•••POWER ENGINEERING

Fourth Class

Edition 3.5

Boiler Safety Devices

Part B

Unit B-3

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Partner in Education

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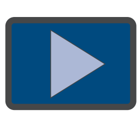
MEDIA 	Media icons show that some form of supporting medium is available. These media may include videos, animations, 2D and 3D models, multi-views of cutaways, simulations, and more. Media elements are available to registered textbook purchasers online via MyPower Study.
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4th Class Edition 3.5 • Part B

UNIT B-3

BOILER SAFETY DEVICES

Unit Introduction

Safety is of paramount concern for owners, operators, designers, installers, and maintainers of regulated pressure equipment. The devices that are used to measure and control conditions within these systems are critical for ensuring their safe operation.

This unit discusses the design and operation of pressure relief valves, firing controls, low water level instruments, and a variety of boiler fittings. Because they must comply with jurisdictional regulatory requirements, they must be designed and operated in alignment with a variety of national and international codes including **ASME Section I, ASME Section IV, ASME Section VIII, ASME CSD-1, and CSA B51**.

Safe operating conditions most often include placing combustion management and water levels at the top of the operational priority list. Because many pressure systems operate under fired conditions it is important to understand the design of components that contribute to the safe operation of burner systems, such as burner management and firing controls. Low water conditions are the most common cause of pressure vessel explosions. The use of reliable water level instruments is imperative for avoiding this often preventable condition.

The use of devices directly attached to the pressure part of a boiler, called fittings, are also regulated under the same codes as boilers themselves. They are necessary for the efficient and safe operation of the boiler and other pressure vessels.

Unit Rationale

The Power Engineer is the principal operator and manager of all regulated pressure vessel systems both fired and unfired. The knowledge of their design, construction, installation, operation, maintenance, and troubleshooting of all equipment, auxiliaries, fittings, and safety devices is central to the Power Engineer's body of knowledge, and makes them unique in their preparation for this role.

Chapter 1

Pressure Relief Valves

Learning Outcome

When you complete this chapter you should be able to:

Explain the code requirements, design, and operation of pressure relief valves for power boilers, heating boilers, and pressure vessels.

Learning Objectives

Here is what you should be able to do when you complete each objective:

1. *Discuss the code requirements, construction, and operation of ASME Section I Pressure Relief Valves and Devices.*
2. *Discuss the code requirements, construction, and operation of ASME Section IV Pressure Relief Valves and Devices.*
3. *Describe the testing and repair of pressure relief valves.*
4. *Describe the construction and operation of temperature and pressure relief valves.*

Chapter Introduction

Boilers, pressure vessels, and pressure piping systems are designed to operate below a specific maximum working pressure. The basic function of pressure relief valves is to protect equipment from damage due to over pressurization. These automatic valves are installed on all pressure equipment, in order to prevent explosions due to over-pressurization. When the pressure approaches a maximum allowable value, pressure relief valves open to release potential energy, thus preventing any further pressure increase.

Pressure relief valves are (with some exceptions) completely mechanically actuated. Because they rely on no outside source of power or external control signals, they are the last reliable line of defense between safe equipment operation and catastrophic pressure explosion. For this reason, pressure relief valves must be carefully selected, installed, tested, maintained, and repaired.

This chapter discusses the design, construction, installation, and operation of pressure relief valves. As well, this chapter contains numerous references to **ASME Section I, ASME Section IV**, and **ASME Section VIII**. The specified sections of these codes should be referenced in the **PanGlobal ASME Academic Extract** while reading this chapter.

Objective 1

Discuss the code requirements, construction, and operation of ASME Section I Pressure Relief Valves and Devices.

Definitions

Pressure relief valves automatically open to relieve pressure, and then automatically reclose. They exist in many different varieties. **ASME PTC-25 Pressure Relief Devices** defines 11 different types.

The many terms used to categorize pressure relief valves can be quite confusing. The words "safety valve," "relief valve," "safety relief valve" and others are used indiscriminately. This is likely because all pressure relief valves have great similarity in construction, operation, and purpose. They are all actuated by, and relieve, pressure from pressurized equipment. They all have pressure set points and capacities. They even look similar.

However, each valve has distinct operating characteristics and applications. Therefore, it is important that the term used to describe each type is accurate and does not create confusion.

ASME BPVC I, Part PG-73.1.4 states:

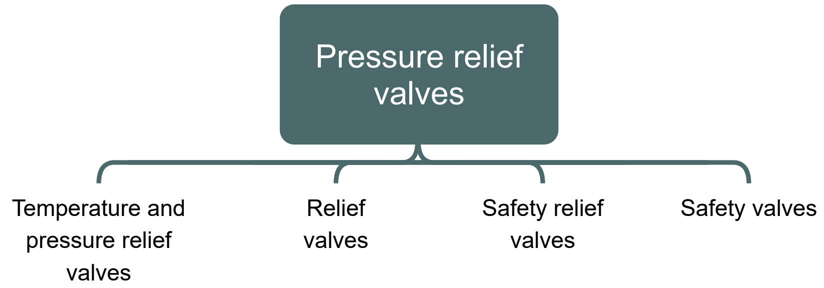
> *Unless otherwise defined, the definitions relating to pressure relief devices in **ASME PTC-25** shall apply.*

ASME PTC-25 Pressure Relief Devices defines pressure relief valves as follows:

> **Pressure Relief Valve:** *a pressure relief device designed to actuate on inlet static pressure and reclose after normal conditions have been restored.*
>
> **Temperature and Pressure (T&P) Relief Valve:** *a pressure relief valve that may be actuated by pressure at the valve inlet or by temperature at the valve inlet.*
>
> **Relief Valve:** *a pressure relief valve characterized by gradual opening that is generally proportional to the increase in pressure. It is normally used for incompressible fluids.*
>
> **Safety Relief Valve:** *a pressure relief valve characterized by rapid opening or by gradual opening that is generally proportional to the increase in pressure. It can be used for compressible or incompressible fluids.*
>
> **Safety Valve:** *a pressure relief valve characterized by rapid opening and normally used to relieve compressible fluids.*

Figure 1 summarizes the main types of pressure relief valves Power Engineers encounter. Note that the term "pressure relief valve" refers to all forms of reclosing pressure relief devices.

Figure 1 – Pressure Relief Valves, According to ASME PTC-25



On Track

The acronym PRV may stand for pressure relief valve or for pressure reducing valve. In this chapter, the acronym PRV will only be used for pressure relief valve.

ASME Boiler and Pressure Vessel Code Section I (BPVC I) Requirements

ASME BPVC I, Part PG-67.1 states:

> *Each boiler shall have at least one pressure relief valve and if it has more than 500 ft^2 (47 m^2) of bare tube water-heating surface, or if an electric boiler has a power input more than 1100 kW, it shall have two or more pressure relief valves.*

PG-67.2 states:

> *The pressure relief valve capacity for each boiler (except as noted in **PG-67.4**) shall be such that the pressure relief valve, or valves, will discharge all the steam that can be generated by the boiler without allowing the pressure to rise more than 6% above the highest pressure at which any valve is set and in no case to more than 6% above the maximum allowable working pressure.*

ASME BPVC I, Part PG-68 addresses the rules that govern superheater and reheater PRVs. **PG-68.1** states: *"the pressure drop upstream of each pressure relief valve shall be considered in the determination of set pressure and relieving capacity of that valve."*

This means that the set pressure of a superheater safety valve must take into consideration that the steam pressure will drop as it flows from the steam drum to the superheater outlet. If set to the steam drum pressure, safety valves on superheaters would likely never open. In an overpressure situation, steam flow through the superheater would cease. The superheater tubes would overheat due to the loss of the cooling steam.

Therefore, a superheater PRV must open before the drum PRVs do. They will also close after the drum PRVs. This ensures that the superheater will always have steam flow.

Safety Valve Construction

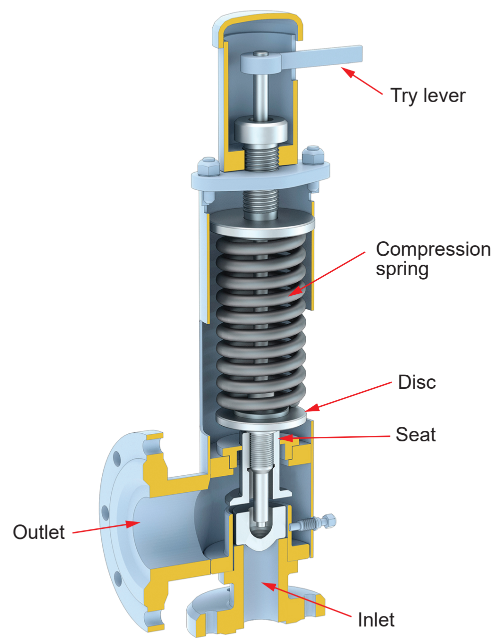
A safety valve is a pressure relief valve characterized by rapid opening, and normally used to relieve compressible fluids. These valves are commonly found on steam boilers, steam lines, compressed air vessels, and refrigerant receivers. The focus here will be on safety valves used in steam service.

Safety valves are made of cast iron, steel, alloy steel, or bronze. Cast iron and bronze safety valves are used for lower pressures and lower temperatures. **ASME BPVC Section I, Part PG-73** prohibits the use of valves with bronze parts for superheaters operating over 230°C. **ASME BPVC Section I, Part PG-68.6** requires all superheater and reheater pressure relief valves to be constructed of steel or alloy steel.

A safety valve is held shut with a spring that holds a valve disc tightly against a seat. When the steam pressure reaches the set point pressure (popping pressure) of the valve, the disc will rise slightly from the seat, and steam will begin to escape.

Figure 2 shows a cutaway of a safety valve approved for saturated and superheated steam service. It has a cast steel body, and flange connections at its inlet and outlet. It also has an exposed spring to prevent the high temperature of superheated steam from weakening the spring.

Figure 2 – Cutaway View of Cast Steel Safety Valve



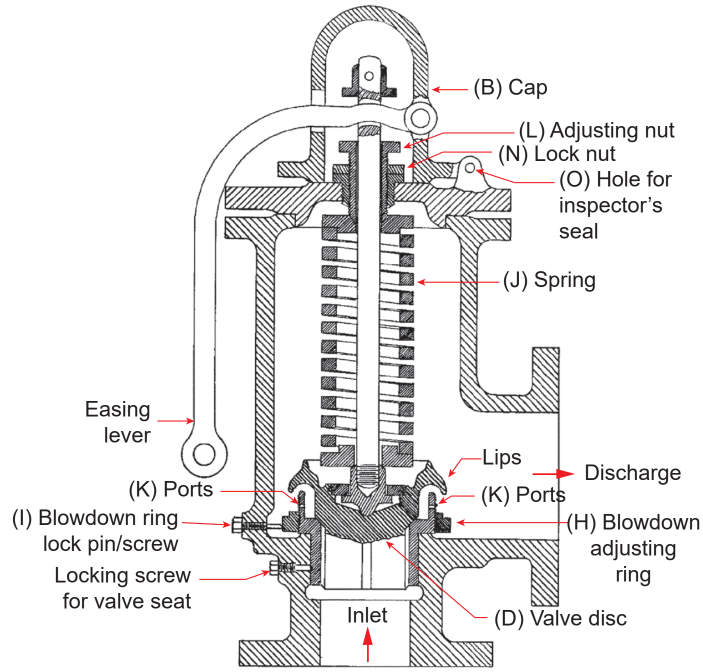
The safety valve shown in Figure 2 has an exposed spring to prevent the high temperature steam from affecting the mechanical properties of the spring.

Figure 3 shows the construction of a safety valve. The safety valve is attached to the drum at the top of the steam space. The valve disc "D" is held firmly on its seat by the pressure of the heavy coil spring "J". Screwing the nut "L" up or down adjusts the point at which the valve will lift and relieve the pressure. This will decrease or increase the compression of the spring "J". Tightening lock nut "N" prevents the nut "L" from shifting. When the valve has been set by nut "L", the cap "B" is put in place. An authorized inspector passes a wire through hole "O", and attaches a seal. This prevents access to the adjusting nut "L".

The **try lever** can manually lift the valve. The lever raises the valve spindle, which is connected to the valve disc. This must only be done if the valve is subjected to a pressure of at least 75% of boiler operating pressure. If the safety valve is opened without pressure in the boiler, the try lever or valve spindle can be damaged. As well, any debris in the safety valve discharge line could fall into the valve, and prevent it from closing **(ASME BPVC I, Part PG-73.2.4).**

In order to ensure consistent operation, tightness, and proper seating of the disc, the valve disc is equipped with guides at the bottom and top. This allows the valve disc to move only in a vertical direction, with no horizontal shifting.

Figure 3 – Safety Valve Construction

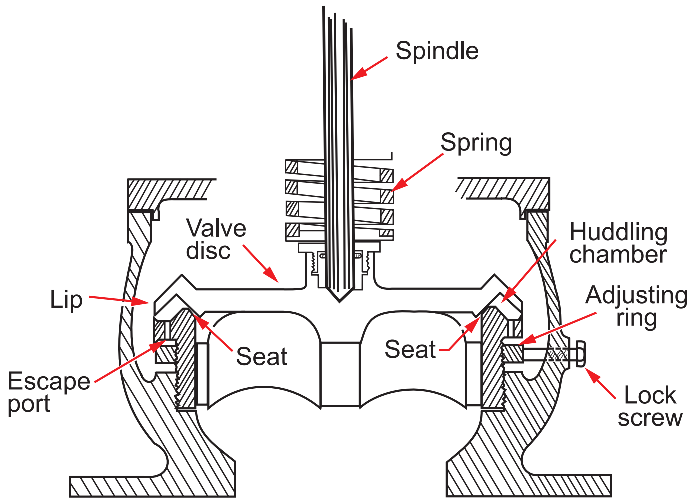


Operation of a Safety Valve

Refer to Figure 4. The safety valve disc has a lip (skirt) that forms a small compartment called a **huddling chamber**. This compartment fills with steam when the valve starts to open, and increases the effective area of the disc.

As soon as the valve lifts, the pressure of the steam acts on this increased disc area, which results in a greater force against the compression spring. This increase in force causes the valve to pop wide open. The valve will remain open until the pressure drops to below the popping pressure.

Figure 4 – Safety Valve – Disc and Seat Detail



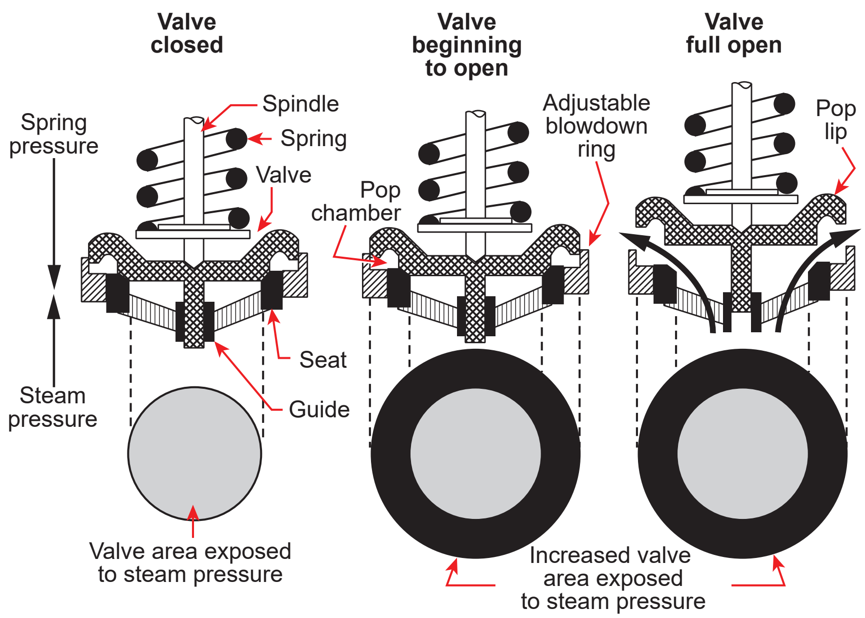
Refer to Figure 5. As the valve begins to lift, steam rushes into the huddling chamber and acts on an increased area (as indicated by the shaded ring). This causes the valve to suddenly lift and "pop" to its full opening.

The lifting force exerted on the disc by the boiler pressure is dependent on:

- The area of the disc exposed to the pressure.
- How freely the steam can escape from under the lip.

When the valve is opening, the lip causes the safety valve to open wide. This action is reversed when the valve is closing. The pressure under the lip decreases when the boiler pressure drops sufficiently to allow the spring to begin closing the valve. This allows the spring to close the valve quickly.

Figure 5 – Pop Action of a Safety Valve



Adjusting the Blowdown

ASME PTC-25, Pressure Relief Devices defines **blowdown** as:

The difference between actual popping pressure of a pressure relief valve and actual reseating pressure, expressed as a percentage of set pressure or in pressure units.

ASME BPVC I, Part PG-72.1 states:

Pressure relief valves shall be designed and constructed to operate … with a minimum blowdown of 2 psi (15 kPa) or 2% of the set pressure.

Figures 4 and 6 show threaded adjustable annular rings called "blowdown adjusting rings." These rings may be moved up or down to vary the size of the huddling chamber escape port opening. Once adjusted to a particular position, these rings can be locked into place with a set screw, and then sealed in position.

The huddling chamber has ports that allow steam to escape from under the lip. The blowdown adjusting ring can completely block off, partially obstruct, or fully open the huddling chamber escape ports.

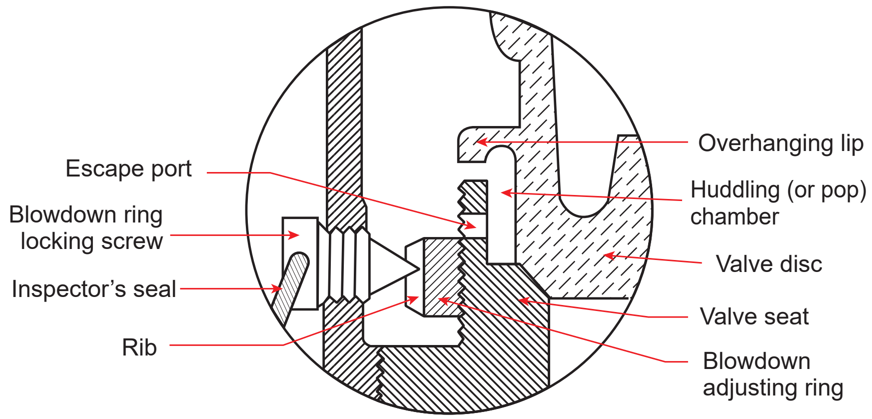
If the adjustment ring blocks the huddling chamber escape ports, the steam under the lip cannot exit from the chamber. This creates a higher pressure under the lip, because the valve is open. The boiler pressure must drop significantly for the valve to reclose.

When the huddling chamber escape ports are fully open, the steam under the lip can exit from the chamber. This creates a lower pressure under the lip, because the valve is open. In this case, the valve recloses with far less drop in boiler pressure.

If the adjustment ring takes an intermediate position (it only partially obstructs the escape ports), the valve will reclose at a pressure in-between the reclosing pressures described above.

To change the position of the blowdown adjusting ring, remove the locking screw, and turn the adjusting ring in the desired direction with a screwdriver. After the adjusting ring is set, lock it into place with the locking screw. To prevent unauthorized persons from tampering with the blowdown adjustment, the locking screw is secured in place by a wire seal, installed by the jurisdictional Boiler Inspector (see Figure 6).

Figure 6 – Detail of Blowdown Adjusting Ring



Adjusting the Popping Pressure

The PRV spring is designed for a certain range of opening (or popping) pressure. The PRV set pressure may be increased or decreased by a maximum of five percent (5%) from the setting marked on the valve. This can be done by changing the compression of the spring.

CAUTION

ASME BPVC I, Part PG-72.3 cautions that when a pressure relief valve's set pressure needs adjustment, it must be done by the PRV manufacturer, its authorized representative, or an assembler. Power Engineers and maintenance personal must not tamper with PRV set pressure adjustments.

The content in this section is for information purposes only. Power Engineers and maintenance personnel, unless specially trained and certified, must never tamper with the set pressure of a PRV. Such an action is considered illegal in all Canadian jurisdictions.

Side Track

ASME BPVC I, Part PG-72.4 permits set pressure adjustments outside of the ± 5% range. This involves the installation of a new spring acceptable to the PRV manufacturer. The spring installation and valve adjustment shall be performed by the manufacturer, his authorized representative, or an assembler.

When a PRV set pressure is changed, a new valve data tag must be furnished and installed on the valve, and the valve must be resealed. The new tag must identify the new set pressure, capacity, and date the valve was reset.

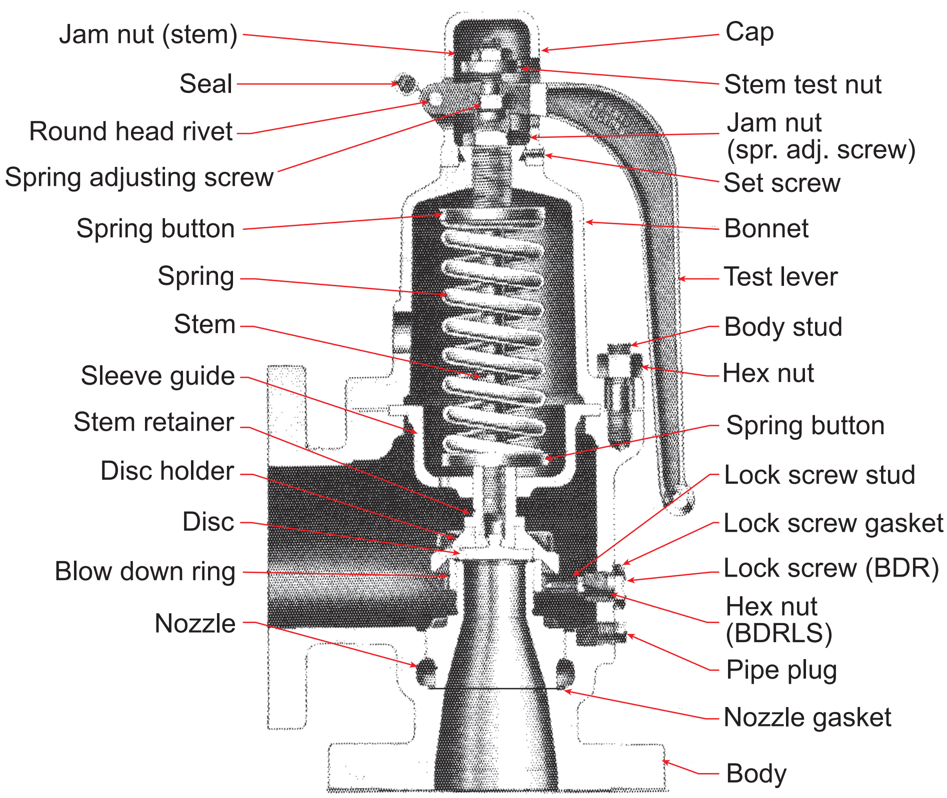
Before adjusting the pressure at which the safety valve opens, the jam nut on the adjusting nut, located on the spindle above the spring, must be loosened.

To increase the popping pressure, screw the adjusting nut down to further compress the spring. To decrease the blowoff pressure, screw the adjusting nut upwards to decrease the spring compression.

More information governing safety valve design, material selection, capacity, testing, adjustments and sealing are covered in **ASME BPVC I.**

Figure 7 shows a cast-iron safety valve. It is suitable for boilers operating at pressures up to 1720 kPa, and steam temperatures up to 230°C.

Figure 7 – Safety Valve with Adjustable Popping Pressure

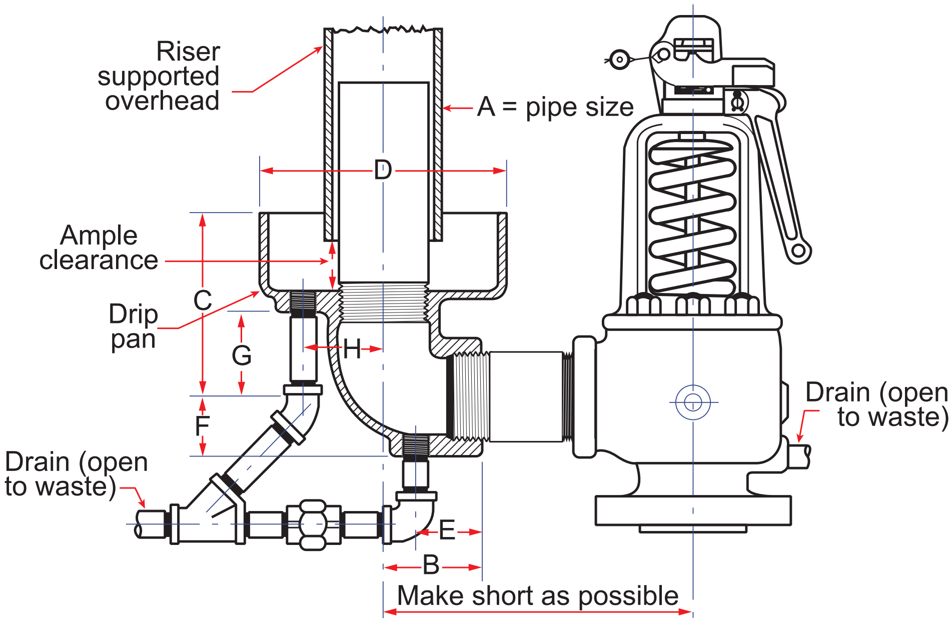


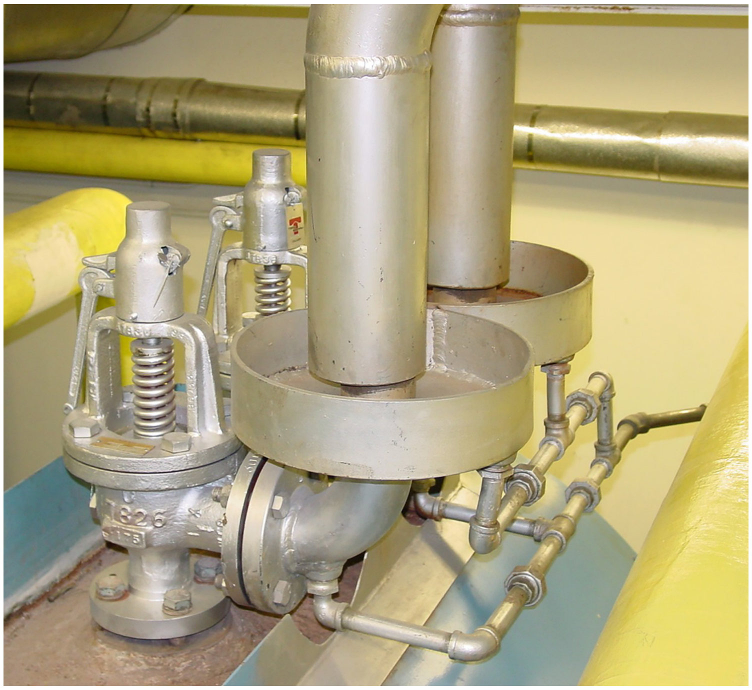
Pressure Relief Valve Mounting

ASME BPVC I, Part PG-71 covers the installation of PRVs. It states that safety valves mounted on the drum, superheater, reheater inlet and outlet headers must be placed in an upright position with the spindle vertical. They must be connected to the boiler independent of any other steam connection, and be located as close as possible to the boiler without any unnecessary intervening pipe or fitting. A discharge pipe, if used, should be separately supported, leaving ample room for expansion so that no force is exerted on the valve.

