjust the altitude gauge that is contained in a tridicator to determine the required pressure to reach the highest heat transmitter. To adjust the altitude gauge, simply turn the altitude needle to the necessary altitude to reach the highest transmitter. The altitude needle will point to the required pressure to get the water to the altitude of the highest heat transmitter. You then adjust the system pressure for that altitude by adjusting the pressure-regulating valve.

Aquastat

The limit control for hot-water heating systems is an aquastat. If it has a factory set differential, you cannot adjust it. An adjustable differential is adjustable over a wide range, from 2 to 45°F. To adjust an aquastat with a differential, turn the limit dial to the desired setting and set the differential knob to the desired performance.

Outdoor weather control (outdoor reset)

To adjust the outdoor reset, turn the dial to the desired setting. This setting will override the operating limit on relatively warm days.

Flow control valve

You can adjust the flow control valve to the automatic position or the manual position. When you turn the adjusting handle clockwise, it is in the automatic position and prevents gravitational flow when the circulating pump shuts off. When you turn the handle fully counterclockwise, it is in the manual position and allows gravity flow to prevent pipes from freezing.

Expansion tank

There are times when an expansion tank loses its "air cushion." When this happens, you must charge the tank. Charge the expansion tank in the following manner:

- Close the system supply valve to isolate the expansion tank from the boiler and system.
- Close the makeup water supply valve and open the tank drain valve (a small quantity of water may come out at this time).
- Open the air vent valve and observe the water level in the gauge glass (the water level will drop).
- Close the drain valve and air vent valve when the water reaches the desired level (approximately one-half full on a warm system)

- Open the boiler feed line.
- To raise just the water level in the expansion tank, open the air vent valve until you obtain the desired water level; then, close the air vent valve.

Burner

We covered burner adjustment earlier. Let us briefly review a few areas that require adjustment.

Gas burner adjustment consists of gas pressure measurement to the unit and to the burner, pilot positioning adjustment (for standing pilot systems), pilot pressure adjustment, and air/fuel ratio for proper combustion efficiency.

Oil burner adjustment consists of adjustment of the electrode assembly, pump pressure, and air/fuel ratio for proper combustion efficiency.

Balancing devices

Adjust balancing devices to match the design flow rate of the heat transmitter. Take temperature measurements and adjust balancing devices until you establish thermal equilibrium throughout the system.

Circulating pump

Centrifugal circulating pumps on large hot-water heating systems may have variable speed motors driving them. The pump speed adjusts automatically according to system requirements. Some large circulating pumps have a bypass line with a bypass valve. If the pump supplies too much water pressure or too many gallons per minute (gpm), the remainder exits through the bypass. Centrifugal pumps rate in specific gpm and head pressure. If the pump is overrated and cannot deliver exactly what the system needs, you can open the bypass valve and divert some discharge water back to the suction side of the pump. Adjust the bypass valve according to pressure gauge readings and gpm readings to match system requirements.

Clean

After you lubricate and/or adjust the components of a hot-water heating system, a general boiler (equipment) room cleanup is required. General cleanup consists of picking up any rags and tools that you have used. Unauthorized items should not be stored in the boiler room.

Dust off all controls, supply and return mains, pumps, and gauge glasses. You can use a broom to sweep off the top of the boiler, boiler room floor, and the boiler room walls. After you sweep, use a water hose to wash the boiler room floor. When you wash the floor, take care not to get pipe insulation and electrical controls and connections wet. If you get electrical connections wet, you could get an electrical shock.

Seasonal overhaul

A seasonal overhaul of a hot-water heating system involves inspecting and cleaning the boiler waterside, fireside, external fittings, expansion tank, and distribution system. Seasonal overhaul is on an annual basis, usually during the spring or summer months when there is little or no demand for heat. You do not want a seasonal overhaul scheduled for the winter because you will have to turn the boiler off for as long as it takes you to clean it. Ensure the overhaul is scheduled for the spring or summer, if it is not, talk to your supervisor and try to get it changed.

Waterside

To perform seasonal overhaul of the boiler waterside, you must isolate the boiler from the makeup water supply and drain it. When possible, open all manual air vents at the top of the system to facilitate complete draining. To flush a hot-water boiler, proceed as follows:

- Drain the boiler completely (as outlined above).
- Remove all hand hole and manhole covers.

- Remove the drain valve from the boiler (sludge, etc. could accumulate in the valve).
- Use high-pressure water and hose down the entire waterside of the boiler.
- Inspect all corners, pockets, and low points in the boiler for sludge accumulation and flush accordingly.
- Flush the boiler until clear water runs out of the drain opening.

After you completely flush the boiler, replace drain valve, hand hole, and manhole covers.

NOTE: Use new hand hole and manhole gaskets. Fill boiler and system with chemically treated water.

Cast-iron boilers

By virtue of the material used in construction, these boilers resist corrosion very well. Cast-iron boilers are primarily used on closed systems with low-makeup requirements so that corrosion is negligible. If makeup requirements are high and the makeup water has no treatment (softened), then the boiler will very likely accumulate harmful scale deposits. Scale deposits are excessive whenever they interfere with heat transfer or whenever they impede water flow through the boiler. When you encounter such scale deposits, remove them with an acid treatment.

Steel boilers

In general, the same theory applies to steel boilers as to cast-iron boilers; however, steel boilers are highly susceptible to corrosion. Slug feed these boilers with caustic soda on an annual basis or more frequently if necessary. Caustic soda increases the alkalinity or pH of the boiler water and, when maintained at a relatively high pH (10.0), reduces the possibility for corrosion. Acid cleaning for scale removal is applicable to steel boilers as well. If corrosion exists to the extent that failure of the metal is possible, then remove the boiler from service and repair or replace it.

Fireside

To perform seasonal overhaul of the boiler fireside, you must secure all firing equipment and allow the boiler to cool slowly. The following paragraphs explain what is necessary to clean a cast-iron boiler and a steel boiler.

Cleaning cast-iron boilers

Clean boilers thoroughly. Use wire brushes to remove all soot, dirt, and scale from flues and firebox surfaces. If controls mount in the smoke pipe, be careful not to disturb them; lubricate hinges of all doors and moving parts of regulators with an approved lubricant. Brush exposed exterior ironwork with a wire brush and, after you remove all rust, paint with rustproof, heat-resistant paint.

CAUTION: Personnel engaged in boiler cleaning must use the proper respiratory and eye protection and suitable protective clothing.

Cleaning steel boilers

Remove manhole and hand-hole flues. Thoroughly brush combustion surfaces with a wire brush to remove all soot, carbon, and scale. Brush or swab (do not spray) a light lubricating oil or used crankcase oil on the fireside surfaces. Clean firebox corners and inside firebox sheets, crown sheet, and front and rear tube sheets—use a wire brush and scraper. Clean soot and carbon from the outside sheets, outer shell, and throat sheet on all bricked-in boilers. Clean inner brick walls and boiler shelves, including combustion chamber, smoke breeching, and box of the stack.

External fittings

When you perform seasonal overhaul of boiler external fittings, you are removing, inspecting, cleaning, and replacing boiler external fittings, including the pressure-regulating valve, safety relief valve, tridicator, dip tube, aquastat, and valves. The following paragraphs explain what is necessary to perform seasonal overhaul of boiler external fittings.

Pressure-regulating valve

Remove the pressure-regulating valve from the system and inspect and clean the strainer using a soft brush; rinse it with water. Inspect the valve for corrosion of the valve body, strainer, and valve disc and seat. If the valve is beyond repair, replace it with a new one. After you inspect and clean the pressure-regulating valve, reinstall it.