Figure 8 shows the discharge piping arrangement for a typical safety valve. This arrangement is similar to that shown in **ASME BPVC, Section VII.**

Figure 8 – Safety Valve Discharge Piping Details





Objective 2

Discuss the code requirements, construction, and operation of ASME Section IV Pressure Relief Valves and Devices.

Heating Boiler Safety and Safety Relief Valves

ASME Code Requirements

A | E

ASME BPVC, Section IV Rules for Construction of Heating Boilers contains the rules for safety valves and safety relief valves installed on heating boilers. Some of the requirements of **Part HG-400.1** and **Part HG-401** are stated below.

HG-400.1 (a): *Each steam boiler shall have one or more officially rated safety valves… of the spring pop type adjusted and sealed to discharge at a pressure not to exceed 15 psi (100 kPa).*

HG-400.1 (b): *No safety valve for a steam boiler shall be smaller than NPS ½ (DN 15) or larger than NPS 4 (DN 100).*

HG-400.1 (e): *The safety valve capacity for each steam boiler shall be such that with the fuel burning equipment installed, and operated at maximum capacity, the pressure cannot rise more than 5 psi (35 kPa) above the maximum allowable working pressure.*

HG-401.1 (h): *A body drain below seat level shall be provided by the Manufacturer for all safety valves and safety relief valves… Body drain connections shall not be plugged during or after field installation. (Note: this drain will prevent the collection of condensate around the valve and seat. This could result in corrosion and subsequent sticking of the safety valve).*

Mounting Safety and Safety Relief Valves on Heating Boilers

A | E

ASME BPVC IV, Part HG-700 Installation Requirements, All Boilers sets requirements for the mounting of safety and safety valves on heating boilers. The following points are covered.

All Safety and Safety Relief Valves

a) Safety valves and safety relief valves must be installed with their spindles vertical.

b) Safety valves must be connected directly to one of the following:
   - A tapped or flanged opening in the boiler
   - A fitting connected to the boiler by a short nipple
   - A y-base
   - A valveless header connecting steam or water outlets on the same boiler

c) Safety valves and safety relief valves must be located in the highest practicable part of the boiler proper.

d) Safety valves and safety relief valves must not be connected to an internal pipe in the boiler.

e) The opening or connection between the boiler and any safety valve or safety relief valve must have at least the same cross-sectional flow area of the valve inlet.

f) No shut-off valve of any description shall be placed between the safety or safety relief valve and the boiler, or on discharge pipes between these valves and the atmosphere.

g) Discharge pipes must be used. The discharge pipe of the safety valve shall be:
   - As short and straight as possible, and arranged so as to avoid undue stress on the valve.
   - Properly drained to prevent collection of water.
   - Arranged so that there will be no danger of scalding the operator.

h) The internal cross-sectional area of the discharge pipe must not be less than the full area of the valve outlet.

i) If a long vertical discharge pipe is required, then it may be necessary to install a flexible joint near the safety valve, so that the expansion of the pipe will not place any stresses on the safety valve.

Specific to Safety Valves (Steam Service)

The safety valve must never be located below the normal operating water level, or below the lowest permissible water level.

Safety Valves

Low-pressure steam heating boilers are designed to operate at no higher than 100 kPa. A safety valve especially designed for low-pressure steam heating boilers is shown in Figure 9.

The valve housing consists of two main parts. The first is the valve body, which is directly connected to the boiler. The second is the bonnet, which is threaded and locked onto the valve body.

The bonnet has an outlet opening to atmosphere. A valve disc closes the opening in the upper part of the valve body. The disc is tightly held down upon its seat by a heavy spring. The adjusting cap in the upper part of the bonnet compresses the spring. The cap is held in position by a locking screw.

Note that unlike a safety valve for a power boiler, this valve does not have an adjustable blowdown ring. **ASME BPVC IV, Part HG-401** does not require low-pressure steam safety valves to have adjustable blowdown.

Figure 9 – Cross-Section of Low-Pressure Steam Safety Valve

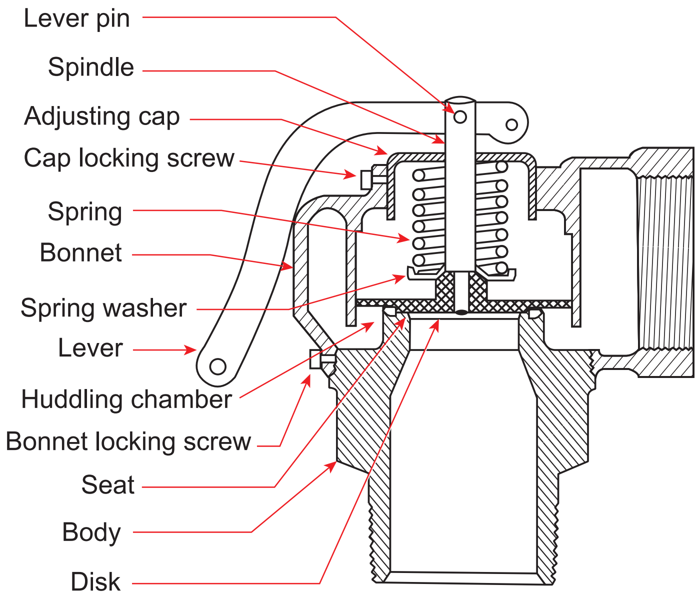


Figure 10 shows a low-pressure safety valve installed on a steam boiler. Low-pressure safety valves are easily recognized, because they are shorter and wider than high-pressure safety valves of the same capacity.

Figure 10 – Low-Pressure Safety Valve, Installed on a Steam Boiler

Safety Relief Valves on Boilers

ASME BPVC IV, Part HG-400.2 states:

> *Each hot water heating or supply boiler shall have at least one officially rated safety relief valve, of the automatic reseating type… and set to relieve at or below the maximum allowable working pressure of the boiler.*

ASME BPVC IV, Part HG-401.1 states that safety relief valves shall have pop action when tested by steam.

The design of the safety relief valve is quite similar to that of the safety valve used for steam boilers. It is spring loaded, has body drain openings, and has a lifting device (try lever). However, safety relief valves do not require blowdown adjustment rings (and seldom have them), do not have bottom guides for the disc, and their pressure is non-resettable.

The safety relief valve opens partially when boiler pressure slightly exceeds the valve setting. However, the slight flow of the escaping water does not have the same lifting effect on the valve lip as steam has, so there is no immediate popping action. On further pressure rise, the valve pops wide open.

Figure 11 shows a typical safety relief valve used with a hot water heating boiler or heating system use.

Figure 11 – Small Safety Relief Valve

Safety relief valves should not open frequently, or leak water, during normal plant operation. If they do, the cause must be found and remedied.

CAUTION

Never, under any circumstances, plug the outlet of a pressure relief valve.

One common cause for frequent safety relief valve operation is a waterlogged heating system. Hot water heating systems are completely filled with water, except for the expansion tank, which contains a volume of compressed air or nitrogen. When the burners fire, the water expands, further compressing the air in the expansion tank. If the expansion tank becomes filled with water, the heating system pressure increases dramatically, because water is not compressible. This causes water to weep from the relief valve. When the burner shuts off, the water cools. Make-up water enters, and keeps the system waterlogged.

In this situation, the expansion tank must be isolated, drained, and returned to service.

Side Track

Part B, Unit 4, Chapter 3 Boiler Operation explains how to inspect, drain, and recharge, both conventional and bladder-style expansion tanks, and return them to service.

Other situations may cause safety relief valves to weep. These include:

- Scale, corrosion products, or chemical residue accumulations on the valve seat, which will prevent it from closing tightly.
- The installed safety relief valve is designed for the wrong pressure range.
- The safety relief valve may have damaged seating surfaces or weakened compression springs from erosion, corrosion, and lengthy service duration.

Each of these situations must be addressed in a timely manner.

Objective 3

Describe the testing and repair of pressure relief valves.

Testing Pressure Relief Valves

Pressure relief valves must be kept in good working condition at all times. Test these valves regularly to make sure they are functioning properly. Common tests include:

- Try lever test
- Pop test

Side Track

Consult **Part B, Unit 4, Chapter 4 Operational Checks**, as well as **ASME BPVC Sections I, IV, VI,** and **VII**, for detailed descriptions of pressure relief valve test procedures.

Try Lever Test

A try lever test determines if a pressure relief valve is operating freely. However, it does not determine if the valve will open at its set pressure. Try lever tests are performed:

- Monthly on steam heating boilers
- Every three months for hot water heating boilers
- Every six months on power boilers that operate below 2760 kPa

These tests are also performed prior to pop tests and accumulation tests.

Boilers must be under pressure before conducting try lever tests. Steam heating boiler pressure must be 35 kPa or higher. A power boiler's pressure must be at least 75% of the setting of the safety valve.

To perform the test:

1. Pull the try lever on the safety valve to the wide-open position.
2. Allow steam to discharge for 5 to 10 seconds.
3. Release the lever.
4. Allow the spring to snap the valve disc to the closed position.

If the valve **simmers** after the test (i.e. steam continues to discharge from the valve), operate the try lever two or three times to allow the disc to seat properly. If the valve continues to simmer, it must be repaired or replaced.

Pop Test

The full operation of the safety valve, including the exact pressures at which it opens and closes, can be checked using the pop test. To perform this procedure:

1. Increase the boiler steam pressure to the safety valve set point.
2. Accurately record the opening and reseating pressures. Once the pressures are established, the blowdown can be determined.
3. Compare the opening pressure and blowdown to the performance tolerances outlined in the relevant section of the **ASME BPVC (I or IV)**. Use this information to determine whether the valve is operating properly, or if it requires repair or replacement.

Pop tests should be performed annually, before taking a boiler off-line for maintenance. This will identify any defective valves so that they can be replaced or repaired prior to the boiler re-entering service.

Repairing Pressure Relief Valves

All **ASME BPVC** sections require that the repair or adjustment of pressure relief valves be done by the valve manufacturer or its authorized repair representative. Consult with the relevant **ASME BPVC** sections, and the local Boiler Inspector, to determine who is qualified to adjust or repair PRVs in a particular jurisdiction.

Objective 4

Describe the construction and operation of temperature and pressure relief valves.

Pressure Relief Valves for Potable Hot Water Heaters

Safety relief valves may be installed on commercial and industrial **potable** water heaters and hot water storage tanks, designed according to **ASME BPVC IV, Part HLW.** These heaters and tanks operate at pressures not exceeding 1100 kPa, and temperatures not exceeding 99°C. The heaters are supplied with cold potable water, and are only used to supply hot potable water.

Though safety relief valves may be used, most potable water heaters and potable hot water storage tanks use temperature and pressure safety relief valves. These valves protect against the additional explosion dangers associated with super-saturated hot water.

ASME BPVC Section IV, Part HLW-800 refers to safety relief valve requirements for industrial and commercial potable water heaters. **HLW-800.1** states:

> *Each water heater shall have at least one officially rated temperature and pressure safety relief valve or at least one officially rated safety relief valve…*
>
> *The pressure setting shall be less than or equal to the maximum allowable working pressure of the water heater. However, if any of the other components in the hot water supply system (such as valves, pumps, expansion or storage tanks, or piping) have a lesser working pressure rating than the water heater, the pressure setting for the relief valve(s) shall be based upon the component with the lowest maximum allowable working pressure rating*

According to **HLW-801**, these pressure relief valves must be installed:

a) Not lower than 100 mm from the top of the shell.

b) Directly to one of the following:
   - A tapped or flanged opening in the top of the water heater
   - A fitting connected to the water heater by a short nipple
   - A y-base
   - A valveless header connecting water outlets on the same heater

c) With their spindles upright and vertical, with no horizontal connecting pipe, unless connected directly to the water heater vessel, with no more than 100 mm of interconnecting piping. In this case, the valve may be installed in the horizontal position with the outlet pointed down.

As well:

d) No piping or fitting used to mount the safety relief valve can be of a nominal pipe size smaller than that of the valve inlet.

e) Safety relief valves shall not be connected to an internal pipe in the water heater or a cold water feed line connected to the water heater.

ASME does not prohibit the installation of relief devices sensitive only to temperature. However, ASME considers these devices to be insufficient for vessel protection. Therefore, if they are installed on hot water heaters or tanks that actuate only on temperature, additional overpressure protection must be provided, in the form of either a safety relief valve or a temperature and pressure relief valve.

Temperature and Pressure (T&P) Relief Valves

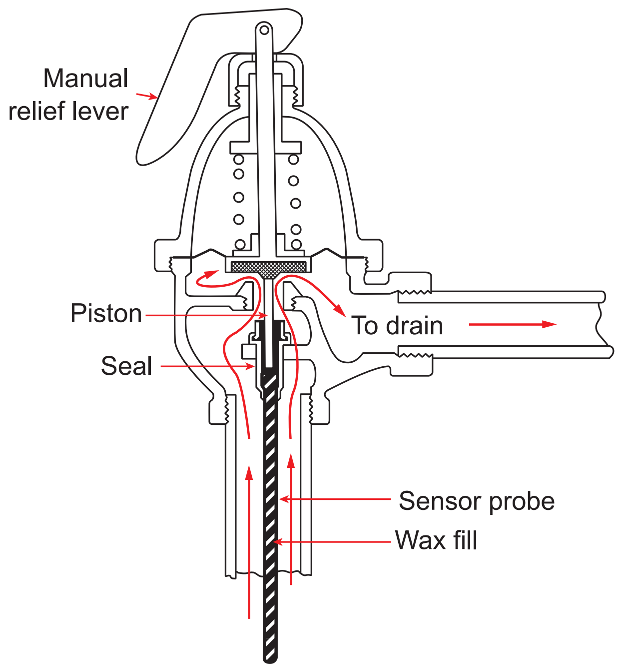
The combination temperature and pressure relief valve provides protection for both over-pressurization, and dangerously high water temperatures. The pressure element opens to relieve excess pressure, usually caused by thermal expansion of water during times of low hot water consumption. The temperature element opens when the water temperature rises to about 99°C. This allows hot water to escape from the system before becoming a **super-saturated liquid**. Cold supply water then enters, and reduces the temperature.

The pressure-sensitive element is similar to the construction of a safety relief valve. A non-adjustable compression spring holds a disc shut against a seat. Unlike the safety relief and safety valve, the T&P valve does not operate with a pop action when over-pressurization occurs.

The temperature sensitive element consists of a wax-filled thermostatic sensor probe that extends into the water storage tank. When exposed to high temperature, the wax in the thermal element expands against the force of the compression spring, and lifts the valve disc off its seat. This causes the valve to discharge the overheated water. When the temperature returns to a safe level (below 99°C), the wax in the thermal element contracts, and allows the spring to reseat the valve.

Figure 12 shows a combination temperature and pressure relief valve. It is recommended that T&P valves receive annual try lever tests.

Figure 12 – Combination Temperature and Pressure Relief Valve



Temperature Relief Devices

Various types of temperature relief devices can be used. However, they must always have additional pressure relief.

One type of temperature relief device employs a fusible element which melts at 99°C, and allows the hot water to escape. Unlike the T&P valve, such a fusible element does not reseat. The water continues to flow until the device is replaced.

Another type of temperature relief device uses the expansion and contraction of a rod and tube arrangement. This opens the device at 99°C, and closes it at 71°C. Like the T&P valve, this device automatically recloses.

Chapter Summary

The basic function of pressure relief valves is to protect equipment from damage due to over pressurization. Pressure relief valves are installed on all pressure equipment. These valves prevent explosions due to over-pressurization. Some of these valves also provide over-temperature protection.

Pressure relief valves include safety valves, safety relief valves, and temperature and pressure (T&P) relief valves. Safety valves are used for compressed gases, such as steam. Safety relief valves are used for non-compressible fluids, such as hot water. T&P valves are used when protection against over-temperature and overpressure are required, such as in potable hot water heaters. All of these devices are designed to release harmful energy before explosions occur.

Pressure relief valves are the last reliable line of defense between safe equipment operation, and catastrophic pressure explosions. They are the Power Engineer's best friend! For this reason, pressure relief valves must be carefully selected, installed, tested, maintained, and repaired.

This chapter covered the design, construction, installation, and operation of various pressure relief valves. As well, this chapter contained numerous references to **ASME BPVC** code sections.

CHAPTER 2

Combustion Safety

Learning Outcome

When you complete this chapter you should be able to:

Explain the design and operation of combustion safety controls on burners and boilers.

Learning Objectives

Here is what you should be able to do when you complete each objective:

1. *Describe the operation of control and safety devices found on boiler fuel supplies.*
2. *Describe the construction and operation of flame detectors.*
3. *Describe the combustion safety controls for boilers and burner systems.*
4. *Describe burner management systems.*
5. *Interpret burner operating sequence charts, and provide a typical sequence of startup and shutdown events.*

Chapter Introduction

Combustion safety is of paramount concern for owners, operators, designers, installers, and maintainers of fuel-burning equipment. Consider two types of boiler explosion: the pressure vessel explosion and the furnace explosion.

The pressure explosion occurs due to the gradual formation of unsafe conditions that weaken the boiler shell. These include corrosion processes, cracking, and overheating. Contributors can be scale formation, inadequate water treatment, restricted thermal expansion, and others. As well, limit controls and safety valves must fail for pressure vessel explosions to occur.

Boilers provide telltale signs of impending failure: pressure parts bulge, small leaks occur, and alarms sound to prompt operators to take corrective action. Boilers sustain pressure vessel explosions only after considerable lead time, during which corrective action can be taken.

Furnace explosions happen instantaneously, and without warning. It only takes the first failure of a single, previously reliable combustion safeguard control for a devastating explosion to occur. For this reason, combustion systems are engineered extensively, with safety in mind.

This chapter explores the components found on boilers that contribute to the safe operation of burner systems. With some modification, the same equipment and principles can be applied to burners installed on all sorts of industrial equipment.

Objective 1

Describe the operation of control and safety devices found on boiler fuel supplies.

Burner systems are comprised of numerous parts that function systematically to ensure combustion safety. The existence of these components is mandated by various construction and design codes, published by organizations such as **CSA**, **ASME**, and **NFPA**.

Natural Gas Fuel Train

Figure 1 shows a single line diagram of a natural gas fuel train, assembled according to **CSA B149.3 Code for the Field Approval of Fuel-Related Components on Appliances and Equipment**. This code does not cover appliances (including boilers) that are constructed and designed to meet an approved standard. Rather, it covers:

1. Natural gas and propane burners installed on appliances for which no approval standard exists.
2. Existing certified burners that are upgraded or modified.

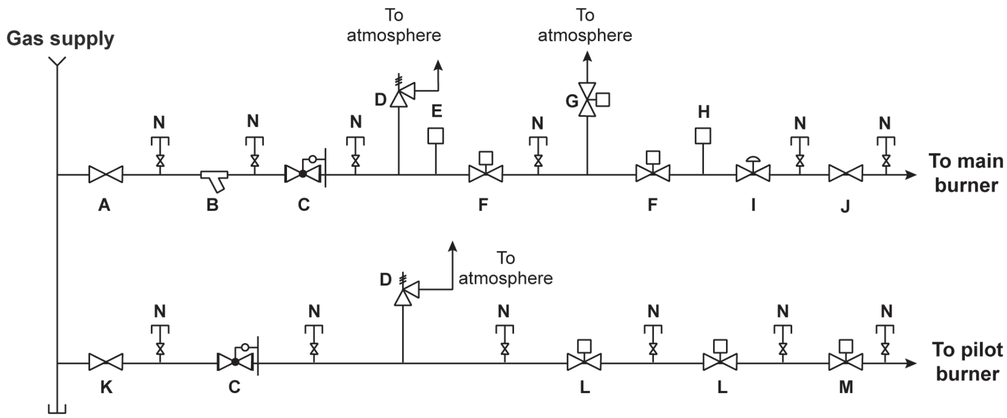
For this reason, **CSA B149.3** serves as a very good guideline for the layout of combustion safety components, especially those found on boilers.

Note that Figure 1 differs from other fuel trains shown in the **PanGlobal Fourth Class** text. There are several reasons for this. Fuel trains become more complex as fuel pressures increase, and as fuel-firing capacity increases. Other fuel trains in the Fourth Class text have been for smaller or larger capacity burners, and may have been configured to meet different codes. The differences may be due to the fact that the **ASME CSD-1**, **NFPA-85**, and **CSA B149.3** codes, though similar in many respects, differ somewhat in the requirements for, and placement of, fuel train components.

The diagram in Figure 1:

1. Is based on a Canadian code, which (in Canada) takes precedence over international codes.
2. Is a fuel train configuration suitable for burners with inputs greater than 3.663 MW (12 500 000 Btuh input or 300 BoHP output). Boilers of this size are common in Third and Second Class plants. In these plants, Fourth Class Power Engineers can serve as Shift Engineers and Assistant Shift Engineers. It is therefore reasonable for those studying Fourth Class Power Engineering to be familiar with these fuel trains.

Figure 1 – Natural Gas Fuel Train for Boilers over 3000 kW Output (CSA B149.3)



A = main gas shut-off valve
B = fuel strainer
C = pressure regulator
D = pressure relief valve
E = low gas pressure cut-off switch
F = main safety shut-off valve (with proof of closure switch)
G = safety vent valve
H = high gas pressure cut-off switch
I = input flow control valve (firing rate control valve)
J = main test firing valve
K = pilot gas manual shut-off valve
L = pilot safety shut-off valve
M = pilot test firing valve
N = fuel pressure test ports

The following comments refer to Figure 1. Note that each component shown serves a critical safety role. Nothing is required that does not serve a specific purpose.

Side Track

Manual fuel train valves are discussed in **Part A Unit 7 Chapter 2 Introduction to Energy Plant Valves.** Automatic fuel safety shut-off valves are covered in **Part A Unit 12 Chapter 2 Fuel Delivery and Firing Systems.**

Gas Supply and Piping

For burners to operate correctly, they must be supplied with fuel at the correct pressure. The **CSA B149.1 Natural Gas and Propane Installation** code limits the maximum fuel pressure inside buildings of various occupancies. Fuel piping must be properly sized to deliver the amount of fuel the burner can consume, without excessive pressure drop through the fuel train.

Gas piping is, with few exceptions, constructed of steel pipe. Smaller diameter pipe may use threaded connections. Welded connections are used for larger diameter and higher-pressure pipe.

Main and Pilot Manual Shut-Off Valves (A and K)

Manual fuel cocks are quarter-turn lubricated plug valves. These valves serve as isolation points for fuel train maintenance. As well, the main manual shut-off valve can be used to test the operation of the low gas pressure cut-off switch.

CAUTION

Never open the main manual shut-off valve when the pilot manual shut-off valve is closed!

Fuel Strainer (B)

Often, existing fuel lines are modified for the installation of new equipment. Drilling, threading, and cutting may introduce debris into fuel lines, which may affect the operation of fuel pressure regulators and control valves. The fuel strainer catches debris before it can have a negative effect.

Fuel Pressure Regulators (C)

The pressure regulators ensure the proper fuel pressure at each of the main and pilot burners. Excessive pressure could lead to over firing. Inadequate pressure may lead to flame instability.

Pressure Relief Valves (D)

If the pressure regulators fail to reduce the fuel pressure, the burner piping components can over pressurize and fail. The pressure relief valves protect the pilot and main burner controls from excessive fuel pressure.

Low and High Gas Pressure Cut-off Switches (E and H)

These switches shut down and lock out the burner if the fuel pressure rises above, or drops below, that required by the burner manufacturer. This prevents flame instability, over-firing, and lifting flames. All unstable flame conditions may lead to furnace explosion.

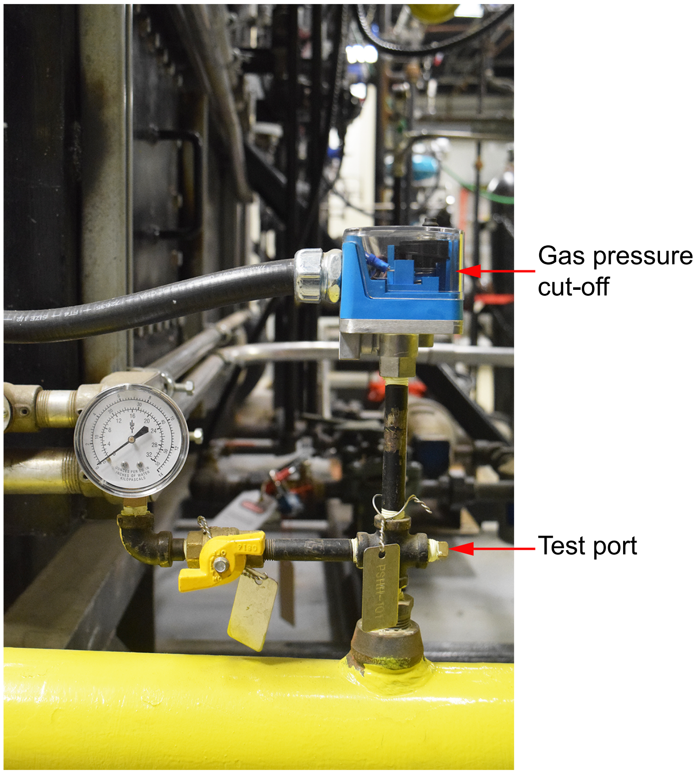
The **high gas pressure cut-off switch** (**HGPCO**) is located just upstream of the input flow control valve. The **low gas pressure cut off switch** **(LGPCO)** is located downstream of the pressure regulator and pressure relief valve.

The following is paraphrased from **CSA B149.3 parts 9.5.1** and **9.5.2**:

> *For appliances with inputs in excess of 120 kW (400 000 Btuh), a low gas pressure safety device shall be installed and shall shut off if the supply of gas if the pressure at the point of connection drops below 50% of the lowest normal operating pressure. The device shall be installed downstream of the pressure regulator, upstream of the safety shut-off valve or valves, and upstream of the flow control valve.*
>
> *Where the failure or an outlet pressure adjustment of the pressure regulator results in unsafe operation, a high gas pressure safety device shall be installed downstream of the pressure regulator and shall initiate shut-off of the supply of gas when the gas pressure at the high gas pressure safety device exceeds 125% of the normal operating pressure at the maximum firing rate.*

Figure 2 shows a gas pressure cut-off switch. A pressure gauge is installed on the test port so that operators can monitor the pressure while the burner is in operation, and observe the pressure at which the cut-off trips.

Figure 2 – Fuel Pressure Cut-off Switch



Main Fuel Safety Shut-Off Valves (SSOVs) (F)

Safety shut-off valves (SSOVs) are essential components on the fuel supply system. SSOVs prevent the accumulation of explosive fuel-air mixtures in furnaces when they are not in operation. In accordance with CSA requirements, these valves must be certified to **CSA 6.5 CSA 6.5-2015 Automatic Valves for Gas Appliances.** When selecting an SSOV, the valve must bear this approval symbol.

Main fuel SSOVs may be slow-opening diaphragm, solenoid, or Hydramotor valves. Though they are slow-opening, they respond to unsafe conditions by closing quickly. Figure 3 shows an SSOV on a main gas fuel train. An indicator at the front of the actuator indicates whether the valve is open or closed. A high gas pressure cut-off switch and a pressure gauge can be seen downstream of the SSOV.

Figure 3 – Main SSOV

Main SSOVs shut off the fuel flow to the main burner under the following conditions:

a) Normal operating limits (boiler pressure or temperature) are satisfied.

b) An unsafe condition exists (low water, high pressure, high temperature, loss of combustion air, flame failure, and so on).

The fuel train shown in Figure 1 requires two SSOVs with proof-of-closure switches to meet **CSA B149.3**. These switches are sensitive to the valve stem position. If the SSOV fails to close completely, fuel gas may leak into the combustion chamber. The proof-of-closure switches prevent the boiler from proceeding with an ignition sequence if an SSOV does not fully close.

Safety Vent Valve (G)

The **safety vent valve** is located between the main fuel SSOVs. Safety vent valves are typically fast-acting, normally-open solenoid valves.