Safety relief valve

First, increase the system pressure to the opening (popping) pressure stamped on the valve. Observe the popping pressure and, if it is not accurate, replace the valve with a new one. Remove the valve and inspect it for damaged seats, foreign matter between the seat and disc, defective parts, and corrosion or erosion. Clean the valve and reinstall it.

Tridicator

Pressure test and temperature test the tridicator. If it is not accurate, replace it with a new one. Set the altitude needle for the height of the system. Inspect the tridicator for corrosion and erosion and clean it as needed. If the face glass is broken, replace it. After you test, inspect, and clean the tridicator, reinstall it.

Dip tube

Remove the dip tube, check it for corrosion, clean it as needed, and reinstall it; if necessary, replace it.

Aquastat

Remove the aquastat and clean the remote bulb device. Remove the immersion well and inspect it for corrosion and erosion. Clean the immersion as needed and replace it. Check the aquastat settings and adjust if necessary. Reinstall the aquastat and ensure that it maintains the boiler water temperature within a tolerable range. If it is defective, replace it with a new one.

Flow-control valve

Remove the flow control valve and inspect it for corrosion, erosion, and scale deposits. Ensure that the weighted stem operates freely. Clean the valve as needed and reinstall it.

Circulating pump

Each year you must dismantle the pump and

1. check wearing ring clearances according to the manufacturer’s instructions. Diametric clearance between 0.005 and 0.25 inch is usual,
2. overhaul the bearings. Examine for wear and check clearances according to the manufacturer’s instructions,
3. check the shaft for scoring, corrosion, or wear at seals; also, check its alignment,
4. check the impellers for corrosion, erosion, or excessive wear,
5. check and calibrate the pressure gauges, thermometers, and flow meters, and
6. inspect the suction and discharge strainers.

Repair or replace any defective parts you find during the yearly inspection. Replace wearing rings when clearances are twice the original or if the leakage reduces significantly the capacity and head of the unit. Replace worn shaft sleeves.

Outdoor reset

Each year, ensure that the outdoor reset installs in the proper location. Check the set point and adjust if necessary and clean as needed.

Expansion tank

To perform seasonal overhaul of the expansion tank, you must drain and rinse it. Remove the air-vent valve and inspect the tank for corrosion, erosion, and scale; clean as needed. Inspect the vent tube and ensure that it is not blocked. Reinstall it after inspection. If a gauge glass is present, remove and clean it; reinstall it after cleaning.

Distribution system

Each year, check the distribution system for signs of leaks, condition of insulation, and pipe corrosion. Inspect balancing devices for leaks and proper setting and inspect air vents and heat transmitters for leaks.

Self-Test Questions

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

645. Preventative maintenance of hot-water heating systems

1. What must you do before lubricating a motor with a grease plug?

2. How is the aquastat set to its desired temperature?

3. What is the first step in charging an expansion tank?

4. What precaution must be taken while washing the floor?

5. When should the seasonal overhaul of a boiler be scheduled?

6. How is the boiler isolated for seasonal overhaul?

7. What should be done with the drain valve when preparing to drain the boiler?

Answers to Self-Test Questions

632

1. The steam at any given temperature and pressure begins to condense if the temperature is slightly lowered and becomes superheated if the temperature is slightly increased.
2. The cost necessary to produce the superheated steam outweighs the benefits gained.
3. It normally cools below the condensing temperature.
4. By increasing the amount of time we supply heat.

633

1. The furnace, in which fuel combustion takes place and (2) the pressure parts, which contain water and/or steam.
2. To maintain the high furnace temperatures required for complete and efficient combustion of the fuel.
3. At the top of the boiler.
4. Weakens the metal and damages the drum.
5. By periodic operation of the bottom blowdown valves.
6. So that the feed water discharges upward rather than downward.
7. (1) The incoming feed water causes the least possible interference with the natural circulation of water in the boiler when it discharges upward. (2) The relatively cool incoming water enters away from the hot drum metal to reduce the possibility of thermal shock.
8. So that the steam must make a sudden change of direction to enter the pipe.
9. Baffles direct the flow of steam or water, ensure adequate circulation throughout the drum, and prevent violent agitation of the water.
10. Prevent excessive surging of the water from one end of the drum to the other.
11. Gas baffles are thin walls or partitions that direct the combustion gases over the heating surfaces with minimum draft loss and maximum heat absorption.
12. At the lowest permissible water level (as determined by the manufacturer) of the boiler.
13. The boiler than has to be taken out of operation to determine what causes the low-water level and to replace the fusible plug.

634

1. It is converted to steam.
2. It is sent to terminal units.
3. Greater flexibility, operation that is independent of weather conditions and flue gas temperature, and greater salvage value.
4. It is more flexible.
5. Centrifugal fans with backward-curved blades.

635

1. Discharge sludge from a boiler, lower the water level rapidly, and reduce the total concentration of dissolved and suspended solids in the boiler water.
2. Lowest water space of the boiler, such as at the bottoms of mud drums and headers.
3. Workers from scalding hazards in boilers that are down for repairs.
4. Mud or sediment is removed from the water column drain.
5. Surge tanks compensate for uneven flows and regulate differences between the demand and supply of water at a given time.
6. These tanks are usually small and are located close to the traps where the pressure release occurs.
7. To pass through heat exchangers.
8. They must be either completely open or closed.
9. The stem position indicates whether the valve is open or closed.
10. It would shut off the burner.
11. Through the water.

636

1. The feed pipe generally enters the boiler at the top of the shell, near the front end.
2. Generally enters through an internal feed pipe.
3. A stop valve.
4. Stop valves.

637

1. Traps or pumps.
2. Mechanical return systems.
3. In systems where no local air vents are provided, the removal of the air is also a function of the piping system.
4. Steam main and returns momentarily may exceed the maximum operating load for severe weather.
5. Railings or other physical barriers.
6. Rolled down.
7. Somewhat oversized so they are easy to remove.

638

1. (1) Holding steam in the radiation heating coils and heat exchangers until its latent heat is given up and (2) while, at the same time, releasing noncondensables and condensate from the steam trap and steam supply mains into the condensate return line.
2. Steam traps are usually regarded as drainage devices that release liquids and gases from a higher to a lower pressure.
3. Steam traps consist of an inlet connection that opens into a chamber or passage into which condensate and noncondensable gases flow, an orifice through which the condensate and fixed gases are discharged, a valve that regulates or throttles the flow through the orifice port, and an outlet connection.
4. It closes in the presence of steam.
5. The trap would blow live steam continuously.
6. Flow of condensate from coils.
7. To prevent freezing.

639

1. Into classes based on working pressure and temperature, fuel used, materials of construction, shape and size, application (such as heating or process), condensing or non-condensing and many other ways.
2. Some steam boilers provide steam for auxiliary uses, such as hot-water heat exchangers, absorption cooling, laundry, sterilizers, and the like.
3. Psig.
4. Installers can move the sections through regular sized doors.
5. CPVC.

640

1. To isolate the boiler from the city/base water supply for maintenance and repair of the boiler and system.
2. In the makeup or cold waterline to the boiler.
3. This valve automatically keeps the closed system supplied with water at a predetermined safe pressure.
4. Loosen the locknut and turn the adjustment stem clockwise.

641

1. To show the level of water proper for, and actually present in, the system.
2. One of the black needles is for the temperature gauge. The other black needle is for the water pressure that is required for the highest heat consumer in the building.
3. The red needle is for altitude and is set manually at the time of installation to indicate the “altitude” of the highest consumer in the system.
4. Psig.
5. Replace the valve.
6. The floor drain.
7. Contacts will open and shut off the burner?
8. At 120 degrees.
9. By conduction and convection.

642

1. Into the bottom.
2. The air vent valve is to adjust the amount of air and water inside the expansion tank.
3. At all times.
4. Operation at higher temperatures, which would be near the boiling point of water at atmospheric pressure (212° F).
5. The relieve valve will open and waste water.

643

1. Closed.
2. For tightness and freedom from obstructions.
3. Open.
4. For proper installation and readiness for operation.

644

1. They must be closed.
2. You could damage the circulators.
3. Open the valves.
4. Heat it to a higher temperature than the temperature anticipated for normal operations but not above the safe limits.
5. Open the boiler drains to eliminate heavy core sand and similar materials which tend to flow to this low part of the system.
6. Open drain valves and keep water flowing slowly.
7. Reopen the air vents (manually) and release all air from the system.
8. Abnormal noise, vibration, or excessive operating temperature.

645

1. Remove the plug.
2. Turn the limit dial to the desired setting.
3. Close the system supply valve to isolate the expansion tank from the boiler and system
4. Take care not to get pipe insulation and electrical controls and connections wet.
5. In the spring or the summer.
6. Isolate the boiler from the makeup water supply.
7. Remove it.

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).

68. (632) Which effect does an *increase* in pressure have on the boiling point?
    a. It decreases it.
    b. It cuts it in half.
    c. It increases it.
    d. It keeps it the same.

69. (632) Which formula is correct when you need to determine the temperature of water in a steam boiler?
    a. psi x 14 + 98.
    b. psi x 14 + 199.
    c. square root of the psi x 14 + 198.
    d. square root of the psi x 18 + 298.

70. (633) Where is the internal feed pipe located in a steam boiler?
    a. Out of the water space near, but not touching, the bottom of the steam drum.
    b. Out of the water space near, but not touching, the top of the steam drum.
    c. In the water space near, but not touching, the bottom of the steam drum.
    d. In the water space near, but not touching, the top of the steam drum.

71. (634) What *must* the mechanical draft systems overcome?
    a. Gas pressure.
    b. Oil pressure.
    c. All draft losses.
    d. Close gas valves.

72. (635) Water-hammer is avoided in the piping system by using
    a. flashtanks.
    b. globe valves.
    c. tandem valves.
    d. blowdown valves.

73. (635) What does the probe-type low water cutoff depend on to operate?
    a. Steam.
    b. The Seebeck effect.
    c. The flow of oil in its gears.
    d. The flow of a low electrical current.

74. (636) Feedwater attaches to discharge below the boiler water line so it
    a. can be drained quicker.
    b. disturbs normal water circulation.
    c. increases the heat load on the boiler.
    d. doesn’t disturb normal water circulation.

75. (636) The check valve location is in the feed line
    a. near the drain.
    b. near the boiler.
    c. near the radiators.
    d. near the gas main.

76. (637) Why are condensate returns necessary?
    a. To keep surge tanks 100% full.
    b. Because some steam converts back to water.
    c. To provide hot condensate for heating systems.
    d. Because steam would never condense without them.

77. (638) Thermostatic traps react to a difference in
    a. volume between steam and fuel oil.
    b. current between steam and condensate.
    c. pressure between steam and condensate.
    d. temperature between steam and condensate.

78. (638) Condensate is subcooled in a thermostatic trap by allowing
    a. no condensate to stay in the trap.
    b. it to back up in the trap and a portion of the upstream drip leg piping.
    c. it to back up in the radiator and a portion of the upstream drip leg piping.
    d. it to back up in the radiator and a portion of the downstream drip leg piping.

79. (638) Which action does condensate trapped in a coil prevent?
    a. Steam in the surge tank.
    b. Even steam distribution.
    c. The burner from firing.
    d. Condensate from heating radiators.

80. (639) Which return water temperatures are condensing boilers designed to support?
    a. Low.
    b. High.
    c. Ultra-low.
    d. Ultra-high.

81. (639) Why are the internal parts and stack of a condensing boiler constructed of corrosion resistant material?
    a. Because condensing boilers are smaller.
    b. Because of the paints used with these boilers.
    c. Because the condensation can become corrosive.
    d. The burners with these boilers create corrosive gases.

82. (640) Why are make-up water requirements low in a closed boiler system?
    a. It is vented to the atmosphere.
    b. The water is open to the atmosphere.
    c. The water circulates in the closed system.
    d. Closed boilers never need make-up water.

83. (640) Which characteristic affects the amount of water that flows through a pressure regulator?
    a. Pipe length.
    b. Stack length.
    c. Spring tension.
    d. Burner efficiency.

84. (640) Identify the proper position of bypass valves during normal operation.
    a. 25% open.
    b. 50% open.
    c. 100% open.
    d. Closed.

85. (641) The action that *will* happen to the safety relief valve if the boiler and system rises *above* the set pressure of the valve is it will
    a. open.
    b. close 25%.
    c. close 50%.
    d. close 100%.

86. (641) Identify the relationship between an aquastat's pump control and cool water on a boiler.
    a. The control prevents the circulation of any water.
    b. The control prevents the circulation of hot water.
    c. The control increases the circulation of cool water.
    d. The control prevents the circulation of cool water.

87. (641) Which connection prevents air and gases that are released from the heated water in the boiler, from entering the distribution system?
    a. Steam traps.
    b. The diptube.
    c. The drain valve.
    d. The blowdown valve.

88. (642) Which device operates the switch that *stops* power to the *main* burner on a float-type low water cutoff?
    a. Float.
    b. Probe.
    c. Thermistor.
    d. Thermocouple.

89. (642) Which device does a hot water system use to handle the expansion and contraction of water?
    a. Blowdown valve.
    b. Expansion valve.
    c. Expansion tank.
    d. Check valves.

90. (643) Which type of tests should water gauge glasses be checked for during a pre-operational inspection?
    a. Insulation.
    b. Ensure they are muddied and dirty.
    c. Hit glass with hammer to test its strength.
    d. Clear visibility of the gauge glasses from the operating floor.

91. (644) Which position should the inlet and outlet valves of the circulators be in when filling a boiler system?
    a. Open.
    b. Closed.
    c. 30% open.
    d. Remove these valves while filling the boiler.

92. (645) Identify what *must* be done if an expansion tank loses its air cushion.
    a. The tank must be charged.
    b. It must be filled 100% with air.
    c. It should be placed in a vacuum.
    d. It must be filled 100% with water.

93. (645) How is *only* the water level raised in an expansion tank?
   a. Open the air vent valve until desired water level is obtained.
   b. Open the blowdown valve until desired water level is obtained.
   c. Close the air vent valve until desired water level is obtained.
   d. Open the safety relief valve until desired water level is obtained.

Please read the unit menu for unit 5 and continue ➔

Unit 5. Contingency Heating Equipment

5–1. WH-400 5–1
646. General description and skid assembly 5–1
647. WH-400 systems 5–3
5–2. 130K Heater 5–4
648. Theory of operation 5–4
649. Main component group descriptions 5–7

YOU MADE IT to the last unit of this volume and now it is time to cover contingency equipment. This unit will cover the WH-400 water heater and the 130K heater. These two pieces of equipment are absolutely critical to operations in a contingency environment. There are some very cold places on this Earth and this equipment provides heating capabilities anywhere our troops need to go.

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 for the sake of this CDC you will be required to study and know the theory of operation of both pieces of equipment. This will help when you are in the field working on this equipment with your technical order.

5–1. WH-400

WH-400 gets its name because it is a *Water Heater* that has a capacity of 400,000 BTU's (fig. 5–1). The purpose of the WH-400 is to provide hot potable water in a field environment. Hot water availability is critical in the field. It is primarily used for sanitary purposes, such as washing dishes and taking showers. In this unit you will learn about the theory of operation for the WH-400. The theory of this equipment is crucial as you develop your HVAC/R warrior ethos. Further training on this equipment is completed at Silver Flag. But for now, all you need to be concerned with is the theory of operation.