Depending on the burner capacity and fuel pressure, fuel trains must be equipped with a double block-and-bleed arrangement on the main (and sometimes the pilot) fuel lines. When the main SSOVs shut, the safety vent valve fails open, and bleeds trapped fuel to the atmosphere. In this way, if the upstream SSOV leaks fuel, its pressure is immediately reduced to atmospheric. At atmospheric pressure, the fuel cannot leak past the downstream SSOV and accumulate in the furnace.

Figure 4 shows a normally-open solenoid valve, used as the pilot safety vent valve for a large natural gas-fired boiler.

Figure 4 – Pilot Safety Vent Valve

Input Flow Control Valve (Firing Rate Control) (I)

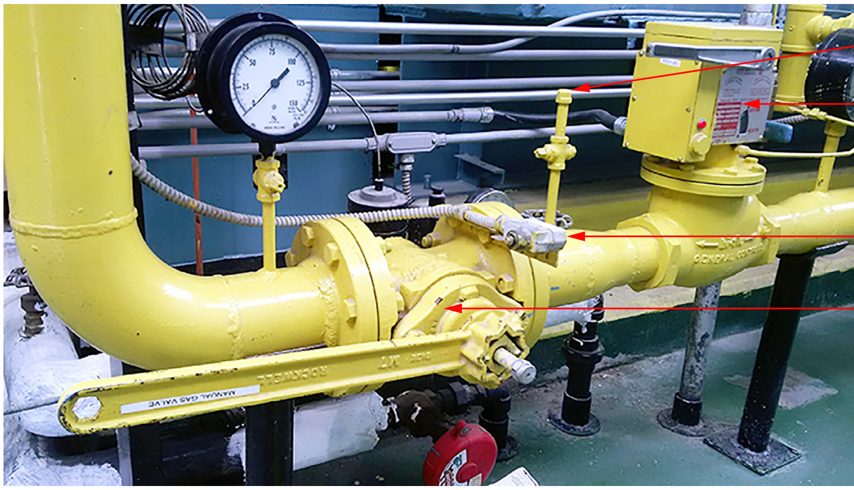
Fully modulating burners must control fuel in accordance with the load demand. The inlet flow control valve is not strictly speaking a safety device. However, its location is important to permit the correct operation of other safety controls.

The firing rate control valve is placed downstream of the low gas pressure cut-off switch. This is so that the LGPCO does not actuate at low firing rates. The firing rate control valve is also located downstream of the HGPCO. If it was not, the high gas pressure cut-off could not detect high fuel pressure conditions due to the pressure drop across the firing rate control valve.

Main Test Firing and Pilot Test Firing Valves (J and M)

Test firing valves are lubricated quarter-turn plug valves. They are used to test the operation of the flame detection devices, and the high fuel pressure cut-off. As well, the test firing valve is often used as a fuel train isolation point.

Figure 5 – Main Test Firing Valve with Supervisory Switch



The main test firing valve shown in Figure 5 has a switch that detects whether the test firing valve is open or closed. The burner cannot begin a start-up sequence when this valve is open. It must be kept closed during the purge period and the **pilot flame trial for ignition period**. It is opened by hand (gradually) at the beginning of the **main flame trial for ignition period.**

CAUTION

Never open the main test firing valve when the pilot test firing valve is closed!

Pilot Safety Shut-Off Valves (L)

Pilot SSOVs are usually fast-acting automatic solenoid valves. They shut off the fuel flow to the pilot burner under the following circumstances:

a) Flame failure during the pilot or main flame trial for ignition period.

b) Normal pilot interruption at the end of the pilot flame trial for ignition period.

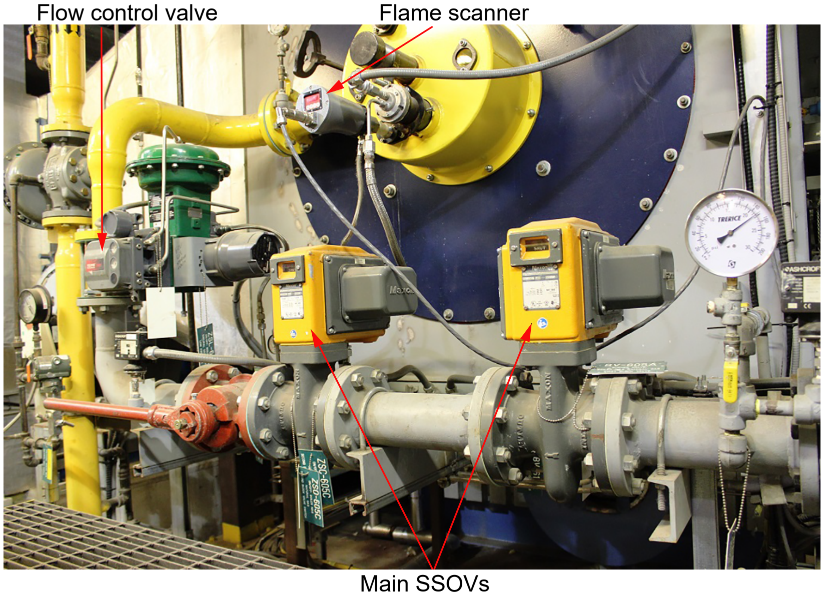
The valves shown in Figure 1 do not have proof of closure. They are arranged as “double blocks” without a bleed. This is considered adequate because pilot burners have a small fuel throughput compared to the main burner (less than 5%). Therefore, the amount of fuel that can bleed into the furnace through a pilot fuel train is quite small compared to the amount of gas that can enter through the main fuel line.

Fuel Pressure Test Ports (N)

Test ports are located at various locations on the fuel train, so that instruments can be connected to check, adjust, or monitor the fuel pressure. Each port is equipped with a quarter-turn isolation valve and a pipe cap. Pressure gauges or electronic instruments can be installed at these points. In this way, the fuel pressure conditions can be monitored, and adjustments made, when the burner is in operation. Often, these test ports have permanently installed pressure gauges.

Figure 6 shows the main fuel train of a boiler with a similar configuration to the requirements shown in Figure 1. Two main SSOVs are visible. The bleed line between the SSOVs is obscured by the piping between the main SSOVs.

Figure 6 – Natural Gas Fuel Train Suitable for Boilers over 3000 kW (300 BoHP)



Oil Fuel Train

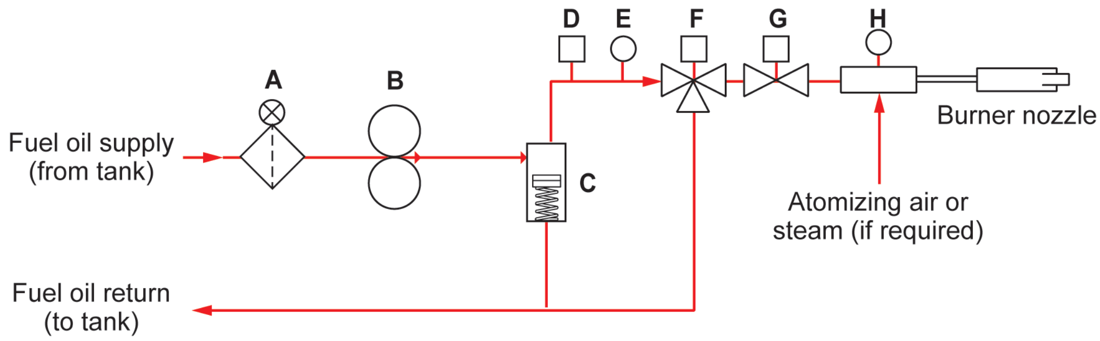
Fuel oil train components are similar in function to those used in natural gas service. A pressure regulator maintains fuel pressure at the nozzle. A pressure relief valve diverts excessive fuel pressure back to the oil tank or suction line. A low fuel pressure cut-off shuts down the burner if the fuel pressure drops below that required for flame stability. Safety shut-off valves stop the flow of oil to the burner when operating limits are reached, or under adverse combustion conditions.

However, fuel oil trains may have unique components not found on fuel gas trains. These include:

- Fuel filter
- Fuel pump
- Low oil temperature cut-off switch
- Low atomizing media cut-off switch.

Figure 7 shows a fuel oil train acceptable to **ASME CSD-1 Controls and Safety Devices for Automatically Fired Boilers**. This code covers all automatically fired heating and power boilers up to 3.663 MW input (300 BoHP output).

Figure 7 – Fuel Oil Train for Automatically Fired Boilers (ASME CSD-1)



A = Fuel filter
B = Fuel pump
C = Shutoff valve and/or pressure relief valve
D = Low oil temperature cut-off switch
E = Low oil pressure cut-off switch
F = Safety shut-off valve
G = Safety shut-off valve
H = Low atomizing media pressure cut-off switch

Fuel Filter

Oil burner nozzles are very sensitive to plugging from suspended fuel contaminants. Contaminants can adversely affect the spray pattern and quality of atomization. Poor atomization leads to incomplete combustion, and create toxic and explosive carbon monoxide. The resulting poor flame patterns can cause flames to impinge on heat transfer surfaces or refractory, and cause damage.

Strainers do not provide adequate protection for oil burners. Therefore, filters are used.

Fuel Pump

Oil trains must have fuel pumps to provide the necessary flow and pressure for proper atomization at the maximum firing rate.

Low Oil Temperature Cut-off Switch

The low temperature cut-off switch is a temperature-actuated device. It stops the flow of fuel to a burner that fires oil which requires preheating, such as **number 6 fuel oil**. This fuel must be preheated to reduce its viscosity so that it can be properly atomized by the burner. If the viscosity is too high, poor atomization will result. Poor atomization leads to incomplete combustion, and the creation of toxic and explosive carbon monoxide. The resulting poor flame patterns can cause flames to impinge on heat transfer surfaces or refractory, and cause damage.

The low oil temperature cut-off is a pre-ignition interlock. It prevents the burner from starting when the fuel oil temperature falls below the lower end of the viscosity range of the fuel, as recommended by the burner manufacturer.

For an operating boiler, this switch causes safety shutdown. This allows the fuel to recirculate through the oil heater, in order to re-establish the necessary oil temperature.

Low Atomizing Media Cut-Off Switch

Atomizing media is essential for burners designed to use atomizing air or steam. Poor atomization leads to incomplete combustion and the creation of toxic and explosive carbon monoxide. Resulting poor flame patterns can cause flames to impinge on heat transfer surfaces or refractory, causing damage.

For a steam or air atomized burner, the atomizing media pressure is supervised by an interlock switch. If the atomizing media pressure falls below the manufacturer's design pressure, this switch causes safety shutdown and lockout.

Objective 2

Describe the construction and operation of flame detectors.

Boiler Flame Failure Detectors

On boilers, various methods are used to detect flame failure. These include:

- Thermocouples
- Thermopiles
- Flame rods
- Photoelectric cells

Thermocouples

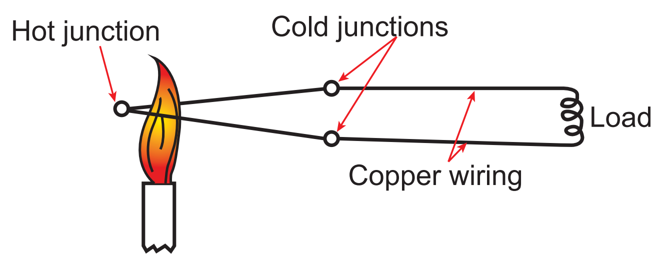
Thermocouples are found on small gas burners that use continuous pilots. Thermocouple flame safeguards are limited in use to pilot burners for small boilers up to 120 kW input (400 000 Btuh or 9.5 BoHP). This is because thermocouples have a slow flame failure response time. It can take up to 90 seconds for a thermocouple to cool off sufficiently to close a safety shut-off valve. In that period of time, significant amounts of unburned fuel can enter a furnace.

A thermocouple consists of two dissimilar wires welded together at one end to form a measuring (or "hot") junction. The opposite ends are connected to an electric circuit, called the reference (or "cold") junction. A basic thermocouple circuit is shown in Figure 8.

Side Track

Construction and operation of thermocouples are discussed in **Fourth Class Part A Unit 9 Chapter 2 "Introduction to Process Measurement."**

Figure 8 – Basic Thermocouple Circuit

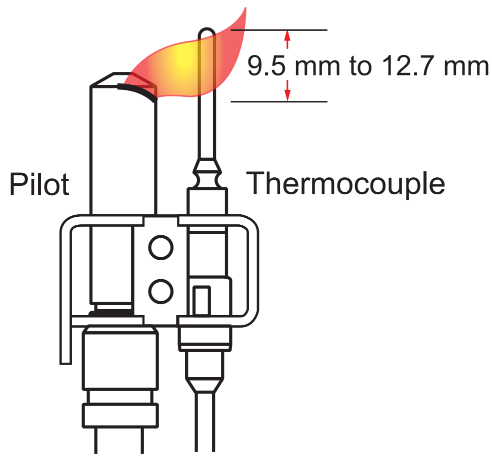


A thermocouple designed for flame monitoring is made of a copper outer sheath and an insulated inner wire of a different metal. The outer copper sheath acts as one of the two conductors. The inner wire is insulated so that it does not contact the copper. The two wires are welded together at the tip of the copper sheath, forming the hot junction.

When the hot junction is exposed to a flame, its temperature increases above that of the cold junction. This generates a small voltage (about 20 to 30 millivolts in an open circuit), capable of causing a small current to flow. This energizes a sensitive relay, called a **pilotstat**, which may be built into an SSOV. When the pilotstat is energized by the thermocouple, an external low voltage power supply energizes the main SSOV, causing it to open. The SSOV stays open until the thermocouple voltage drops below about 7 millivolts, which may occur due to pilot flame failure.

Figure 9 shows a pilot burner assembly that uses a thermocouple to supervise the pilot.

Figure 9 – Pilot Burner with Thermocouple



Quite often, pilotstats are combined into a single valve body with the following components:

- Gas pressure regulator
- Safety shut-off valve
- Manual gas valve

This type of SSOV is called a **combination gas valve**. These are common on smaller gas appliances with inputs up to 120 kW.

Pilotstats can also be external to the SSOV. These external pilotstats may function to interrupt the main flame only (called 50% shutoff), or both the pilot and main flames (called 100% shutoff). Figure 9 shows an external pilotstat that provides 100% shutoff. It interrupts the gas to the pilot burner, and interrupts the main SSOV circuit, when the pilot flame is extinguished.

Combination gas valves, and pilotstats that provide 100% shutoff, must be manually reset in order to light the pilot. Refer to Figure 10. To relight the pilot:

1. Close the main manual shutoff valve (the "A" valve).
2. Open the pilot gas valve (the "B" valve).
3. Provide a source of ignition to the pilot burner.
4. Depress the pilotstat manual reset button, for about 90 seconds, until the pilotstat remains energized.

If the pilot flame fails, the thermocouple does not generate electric current. This interrupts the 24 V control circuit at the pilotstat, and prevents the main SSOV from opening. During main burner operation, if the thermocouple does not detect a flame, the pilotstat de-energizes. Then, the pilotstat stops the flow of gas to the pilot burner, and de-energizes the SSOV. This stops the gas flow to the main burner.

Figure 10 – Gas Burner Control System

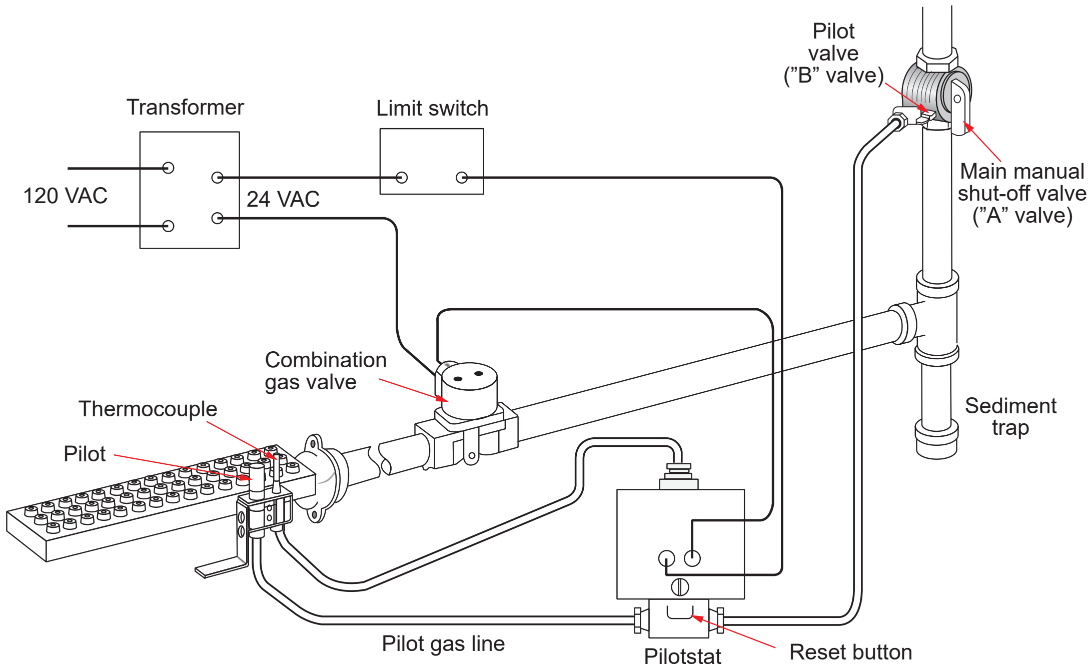


Figure 10 shows a limit switch in the SSOV circuit. In a boiler, there can be several limit switches in series. Any one of these switches can prevent the burner from operating. Switches may include low water cut-offs, high temperature cut-offs, high pressure cut-offs, aquastats, and pressuretrols. If any of these switches open, the main SSOV will close. However, the pilot burner remains lit.

Thermopiles

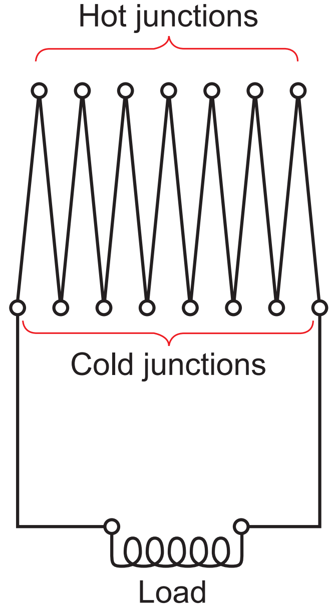
The voltage supply generated by a thermocouple is usually not more than 30 millivolts, so its electrical power is not sufficient to operate a SSOV directly. For the SSOV to operate, a transformer must supply power from the electrical main. However, multiple thermocouples in series can develop enough voltage to operate a SSOV. Such a flame detector is called a **thermopile** (see Figure 11).

Thermopiles develop sufficient voltage to operate an SSOV independently from any external power source. This system is called a **millivolt system**. Typical thermopiles generate around 750 millivolts. Special combination gas valves are designed to operate on this small voltage.

An advantage of a millivolt system is that the SSOV and burner control system operate without external power. Small residential boilers with millivolt systems can function even during a power failure.

Like thermocouples, thermopiles are limited to burners not exceeding 120 kW input.

Figure 11 – Basic Thermopile Construction



Flame Rod

The **flame rod** is a flame detection device that operates on the principle that flames can conduct electricity. A complete flame circuit consists of three elements: two electrodes and a flame. One of the electrodes is the flame rod. The other electrode is the burner itself. The flame conducts electricity between the flame rod and the burner.

A flame rod is a heat-resistant, small diameter metal rod, supported by a ceramic holder that keeps the rod electrically insulated from the burner. For continuous or intermittent pilots, the rod is located in the path of the pilot flame. With interrupted pilots, the rod penetrates the main and pilot flames. Therefore, the flame rod can be used to detect both pilot and main flames.

Alternating current (AC) is applied to the circuit. The current that flows through the flame is a pulsating direct current (DC). When AC is converted to DC, the process is called rectification. There are two reasons why the AC gets rectified to pulsating DC:

1. The flame rod and burner have very different surface areas. The burner can emit more electrons than the flame rod. For this reason, electrons flow primarily from the burner to the flame rod, effectively rectifying the applied AC.

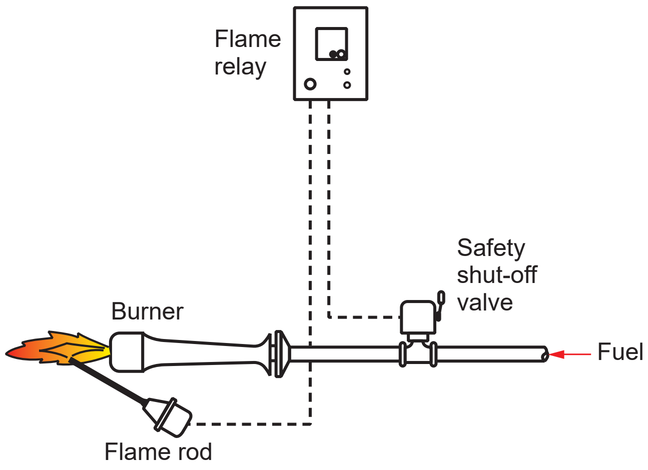
2. The flame pulsates at a particular frequency while in operation. The pulsations cause pulsating DC flow from the burner to the flame rod.

The burner monitoring circuit is designed to recognize a pulsating DC current. If the flame is extinguished, current stops, and the main and SSOVs close. If the flame rod is accidentally grounded to the burner, AC current flows through the circuit. The burner monitoring circuit does not accept the AC signal, and shuts off the SSOVs. Grounding can occur due to:

a) Soot bridging between the flame rod and the burner.
b) A cracked flame rod insulator.
c) A flame rod that has been warped or knocked out of position, so that it contacts the burner or other grounded metal part.

A basic flame rod system is shown in Figure 12. The flame rod extends into the burner flame. When the flame is present, the rod, burner, and flame close the **flame relay** circuit. This relay amplifies the signal from the flame unit, and provides sufficient power to keep the safety shut-off valve open. If the flame fails, the circuit opens, and the SSOV closes. During boiler startup, the main SSOV cannot be opened unless the rod senses the pilot burner flame.

Figure 12 – Basic Burner with Flame Rod



Unlike thermocouples and thermopiles, flame rods offer fast flame failure response time. Because of this, they are used in burners over 120 kW input.

For automatically fired boilers, flame rod monitoring systems are more complex than that shown in Figure 12. The firing equipment will also include a pilot burner, pilot SSOV, and an ignition system. In such a system, the relay is only a component of the burner management system (BMS). The BMS sequences the startup and the shutdown of the firing equipment, as well.

Flame rods are commonly used with gas burners. When used with oil-fired burners, the rod can become coated with carbon deposits, which may cause soot bridging and nuisance outages.

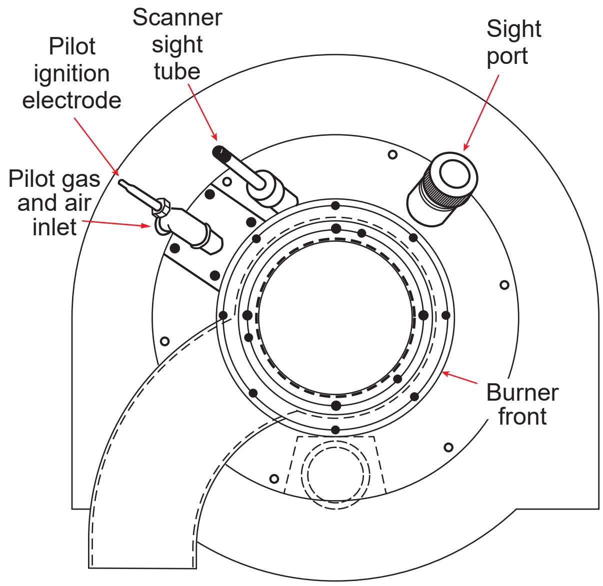
Photoelectric Cell

A photoelectric cell is a device that reacts to infrared, ultraviolet, or visible light emitted by fire. The cell is mounted on the boiler in such a way that it can observe the flame. Photoelectric cells are commonly called flame scanners.

Figure 13 shows a scanner. The lens at the end is inserted into a carefully aimed sight tube, so that the scanner can see the flame. A threaded ring secures the scanner on the sight tube. Figure 14 shows a scanner mounted on a power burner assembly.

Figure 13 – Photoelectric Scanner

Figure 14 – Scanner Mounting



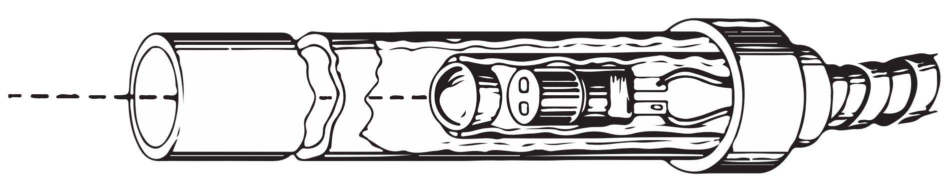
There are various types of photocells in use, including:

- Infrared scanner
- Ultraviolet scanner
- Rectifying photocell

Infrared (IR) Scanner

The scanner illustrated in Figure 15 uses a lead-sulfide cell that responds to infrared rays. The cell is a semiconductor whose electrical resistance decreases with an increase in the amount of infrared light it receives from the flame. Flame pulsations cause the resistance of the cell to fluctuate. This causes a fluctuating voltage (called the **flame signal**), which is amplified by an electronic amplifier to hold the flame relay in the closed position.

Figure 15 – Sulfide Cell Scanner



The flame relay controls the power supply to the main SSOV. When a flame failure occurs, the scanner does not sense a flame. Its resistance increases, and causes the flame relay to open. The power supply to the SSOVs is cut-off, which shuts off the fuel to the burner.

During boiler startup, when the scanner senses the pilot flame, the flame relay closes and the main SSOV opens. This permits fuel flow to the main burner. If the main burner does not light, or if the pilot flame goes out, the scanner opens the flame relay circuit, which causes the SSOVs to close.

Most boilers equipped with a photoelectric safeguard system use a single scanner to sight both the pilot flame and the main burner flame. A basic diagram of a lead sulfide scanner installation is shown in Figure 16. The scanner is mounted on the end of a sighting tube in such a way that its temperature will not exceed 50°C. The tube is aimed so the scanner can observe the pilot and the main burner. Figure 16 also shows the size of pilot flame required to keep the burner circuit energized.

Figure 16 – Scanner Installation

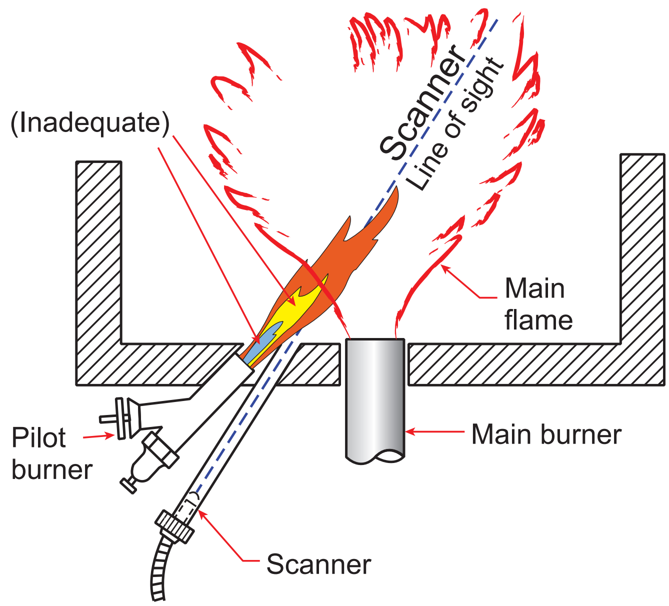
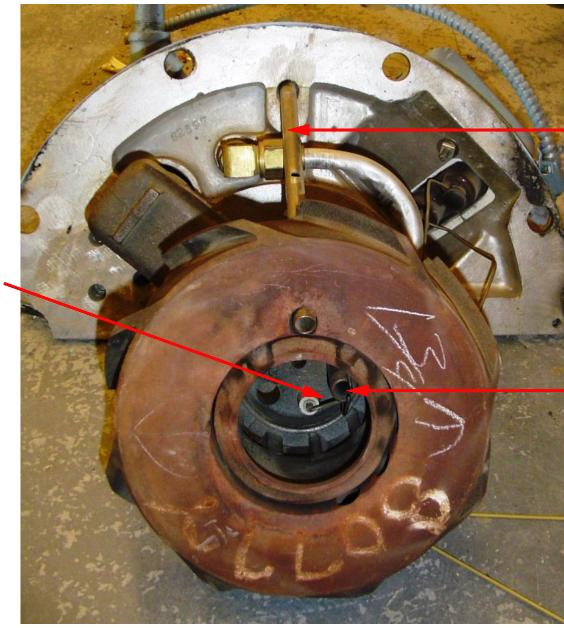
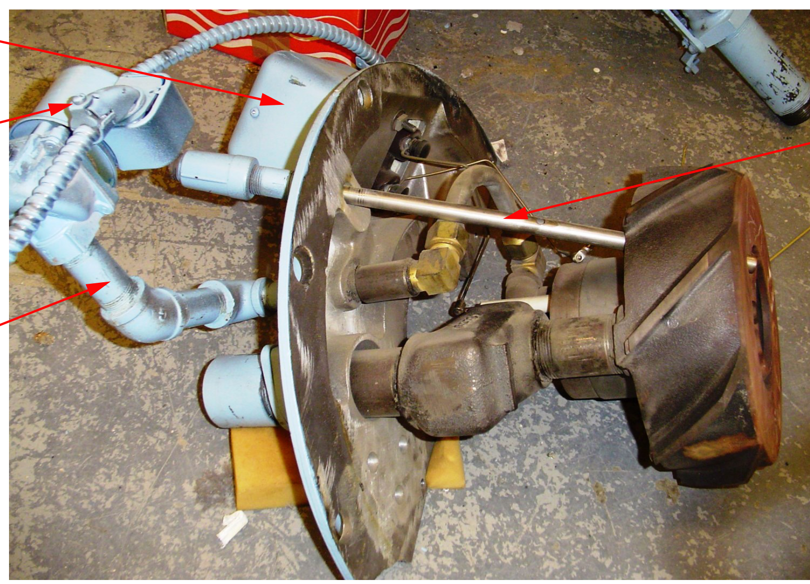


Figure 17 shows an end view and a side view of a firetube boiler burner assembly. The scanner sight tube is clearly visible at the top of the photo. The spark igniter electrodes are adjacent to the pilot burner. The pilot burner is surrounded by the main burner, which is a donut-shaped metal casting.

Figure 17 – Scanner Installation





Note the angle of the sight tube. This permits the scanner to observe the pilot and the main burner.

Ultraviolet (UV) Scanner

The principle of operation and mounting of the ultraviolet scanner is quite similar to the infrared. However, this scanner responds only to the ultraviolet rays emitted by the flame. UV scanners are mounted as close as possible to the flame, without being subjected to a temperature over 100°C.

Igniter sparks give off UV light, and can fool a UV scanner into mistaking the spark for a pilot flame. Newer burner management systems may be able to recognize the frequency of a spark, and can distinguish sparks from flames. However, it is best practice to ensure the scanner cannot see the igniter spark.

Case Study

The boiler was down for regular maintenance. During shutdown, I replaced the furnace sight glass. The old one was dirty and cloudy, so I put in a shiny new one.

After the boiler was back together and ready to go, it was time to check the burner safeguard controls. I shut the main and pilot test firing valves, and did an ignition spark response test. I couldn't believe that I got a flame signal of 3.5 volts off of the spark! The programming controller opened up the main safety shutoff valves, too! Good thing the test firing valves were closed. I can imagine the explosion if it tried to light off the main burner from that little spark.

I tried the test again, but this time I pulled the scanner and looked down the sight tube. It turns out that the new sight glass was so shiny that the igniter spark reflected off of it back to the scanner. The sight lines were just right!

Rectifying Photocell

The rectifying photocell is also known as a **cad cell**. It consists of a glass vacuum tube containing a curved metal cathode made of cadmium oxide and an anode wire, which form part of an electronic circuit. When the cathode is exposed to visible light from a flame, it emits electrons that are picked up by the anode. This creates a signal that closes the contact points of a flame relay. This relay keeps the main safety shut-off valve energized and open. Failure of the flame causes it to close.

The cell is often mounted inside the combustion air supply tube of small packaged oil burners. Here, it is kept relatively cool and clean, while still having an unobstructed view of the flame.

Objective 3

Describe the combustion safety controls for boilers and burner systems.

Boilers and burner systems require other safety controls, in addition to the fuel train components covered in Objective 1. These controls are not part of the fuel train, but interact with fuel train components to turn off the burner, or prevent the burner startup sequence from beginning, if unsafe conditions exist.

Safety Switches

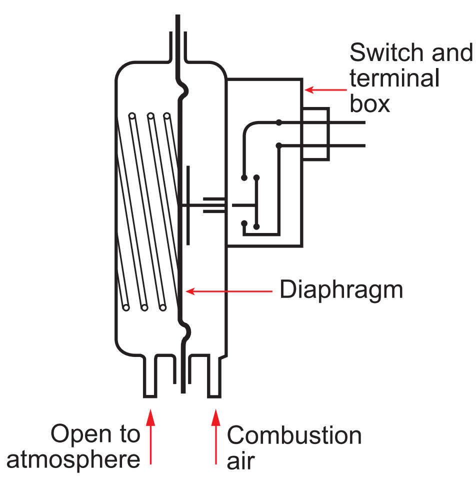
The safety switches used on boilers equipped with power burners include:

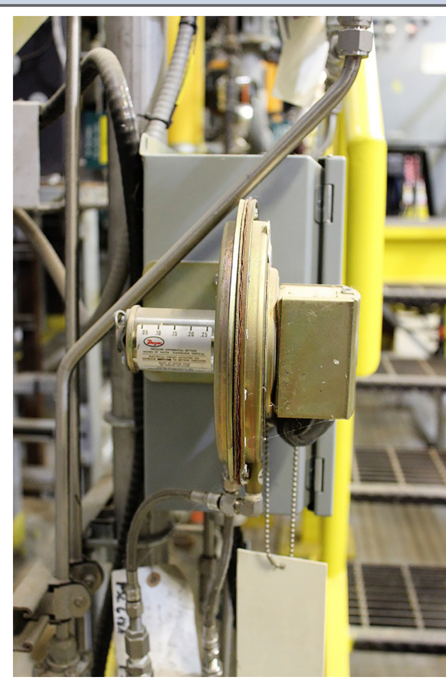
- Low combustion air pressure fuel cut-off switch
- Low-fire start switch
- High airflow purge switch
- Fuel valve supervisory switch

Low Combustion Air Pressure Fuel Cut-Off Switch

This device is used to prevent burner operation when insufficient combustion air is supplied to the burner for safe combustion to occur. Figure 18 shows a schematic drawing and a photo of a low combustion air pressure switch.

Figure 18 – Low Combustion Air Pressure Cut-Off Switch





This switch consists of a sealed housing divided by a flexible diaphragm. The diaphragm is connected to a switch which interrupts or completes the burner limit control circuit, depending on whether there is adequate combustion air. One side of the housing is open to atmosphere, and the other is connected to the windbox. When the forced draft fan is not in operation, or if it develops insufficient air pressure, the spring acting on the diaphragm opens the switch. This causes the flame safeguard controller to shut the SSOVs.

When the forced draft fan is running, there should be sufficient air pressure in the windbox to move the diaphragm against the force of the spring. This closes the switch, which signals the flame safeguard control that adequate combustion air pressure exists.

If the windbox pressure drops below the safe minimum, the cut-off switch opens, de-energizes the SSOVs, and shuts down the burner.

Low-Fire Start Switch

Boilers controlled by a high-low or modulating burner commonly have modulating motors, to position both the inlet flow control valve (firing rate fuel valve) and the combustion air damper. The modulating motor maintains the air and fuel in the correct ratio, according to the load on the boiler. In addition to positioning the fuel and air, modulating damper motors often have switches that signal when the air and fuel are in the high-fire position, and when they are in the low-fire position. The latter switch is called the low-fire start switch.

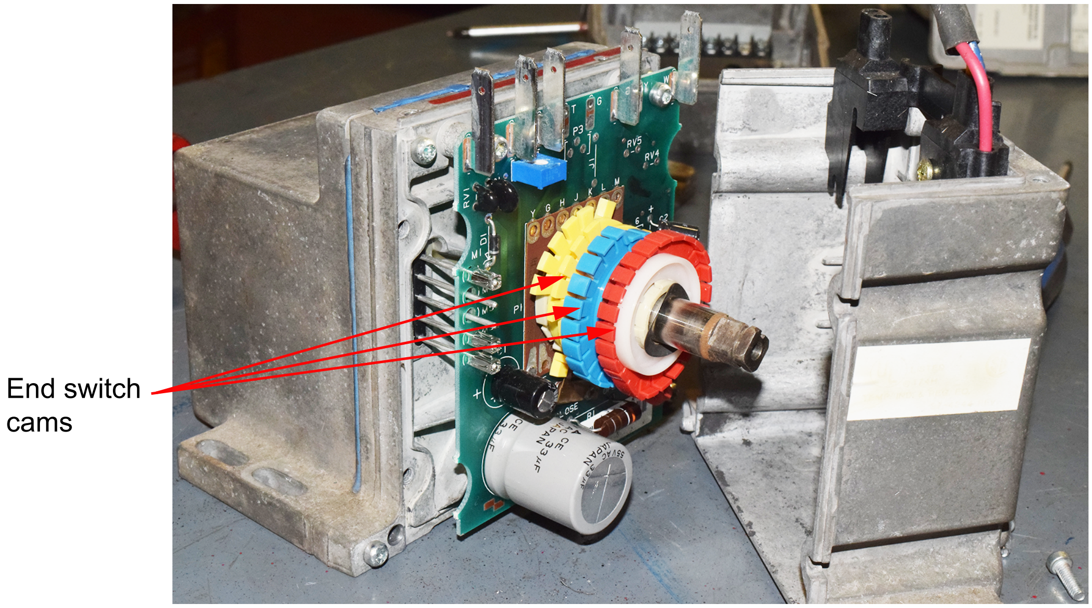
Figure 19 shows a modulating motor with the end cover removed. Inside are adjustable cams that operate the low and high-fire switches.

The pilot burner must ignite on low fire. If excessive airflow occurs during pilot ignition, the pilot may be blown out, or made too weak to adequately light the main burner. If this occurs, the burner will shut down on flame failure.

The main burner must also ignite on low fire. If excessive fuel flow occurs during main ignition, a furnace explosion may occur.

CSA B149.3 Code for the Field Approval of Fuel-Related Components on Appliances and Equipment requires proven low-fire start for any appliance (boilers included) over 300 kW input (24 BoHP). The low-fire start switch forms an essential part of the burner safety circuit. It prevents ignition of the pilot or main burner if the air and fuel are not in their low-fire positions.

Figure 19 – Modulating Motor Cams for High-Fire and Low-Fire Switches



High Airflow Purge Switch

CSA B149.3 also requires burners that use any form of mechanical draft to have a proven high-fire pre-purge:

> *When either an intermittent or an interrupted pilot or a direct transformer spark igniter is used to light the main burner and the combustion air supply is by mechanical means, the appliance control system shall provide a proven purge period prior to the ignition cycle. This purge period shall provide at least four air changes of the combustion zone and flue passages. The airflow rate during purge shall be not less than 60% of that required at maximum input.*

To summarize:

- The purge shall be at least 60% of the airflow when the burner is at high-fire. This ensures combustible gases are swept clear of the furnace prior to ignition.
- The purge must last long enough so that four air changes can take place.
- The purge shall be proven. This means that a device must prove the airflow and the purge duration.

Proof of airflow comes in three forms:

1. Damper or modulating motor end switches
2. Variable frequency drive (VFD) contact closures
3. Calibrated airflow switches

Combustion air dampers may be equipped with limit switches, so that the purge timer begins only when the combustion air damper reaches the high-fire position.

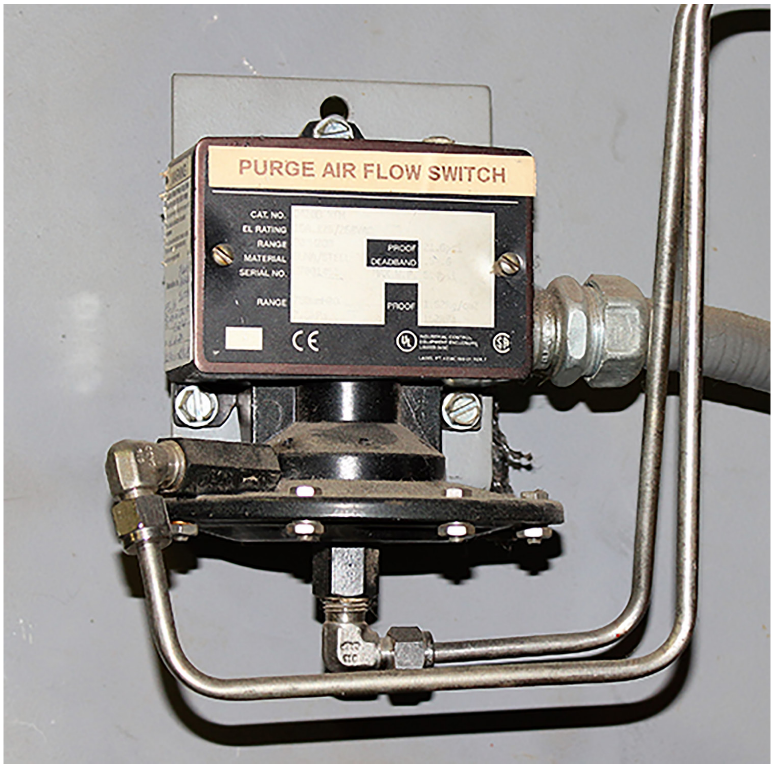
Modulating motors with high-fire purge switches can also be used. When the modulating motor drives the damper to the high-fire position, the high-fire switch signals the burner management system to begin timing the purge.

Variable frequency drives may be equipped with dry contact closure outputs. If a VFD is used to drive the forced draft fan, the contact closure can be programmed to begin the purge timer when the VFD frequency is at least 36 Hz (60 % of the maximum airflow).

With each of the above, if the draft fan motor trips, or becomes mechanically uncoupled, the purge timer may count even if the fan is not supplying air. The low combustion air pressure cut-off will prevent the purge from proceeding if there is inadequate windbox pressure.

A larger boiler may have a dedicated airflow-proving switch that starts the purge timer at maximum airflow. Such a switch is shown in Figure 20. A differential pressure switch senses the airflow from the forced draft fan. At maximum airflow, the differential pressure is greatest, and the switch closes. This starts the purge timer. If the fan becomes mechanically uncoupled, the airflow decreases and the purge switch opens, which interrupts the purge.

Figure 20 – High Airflow Purge Switch



Combustion Air Supply and Burner Interlocks

For proper and safe combustion, all burners require adequate fresh air.

Section 8 of the **CSA B149.1 Natural gas and propane installation code** stipulates the size and location of combustion air openings for all gas and propane fired appliances, including boilers. The combustion air requirements change with the type of burner. Natural draft burners require larger combustion air openings per kW input than power burners.

Section 11 of the **CSA B139 Installation code for oil-burning equipment** has similar requirements for the size and location of combustion air equipment. The combustion air size and location requirements are quite similar to the requirements for gas-fired power burners.

Without adequate combustion air, burners produce carbon monoxide and soot. In extreme cases of air starvation, natural draft burners can spill combustion products into the building interior. This can lead to carbon monoxide poisoning and death. For this reason, **CSA B149.1** and **CSA B139** stipulate a number of requirements. The following is a brief overview of the requirements common to both codes.

Inlet Screens

It is important that combustion air openings are kept unobstructed. Occasionally, screens are placed on combustion air openings to prevent rodents or birds from entering the mechanical space. Screens, if used, must not have a mesh size smaller than 6 mm (1/4 inch). Smaller mesh sizes are prone to obstruction by dirt, debris, and frost.

Height above Grade

The combustion air inlet from the outdoors must not be located lower than 300 mm (12 inches) above the outside grade level. This is to prevent accumulations of snow from blocking the combustion air opening.

Ventilation Air

In addition to the combustion air requirements, there must also be ventilation air openings. **CSA B149.1** stipulates that these openings must be at least 10% of the required combustion air opening, but not less than 6500 mm^2 (10 in^2) in cross-section. The ventilation air opening should be opposite the combustion air opening, and as near as possible to the ceiling.

Mechanical Dampers and Damper Interlocks

Manual air dampers or louvres must not be installed in combustion air openings. However, a fully automatic damper or louvre can be used to shut off the combustion air when the boiler and other appliances are off. In this case, all burners must be interlocked with the damper assembly, so that the burners cannot fire unless the dampers are completely open.

Mechanical Air Supplies and Interlocks

An airflow-sensing switch must be installed when combustion air is supplied by mechanical means, such as with a small, dedicated air-handling unit. This switch must be wired into the burner management system safety limit circuit to turn off the burners if the mechanical air supply fails.

Protection against Freezing

Care should be taken to ensure that no water, oil, or steam lines are run in the direct path of cold fresh air entering from any of the outside air openings. Heated heavy oil lines should be protected from cold air. They should be electrically or steam heat traced and insulated.

Objective 4

Describe burner management systems.

Burner management systems tie the fuel train components and other burner safety controls together into a coordinated safety system. The operation of pilot SSOVs, igniters, combustion air switches, and the like communicate with the BMS to ensure safe burner operation.

The **NFPA 85 Boiler and Combustion Systems Hazard Code** defines a burner management system (BMS) as:

> *"The control systems dedicated to combustion safety and operator assistance in the starting and stopping of fuel preparation and burning equipment and for preventing misoperation of and damage to fuel preparation and burning equipment."*

Most burner management systems are small programmed combustion controls that offer little or no opportunity for custom program configuration. According to Factory Mutual (FM), such a controller permits operators and burner technicians to customize "*a limited selection of safety parameters such as purge, trial for ignition and flame failure response time.*"

Figure 21 – Honeywell Programming Controller (BMS)

The principal purposes of BMS are to:

a) Prevent burners from starting when unsafe conditions exist.

b) Protect against unsafe operating conditions.

c) Operate combustion equipment (such as fans, fuel valves, igniters, and so on) in the correct sequence for reliable light off and shutdown.

d) Provide operators with run status and troubleshooting information.

The unsafe conditions referred to above are primarily those associated with burner operation. However, unsafe conditions related to the specific burner application are also linked to the BMS operation. Therefore, BMS systems prevent startup or operation due to:

a) Conditions specific to the burner, such as irregular fuel pressure and flame failure.
b) Conditions specific to the appliance served by the burner, such as high temperature, high pressure, and low water.

In summary, effective BMS should monitor, control, diagnose, and maintain the various aspects of fuel burning equipment, including the ability to safely carry out a startup procedure, or a shutdown procedure if an unsafe condition exists.

Types of Burner Management Systems

The three main categories of burner management systems, from the simplest to most complex, are the:

1. Flame relay
2. Primary control
3. Programming control

Flame Relays

The simplest burner management system is the simple flame relay. These relays have a flame detection device, an amplification circuit, a relay, and a safety shut-off valve. These controls merely detect the existence of a flame, amplify the flame signal to hold in a flame relay, and permit the SSOV to remain energized.

Primary Controls

Primary controllers are more sophisticated devices. They provide necessary functions when intermittent or interrupted pilots are used:

- Safe Start Checks
- Timed Ignition period
- Timed Pilot Trial-for-Ignition period
- Timed Main Flame Trial-for-Ignition period
- Timed Flame Failure Response
- Interlock circuitry for the fuel safety shutoff valves

Safe Start Checks

A **safe start check** ensures no flame is present during the burner off-cycle. If a flame is present, the primary control does not permit a start sequence to begin. This is because the safety shut-off valves cannot completely shut off the flame.

Primary controls used with continuous pilots do not conduct a safe start check.

Timed Ignition Period

The primary control times the pilot ignition. If ignition does not occur in a short period of time, the primary control turns off the pilot SSOV and the igniter. Excessive ignition times may be the result of a defective ignition transformer. If ignition was to proceed for too long, explosive fuel accumulations could build in the furnace.

Timed Pilot Trial-for-Ignition Period

Once the pilot flame is established, the primary controller waits to see if the pilot remains lit, and is large enough to light the main burner. **CSA B149.3** limits the pilot trial for ignition period to a maximum of 10 seconds. If the pilot is unstable or fails during the pilot trial for ignition period, the primary control goes to safety shutdown and lockout.

Timed Main Flame Trial-for-Ignition Period

For burners with interrupted pilots, the primary control keeps both the pilot and main SSOVs energized for a period of time, to ensure the burner flame is stable. **CSA B149.3** stipulates a maximum of 10 seconds main flame establishing period. After the main flame ignites, the primary controller maintains both pilot and main flame.

Timed Flame Failure Response

Primary controls must be able to shut off a flame within a prescribed period of time. **CSA B149.3** stipulates a maximum 4-second flame failure response time for burners over 120 kW input. If the SSOVs stay open for longer than 4 seconds, explosive gas concentrations could arise in the furnace.

Interlock Circuitry for the Fuel Safety Shutoff Valves

The interlock circuitry has been discussed in previous objectives. Burner safety interlocks wired to the primary control may include:

- High and low gas pressure cut-offs
- Low fuel temperature cut-off
- Low atomizing medium cut-off
- Combustion air damper interlock
- Low combustion air pressure or flow

Other interlocks depend on the nature of the appliance served by the burner. For boilers, these may include:

- Low boiler water level
- High temperature cut-off
- High pressure cut-off
- Low water flow switch
- Operating temperature or pressure control

Programming Controllers

Programming controllers are commonly installed on packaged commercial and industrial boilers that use mechanical draft systems. They are both flame safeguards and burner startup sequence controllers. Programming controllers are singular in purpose, and have internal programming that does not permit custom configuration.

Programming controllers perform all the functions that primary controls do. However, they also have the following features:

- Pre-ignition interlock circuitry
- Fixed tamper-proof sequence timers
- Purge proving circuitry
- Low-fire position start circuitry

Nearly every burner management system Fourth Class Power Engineers operate will be a programming controller.

On Track

Programming controllers are also known as combustion programmers and programmed combustion controls.

Pre-Ignition Interlock Circuitry

Pre-ignition interlocks are switches that must be in a particular state before pre-purge occurs. If not, the burner will go to safety shutdown and lockout.

Pre-ignition interlocks prevent a purge from beginning if the SSOV proof-of-closure switches are not shut. Pre-ignition interlocks are also used to ensure the combustion air proving switch is open prior to the draft fan starting.

Combustion air dampers and mechanical combustion air supplies must have proving switches interlocked with the programming control as a pre-ignition interlock.

Fixed Tamper-Proof Sequence Timers

Formerly, programming controllers had electro-mechanical drum sequencers, driven by timer motors. Unfortunately, such controllers permitted access to the timer motor so that purge periods, ignition periods, and others could be shortened or bypassed altogether, resulting in dangerous conditions. Modern programming controllers are electronic devices that do not permit alteration of sequences or sequence timing.

Purge Proving Circuitry

Purges are necessary to prevent the accumulation of combustible gas in the furnace. These combustible gases could be products of combustion (such as carbon monoxide) left over from the previous operating cycle, or fuel introduced to the furnace during the off cycle, due to leaking SSOVs.

Unlike the primary control, the programming control has the ability to initiate and "prove" a purge. The programming control has built-in purge timer circuitry, to provide (typically) a 30, 45, 60, or 90 second purge. The purge duration must permit four furnace air changes to occur at 60% of the maximum burner airflow. For this reason, the boiler manufacturer selects the purge duration.

To prove the purge, the programming control must know when the airflow is at 60% or greater. The previous objective discussed the means to accomplish this. When the purge airflow is adequate, the programming control begins to count the purge, so that it lasts long enough for four air changes occur.

Low-Fire Position Start Circuitry

The programming control also recognizes when the airflow is low enough for the pilot burner to be lit without being blown out by excessive combustion airflow.

In addition to these features, some programming controls can manage burner firing rates, and maintain the correct air-to-fuel ratio while the burner is in operation.

Objective 5

Interpret burner operating sequence charts, and provide a typical sequence of startup and shutdown events.

Operating Sequence of BMS (Programming Control)

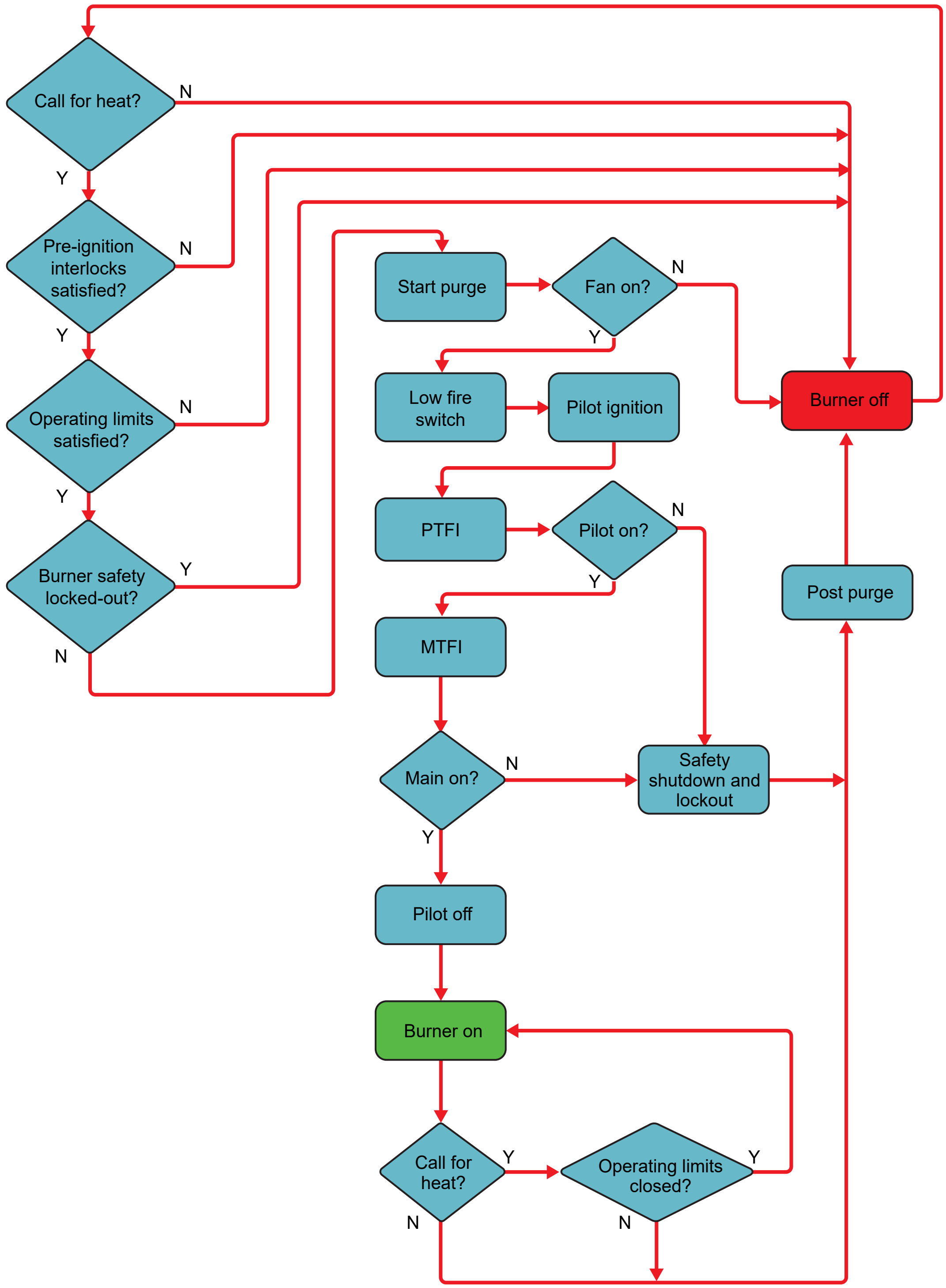
Power Engineers must become familiar with the programming controller installed on each boiler they operate. They will likely have different types of flame amplifiers, purge timers, pre-ignition interlocks, airflow sensing devices, and permissives. These variations depend on the fuel used, the burner input, the furnace volume, the fuel pressure, and the age of the equipment.