646. General description and skid assembly

In this lesson we discuss the general description of the water heater, its skid assembly, and concludes with general safety warnings.

NOTE: To avoid any confusion this information is verbatim from the technical order TM10-4520-266-13&P, *Heater, Water, 400,000 BTU*. The only difference is the formatting of the information.

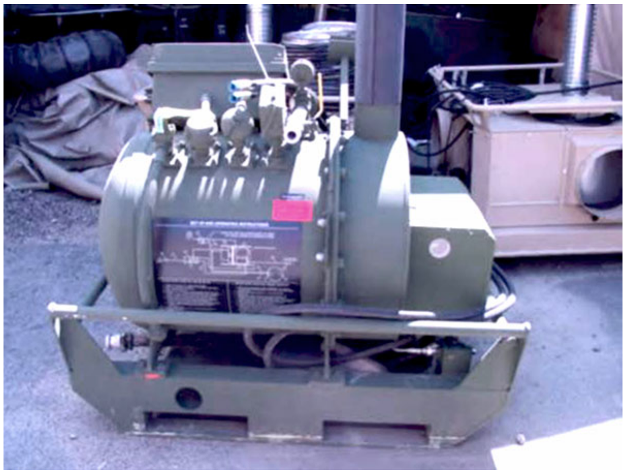

Figure. 5–1. Water Heater 400.

General description

The WH-400 is designed for use as the primary water heater for the US Army. The concept of operation involves a skid-mounted vessel holding approximately 23 gallons of water being heated by a fuel oil burner. The heater is a motor-driven fuel pump that supplies diesel fuel to the burner. It possess a blower assembly with an adjustable air louver which provides the required air to the combustion chamber. Combustion is initiated when the operator activates the power switch, which inturns sends 110 VAC power to the transformer, which powers two electrodes. Combustion gases are vented through a stack and water enters and exits the vessel through separate inlet and outlet manifolds.

Skid assembly

The skid is a welded assembly that consists of the basic skid handrail. The skid incorporates forklift pockets for handling the heater and provides a stable platform for heater operation. Use care when connecting the power plug to the power inlet receptacle.

CAUTION: Remove rings, watches, and other metallic objects that may cause shock or burn hazards. Electrical high voltage cannot be seen and gives no warning or symptoms to be wary of, but it can kill you, render you unconscious, or severely burn you. Failure to do so may result in injury or death to personnel.

General safety warning description

In the following table you will find WH-400 safety warning, these warnings are referenced directly from the technical manual.

WH-400 Safety Warnings
DO NOT operate the WH-400 in an indoor space or where products of combustion can accumulate in an indoor space. These products of combustion can contain unsafe levels of carbon monoxide. Exposure to carbon monoxide can lead to injury or death.
DO NOT use the WH-400 if any part has been under water. Immediately contact service maintenance to inspect the unit and replace any part of the control system, and any other items affecting safe operation. Failure to follow these instructions may result in property damage, personal injury or loss of life.
DO NOT allow hot water to come in contact with skin. Water that is 140°F requires only 5 seconds to inflict a second degree burn. Failure to prevent water from contacting skin may causes burns or other serious injury.
Electrical high voltage cannot be seen and gives no warning or symptoms to be wary of but it can kill you, render you unconscious, or severely burn you. To ensure your safety and that of other maintenance personnel, always disconnect equipment from external power before attempting maintenance. Failure to do so may result in injury or death to personnel.
DO NOT store or use gasoline or other flammable vapors and liquids in the vicinity of the WH-400. Storage of or use of gasoline or other flammable vapors or liquids of the WH-400 may result in property damage, personal injury, fire, explosion, exposure to hazardous materials, or death.
Never use the WH-400 with any fuel other than DF-1, DF-2, and JP-8. Igniting the burner with another type of fuel could result in property damage, serious injury, or death.
Fuel is toxic and highly flammable. Be sure to place a petroleum absorbent mat or tray below the immediate work area to collect any fuel. Wear protective gloves and be sure to wipe up any spills with rags. Dispose of rags in accordance with unit's SOP and local environmental regulations. Avoid contact with skin, eyes, and clothes and don't breathe vapors. Failure to observe this warning may cause injury or death to personnel.
Do not attempt to connect a fuel line to the WH-400 in the vicinity of any open flame. Ensure that the fuel hose connections are made properly to avoid fuel spillage. Prevent a possible fire hazard by having rags on hand to absorb any spillage. Failure to observe safety precautions may result in injury or death to personnel.

Self-Test Questions

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

646. General description and skid assembly

1. How is the 23 gallons of water heated?

2. What provides the required air to the combustion chamber?

3. How are combustion gases vented through a stack?

4. What two parts form the skid?

5. What could result if the WH-400 is operated after it has been under water?

6. What action ensures safety before attempting maintenance?

7. What could result if gasoline is stored in the vicinity of the WH-400?

647. WH-400 systems

Now the theory of operation for each system of the water heater will be covered. This includes the power and fuel system, electrode/nozzle assembly, flame safeguard control, and temperature control system.

Power system

The WH-400 operates on 208 VAC power. A power source, either commercial or appropriate generator, must be connected to the receptacle on the control box assembly. When the control switch is in the ON position, power is conveyed to the electrodes through a transformer and ignition springs.

Fuel system

The WH-400 operates on the fuels specified under Equipment Data in technical manual WP 0002, TM10-4520-266-13&P, *Heater, Water, 400,000 BTU*. Fuel is drawn by the fuel pump through the fuel supply hose connected to the fuel filter and the SUPPLY fitting located on the Fuel Drum Adapter, installed on a 55-gallon fuel drum. Excess fuel is returned through a fuel return hose connected to the bottom of the fuel pump and the RETURN fitting on the Fuel Drum Adapter.

Electrode and nozzle assembly

The electrode and nozzle assembly at the center of the combustion chamber serves as a mounting platform for the fuel nozzle, head assembly, and two electrodes. The nozzle sprays a fuel mist that is ignited by sparks from the electrodes.

Flame safeguard control

The flame safeguard control system uses a CAD cell flame sensor mounted on the burner to monitor the flame within the combustion chamber. The flame safeguard control system shuts the heater down when combustion fails.

Temperature control system

The system consists of the operating and high limit controls. The operating control maintains water temperature between 100°F and 210°F. The high limit control will deactivate the fuel solenoid valve when the temperature exceeds 190°F.

Self-Test Questions

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

647. WH-400 systems

1. How is the power source connected to the control box assembly?

2. How is fuel drawn through the fuel supply hose?

3. What serves as a mounting platform for the fuel nozzle and head assembly?

4. How does the flame safeguard control system monitor the flame?

5–2. 130K Heater

The contingency heating system we will cover in this section can be described in many ways. According to its' technical manual it is a "Heater, 130K, multi-fueled, portable, duct type, 130,000 BTUH model Polar Bear1, with a National stock number of 4520-01-521-2076EJ. Wow, that is a comprehensive description. Commonly this system is called the 130K heater. For the sake of this discussion we will call it the *130K heater* and in this section we will cover its theory of operation. Further training on the operation and troubleshooting of this system will be covered in your Silver Flag training.

648. Theory of operation

The theory of operation for this system is covered in TO 35E7-3-4-1, *130K Heater* in chapter 4-2. To ensure a comprehensive understanding of the 130K's heater theory of operation ensure to refer to your trainer, the TO and the information provided within this lesson.

Theory of operation

The following text describes the operation cycle of this heater. The heater function consists of four types: (1) manual mode, (2) automatic mode, (3) vent mode, and (4) stop heating. The following table provides a description of each.

Heater Function Types	
Functions	**Description**
Manual Mode	This heater is activated by turning the heat control switch to either low, med, or high heat. Selecting a heat setting activates the heater control unit (HCU), which monitors the status of combustion components through thermostatic sensors. Select MANUAL on Mode switch.
	When a heat setting (LOW/MED/HIGH) is selected, HCU compares reading of outlet air sensor with programmed values of HCU. If sensor temperature is lower than programmed value (which is always case during initial startup), the HCU energizes the fuel burner motor and spark igniter, inturn activates the burner control unit (BCU). The fuel burner motor drives an integrated combustion air blower and high-pressure fuel injection pump of burner.
	Once activated, the BCU performs a 3 to 4 second self-test of all its functions, a 10-second pre-purge of the Combustion Chamber, and then opens solenoid valve (SV) of burner. High-pressure injection pump forces fuel through the valve and injection nozzle, where fuel is atomized and sprayed into combustion chamber. He spark between igniter electrodes ignites atomized fuel.
	After ignition, the BCU monitors combustion through a photocell located inside the burner tube. If a flame is not established within 15 seconds (photocell “sees” no light) after fuel valve is opened, the BCU closes alarm contacts and LED display indicates burner failure by a blinking text “Brn”. If the flame is lost during normal operation for more than 1.2 seconds, the BCU will perform a 65 second safety recycle and start burner again.
	Once a constant flame is established, the HCU monitors the temperature inside the heater body through chamber sensor, fan control (SFC). When the heater inside temperature reaches 140 °F, the HCU starts the main air blower through contactor K1. If the temperature is not reached within 45 seconds, the HCU will start the blower through a timer function. The blower now produces a steady clean airflow through heater and outlet air adapter.
	The HCU continues to monitor the temperature in outlet air through sensor, burner control (SBC). When upper limit of selected temperature setting is reached, the HCU deactivates the BCU. The BCU in turn closes fuel valve of burner and flame is extinguished. The main air blower continues operating, cooling heat exchanger surfaces until outlet air temperature falls below lower limit. The HCU senses this through the SBC and combustion cycle is repeated. During heater operation control panel display provides constant reading, in five degree increments, of outlet air temperature.
Automatic Mode	In automatic mode, the burner on-off cycles are controlled by the remote thermostat. To switch to automatic, the remote thermostat cable must be connected to the heater control box and the thermostat placed in a central location in the space to be heated. Select the HIGH setting on heat control switch, AUTO on mode switch, and set remote thermostat desired temperature.
Vent Only Mode	This heater can be operated in “Vent Only” mode by turning the heat control switch to the VENT position. The HCU starts the main air blower through contactor K1. Un-heated air flow for ventilation will be maintained as long as heat control switch remains in vent position.

Heater Function Types	
Functions	**Description**
Stop Heating.	When the heat control switch is turned to Stop, the HCU deactivates the BCU, which closes the fuel valve, extinguishing flame. Combustion components are still very hot, so to avoid damage and deterioration to these components, the HCU has an after-cooling function. The HCU monitors the SBC temperature and will keep the main blower operating until the chamber has cooled down sufficiently (approximately 2 Minutes). During after-cooling, display reads AFC. Once temperature has reached safe levels and HCU deactivates main air blower, display will read “OFF”. This indicates it is safe to disconnect power cable.

Self-Test Questions

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

648. Theory of operation

1. What effect will turning the heat control switch to high heat?

2. What two values are compared by the HCU when a heat setting is selected?

3. What effect does the spark between the electrodes have on the atomized fuel?

4. What effect does “no flame established within 15 seconds” have on the BCU?

5. What effect will a lost flame during normal operation for more than 1.2 seconds have on the BCU?

6. What happen with the HCU if temperature is not reached within 45 seconds?

7. What will the HCU do to the BCU when the upper limit of selected temperature setting is reached?

8. Where would you read the outlet air temperature display?

9. Where must the remote thermostat cable be connected for the system to run in Automatic?

10. What occurs after the heat control switch is placed in VENT position?

649. Main component group descriptions

Now we will continue our discussion by describing the main component groups. Understanding the main component groups will further your understanding of the theory of operation.

Main component group description

Major component groups are the combustion component group, controls group, fuel group, and control panel. The following table provides descriptions of each.

Combustion Component Group	
Fuel Burner	The fuel burner (fig. 5–2) a standard, commercial fuel burner. It consists of an electric motor to drive combustion air blower and high-pressure fuel injection pump, and an ignition transformer, all of which are visible and accessible outside of burner frame.
	Fuel ignition points and fuel nozzle, together with photocell, are located inside the burner tube which, when the burner is mounted, extends inside combustion chamber. A separate BCU is located inside heater's control box. Burner electric motor, SV, and ignition transformer are all controlled by HCU and BCU. When HCU is activated for heat, BCU starts the burner motor and ignition, and, after a safe purge period of ten seconds, energizes SV to open position allowing fuel to flow through nozzle into combustion chamber. SV closes when upper limit of air outlet temperature has been reached.
	Burner is operated under intermittent spark ignition system. Spark is on for 15 seconds in beginning of burner on- cycle. At the beginning and end of every on-off cycle of the burner, electric motor driving injection pump and combustion air blower performs a 10-second purge cycle. This purge airflow through combustion chamber is a safety feature—the chamber is purged free from residual fuel. Setting fuel injection pressure to 140 pounds per square inch (PSI) and adjusting combustion air for best performance brings combustion efficiency and cleanliness to an optimum.
	NOTE: Fuel pressure shall never be adjusted above given value of 140 PSI.
	Revolutions per minute (RPM) of the burner motor has no direct bearing on injection pressure. Pressure is controlled by a pressure valve and remains constant at set value.
	Regardless of selected output temperature range (LOW-MED-HIGH), injection pump pressure is always constant. Different output temperatures are maintained automatically by cycling burner on and off accordingly, controlled by the HCU.
Combustion Chamber	The heater combustion chamber (fig. 5–2) houses the fuel burner tube and provides an exit route for exhaust gases. Flame is contained inside the burner chamber; only hot exhaust gases exit chamber to heat exchanger.
Photocell	Located inside the burner tube is a photocell which monitors existence of flame inside combustion chamber. The photocell is mounted on a holder and wired to the BCU. Resistance of photocell varies by the intensity of light present. When cadmium sulphide in the photocell is exposed to light, its normally high resistance becomes very low. This reduced resistance of photocell in presence

Combustion Component Group	
	of light is used by the BCU to verify presence of flame. This is one of safety features of BCU.
Heat Exchanger	Hot combustion exhaust gases pass through the heat exchanger (fig. 5–3) during burner operation. Thermal energy is conducted and transferred into discharge air, which is blown past heat exchanger channels by main air blower. Exhaust gases remain completely separated from heated air and exit through exhaust opening (5) and exhaust duct extension into open air.
Main Air Blower	Heater blower (fig. 5–1) operates at a nominal 1000 cubic feet per minute (CFM) and forces heated air through heater housing, around the burner chamber, and through the heat exchanger. Thermal energy is transferred from hot surfaces of combustion components into circulating air. Heated air is directed where required via flexible ducts. Electric motor driving blower is a 120 Volt 60 Hz integral motor running at 1700 RPM.