The following sequence of operation is typical for most programming controllers. The steps are similar, whether firing natural gas or oil.

1. **Pre-ignition Interlocks.** The BMS checks the permissives and pre-ignition interlocks. The startup sequence proceeds if all are satisfied.
2. **Start draft fan.** If permissives and pre-ignition interlocks are satisfied, and there is a **call for heat**, the BMS starts the draft fan or fans.
3. **High airflow.** When the fan is running, the BMS increases the fan speed or combustion air damper position to the high-fire position.
4. **Start purge.** If high airflow is detected, the BMS purge counter begins.
5. **Low airflow.** When the purge is complete, the BMS returns the combustion airflow to low fire.
6. **Ignite pilot**. If the airflow is proven to be at low fire, the BMS starts the igniter and opens the pilot SSOV. The BMS will wait up to 10 seconds for the pilot to stabilize. This is the pilot trial for ignition period (also called the **pilot flame establishing period**). If the pilot is of inadequate strength, or too small to reliably light off the main burner, the BMS will shut the pilot SSOV, and lockout the burner system to prevent it from starting. This is called a “safety shutdown and lockout.” Safety shutdowns require manual reset.
7. **Light main burner**. If the pilot is stable and of adequate size, the BMS opens the main SSOVs to light the main burner. During this time, both the pilot and main SSOVs are open. This is the main flame trial for ignition period (or **main flame establishing period**). If the main flame is not established in 10 seconds, the BMS will shut the pilot and main SSOVs, and go into safety shutdown and lockout, which requires manual reset.
8. **Run period**. If the ignition system uses an interrupted pilot, the BMS shuts the pilot SSOV. During the run period, permissives and elements of the safety circuit are monitored. If a permissive should open (e.g. low water cut-off, operating pressure limit control, etc.) the BMS automatically shuts off the SSOVs, and conducts a post-purge of the furnace. The BMS waits for conditions to normalize, and then repeats its startup sequence. If a burner safety limit opens (e.g. flame failure, loss of combustion air, etc.), the BMS performs a safety shutdown and lockout.

These steps are shown in Figure 22.

Figure 22 – BMS Startup Sequence and Logic



On Track

Boiler permissives are monitored during every step of the startup sequence, and can cause shutdown at any time.

The BMS indicates where it is in the startup or run sequence, with small LED lights or readouts.

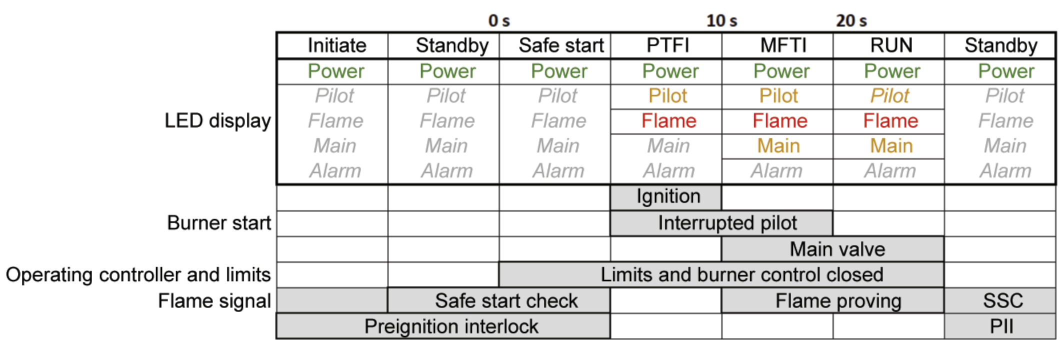
If safety shutdown occurs, the BMS shows what caused the safety shutdown and the part of the sequence where it occurred. See Figure 21.

The BMS indicates **ALARM** when lockout occurs due to flame failure during PTFI, MTFI, or the RUN period.

Operating Sequence Charts

The sequence of operation of a BMS can be illustrated with a chart like that shown in Figure 23. This chart is based on the operation of a Honeywell programming controller, like that shown in Figure 21.

Figure 23 – Programming Control Operating Sequence Chart



The following is a description of the events during each stage shown on the operating sequence chart.

Initiate

The initiate stage is entered when the primary controller is first powered. During this stage, the power quality is determined. If there is a **brownout** condition (low voltage), excessive AC line noise, or if the power flickers, the initiate stage is maintained until the supply voltage conditions have normalized. This stage normally lasts for 10 seconds. If the poor voltage conditions persist for greater than 4 minutes, the controller locks out.

Standby

In the standby stage, the controller is ready to begin a burner startup, as soon as there is a call for heat.

Safe Start

If there is a call for heat, and all permissive switches are in the correct state, the controller begins a safe start check. The safe start check primarily looks for a flame (or any condition that may simulate a flame) before the ignition period has begun. If a flame is detected, the controller returns to standby mode, and does not proceed further in the startup sequence.

Also, the programming controller checks to see if there is power at any of the fuel SSOV terminals. If there is power, the SSOVs may be open due to an electrical or mechanical fault.

Note that safe start checks are conducted both before and after the call for heat is established.

Ignition Trials

When the safe start is complete, the programming control begins the purge. The purge timer beings counting when high airflow is established. After the purge, the low-fire proving switch must be closed before ignition trials begin.

Pilot Trial for Ignition (PTFI)

When purge is complete and the low-fire start switch is satisfied, the pilot trial for ignition period begins. The ignition transformer and pilot SSOV are energized, and the pilot burner ignites. The pilot flame must be proven within 10 seconds; otherwise, a safety shutdown will occur. Figure 21 shows the display of a Honeywell programming controller after a pilot failure during PTFI.

Main Flame Trial for Ignition (MTFI)

After the PTFI period, the ignition transformer is de-energized, and the main SSOVs open. The pilot SSOV stays energized throughout the MTFI period. If after 10 seconds the main flame is stable, the pilot SSOV closes. If the main flame is not established within 10 seconds, a safety shutdown and lockout will occur.

Run

If the main flame remains stable, the controller enters the **RUN** period. The burner continues to run until a burner limit or a boiler operating limit switch opens. When a limit switch opens, the programming control conducts a 15-second post-purge, and then re-enters standby mode.

Though the sequence described above is based on a Honeywell programming controller, the sequence of operation is similar for those made by other manufacturers.

Safety Shutdown and Lockout

A safety shutdown is a built-in feature of every programming controller. When a condition that can cause unsafe burner operation is detected, the programming controller closes all SSOVs and locks itself out. The controller leaves the burner in a safe condition, and will not attempt to recycle or re-ignite. An operator must manually reset the programming control, using the reset button on the front of the controller.

Safety shutdown is indicated directly on the controller with an **ALARM** light, an alarm horn, or an expanded visual display.

CAUTION

Do not reset a programming controller or a primary control without first determining the cause of the lockout and correcting the condition. Modern programming controllers have readouts and first-out annunciators to help operators determine the cause of the lockout.

Careless resetting of a programming controller could re-establish an unsafe condition. It may be necessary to employ a certified oil fitter, gas fitter, or burner mechanic to troubleshoot and repair the problem.

Safety shutdown and lockout occurs under the following conditions:

During the **INITIATE** period:

a) If an AC line power error occurred.
b) If power quality problems persist for over 4 minutes.

During the **STANDBY** period:

c) If a flame signal is present for 4 minutes.
d) If the ignition transformer, the pilot SSOV, or the main SSOVs are energized.
e) If an SSOV proof-of-closure switch opens.

During the **SAFE START CHECK**:

f) If the ignition transformer, the pilot SSOV, or the main SSOVs are energized.
g) If an SSOV proof-of-closure switch opens.

During the **PILOT TRIAL-FOR-IGNITION PERIOD (PTFI)**:

h) If the airflow proving switch opens.
i) If the ignition transformer and the pilot SSOV are NOT energized.
j) If the main SSOV is energized.
k) If there is no pilot flame present at the end of the PTFI period.

During the **RUN** period:

l) If the airflow proving switch opens.
m) If the ignition transformer is energized.
n) If the main SSOV is NOT energized.
o) If there is no flame present. This condition is often called **flame out**.
p) If the pilot is intermittent, the pilot SSOV is NOT energized.
q) If the pilot is interrupted, the pilot SSOV IS energized.

Burner management systems must have built-in self-diagnostics. If the BMS detects an internal fault, at any stage of operation, it performs a safety shutdown and lockout.

Shutdown without Lockout

For an automatically fired boiler, each time an operating control opens, the burner shuts off. These controls include:

- Boiler on-off switch
- Operating limit control (pressuretrol or aquastat)
- High pressure or high temperature cut-off
- High/low fuel pressure cut-off switches
- Low water fuel cut-off

When these switches open, the burner shuts off, but the BMS does not lockout, and therefore does not go into **ALARM**. The burner restarts automatically when the switch closes.

On Track

Even though the BMS does not perform a safety shutdown and lockout on these controls, they may still require local manual reset. Low water cut-offs, high pressure cut-offs, high temperature cut-offs, and gas pressure switches are usually equipped with manual reset buttons mounted directly on the switch. These switches prevent automatic recycling of the boiler, so that operator intervention is required.

Application of Burner Management Systems to Boilers

Burner management systems are required for all fuel-fired boilers. Smaller natural draft boilers with atmospheric burners do not require controllers with the ability to start draft fans and prove purge conditions. Those with continuous pilots may require simple primary controllers. Small oil-fired boilers may use stack temperature relays to detect flame failure.

Natural Draft Gas-Fired Boilers

When used on natural draft gas-fired boilers with intermittent pilots and spark ignition, programming controllers work as follows:

1. The operating control (aquastat or pressuretrol) initiates a startup, and closes its switch. This condition is referred to as a "call for heat."
2. On boilers so equipped, the primary controller opens the uptake damper, and permits natural draft to purge the furnace for 30 seconds.
3. The primary control energizes the ignition transformer and the pilot SSOV to light the pilot flame. Typically, a rectifying flame rod is used to detect the pilot flame.
4. When the pilot flame is established, the flame detector senses the flame and causes the primary control to energize the main gas SSOV.
5. The main SSOV opens, and the pilot flame ignites the burner.
6. When the main flame is established, the ignition transformer is de-energized. The pilot SSOV remains open during the run period.

The primary control will keep the main burner in operation until the desired preset operating steam pressure or water temperature is reached. At this time, the operating control will open, which causes the programming control to close the main SSOV. The primary control system is now ready to restart when the boiler steam pressure or water temperature drops to the lower desired value.

If the pilot does not light within 15 to 90 seconds (depending on the configuration of the controller), the primary controller will either retry ignition, or will go into safety shutdown and lockout. This depends on the boiler manufacturer specifications and code requirements.

If the controller is configured to retry ignition, it first waits for 5 minutes, to allow the furnace to naturally purge. Then, the ignition transformer energizes, and the pilot SSOV opens.

Primary controls are often configured to permit a single pilot ignition retry. If the pilot is not established on the second attempt, the primary controller goes to safety shutdown and lockout. To reset the primary control, it is often necessary to turn off the power to the boiler.

If the main flame goes out during the run period, the burner goes into safety shutdown and lockout. However, many primary controls immediately begin the PTFI cycle on loss of main flame. If the number of main flame failures in a particular call for heat cycle reaches 5, the primary controller may perform a 5-minute natural draft purge before attempting to establish a pilot.

Oil-Fired Boilers with No Pilot

The following sequence of events are performed by a BMS applied to small mechanically-atomized packaged oil burners.

1. The boiler pressuretrol or aquastat signals a call for heat, by closing when the water temperature or steam pressure drops below the desired set point.
2. The programming controller energizes the motor that drives the draft fan and fuel oil pump, and purges the furnace.
3. The programming controller energizes the ignition transformer and the fuel oil SSOV.
4. The spark ignites the main burner.
5. The flame detector senses the flame and causes the flame relay to close.
6. The ignition transformer de-energizes. Some burners operate with the ignition transformer energized throughout the entire run cycle.

In case of ignition failure during boiler startup or main burner failure during operation, the programming control will lock out. The operator must correct the problem, and reset the control before the ignition sequence can start again.

Programming Controller Sequence of Fully Automatic Boilers

Fully automatic packaged boilers use highly sophisticated programming controls that include one or more timers, and several relays. Programming controls used on boilers vary in their operation, especially in the timing of the programming sequence, as different types of burners, fuels, methods of ignition, and operating controls may be used. However, the principle of operation for all programming controllers is very similar.

Since it is impossible to give a detailed description of the operation of every type of programming control used on boilers, only a general description of operation of a typical programming control will be described. The boiler or burner manufacturer operations manual must be consulted for specific instructions.

On Track

The following procedure refers to boilers with fully automatic burner management systems. An automatically fired boiler cycles in response to a control system. Unlike boilers with semi-automatic or manual burner management systems, fully automatic boilers do not require manual operator intervention to permit recycling, and therefore do not have supervised test firing valves.

Pre-Start Conditions

Before a steam or hot water boiler can be started by its programming controller, several conditions, known as permissives and pre-ignition interlocks, must be satisfied. Until satisfied, the programming controller will not initiate the automatic startup sequence. The conditions listed below, while not comprehensive, are typical permissives:

a) The water in the boiler drum must be above the cut-off point of each of the low water fuel cut-offs. Manual resets on the cut-offs must be reset.

b) The steam pressure or water temperature must be at or below the cut-in setting of the operating control. The switches for the high pressure and high temperature limit controls must also be closed. Manual resets on the cut-offs must be reset.

c) If the boiler is gas-fired, the fuel supply pressure to the burner valves must be above the cutout point of the low gas pressure cut-off switch. The fuel pressure must also be below the cutout point of the high gas pressure cut-off switch. Manual resets on the cut-offs must be reset.

d) If the boiler has SSOVs with proof-of-closure switches, these switches must be closed.

e) If the boiler is so configured, the low combustion air pressure fuel cut-off switch must be open.

f) Any combustion air damper or air supply interlocks must be satisfied.

g) If the boiler is oil-fired, the oil pumps must be running to satisfy the low fuel pressure cut-off switch.

h) If the boiler is oil-fired and uses atomizing media, the atomizing medium must be at the proper pressure to satisfy the low atomizing medium cut-off switch. This may involve starting the atomizing air pump. Manual resets on the cut-offs must be reset.

i) If the burner uses oil that requires preheating to reduce its viscosity, the oil must be hot enough to satisfy the low oil temperature cut-off switch.

j) For dual fuel boilers, a fuel selector switch must be placed on either oil or gas, depending on the fuel used.

Other preparatory steps are not permissives, but must still be performed.

a) The main electrical disconnect switch or breaker must be closed for the electronic circuit in the programming control panel to energize. This will place the programming controller in initiate mode.

b) Often, draft fans have a separate electrical feed. These breakers or disconnects must also be closed. Motor starters must be reset.

c) For initial startup, the on-off switch should be open. Once the on-off switch is closed, the operating control will start the firing sequence on a call for heat.

d) If the boiler is gas fired, the pilot and main test firing valves must be open. Other fuel line manual shutoff valves must also be open.

e) If the boiler is oil-fired, the fuel lines and oil pump must be properly primed to assure uninterrupted fuel supply to the burner SSOVs. Manually operated valves in these lines must also be open.

Startup Sequence

1. Boiler ignition sequence is initiated when the on-off and operating control switches are closed. This moves the programming controller from standby mode to safe start check mode.

2. When the safe start checks are complete, the programming controller starts the draft fans to begin the purge. When the airflow to the burner is established, the low combustion air pressure fuel cut-off switch closes.

3. When the combustion airflow reaches at least 60% of the high-fire airflow, the programming controller begins counting the purge. Air blows through the furnace to purge it of any combustible gases which may have collected there.
4. When the purge period is completed, the programming controller returns the combustion airflow to the low-fire position. The controller confirms the low-fire position using modulating motor end switches, or some other means.
5. When the airflow is proven to be at the low-fire position, the programming controller energizes the ignition transformer, and opens the pilot gas valve. The spark generated by the ignitor lights the pilot flame.
6. The flame detector senses the pilot flame. Its signal is amplified by an electronic circuit to satisfy the programming controller flame failure logic.
7. After allowing 10 seconds for the pilot flame to be established, the programming controller energizes the main SSOV. The main SSOV opens slowly, and the main burner is lit by the pilot burner.
8. If the pilot is interrupted, the programming controller opens the circuit to de-energize the igniter and pilot gas valve, after the main flame is established. The flame detector or scanner now supervises the main burner flame only. This is called the run period.
9. The burner continues to run until a permissive, a manual on-off switch, or a burner safety switch shuts it off.

On Track

This programming sequence can also be applied to an oil-fired boiler equipped with a pilot. Oil burners for large automatically fired boilers are often lit by gas pilots, though some have small oil burners that act as ignitors. For many oil burners, the pilot is intermittent rather than interrupted. This is to help stabilize the flame when firing rates are low.

Shutdown

Shutdown Sequence

1. When the steam pressure or hot water temperature rises above the set point of the operating control, the call for heat ends. This causes the programming controller to de-energize the SSOVs, which extinguishes the flame.
2. The programming controller begins a post-purge (usually about 15 seconds).
3. The programming controller returns to its standby mode. During standby, the controller allows 5 seconds for the SSOV proof-of-closure switches to close. If the switches do not close, the controller remains in standby until the condition is corrected.
4. If there is a call for heat, and all permissives and pre-ignition interlocks are satisfied, the programming controller repeats the startup sequence.

CHAPTER SUMMARY

Combustion safety is of paramount concern for owners, operators, designers, installers, and maintainers of fuel-burning equipment.

Furnace explosions occur without warning. It only takes the first failure of a single combustion safeguard control for a devastating explosion to occur. For this reason, combustion systems are engineered extensively, and designed with safety in mind.

This chapter explored components found on boilers that contribute to the safe operation of burners. These included:

- Fuel train components
- Flame detection devices
- Burner safety switches
- Burner management systems

Together, these components operate as a system for safe burner and safe boiler operation.

CHAPTER 3

Water Level Safety Controls

Learning Outcome

When you complete this chapter you should be able to:

Describe feedwater devices, and control methods used on boilers.

Learning Objectives

Here is what you should be able to do when you complete each objective:

1. *Describe the construction and operation of boiler low water level fuel cut-off equipment.*
2. *List the CSA and ASME code requirements regarding low water fuel cut-off devices.*
3. *Describe direct and indirect type boiler water level indicators.*

Chapter Introduction

The importance of maintaining boiler water level cannot be overstated. Often, this is described as the Power Engineer's primary job. This is because low water conditions are one of the most common causes of pressure vessel explosions. When boiler water drops below its lowest permissible water level, pressure-retaining components overheat, weaken dramatically, and fail under pressure. The results are devastating.

To help Power Engineers maintain water level, boilers must be equipped with reliable water level instruments. Some indicate water level. Others are feeders, cut-offs, and alarms. The **CSA** and **ASME** has developed numerous code requirements for water level controls and indicators. For these controls and indicators to be reliable, operators must flush, test, and validate them on a regular basis.

This chapter covers low water cut-offs, combination cut-off/feeder controls, water level indicators, and the codes that apply to these instruments and controls.

Objective 1

Describe the construction and operation of boiler low water level fuel cut-off equipment.

Purpose of the Low Water Fuel Cut-Off

The low water fuel cut-off (LWCO) is a float or probe-operated switch that directly detects the level of water in a boiler. Its function is to shut off the boiler burner system if boiler water level drops to a predetermined unsafe level. This prevents overheating and weakening of the pressure-retaining parts of the boiler, which are normally cooled by water.

All boilers require low water fuel cut-offs, except for:

- Electrode-type electric boilers.
- Coil tube and fin tube boilers that require forced circulation to prevent overheating.
- Those under continuous operator attendance.

Each boiler design has a unique lowest permissible water level (LPWL), identified by the boiler manufacturer. This is the lowest water level at which a boiler can be safely operated. The LWCO turns off the burner system before the water level drops to the LPWL. Because of this, it is a very important boiler safety control.

On Track

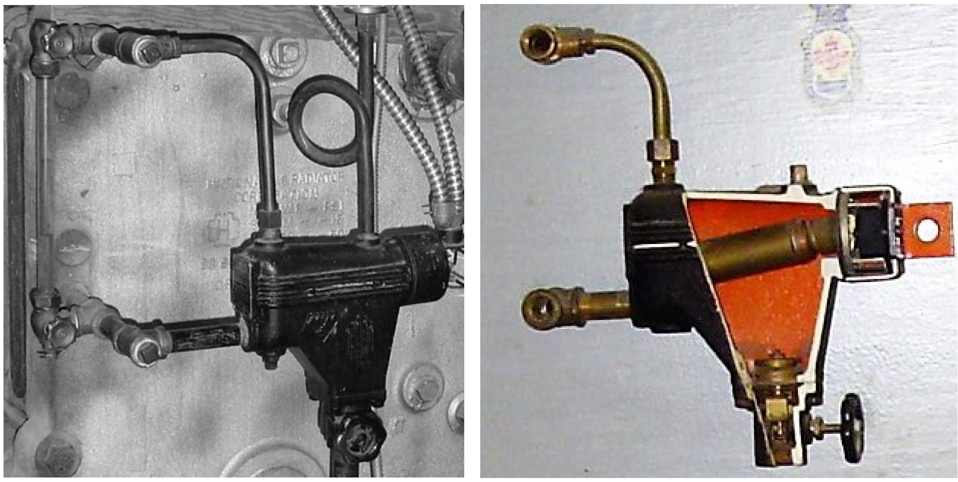
Like all boiler fittings, low water cut-offs have maximum allowable working pressures (MAWP). When repairing or replacing LWCOs, make sure the components are suitable for the boiler MAWP.

Float Operated Low Water Fuel Cut-Off

The low water fuel cut-off device shown in Figure 1 is often used on low capacity cast iron sectional heating boilers. This device consists of a float chamber connected to the same boiler openings as the directly connected water gauge glass. Therefore, the water level in the float chamber is the same as that in the boiler and the gauge glass.

The float inside the chamber, which follows the changes in water level in the boiler, is directly connected to an electric switch, attached to the float chamber. The switch is separated from the water chamber by a flexible diaphragm, which acts as a seal.

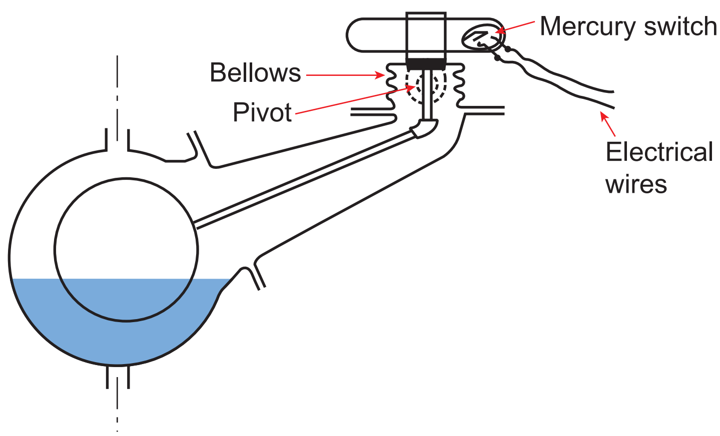
Figure 1 – Low Water Fuel Cut-Off Device



When the water in the boiler is above the lowest permissible level, and is still visible in the gauge glass, the float keeps the electrical switch in the closed position. This allows power to energize the safety shut-off valve (SSOV). If the boiler water drops below the minimum safe level, the float switch opens, which causes the SSOV to close. This stops the fuel supply to the burner.

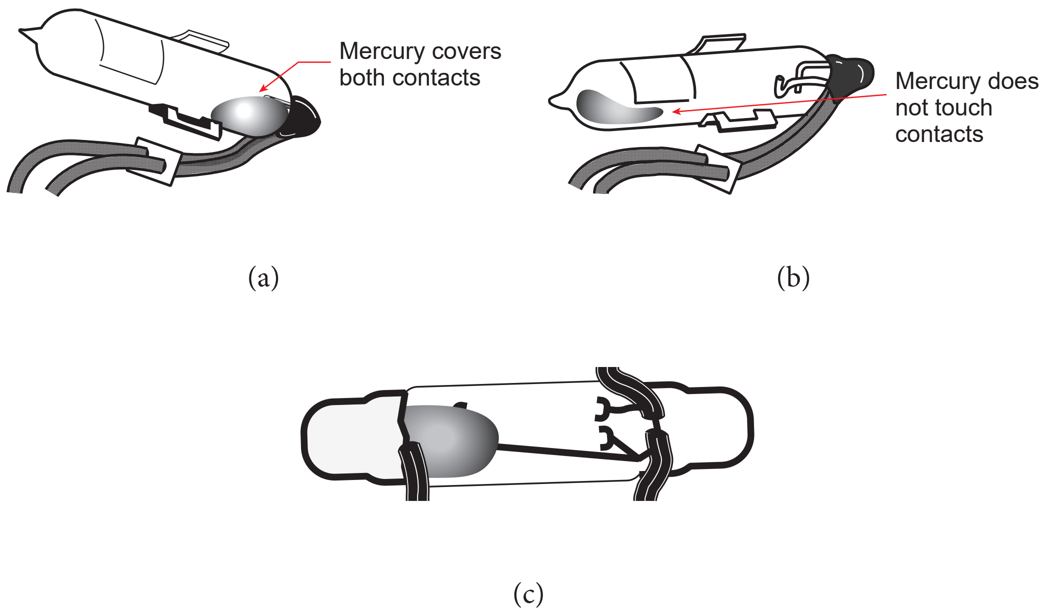
Figure 2 shows a sketch of a LWCO design more commonly used for power boilers or larger heating boilers. The float chamber is connected directly to the steam and water space, independent of the gauge glass. The water level in this chamber will follow the level in the boiler very closely. A float, which follows the fluctuations in water level, is connected to a rod that pivots in the upper part of the chamber. Movement of the short end of the rod is transmitted through the bellows assembly to a lever system that tilts the mercury switch. The bellows assembly forms a flexible steam and watertight seal between the float housing and the electrical junction box.

Figure 2 – Low Water Fuel Cut-Off Device



The mercury switch, used in the low water fuel cut-off and many other controls, consists of a small glass bulb. Electrical contacts that form part of an external wiring circuit are mounted inside the bulb at either one end or both. The bulb also contains a small quantity of mercury, and is used to open or close the electrical contacts inside the bulb. The interior of the bulb is under a high vacuum to prevent oxidation of the mercury and corrosion of the electrical contacts. By tilting the bulb to one side or the other, the mercury opens or closes the circuit.