Controls Group	
Electrical System	Heater is powered by 120 VAC, 60/ 50 Hz electric current. The maximum external circuit breaker size 20A. Electrical system operates and controls heating functions.
Control Box	Control box includes all main control components required for function of the heater. See figure 5–5 for control panel components, figure 5–6 for components inside the control box for wiring diagrams.
	Panel Light Switch (fig. 5–5) activates the panel light to illuminate the panel and short operating instructions located on panel door.
	Heat Control Switch (fig. 5–5) is used to select “LOW”, “MED” or “HIGH” temperature settings or “VENT” for unheated air flow only. Combustion begins once a temperature setting is selected. Combustion cycles are controlled by the HCU and BCU.
	Outlet Air Temperature/Heater Status Display (fig. 5–5) displays outlet air temperature in 5 °F increments. It also displays messages about heater status. Display is an integral part of HCU.
	Flame Failure Reset Button (fig. 5–5) reactivates the burner in case of a flame failure.
	Heater hour meter (fig. 5–5) displays total number of hours of heater operation.
	NOTE: The following active control components control various heater functions.
Heater Control Unit (HCU)	HCU is located inside the control box (fig. 5–6). The HCU is a microprocessor equipped control unit that controls cycling of burner and main air blower according to the heater control switch setting and signals received from SBC and SFC. HCU also includes digital displays indicating outlet temperature, function, and failure messages. An overheat shutoff is a safety function of the HCU. ***NOTE:*** HCU functions and switching points are described as follows in the remaining table.
Sensor, Fan Control (SFC) Controlled Functions	SFC is located in controls/burner compartment front wall, with sensor tip extending close to combustion chamber next to the fuel burner. ***NOTE:*** By monitoring chamber temperature, HCU performs the following operational and safety features.

Controls Group	
	CAUTION: If the main air blower fails to operate when temperature reaches 140 °F, for a period exceeding 45 seconds, turn the heater control switch to “stop”. Allow the unit to cool and determine the cause of malfunction to avoid damage to heat exchanger.
	a. After any of the three temperature settings available has been selected on the heat control switch, the HCU activates the main air blower ON at chamber sensor temperature 104°F, or 45 seconds after burner is started, whichever occurs first. The main air blower is switched on through contactor K1 (fig. 5–5, 8).
	b. When the operator has turned the heater off by switching the heater control switch to “stop”, the HCU switches main air blower off automatically at completion of after-cooling period.
	c. When the protective overheating switch is turned off, that normally occurs when airflow is blocked by kinked ducts or a blocked main air blower intake. When chamber temperature reaches 194 °F, the HCU shuts off burner. Forced cooling continues until chamber has cooled down. The burner will re-ignite automatically and an error signal is not displayed.
Sensor, Burner Control (SBC) Controlled Functions	SBC and the separate high limit switch senses outlet air temperature. This information is used as follows: a. **Low Capacity Temperature Control:** When the heater control switch is placed in “LOW” position, the HCU cycles burner off and on to keep outlet temperature at an average between 80 and 140 °F.
	b. **Medium Capacity Temperature Control**: When the heater control switch is placed in “MED” position, the HCU cycles burner off and on to keep outlet temperature at an average between 100 and 160 °F.
	c. **High Capacity Temperature Control:** When the heater control switch is placed in the “HIGH” position, the HCU cycles burner off and on to keep outlet temperature at an average between 120 and 180 °F.
	Additional Safety Item: High Limit Switch is located at the air outlet. This safety device is set at 225 °F. Should this be exceeded, the switch will deactivate the HCU, and the burner will be shut off.
	d. Error overheat limit for the SBC is set at 212 °F outlet air temperature. When activated, the HCU shuts the burner off. Forced cooling continues for five minutes. A blinking “HI” error signal will display.
Burner Control Unit (BCU)	BCU is located inside control box (fig. 5–6). The BCU is a microprocessor- equipped control unit which controls functions and safety of fuel burner. Combustion is cycled by opening and closing SV on burner. Pre- and post-purge flushing of combustion chamber ensures that uncombusted fuel will not collect in burner chamber and cause explosion hazard. The main function of BCU is *COMBUSTION SAFETY*. For that purpose, various operational steps are automatically performed by BCU.

Controls Group	
	a. **Self-Test and Pre-Purge.** At the beginning of each burner cycle (when heat is called for by HCU), the BCU performs a 3-4 second self-test of its functions before entering pre-purge phase. After self-test, the BCU performs a 10-second pre-purge operation by allowing burner blower to rotate for ten seconds before activating the SV to open for fuel injection and starting ignition.
	b. **Trial for Ignition (TFI).** After opening the SV and starting ignition spark, the BCU monitors resistance reading of photocell located inside the fuel burner. If a flame is not established within 15 seconds after opening of fuel valve, the BCU will go into a "flame failure" state, close the solenoid fuel valve and activate the burner failure display message. Reset by momentarily pressing the burner failure reset button on the control panel.
	NOTE: If the heater has run out of fuel, a burner failure message may illuminate during the first start-up after refueling; reset as above. Resetting once or twice will allow the burner injection pump to bleed itself automatically.
	c. **Lock-out.** If the BCU detects a flame failure at initial start-up or later during the operation, it will enter Lock-out status, closing the fuel valve. A "Blinking "Brn" message is displayed on control panel display. Reset by momentarily pressing the burner failure reset button on control panel.
	d. **Latch-up.** If the BCU locks out and is reset three (3) times during the same burner cycle, a latch-up state will occur. To reset from latch-up, push the burner reset button and hold it down for 60 seconds, then release. The burner will restart automatically.
	e. **Loss of Flame.** If, after a successful TFI, flame is lost during the normal burner "on" cycle for more than 1.2 seconds, the BCU will perform a 65 second recycle period and restart automatically. Loss of flame may occur if there are air or water bubbles in fuel, clogged nozzle, etc.
	f. **BCU Function Indicators.** There are two indicator LED's on the BCU, visible only after opening the control box cover.