Figure 3 – Operation of Mercury Switch



CAUTION

Mercury switches eventually fail. Small cracks in the glass permit oxygen to enter the glass and oxidize the mercury. When this occurs, the mercury loses its lustre, and may appear rusty. The mercury will not flow properly, and will not close or open the switch contacts reliably. When this occurs, the control must be replaced.

When replacing any control that contains mercury, the mercury must be treated as a hazardous material. Wear correct personal protective equipment. Dispose of the mercury according to environmental regulations.

Figure 3(a) shows a single-pole mercury switch in the closed position. This is the position of the switch when the boiler water is above the LPWL.

As the boiler water level drops, the float follows the changing level in the float housing and tilts the mercury switch to the opposite side by means of the rod and lever system. At a predetermined level, the bulb tilts enough so that it shifts the mercury to the opposite end of the bulb, and the circuit will be opened as shown in Figure 3(b).

Some mercury switches, like in Figure 3(c), use three wires instead of two. When there is a drop in water level, the mercury moves to the opposite end of the bulb. This opens the electrical circuit to the SSOV, and closes alarm circuit contacts at the opposite end. This warns the operator that the burner has shut down due to low water.

Figure 4 shows a float arrangement that combines a feedwater pump control switch with a low water fuel cut-off and alarm. In this design, one bulb contains a two-wire switch that controls the feedwater pump circuit. The bulb with the three-wire switch controls a low water fuel cut-off and an alarm.

As the boiler water level drops, the float closes the two-wire switch. This starts the feedwater pump when the water is still above the lowest permissible level. If the pump fails to start, or some other problem causes the drum level to continue dropping when the feedwater pump is running, the bulb with the three-wire switch acts as a boiler emergency shutdown. The electrical circuit to the SSOV opens, and it shuts off the burner before the water in the boiler reaches the lowest permissible level. An alarm circuit will also energize.

Figure 4 – Combined Pump Control and Low Water Cut-Off

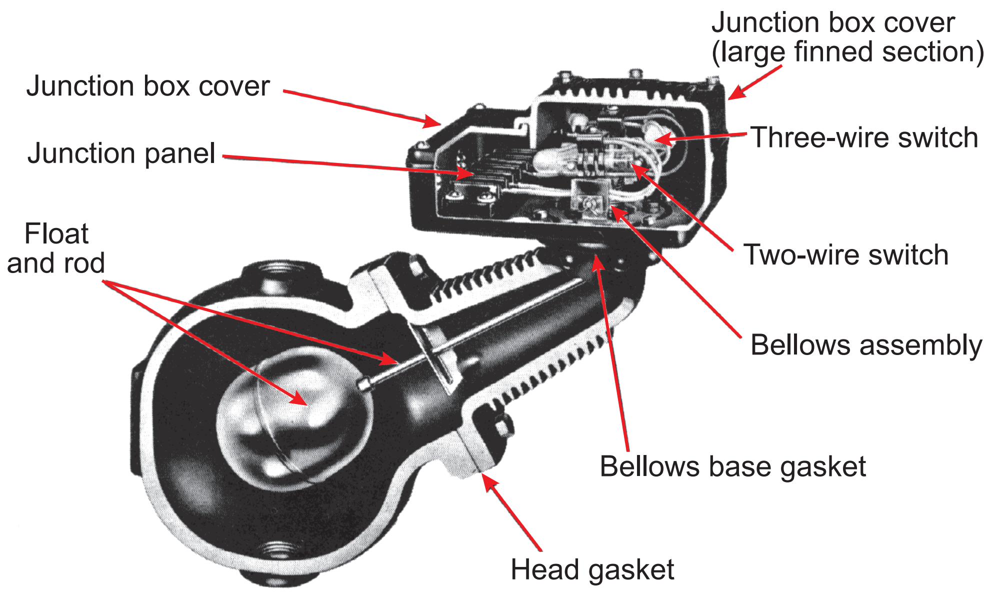
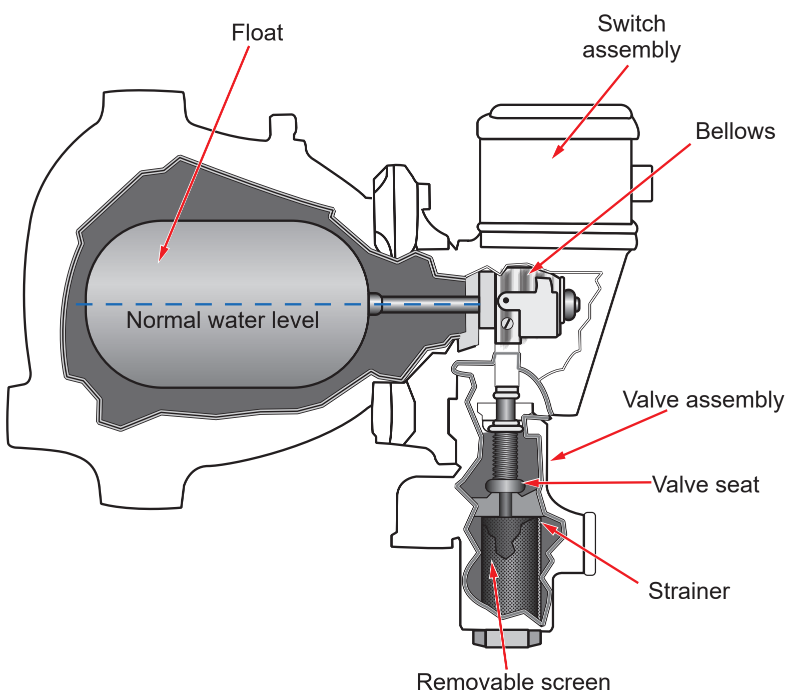


Figure 5 shows a float controlled make-up water valve combined with a low water fuel cut-off. If the boiler drum level drops, the float in the chamber moves to a lower position, which opens the make-up valve further to admit more water into the boiler. As the water level rises, the float moves up and decreases the valve opening.

Figure 5 – Combined Feeder/Cut-Off Control



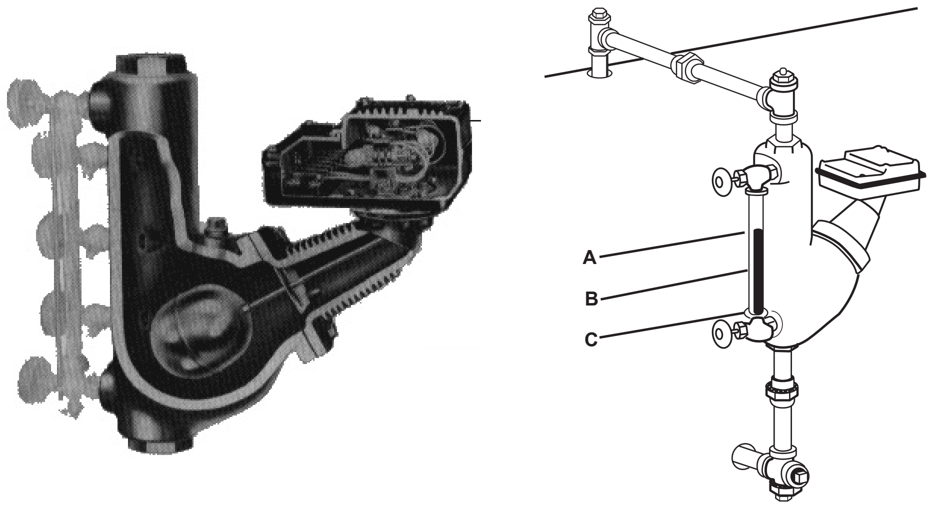
If the water level continues to drop when the make-up water valve opens, the switch will shut down the burner.

Even though the low water fuel cut-off opens the SSOV, there is always a possibility that the fuel valve will stick in the open position and firing will continue. The boiler temperature or pressure will continue to rise until the pressure relief valve opens. The water level could drop to the point where heat transfer surfaces could overheat. To safeguard against this a combination low water cutoff and feeder valve offers the best protection for low-pressure steam heating boilers.

Some boilers have the float chamber of the low water fuel cut-off combined with the water column, as shown in Figure 6(a). Its operation is similar to the LWCO controls already discussed.

Figure 6(b) is an exterior view of the water column and float chamber shown in Figure 6(a). Level A is the highest normal operating level in the boiler. At level A, the feedwater supply switch is open, and the boiler feed pump is off. When the water level drops to level B, the control switch closes, the feedwater pump starts, and feedwater supply resumes. During normal operation, the water level alternates between level A and level B.

Figure 6 – Column with Low Water Fuel Cut-Off



(a) (b)

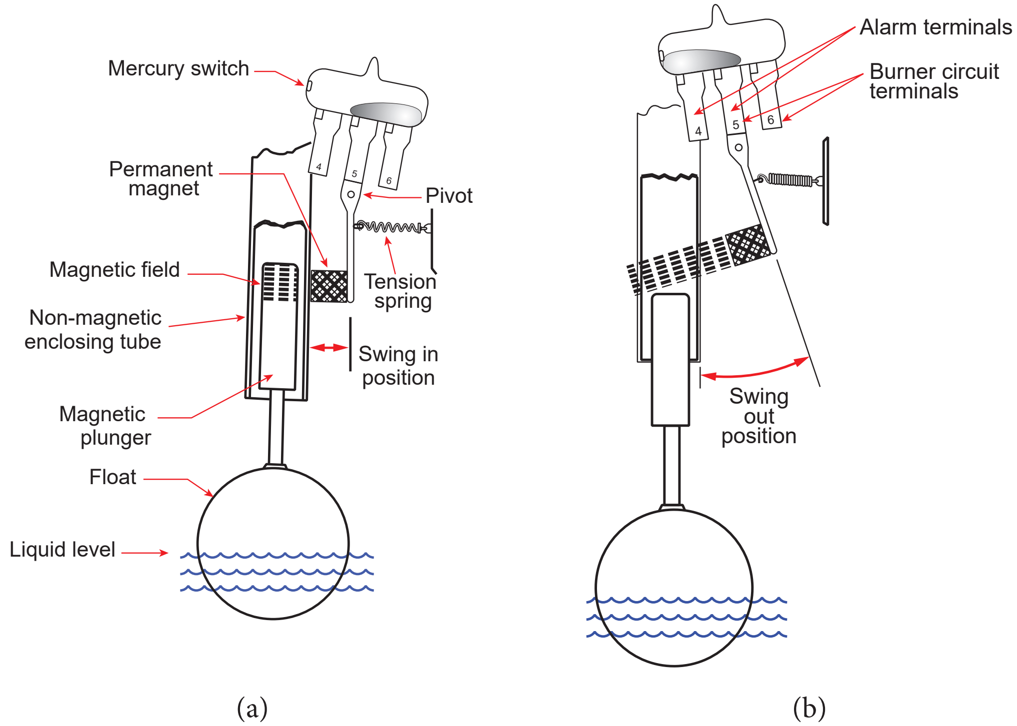
If the supply of make-up water fails or is insufficient, the water level will continue to drop. When the water level drops to level C, the cut-off switch opens the burner circuit before the level drops to the lowest permissible water level. At the same time, the alarm switch closes, and energizes the alarm circuit. The boiler cannot restart until the water level is restored to above level C. In some cases, the switch may also have to be manually reset.

Magnetic Low Water Fuel Cut-Off

Figure 7 shows the operation of a low water fuel cut-off actuated by a float and magnet. At normal water levels, the permanent magnet attached to the pivoted mercury switch is drawn toward the magnetic plunger. The mercury switch tilts, which closes the contacts and keeps the burner in operation.

As the water level drops, the float is lowered together with the plunger. At the cut-off point, the plunger drops entirely outside of the magnetic field (Figure 7(b)). Then, the tension spring pulls the permanent magnet away, and the three-wire mercury switch tilts to the opposite position. The contacts then open, which opens the burner circuit, and shuts off the fuel supply. This energizes the alarm circuit.

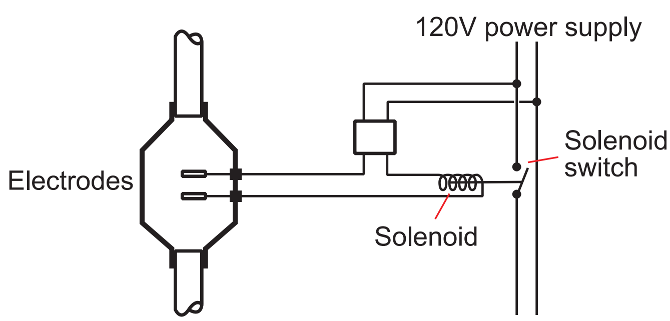
Figure 7 – Magnetic Low Water Fuel Cut-Off



Electric Probe Type Low Water Fuel Cut-Off

This cut-off usually consists of two electric probes, or electrodes, immersed in the water. These probes may be mounted directly on the boiler shell, on the water column, or in a special probe housing. The schematic of one design is shown in Figure 8.

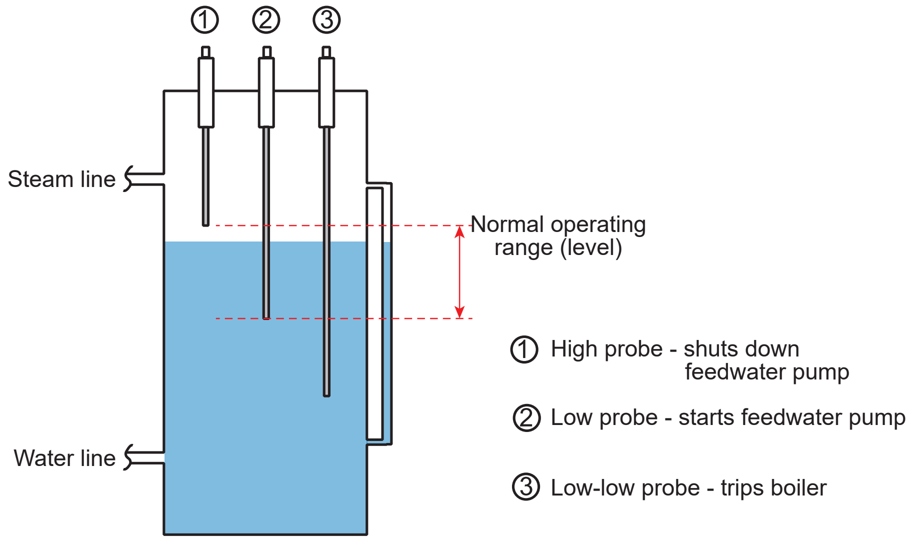
Figure 8 – Electric Probe Type Low Water Fuel Cut-Off



As long as water covers both probes, a small current will flow through the water between the probes. This closes the electric circuit that energizes an electro-magnetic coil, or solenoid switch, in the power circuit to the fuel valve, and keeps the switch in the closed position. This allows the fuel valve to be in an open position. When the water level drops below the upper probe, the flow to the solenoid will stop, and the switch opens. This interrupts the power supply to the fuel valve, and shuts off the fuel.

Another design of the probe type low water fuel cut-off has only a single probe. The boiler shell or probe housing acts as a second probe (see Figure 9).

Figure 9 – Electric Probe Type Low Water Fuel Cut-Off



Water column level probes (conductivity)

The advantage of the electric probe type cut-off is its simplicity. It contains no moving parts, so the possibility of mechanical failure is eliminated.

It is necessary to check and clean the probes at regular intervals. Scale or sediment on the probes can reduce or completely stop the current flow, which results in a boiler shutdown.

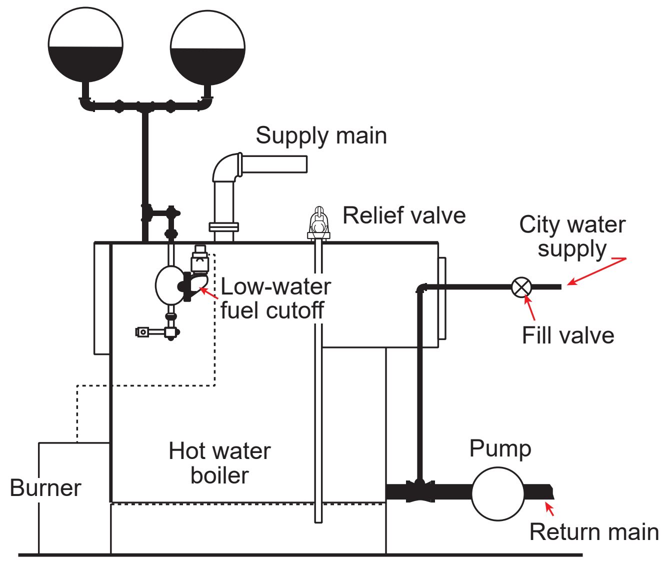
Low Water Fuel Cut-Off for Hot Water Heating Boilers

Hot water boilers are completely filled with water, and are usually equipped with an automatic fill valve connected to the water supply. This keeps the system filled at all times.

Low water conditions can develop in hot water heating boilers, as well as in steam boilers. In this case, the condition is usually due to human error or mechanical failure. The construction of a hot water boiler is not much different from that of a steam boiler. So, the effects of a low water condition can be just as disastrous.

The same type of cut-off device used on steam boilers can be applied to hot water boilers, provided the pressure rating of the device is high enough. Hot water boilers may operate at a higher pressure than steam heating boilers. Figure 10 shows a float operated low water fuel cut-off device installed on a hot water heating boiler.

Figure 10 – Low Water Fuel Cut-Off on a Hot Water Boiler



There is considerable freedom in the arrangement of the low water fuel cut-off on hot water heating boilers. Since no normal water level has to be maintained, the control may be installed at any point above the lowest permissible water level specified by the manufacturer.

Possible Causes of Low Water Level

A rapidly falling water level in the boiler may be caused by:

- A faulty feedwater level controller.
- Feedwater or condensate pump failure.
- Interruption of the water supply to the feedwater pump.
- Leakage from the boiler, due to ruptured tubes or open blowoff valves.

Other causes may produce a gradual reduction in boiler water level. Each of these only occurs if the make-up water or condensate return systems are not working properly. These causes include:

- Leaks in hot water supply or return piping.
- Damaged condensate return piping.
- Defective condensate return pumps.
- Excessive blowoff or blowdown.
- Relief valve discharge caused by full expansion tanks.

Normally, when the level drops to the low water cut-off point, the boiler will shut down automatically. However, if the cut-off fails to shut the boiler down, the water level may drop to a dangerous level. It is essential for the plant operator to conduct regular tests of the low water cut-off.

Side Track

Procedures for testing low water cut-offs, and emergency response to low water conditions, are covered in **Part B, Unit 4, Chapter 3 Boiler Operation**.

Objective 2

List the CSA and ASME code requirements regarding low water fuel cut-off devices.

CSA B51 Boiler, Pressure Vessel, and Pressure Piping Code

In Canada, the **CSA B51 Boiler, Pressure Vessel, and Pressure Piping Code** takes precedence over the **ASME codes**, unless specifically stated otherwise in the relevant jurisdictional legislation.

With regard to steam boilers, **CSA-B51 6.3.2.1** states:

> *Steam boilers not continuously attended by a certified operator shall be equipped with at least two low-water fuel cut-off devices, each of which shall be independent of the other or others. These devices shall be installed so that they cannot be rendered inoperative. The installation shall be such that the devices can be tested under operational conditions.*

The words "cannot be rendered inoperative" mean that no valves may be installed on the low water cut-off piping, because they interfere with the operation of the control. As well, no switches may be installed that render the cut-off inoperable.

Large capacity boilers may be required to run continuously. A boiler trip may have negative consequences for plant operations. In order to blow down the low water cut-off without tripping the boiler, a momentary contact switch may be installed in parallel to the low water cut-off switch. The operator must maintain pressure on the bypass switch during a blowdown. When the blowdown is over, and the water level in the cut-off chamber is normal, the operator can release the pushbutton to restore the operation of the low water cut-off control.

With regard to hot water boilers, **CSA-B51 6.3.2.2** states:

> *Automatically fired hot water boilers not continuously attended by a certified operator shall be equipped with a low-water fuel cut-off device, except as specified in Clause 6.3.2.3. This device shall be installed so that it cannot be rendered inoperative. The installation shall be such that it can be tested under operational conditions.*

It may be difficult to test the low water cut-off for hot water boilers without draining significant amounts of water from the system. Therefore, special "test and check" fittings may be installed to prevent the system from draining while testing the low water cut-off. In normal operation, these valves permit free circulation of water through the connecting piping and float chamber. A sudden onrush of water, such as that caused by opening the low water cut-off drain valve, causes dampers located in each valve to restrict water flow to the float chamber. The water level in the float chamber quickly falls, and trips the low water cut-off with a minimum loss of boiler water. When the float chamber drain is closed, the dampers return to their normally open position.

The **CSA B51 Code** exempts some hot water boilers from the low water cut-off requirements of **6.3.2.2**. Regarding these exemptions, **6.2.2.3** states:

> *In lieu of a low-water fuel cut-off device, automatically fired hot water boilers requiring forced circulation to prevent overheating (e.g., coil or fin-tube type boilers) shall be equipped with a flow-sensing device to automatically cut off the fuel supply to the burner if the flow rate is reduced to a point where it is inadequate to protect the boiler against overheating. The device shall be installed on the boiler outlet piping… and installed so that it cannot be rendered inoperative. The installation shall be such that it can be tested under operational conditions.*

ASME Codes

ASME BPVC I Rules for Construction of Power Boilers

ASME BPVC I does not require the installation of low water fuel cut-off devices on fuel-fired or waste heat fired boilers. However, low water cut-offs are required on some electric boilers. Part **PEB-13.2** states:

> *Electric boilers of the resistance element type shall… be equipped with an automatic low-water cutoff on each boiler pressure vessel so located as to automatically cut off the power supply to the heating elements before the surface of the water falls below the visible level in the gage glass.*

Part **PEB-16** goes on to say:

> *Electric boilers shall be provided with pressure and/or temperature controls and an automatic low-water fuel cutoff. No low-water cutoff is required for electrode type boilers.*

ASME BPVC I, Part PG-61.1 requires "two means of feeding water" for boilers with more than 47 m^2 (500 ft^2) of water heating surface. This is to reduce the likelihood of a low water condition occurring. **PG-61.2** permits the use of a low water cut-off as an alternative to a secondary means of feeding water, but only for boilers fired by gaseous, liquid, or solid fuels in suspension. **PG-61.2** stipulates the LWCO must function prior to the boiler water reaching the lowest permissible water level.

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ASME BPVC VII Recommended Guidelines for the Care of Power Boilers

ASME BPVC VII Part C5.100 recommends that each automatically fired boiler have two independent low water cut-offs. Note that this is only a recommendation, and not a requirement.

ASME VII Parts C2.423 and **C9.220** state:

> *Where water columns are equipped with automatic low water boiler trips, suitable operating procedures should be developed to preclude tripping the boiler while determining that the water column is functional and in good operating condition.*

For this reason, larger capacity power boilers often have momentary contact bypass switches to prevent them from tripping when their low water cut-off float chambers are blown down.

ASME BPVC IV Rules for Construction of Heating Boilers

Unlike **ASME I**, **ASME IV** has extensive and specific requirements. **Part HG-604** states the installation requirements for steam heating boilers:

> *If the water column, gage glass, low-water fuel cutoff, or other water level control device is connected to the boiler by pipe and fittings, no shutoff valves of any type shall be placed in such pipe, and a cross or equivalent fitting to which a drain valve and piping may be attached shall be placed in the water piping connection at every right angle turn to facilitate cleaning.*

Note that ASME also prohibits the installation of valves in the interconnecting piping of the LWCO. Valves would render the LWCO inoperative, which could be extremely hazardous.

Part HG-606 states the LWCO requirements for steam heating boilers:

> *Each automatically fired steam or vapor-system boiler shall have an automatic low-water fuel cutoff... so located as to automatically cut off the fuel supply before the surface of the water falls below the lowest visible part of the water gage glass.*

Part HG-607 refers to the rules for modular steam heating boilers:

> *Each module of a modular steam heating boiler shall be equipped with… (a) low water cutoff.*

Part HG-614 refers to the LWCO requirements for hot water heating boilers:

> *Each automatically fired hot water boiler with heat input greater than 400,000 Btu/hr (117 kW) shall have an automatic low-water fuel cutoff. This device shall be so located as to automatically cut off the fuel supply… above the lowest safe permissible water level established by the boiler manufacturer.*

Note that the **ASME BPVC** always defers to the boiler manufacturer LPWL determination.

Part HG-614 goes on to state rules for forced circulation coil-tube boilers:

> *A coil-type boiler or a watertube boiler with heat input greater than 400,000 Btu/hr (117 kW) requiring forced circulation to prevent overheating of the coils or tubes shall have a flow-sensing device installed in lieu of the low-water fuel cutoff… to automatically cut off the fuel supply when the circulating flow is interrupted.*

Note that this is similar to the requirements of **CSA B51. B51**, though, requires the flow-sensing device to be installed at the hot water outlet. As well, the **CSA B51** does not specify a minimum boiler capacity. Rather, it defines a boiler as "a vessel as defined in the Act." This permits jurisdictions to define what capacity of hot water boiler the flow switch requirement applies to.

Part HG-614 also requires a means of testing the low water cut-offs of hot water boilers:

> *A means shall be provided for testing the operation of the external low-water fuel cutoff without resorting to draining the entire system. Such means shall not render the device inoperable except as described as follows. If the means temporarily isolates the device from the boiler during this testing, it shall automatically return to its normal position. The connection may be so arranged that the device cannot be shut off from the boiler except by a cock placed at the device and provided with a tee or lever-handle arranged to be parallel to the pipe in which it is located when the cock is open.*

The "test and check" valves discussed previously comply with this code requirement.

ASME CSD-1 Controls and Safety Devices for Automatically Fired Boilers

CSD-1 is a code that addresses the unique hazards of boilers, in capacities up to 300 boiler horsepower output, that are automatically fired. Due to the variations in jurisdictional requirements, many of these boilers may be legally exempt from supervision requirements. For this reason, **CSD-1** has fairly stringent and specific control requirements that are not found in the **ASME BPVC**.

Low Pressure Steam Boilers

Regarding LWCO requirements for steam heating boilers, **ASME CSD-1 Part CW-120** states:

> *Each automatically fired, low-pressure steam… boiler shall have at least two automatic low-water fuel cutoffs, one of which may be a combined feeder/cut-off device. When installed external to the boiler, each device shall be installed in individual chambers (water columns), which shall be attached to the boiler by separate pipe connections below the waterline. A common steam connection is permissible. Each cutoff device shall be installed to prevent startup and to cut off the boiler fuel or energy supply automatically, prior to the fall of the surface of the water below the level of the lowest visible part of the gage glass.*

Note that the two cut-offs can share a steam piping connection, but cannot share a water connection. This is because water connections are prone to plugging, but steam connections are not. If the cut-off devices shared a common water connection, and the water connection became plugged, both cut-offs would fail. Independent water connections provides contingency, due to the unlikely occurrence that both water connections would plug simultaneously.

CW-120 goes on to state:

> *One cut-off control shall be set to function ahead of the other… the lower of the two cut-off controls shall cause safety shutdown and lockout.*

The lowest cut-off must be situated above the LPWL, and in no cases lower than the lowest visible part of the gauge glass. This is so that when a cut-off occurs, the boiler water level can be identified and determined to be high enough to prevent boiler damage.

Hot Water Boilers

ASME CSD-1 Part CW-130 states the rules for hot water boilers.

- *Each automatically fired, hot-water heating boiler… shall be protected by a low-water fuel cutoff intended for hot-water service*
- *The low-water fuel cutoff can be located any place above the lowest safe permissible water level established by the boiler manufacturer*
- *If the low-water fuel cutoff is connected to the boiler by pipe or fittings, no shutoff valves of any type shall be placed in such piping. A cross, or equivalent fitting, shall be placed in the water piping connection at every right angle to facilitate cleaning and inspection.*
- *Functioning of the low-water fuel cutoff due to a low-water condition shall cause safety shutdown and lockout.*
- *A means shall be provided for testing the operation of the low-water fuel cutoff without resorting to draining the entire system.*

Note that these rules are similar to those in the **CSA** and **ASME BPV** codes.

High-Pressure Steam Boilers

The rules in **ASME CSD-1 Part CW-140** for high-pressure steam boilers are similar to those in **CW-120**:

- *Each automatically fired, high-pressure steam boiler… shall have at least two automatic low-water fuel cut-off devices.*
- *Each device shall be installed in individual chambers (water columns), which shall be attached to the boiler by separate pipe connections below the waterline. A common steam connection is permissible.*
- *Each cut-off device shall be installed to prevent startup and cut off the boiler fuel or energy supply automatically when the surface of the water falls to a level not lower than the lowest visible part of the gage glass.*
- *One control shall be set to function ahead of the other.*
- *Functioning of the lower of the two controls shall cause safety shutdown and lockout.*
- *If the low-water fuel cutoff is connected to the boiler by pipe or fittings, no shutoff valves of any type shall be placed in such piping.*
- *The steam and water connections to a water column shall be readily accessible for internal inspection and cleaning.*

CSD-1 also states that the lowest of the cut-off devices must cause safety shutdown and lockout. This will prevent the boiler from restarting if the water level is restored to normal. In other words, a low water condition requires manual operator intervention to reset the cut-off, and restart the boiler. The assumption is that the operator will determine the cause of the low water condition, and take steps to correct the root cause before restarting the boiler.

Frequency of Testing

ASME BPVC VII and **CSD-1** recommend testing frequencies and test procedures for low water cut-offs in heating boiler and power boiler service. Three common low water cut-off tests are recommended:

1. Rapidly draining the float chamber, to see if the boiler shuts off.
2. Isolating the feedwater, and blowing off the boiler (a slow drain test).
3. Isolating the feedwater, and allowing the boiler to steam off water.

These test methods and frequencies are covered in **Part B, Unit 4, Chapter 4 Operational Checks**.

Objective 3

Describe direct and indirect type boiler water level indicators.

Boiler water level can be determined through direct or indirect methods. Direct methods include gauge glasses of various designs. Indirect methods include various remote water level indicators that continuously measure, transmit, and display water level. Many power boilers use both methods.

Code Requirements for Boiler Water Level Indicators

Power Boilers

ASME BPVC I Part PG-60.1 states that "*All boilers having a fixed water level (steam and water interface) shall have at least one gage glass.*" It further states that "*boilers having a maximum allowable working pressure exceeding 400 psi (3 MPa) shall have two gage glasses.*" This is because of how critical it is to know the boiler water level at all times, especially with boilers operating at higher pressures. **PG-60.1** also states that "*The lowest visible water level in a gage glass shall be at least 2 in. (50 mm) above the lowest permissible water level, as determined by the boiler Manufacturer.*"

ASME BPVC I Part PG-60.1.1.1 also provides for the use of remote water level indication: "*Instead of one of the two required gage glasses, two independent remote water level indicators… may be provided.*"

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Heating Boilers

ASME BPVC IV Part HG-603 requires each steam heating boiler to have "*one or more water gage glasses attached to the water column or boiler by means of valved fittings not less than NPS ½ (DN 15).*" The lower fitting must have a drain valve "*having an unrestricted drain opening not less than ¼ in. (6 mm) in diameter to facilitate cleaning.*"

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The lowest visible part of the gage glass must be "*at least 1 in. (25 mm) above the lowest permissible water level recommended by the boiler Manufacturer.*" To facilitate this, each boiler must be provided at the time of the manufacture with a permanent indicator of the lowest permissible water level.

Direct Methods

A gauge glass is a transparent device that permits continuous visual determination of a liquid level. On a boiler, the liquid is the water level in the drum or shell. Various types of gauge glasses include:

- Tubular
- Armored-type (flat)
- Bicolour

Tubular Gauge Glass

The simplest and least costly gauge glass is the tubular design. These are simply transparent vertical tubes, with their lowest visible point connected to the boiler at a certain distance above the lowest permissible water level (LPWL). Isolating valves are placed above and below the gauge glass connections.

Two slightly different valve types are shown in Figures 11 and 12. Figure 11 shows a gauge glass with slow closing valves. In Figure 12, the valves are the quick closing type. With these, a one-quarter turn of the valve handle fully opens or fully closes the valve. The valve spindles are fitted with levers to which chains may be attached to operate the valves from ground level if the boiler drum is located too high to reach.

On Track

CSA B51 Part 6.3.1.1 addresses gauge glass installations that are difficult to reach:

> *When the top connection of a water gauge is more than 2 m and less than 6 m from the floor or working platform of a boiler room, it shall be fitted with rods or chains so that it can be operated from the floor or working platform.*
>
> *When the top connection of a water gauge is 6 m or more from the operating floor level, it shall be of the inclined type or other accepted type.*

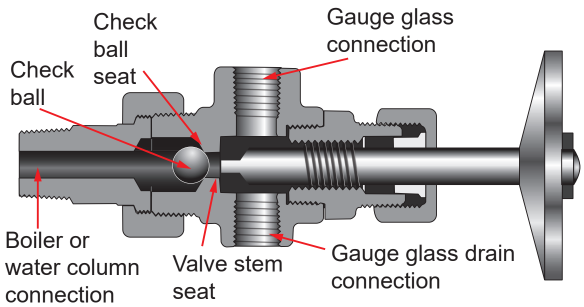
For boilers, drain valves or cocks must be installed on the lower gauge glass fitting to remove any solid material that may collect.

Figure 11 – Gauge Glass

Figure 12 – Water Gauge with Quick-Closing Valves and Chains

Since many boilers are not under continuous supervision, if a gauge glass breaks, a large amount of fluid can escape. To prevent this, the lower valve on the gauge glass is often equipped with a safety shutoff device consisting of a stainless steel check ball. This ball closes off the fluid passage when the glass breaks. Figure 13 shows this type of valve.

Figure 13 – Safety Shut-Off Gauge Valve



Under normal conditions, the steel ball remains in the recess in front of the valve seat. However, when the gauge glass breaks, the sudden rush of fluid through the valve forces the ball against the valve opening, thereby stopping the flow.

The gauge glass is usually surrounded by a number of metal rods, or a transparent shield, to protect it from breakage. The shield also protects operators from flying glass in case the gauge shatters.

Gauge glass tubing comes in several styles and pressure ratings. Some tubes have red lines to make it easier to view the water level. Pressure ratings are determined by the manufacturer, and vary according to the:

- Glass material
- Thickness of the glass
- Diameter of the gauge glass
- Temperature at which the gauge glass operates

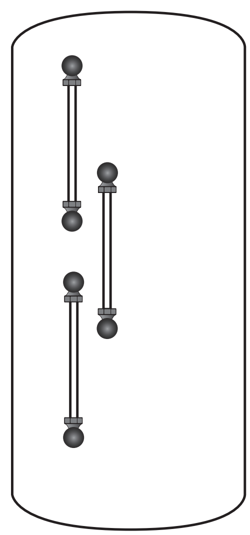
Because of this, the gauge glass manufacturer's literature must be consulted and adhered to when selecting replacement gauge glass material.

The use of tubular gauge glasses is limited to relatively lower pressures and temperatures. Excessively long gauge glasses should be avoided. For applications where a broad range of levels must be observed (as with some types of electrode boilers), two or more gauge glasses should be installed. The visible portions of the gauge glasses must overlap, as shown in Figure 14. **ASME BPVC I Part PG-60.1** addresses this situation as follows:

Gage glass assemblies having multiple sections, whether of tubular or other construction, shall be designed in such manner that will ensure a minimum of 1 in. (25 mm) overlap of all adjoining sections in which the water level may be visible.

The gauge glass tube is held tightly in place at each end by a washer or packing ring and a nut. If the gauge glass leaks, the isolating valves should be closed, and the drain opened, to prevent injuries before any maintenance is done.

Figure 14 – Multiple Gauge Mounting



Boiler Gauge Glass Installations

ASME BPVC I Part PG-60.3.1 and **BPVC IV Part HG-603** both permit gauge glasses to be connected either directly to the shell or drum of the boiler, or to an intervening water column. When two gauge glasses are required by **ASME I**, both may be connected to a single water column.

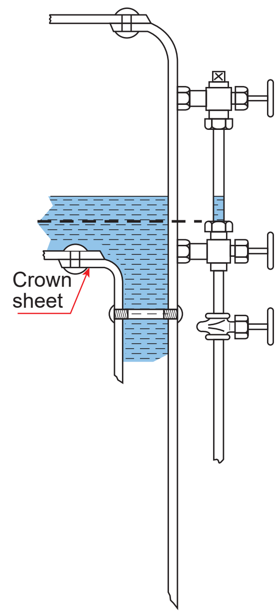
According to **ASME BPVC I Part PG-60.3.4**, the size of piping connecting a water column to a steam boiler shall be at least NPS 1 (DN 25). **Part PG-60.2.3** states that each water column must have a connection of at least NPS ¾ (DN 20) to install a valved drain for blowing down the water column. **Part PG-60.3.6** stipulates that the steam and water connections to a water column or a gauge glass shall be readily accessible for internal inspection and cleaning.

ASME BPVC IV Part HG-604 agrees with **ASME I Parts PG-60.3.4**, **PG-60.2.3**, and **PG-60.3.6**.

The installation shown in Figure 15 uses a gauge glass similar to the one shown in Figure 11. Note the drain valve which permits all the connections to be blown through. This daily activity ensures the gauge glass connections are not plugged with sludge or sediment. The valves can be slow or quick opening.

This method of attachment is used only on some firebox, locomotive, vertical firetube, and cast iron sectional boilers.

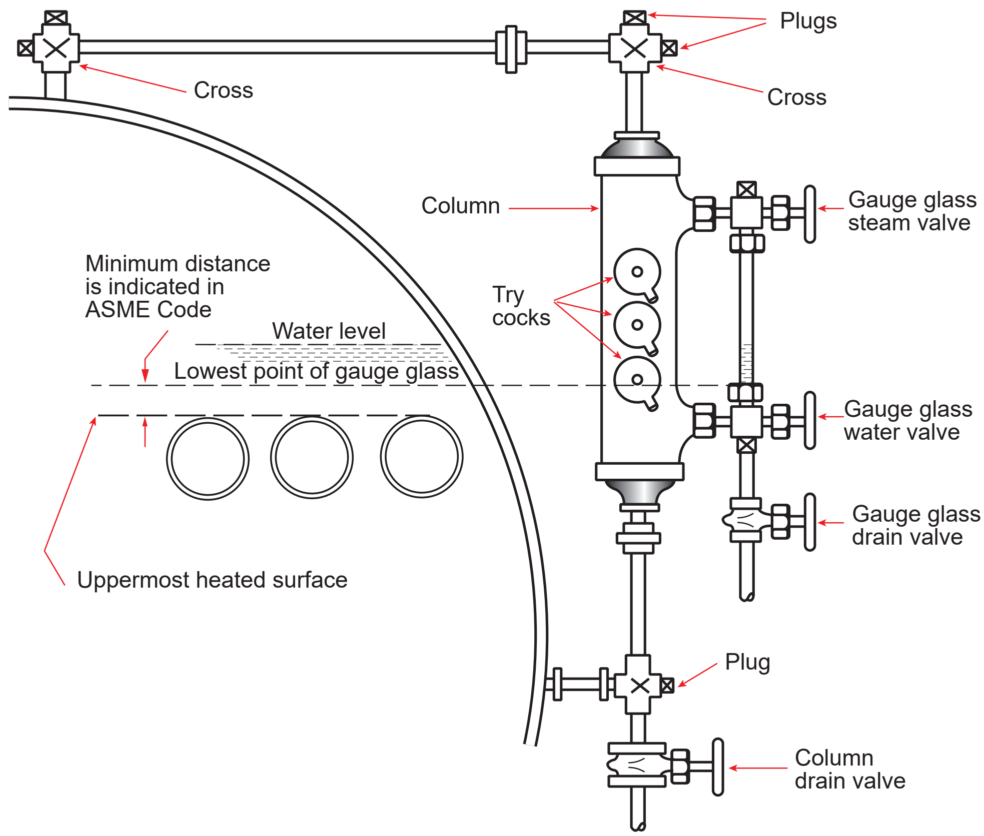
Figure 15 – Direct Connected Gauge Glasses on a Firebox or Locomotive Boiler



More often, gauge glasses are connected to a water column which, in turn, is connected to the boiler as shown in Figure 16. The water column acts as a reservoir to dampen agitation in the water.

In addition, the column traps sludge or sediment, and prevents it from collecting in the glass connections. The column also provides a place for installation of high and low level alarms and controls. Try cocks were once commonly installed on the column to provide a means of point level detection when the gauge glass is being replaced. Try cocks are no longer an **ASME BPVC** requirement.

Figure 16 – Water Column and Gauge Glass



The ASME codes have very specific rules for the location of the gauge glass in relation to the lowest permissible water level in a boiler. The rules are not the same for all boilers.

ASME BPVC I Part PG-60.1 states that *"The lowest visible water level in a gage glass shall be at least 2 in. (50 mm) above the lowest permissible water level, as determined by the boiler Manufacturer."* However, for horizontal firetube boilers and locomotive boilers, **ASME BPVC I Part PFT-47.1** and **47.2** provide different measurements, depending on boiler shell diameter. **PFT-47.1** states that for a horizontal firetube boiler with diameter greater than 400 mm, the *"lowest visible water level in the gauge glass must be at least 75 mm above the lowest permissible water level."*

Steam heating boilers have different requirements. **ASME BPVC IV Part HG-603** states *"The lowest visible part of the water gage glass shall be at least 1 in. (25 mm) above the lowest permissible water level recommended by the boiler manufacturer."* Obviously, the **ASME BPVC** requires a greater safety margin for power boiler water level indicators as opposed to those for heating boilers.

Tubular Gauge Glass Replacement

Gauge glasses are susceptible to corrosion caused by alkalinity and silica depletion at higher temperatures. Alkalinity causes thinning of tubular glasses below the water line. This action becomes more aggressive as the pH of the water rises. Condensate formed due to cooling of steam in the gauge glass dissolves some of the silica in the glass and weakens it. Both cause eventual failure of the glass. Misalignment of fittings also causes premature gauge glass failure.

The following steps should be taken when a gauge glass fails:

1. Shut off the steam and water valves on the gauge. These valves are usually equipped with chains and levers so they can be closed from the operating floor.
2. Open the drain valve on the gauge.
3. Unscrew the nuts at each end of the glass, and remove the washer and broken glass.
4. Crack open the gauge glass valves to blow out any fragments of glass, and then close the valves again. A suitable face shield should be worn to avoid injury.
5. If there is no gauge glass of correct length, cut a new glass to the correct length using a glass cutter. Ensure the new glass is made of the correct material, and meets the pressure and temperature specifications of the boiler.
6. Place the nuts and new washers on the glass. Install the gauge in the gauge fittings. Putting graphite on the washers to act as a lubricant between the washers and nuts will prevent the glass from turning when tightening the nuts. The nuts should be only hand tightened. Tighten them alternately by holding one while tightening the other. If "O" rings are used instead of washers, tightening with a wrench will be required. Note that the top fitting of the gauge glass is deeper than the bottom so that the gauge glass must be inserted into the steam fitting first, and then lowered into the bottom of the water fitting before tightening the nuts.
7. Heat the glass slowly by cracking open the steam valve and leaving the drain valve open. Then, when the gauge glass is up to temperature, close the drain valve, and partially open the water valve. Open the gauge steam and water valves fully when the water level in the glass stabilizes.

The operator should wear a face shield to prevent injury when opening the valves, especially if the gauge valves are not equipped with chains for remote operation.

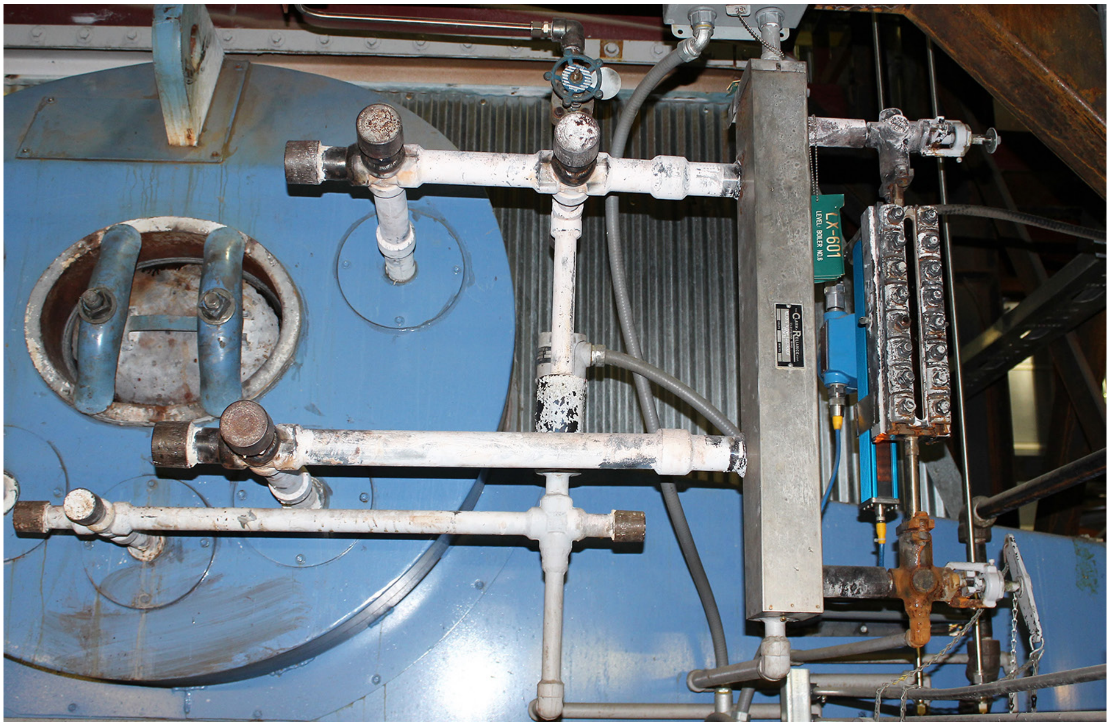
If the gauge glass leaks when put into service, do not tighten the nuts while the glass is under pressure. Always close the steam and water valves on the gauge, and open the drain before tightening the nuts.

During the time that the gauge glass is out of service, the boiler drum level may be checked by means of try cocks, a second gauge glass, or a drum level recorder if so equipped.

Armored-Type (Flat) Gauge Glass

Tubular gauge glasses are not available for pressures greater than about 3000 kPa. For higher pressures, a flat type gauge glass is used, consisting of glass plates bolted in a steel forged housing. A flat gauge glass is shown attached to a water column in Figure 17.

Figure 17 – Water Column and Flat Glass



Transparent and reflex gauge glasses use armoured glass. They are suitable for temperatures exceeding 250°C, and pressures up to 70 000 kPa.

Transparent Gauge Glass

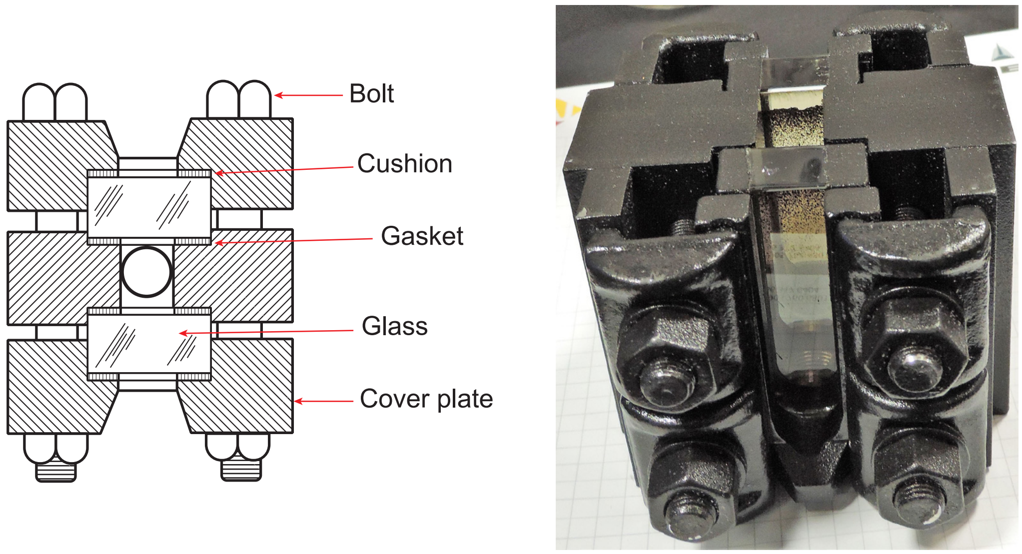
The transparent gauge glass, shown in Figure 18, has a one piece central chamber with cover plates on each side that hold the two glass windows.

The chamber and cover plates have machined recesses that keep all the parts aligned, and prevent the gaskets and cushions from shifting. The inside surfaces of both glasses are lined with a protective coating of transparent mica. After prolonged exposure to high temperature chemically treated water, the mica becomes opaque. This discolouration indicates failure of the mica, and that water is now directly contacting the glass. When this condition is observed, the glass should be changed before it fails.

The glass is tempered for resistance, to both mechanical and thermal shock. Care must be taken when assembling the unit and tightening the bolts to prevent glass failure. It is safest to use the crossover method of tightening by starting at the centre and working outwards.

Besides being suitable for high pressure steam applications, flat gauge glasses are also effective for caustic and acidic liquids, dirty materials, and other service where it is necessary to illuminate the glass from the rear.

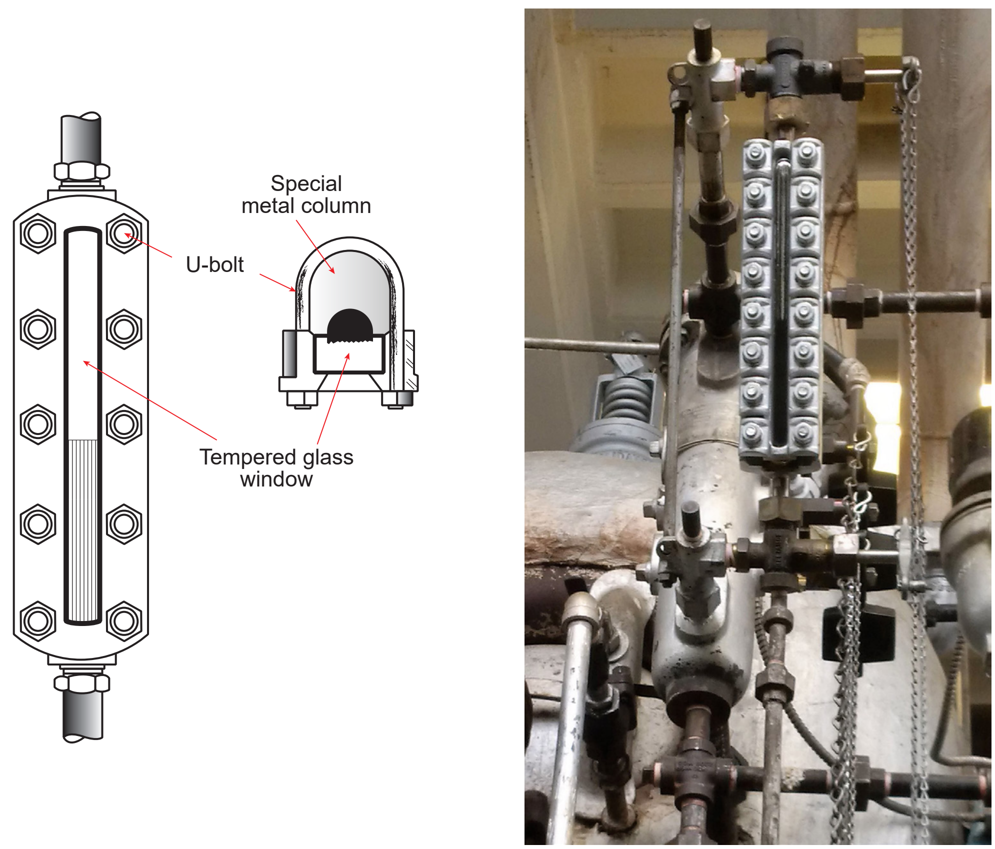
Figure 18 – Transparent Gauge Glass (Cross-Sectional Views)



Reflex Gauge Glass

A reflex gauge is shown in Figure 19. This gauge has special optical properties that create a sharp line of demarcation at the liquid level. A dark area represents the liquid in the glass gauge, contrasted by a light area above the liquid.

Figure 19 – Reflex Gauge Glass



Armored-Type (Flat) Gauge Glass Replacement

The following procedure is recommended when changing the glass:

1. Close the steam and water valves on the gauge glass. Open the gauge glass drain.
2. Remove the bolted covers, glass, gaskets, and the mica. At this time, the threads on the studs should be coated with graphite, and the nuts run down to clean the threads.
3. Remove any remaining gasket material, being careful not to create low spots on the surfaces of the joints. Scraping the gasket off the metal surfaces may form burrs.
4. Clean both ends of the gauge so gasket material will not plug the valves on the gauge.
5. Polish the gauge surfaces perfectly smooth. Check the surfaces to be sure they are perfectly level with no high or low spots. Checking includes the surfaces of the gauge body and the bolted covers.
6. Apply molybdenum disulfide on the contact surfaces of the new glass. This permits the glass to slip into place easily. Never reuse old gauge glasses. Be sure that the glass is suitable for high temperature high-pressure service.
7. Install a new gasket, new mica, and new glass on one side, and install the cover. Replace the nuts on the cover.
8. Tighten the nuts on the cover evenly. It is best to start at the centre of the glass, and tighten evenly on both sides of the glass.
9. Repeat steps 6, 7, and 8 on the other side of the glass.
10. If the boiler is in service, allow the new glass to warm up gradually, through heat conduction. Never open the gauge valves until the new glass is heated up.
11. With the drain valve still open, crack open the steam valve, and permit steam to slowly blow through to heat the glass further.
12. When the glass is at operating temperature, close the drain valve, and crack open the water valve to allow water into the glass.

If everything appears normal and a water level is visible in the glass, open the steam and water valves fully.