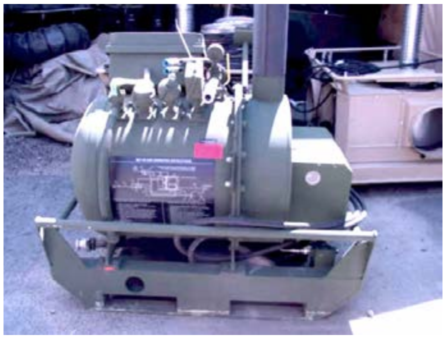

Figure 5-1. Major Operating Components

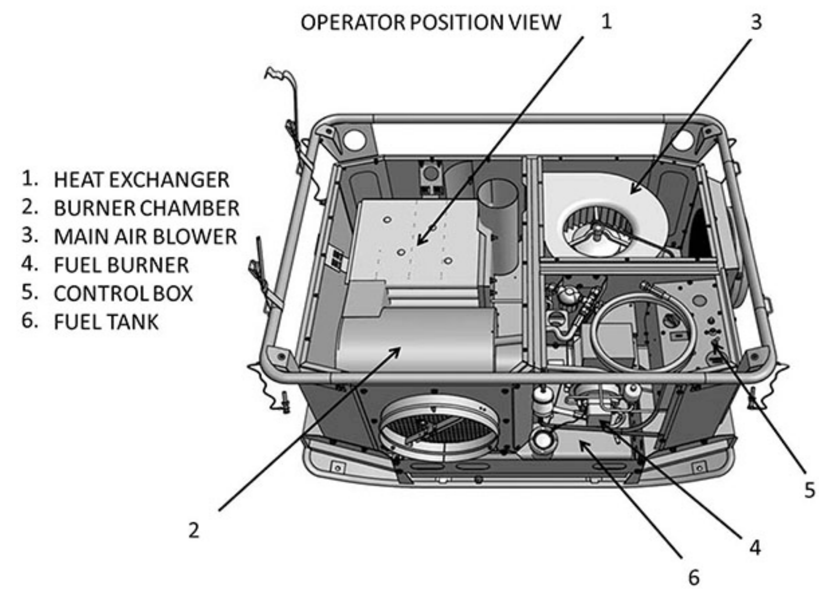

Figure 5-2. Combustion Key Components

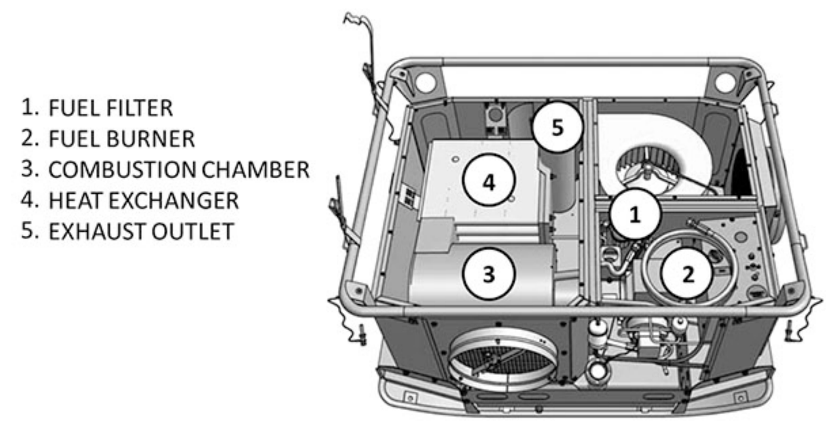

Figure 5-3. Circulation Air Flow

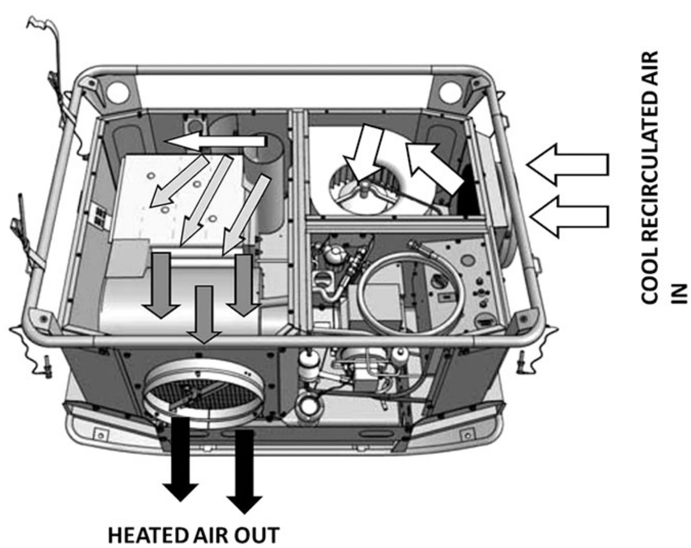

Figure 5-4. Control Panel

1. HEATER CONTROL SWITCH (TEMPERATURE RANGE SELECTION)
2. HEATER MODE SWITCH (AUTO/MANUAL)
3. FUNCTION DISPLAY (AIR TEMPERATURE/ MESSAGES)
4. FLAME FAILURE RESET
5. CIRCUIT BREAKER RESET
6. CONTROL PANEL LIGHT
7. PANEL LIGHT SWITCH
8. HEATER HOUR METER
9. MAIN ON INDICATOR (POWER PRESENT)

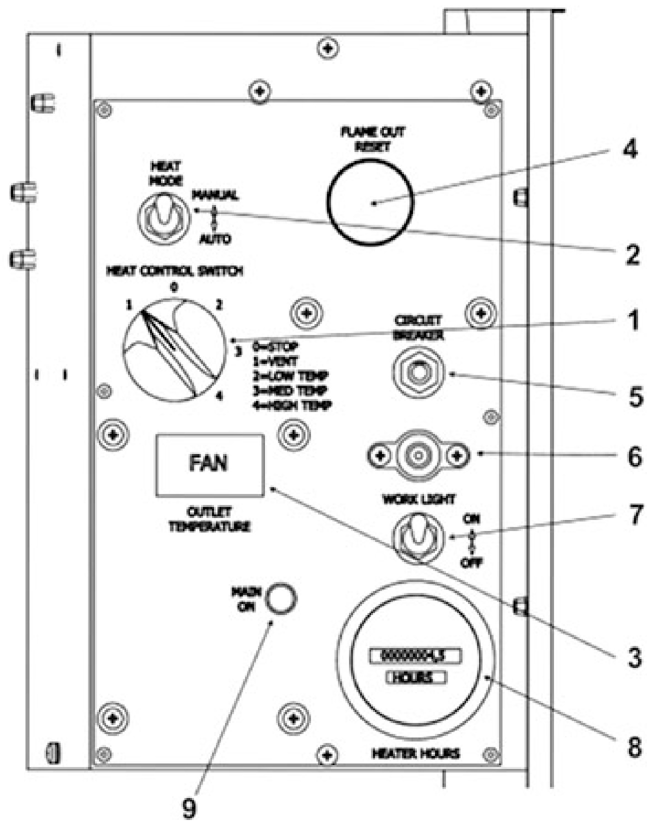

Figure 5-5. Heater control box (cover open).

Fuel Group	
Fuel Group	Heater fuel system (fig. 5–6) consists of an all-metal 21-gallon fuel tank fitted with a mechanical float-type fuel gauge/refill cap. A separate filler strainer is provided inside the burner/control compartment. The fuel tank provides fuel for heater operations. Alternatively, fuel can be drawn from an external fuel tank via fuel hose provided. A three-way fuel valve is used to select the fuel source used. See figure 5–6 for valve positions. The fuel burner has a high-pressure injection pump. This pump draws fuel from the fuel tank through a burner fuel filter, then pumps fuel through the SV into burner nozzle.

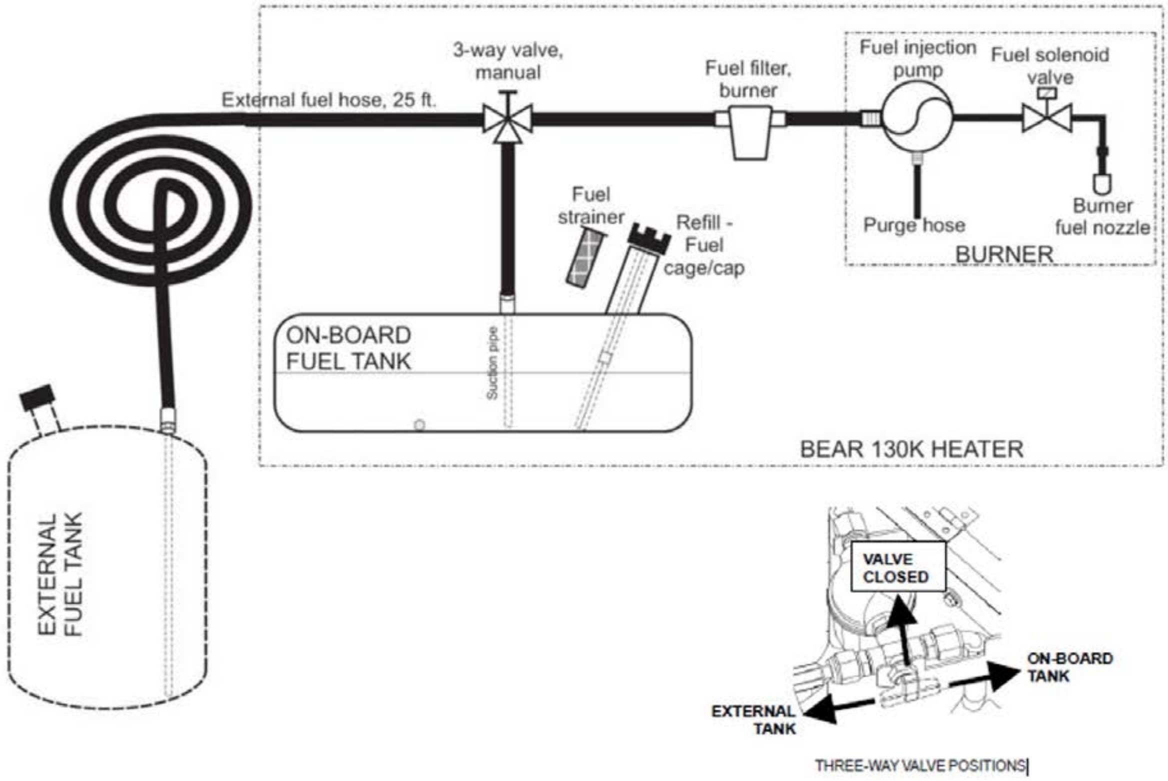

Figure 5-6. Fuel System.

Control Panel Display Messages	
OFF	Heat Control Switch in “STOP” position, power source connected. The heater is cool/cold and the burner is off. The main air blower is off after cooling and the power cable can be disconnected.
AFC	Heat Control Switch turned from HIGH, MED, or LOW output setting to “STOP” position. After-cooling (AFC) is in process. Main air blower is still on. DO NOT disconnect power cable before display shows “OFF”.
FAN	Heat Control Switch in “VENT” position. Main air blower is blowing. No heating; burner is off.
LO	Heat Control Switch in “HIGH/MED/LOW.” Air outlet temperature 39 °F or less. The burner is on but has not yet raised the outlet temperature above 39 °F.
	NOTE: LO and/or HI (Blinking) error message situations can be corrected by turning the heat control switch momentarily to the “stop” position, then back to the heating position.
LO	(Blinking): The burner has been on for at least five minutes and air outlet temperature is below 32 °F. Probable cause of this condition is either sensor/sensor wiring problem or burner failure. To Reset, see the **NOTE** above.
HI	(Blinking): Error outlet air overheating (225 °F or above) situation, sensor problem or sensor wiring problem. Forced main air blower cooling occurs. To Reset, see the **NOTE** above.

Self-Test Questions

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

649. Main component group descriptions

1. Where are the fuel ignition points, fuel nozzle and photocell located?

2. What controls the burner electric motor, SV and ignition transformer?

3. What type of spark ignition system does the 130K heater have?

4. What occurs at the beginning and end of every on-off cycle of the burner?

5. What effect does light have on the resistance to cadmium sulphide?

6. What effect would a chamber temperature of 194 degrees have on the burner?

7. How does the system operate when heater control switch is placed in the “LOW” position?

8. How does the system operate when heater control switch is placed in the “MED” position?

9. How does the system operate when heater control switch is placed in the “HIGH” position?

10. What is the high limit switch set point?

11. How are the functions and safety of the fuel burner controlled?

12. What occurs after the system performs a self-test?

13. How do the burner and main air blower operate in if the heat control switch is in “VENT”?

14. What is the probable cause if the burner has been on for five minutes and the air outlet temperature is below 32 degrees?

Answers to Self-Test Questions

646

1. By a fuel oil burner.
2. Blower assembly.
3. Through a stack.
4. The basic skid and handrail.
5. Property damage, personal injury or loss of life.
6. Disconnect equipment from external power.
7. Property damage, personal injury, fire, explosion, exposure to hazardous materials, or death.

647

1. To the receptacle.
2. The fuel pump.
3. Electrode and nozzle assembly.
4. A CAD cell flame sensor.

648

1. The heater is activated.
2. The outlet air sensor with programmed values of HCU.
3. It ignites the fuel.
4. BCU closes alarm contacts and LED display indicates burner failure by a blinking text.
5. It will perform a 65 second safety recycle and start the burner again.
6. HCU will start blower through a timer function.
7. Deactivate the BCU.
8. On the control panel display.
9. Heater control box.
10. HCU starts main air blower through contactor K1.

649

1. Inside the burner tube.
2. HCU and BCU.
3. Intermittent spark ignition system.
4. A 10 second purge cycle.
5. Resistance becomes low.
6. The HCU shuts off the burner.
7. HCU cycles burner off and on to keep outlet temperature at an average between 80 and 140 °F.
8. HCU cycles burner off and on to keep outlet temperature at an average between 100 and 160 °F.
9. HCU cycles burner off and on to keep outlet temperature at an average between 120 and 180 °F.
10. Degrees Fahrenheit.
11. By the BCU microprocessor equipped control.
12. A 10 second pre-purge.
13. Main air blower is blowing and the burner is off.
14. Either the sensor or sensor wiring or burner failure.

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).

94. (646) How is diesel fuel supplied to the combustion chamber on a WH–400 system?
   a. Venturi action.
   b. Manual hand valve.
   c. A belt driven fuel pump.
   d. A motor-driven fuel pump.

95. (647) How is the fuel mist ignited in a WH–400 system?
   a. Sparks from the electrodes.
   b. The BCU lights the mist with 120 volts.
   c. The HCU lights the mist with 120 volts.
   d. Sparks from the solenoid valve and HCU.

96. (648) When will the heat control switch (HCU) energize the fuel burner motor and spark igniter on 130K heater?
   a. After a 15 second delay.
   b. After a 15 minute delay.
   c. If sensor temperature is higher than programmed value.
   d. If sensor temperature is lower than programmed value.

97. (648) Identify what the burner control unit do after ignition on a 130K heater.
   a. Monitors combustion through a photocell.
   b. Immediately initiates post purge.
   c. Immediately initiates pre purge.
   d. A 35 second safety recycle.

98. (649) Identify the *maximum* circuit breaker size for a 130K heater.
   a. 3A.
   b. 15A.
   c. 20A.
   d. 35A.

99. (649) When does the “protective overheating switch-off” occur on a 130K heater?
   a. When combustion won’t start.
   b. When air flows freely in ducts.
   c. When fuel solenoid valve is stuck closed.
   d. When airflow is blocked by kinked ducts or blocked main air blower intake.

100. (649) Which state will occur if the burner control unit (BCU) locks out and is reset three times during the same burner cycle on a 130K heater?
   a. Lock-up.
   b. Latch-up.
   c. Closed-up.
   d. Opened-up.

Glossary of Abbreviations and Acronyms

AC	alternating current
AFC	after cooling
AFI	Air Force instruction
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
BCU	burner control unit
BS&W	bottom sediment and water
BTU	British thermal unit
C	Celsius
Cad	Cadmium
cds	cadmium sulfide
CFM	cubic feet per minute
CO	carbon monoxide
CO_2	carbon dioxide
CPVC	chlorinated polyvinyl chloride
DC	electric voltage; direct current
EPA	Environmental Protection Agency
F	Fahrenheit
FFRT	flame failure response time
FL DET	flame detector
FSC	flame safeguard control
ft.	foot/feet
gal	gallons
GPM	gallons per minute
HCU	heater control unit
HDPE	high-density polyethylene
hp	horsepower
HVAC/R	heating, ventilation, air conditioning and refrigeration
Hz	hertz
I/O	input/output
K	Kelvin
kPa	Kilopascal
kw	kilowatt
L	length
lb.	pound
LED	light emitting diode
LPG	liquefied petroleum gas
m	meter
MRT	mean radiant temperature
MSOV	manual shutoff valve
NC	normally closed

NFPS 31	National Fire Protection Standard 31
O_2	oxygen
OD	outside diameter
osig	ounces per square inch gauge
pH	potential of hydrogen
PM	preventative maintenance
PRV	pressure-regulating valve
psi	per square inch
psig	per square inch gage
rpm	revolutions per minute
SFC	sensor fan control
SSOV	safety shutoff valve
SV	solenoid valve
TFI	Trial for Ignition
TO	technical order
USB	Universal Serial Bus
UST	underground storage tanks
UV	ultraviolet
VAC	voltage, alternating current
WC	water column

Student Notes

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