CAUTION

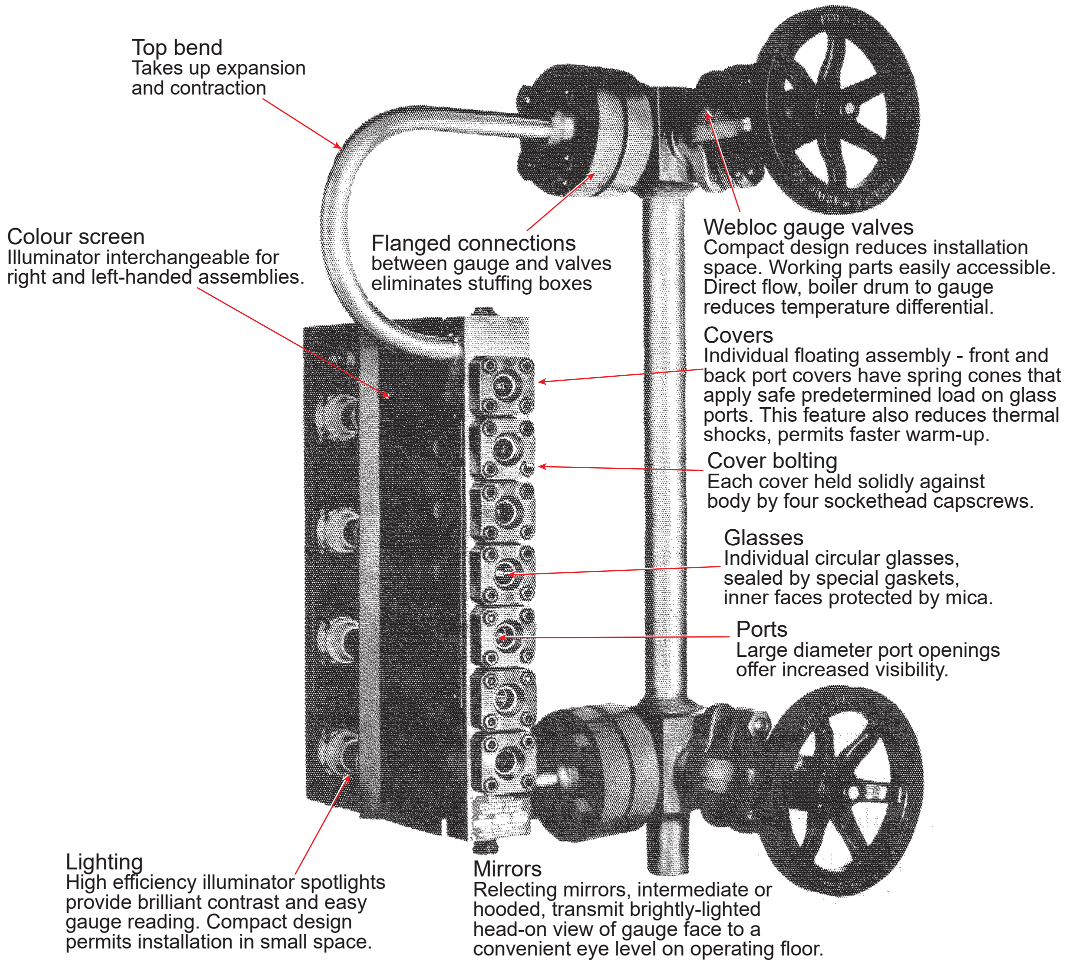
On high-pressure boilers, many gauge glass failures occur because the new glass is not heated gradually.

Bicolour Gauge Glass

Some gauge glasses show the steam and water as different colours. This permits easy identification of the water level at a distance. These are known as bicolour gauge glasses.

Figure 20 shows a type of bicolour multiport gauge glass using the point level method of indication. Instead of a water column, this gauge is attached to a circulating tie bar that has top and bottom connector blocks with gauge valves, plus a bottom connection for a drain line. The gauge glass consists of a number of sealed circular glasses (or double bullseye assemblies) with floodlights connected at the back. The steam space is indicated in red, while the water space is green.

Figure 20 – Bicolour Multiport Gauge Glass



(Courtesy of Jerguson Gage and Valve Co.)

Figure 21 shows this type of gauge glass in service.

Figure 21 – Column with Low Water Fuel Cut-Off

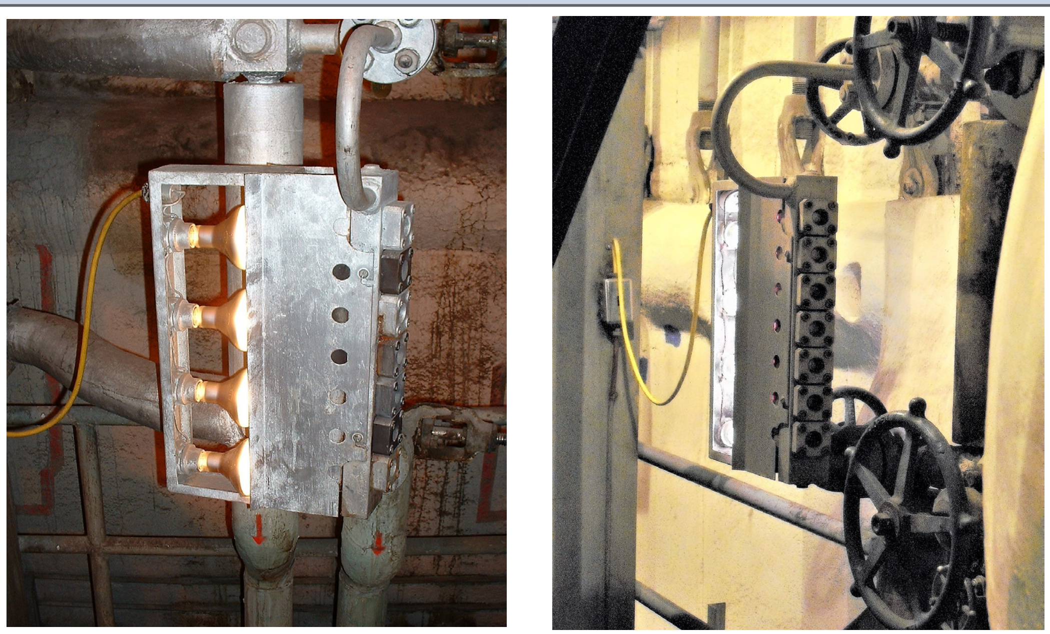
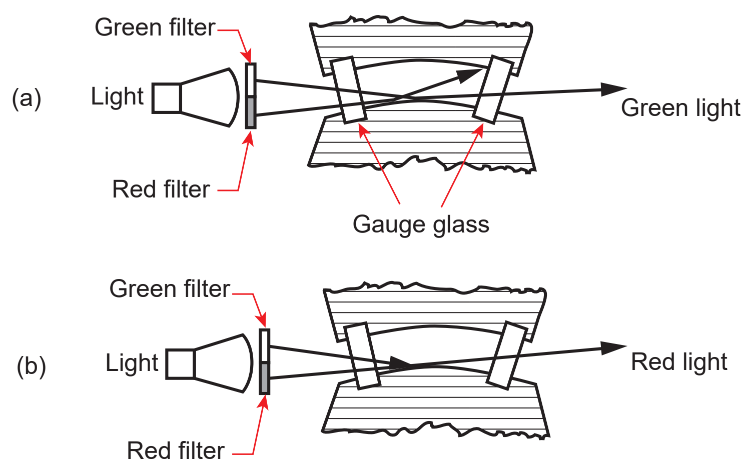


Figure 22 shows the method used for indicating the drum level. Green and red filters are placed between the lamp and each circular glass. These glasses are placed at a slight angle, to permit the light to be diffracted.

Figure 22(a) shows the passage of light through the water in the gauge glass. Only the green light can pass through the water and both glasses without excessive diffraction. The red light is diffracted so that it does not pass through. Therefore, only the green light is visible in the section of the gauge glass occupied by water.

Figure 22(b) shows the passage of light through the steam in the gauge glass. Only the red light can pass through the steam and both glasses without excessive diffraction. The green light is diffracted, so that it does not pass through. Therefore, only the red light is visible in the section of the gauge glass occupied by steam.

Figure 22 – Bicolour Gauge Glass Operation

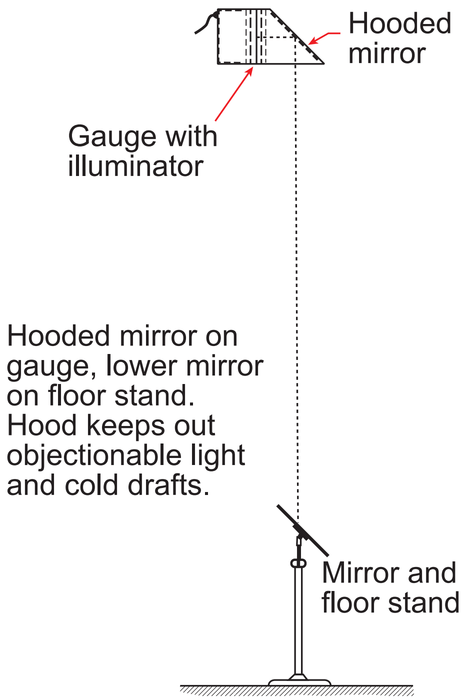


When boilers are several stories tall, the gauge glass is located high above the operating floor. Several means can be used to inform the operator of the drum level. **ASME BPVC I Part PG-60.1.1.1** states:

> *When the water level in at least one gage glass is not readily visible to the operator in the area where control actions are initiated, either a fiber optic cable (with no electrical modification of the optical signal) or mirrors shall be provided to transfer the optical image of the water level to the control area.*

Figure 23 shows how a bicolour gauge glass can indicate the drum level to a person on the operating floor below. A hooded mirror is connected directly to the front of the gauge glass and adjusted to a proper angle, so it will reflect the red and green light to another mirror on the operating floor. The photo shows an application for an eight-storey tall boiler. The red ports of the gauge glass can be seen in the lower part of the mirror.

Figure 23 – Mirror Arrangement



Gauge Glass Error

During normal boiler operation, the gauge glass generally indicates a water level lower than the actual level in the boiler drum. This is because the water in the gauge glass, water column, and interconnecting piping is cooler and denser than the water within the boiler drum. The amount of the error depends on the temperature difference between the water in the gauge and its connection, and the water in the drum.

Error is affected by such factors as the:

- Ambient temperature
- Length of the gauge glass
- Level of the liquid in the gauge glass

Testing of Water Column and Gauge Glass during Operation

Water and steam connections to both a water column and a gauge glass must always be unobstructed. Obstructions may be caused by closed valves on water level control piping, or due to sediment deposits within the control piping.

If the steam connection piping is blocked (say, with a closed valve), the steam in the gauge glass, water column, or level control float cage will condense, and form a vacuum. This will draw water in through the water connection, filling the void left by the condensed steam. The result will be a high water level that can fool both operators and controllers into believing the boiler is full of water, when it may, in fact, be empty.

If the water connection piping is blocked (say, with a closed valve or heavy deposits), the steam in the gauge glass, water column, or level control float cage will condense. The condensate accumulates in the float cage, column, or gauge glass, but will be unable to return to the boiler through the obstructed water connection. Again, the result will be a high water level that can fool both operators and controllers into believing the boiler is full of water, when it may, in fact, be empty.

For these reasons, it is imperative that all piping connections to water level controls, water columns, and gauge glasses be kept clear, so that the boiler water level will be properly communicated to the level instruments. This is done by regular water column, gauge glass, and level control blow down.

On Track

Some high-pressure steam boilers have isolation valves in the steam and water piping, between the water column and the boiler. **ASME BPVC I Part PG-60.3.7** permits this only under specific conditions. If valves are provided, they must indicate whether they are open or shut, and must be locked in the open position. For steam heating boilers, **ASME BPVC IV Part HG-604** entirely prohibits such isolation valves.

The water column and gauge glass should be blown down every shift to remove any sediment that may collect. This procedure is highly recommended on smaller high-pressure boilers. On large boilers, where the gauge glass contains mica, blowing down of the gauge glass would be less frequent. Frequent blowing down will shorten the life of the mica, and increase maintenance costs.

Gauge glasses should be renewed if they become obscured by internal corrosion or deposits. Every plant should carry a substantial reserve of gauge glasses, and washers or packing rings. Gauge glasses should be stored in a safe place where they will not be damaged.

Side Track

Gauge glasses and water column blow down procedures are covered in **Part B, Unit 4, Chapter 4 Operational Checks**.

Indirect (Remote) Level Indicators

Remote water level indicators are used to show the water level at a remote location, such as in a control room, adjacent to boiler blowoff valves, or at particular operating location.

ASME BPVC I Part PG-60.1.1.1 states:

> *When the water level in at least one gage glass is not readily visible to the operator in the area where control actions are initiated, either a fiber optic cable (with no electrical modification of the optical signal) or mirrors shall be provided to transfer the optical image of the water level to the control area. Alternatively, any combination of two of the following shall be provided:*
>
> *(a) an independent remote water level indicator*
>
> *(b) an independent continuous transmission and display of an image of the water level in a gage glass.*

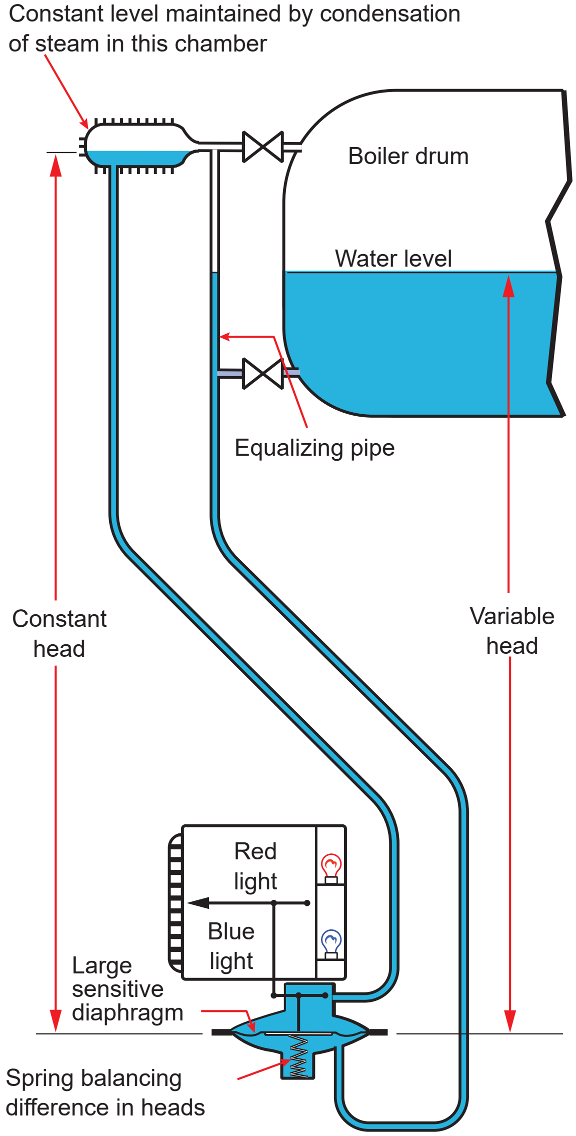
Figure 24 shows a type of remote water level indicator of entirely mechanical operation. The operating element consists of a large sensitive diaphragm with the top side connected to the steam space of the boiler, and the bottom to the water space.

A condenser at the boiler drum maintains a constant head of water pressure on the steam side. The waterside is connected at the minimum permissible water level. This connection varies in head with variations in drum level. The difference in head pressure on the two sides of the diaphragm is balanced by a spring when the level is at minimum, so the diaphragm moves up and down in accordance with the water level. As the water level in the drum rises, the pressure due to the varying head of water increases. This causes the diaphragm to rise and move the indicator upwards. As full boiler pressure is exerted equally on both sides of the diaphragm, boiler pressure has no effect upon its movement.

Coloured screens illuminate the inside of the indicator with blue in the lower portion, representing the water, and red in the upper part to represent steam. These two colours are separated by a shutter.

The motion of the diaphragm is transmitted to the shutter through a lever mechanism. If the drum level rises, the increased force under the diaphragm causes it to rise, and move the shutter upwards so more blue shows. The opposite occurs when the drum level drops. The shutter may also be used to energize high and low drum level alarms.

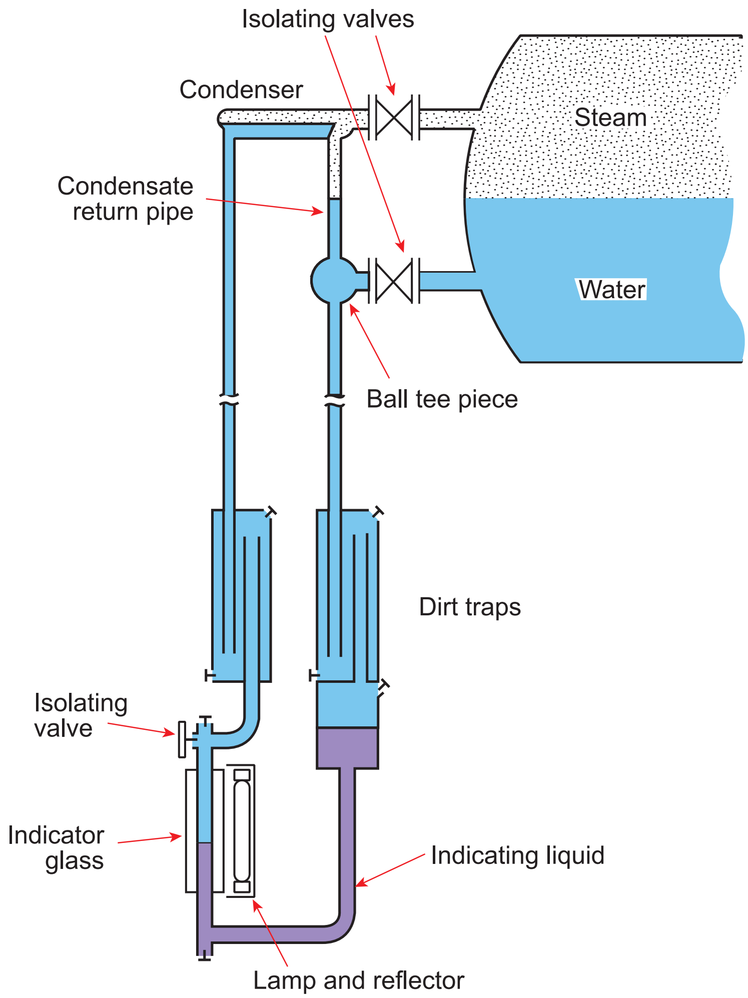
Figure 24 – Remote Water Level Indicator



Another type of remote level indicator is shown in Figure 25. The indicator is basically a manometer with one transparent leg. The manometer is filled with a blue or green insoluble liquid that is denser than water. The steam condenser maintains a constant head of water acting on one leg of the manometer. The other leg of the manometer is connected to the waterside of the boiler. The head pressure in this leg varies with boiler water level.

When the level in the boiler steam drum is at a minimum, the pressure differential between the two heads will be the greatest. The indicating liquid will be forced to the bottom of the indicator glass by the difference in pressure. As the drum level rises, the indicating liquid rises in the glass, and shows the level to engineers on the operating floor.

Figure 25 – Remote Water Level Indicator



Dirt traps are installed to prevent contamination of the indicating liquid. Care must be taken when adding indicating liquid. Overfilling will make the indicated level too high.

An advantage of this remote indicator is that there are no moving mechanical parts.

Some remote water level indicators are electronic devices. They use various methods to sense and transmit level. The level indication can be graphical representations of the water level, digital representations, or displays on computer screens.

Figure 26 shows a common type of remote water level indicator. The system is comprised of three major components:

- A water column with up to 24 water detection probes.
- An electronic detection and verification unit.
- One or more remote LED displays, customized according to the number of water level probes.

The probes detect the presence of water or steam. The detection and verification unit determines the validity of the reading, and transmits the level to LED displays. The displays can be located up to three different locations. Alarm set points and shutdowns can be programmed in the control system.

Often, one LED display is located near the gauge glass. This is so the drum level shown on the electronic display can be verified against the actual gauge glass indication.

Figure 26 – Aquarian Electronic Water Level Gauge

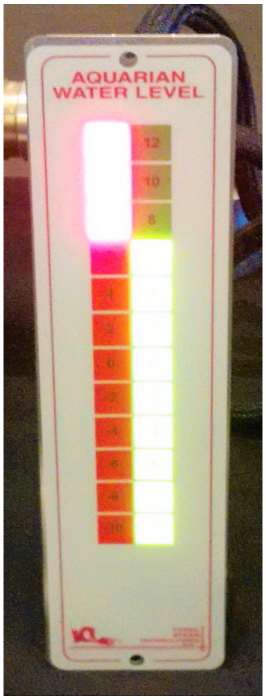


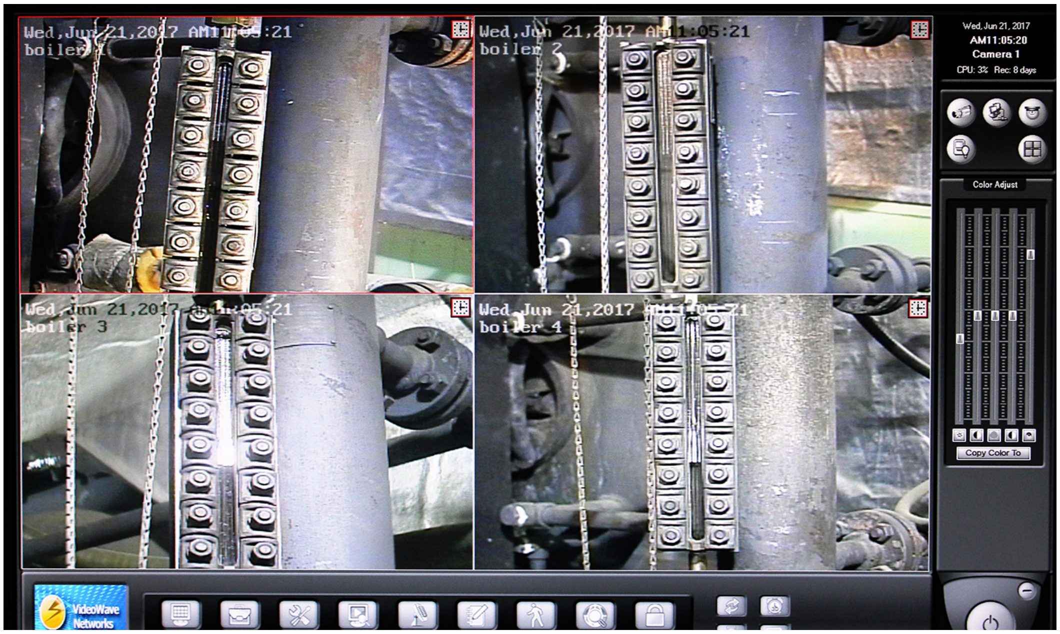
Figure 27 shows a digital water level indicator beside a set of bottom blowoff valves. This indicator receives a standard 4 to 20 mA signal from a drum level transmitter, and displays the level on an LCD display, in user-configurable engineering units, such as millimetres or inches. This indicator shows drum level in millimetres. When the reading is "0 mm," the drum level is at set point (usually ½ way up the gauge glass). Levels above or below set point are indicated as positive or negative readings, also in millimetres.

The display shown in Figure 27 is located conveniently for operators to monitor boiler water level when blowing off the boiler. Other useful locations for such a digital readout include near boiler feed pumps, and feedwater bypass valves.

Figure 27 – Loop-Powered Digital Indicator for Drum Level

Figure 28 shows four reflex-type gauge glasses for four different boilers, displayed on a single computer display, in a central control room. Cameras monitor the water levels and transmit the information to the control room in real time. The control room operator will continuously rely on this computer screen.

Figure 28 – Digital Remote Water Level Indicator



In order for any remote water level indicator to be used to meet the requirements of **ASME BPVC I Part PG-60.1.1.1**, it must be designed and installed to meet the requirements of **ASME BPVC I Part PG-60.1.1.2**, which states:

> *The display of a remote water level indicator shall have a clearly marked minimum water level reference at least 2 in. (50 mm) above the lowest permissible water level, as determined by the Manufacturer.*

This does not exclude other remote indication devices (like the cameras and loop powered indicators discussed) from being used as operator aids.

CHAPTER SUMMARY

Maintaining boiler water level is the Power Engineer's number one job. Low water conditions are one of the most common causes of boiler pressure vessel explosions.

To help prevent these devastating explosions, Power Engineers rely on various boiler water level instruments. This chapter discussed low water cut-offs, combination cut-off/feeder controls, and water level indicators.

CSA B51, **ASME BPVC IV**, and **ASME CSD-1** require low water fuel cut-offs on nearly all steam and hot water boilers, regardless of pressure. Some exceptions are made for low capacity boilers, forced circulation hot water heating boilers, and boilers in continuous attendance.

The same codes, as well as **ASME BPVC I**, have strict rules for installing water columns and water level indication devices. To be reliable operator tools, these devices must be correctly installed and operated. They must also be flushed, tested, and validated on a regular basis. Doing so minimizes the likelihood of boiler failure due to low water.

CHAPTER 4

Boiler Fittings

LEARNING OUTCOME

When you complete this chapter you should be able to:

Relate the code, operation, and required fittings to the operating principles of fittings found on boilers.

LEARNING OBJECTIVES

Here is what you should be able to do when you complete each objective:

1. *Explain the code references for boiler fittings.*
2. *Describe the code requirements for pressure gauges on steam boilers.*
3. *Describe the code requirements for the boiler connections and valves on steam boilers.*
4. *Describe the code requirements for fittings on hot water heating boilers.*
5. *Describe the non-code fittings used on boilers.*

Chapter Introduction

Boiler fittings are devices directly attached to the pressure parts of boilers. They are necessary for the proper operation of the boiler, as well as its protection. Some examples of boiler fittings are the safety valve, pressure gauge, and gauge glass. Properly functioning fittings aid in efficient and uninterrupted boiler operation. They also protect the safety of the operator, and (in the case of heating boilers) ensure the safety and comfort of the building occupants.

Boiler fittings must comply with the requirements set out in the **ASME Boiler and Pressure Vessel Code (BPVC)**. In Canada, they must also comply with the rules in the **CSA B51 Boiler, Pressure Vessel, and Pressure Piping Code,** as well as jurisdictional requirements. Fittings must be approved and registered by the regulating agency of the jurisdiction in which they are to be used.

This chapter begins with an overview of the **CSA** and **ASME Code** requirements for various categories of boilers. Specifically, the fittings required by **ASME BPVC I Power Boilers, ASME B31.1 Power Piping**, and **ASME BPVC IV Heating Boilers** will be discussed.

On Track

Numerous code references are made throughout this chapter. Readers are advised to keep the **PanGlobal ASME Academic Extract** handy while studying this chapter.

Objective 1

Explain the code references for boiler fittings.

CSA B51 Boiler, Pressure Vessel, and Pressure Piping Code

Registration of Boiler Fittings

Every valve, piping component, or instrument connected to the pressure side of a boiler becomes pressurized. These fittings will fail when applied inappropriately. All fittings must meet the required service designation for the boiler to which they are installed. Consideration must be made to the following service conditions:

- Operating temperature
- Operating pressure
- Material compatibility

The **CSA B51 Boiler, Pressure Vessel, and Pressure Piping Code** requires all pressure fittings to be registered as pressure components, if designed for service at:

- Pressures greater than 103 kpa and temperatures above 65°C, or
- Pressures greater than 1720 kpa

The registration process is complicated. The manufacturer of the fitting must have high quality control standards, and proof that the fitting can endure the type of service it was designed for. An application for registration is made in the jurisdiction where the fitting will be used. Design engineers employed with the jurisdiction review the application, and the evidence provided. If the fitting is found suitable for pressure service, the registering jurisdiction issues the fitting a **Canadian Registration Number (CRN).**

Fittings that require registration include:

- Pipe fittings, including couplings, tees, elbows, wyes, plugs, unions, pipe caps, reducers, flanges, and valves
- Expansion joints, flexible connections, and hose assemblies
- Strainers, filters, separators, and steam traps
- Measuring devices, including pressure gauges, level gauges, sight glasses, levels, and pressure transmitters
- Pressure relief devices and fusible plugs, used for overpressure protection on boilers, pressure vessels, and pressure piping

When installing or replacing piping or fittings, the supplier of the fittings must be able to provide the registration material (including the CRN) for every item purchased and installed. In this way, the installer and the end-user of the fittings are assured of reasonable quality and suitability for pressure service. Most jurisdictions prohibit the use of non-registered fittings in pressure service.

Side Track

CSA B51 Clause 4.2 covers the registration of fittings in detail.

Despite being registered, a fitting may still be unsuitable, given a specific application. For example, consider a valve made of a copper alloy that is strong enough for the pressures encountered in an ammonia refrigeration system. Ammonia, however, is incompatible with copper and copper alloys, and the valve would fail in very short order. Similarly, **austenitic stainless steel** components must never be used on water-wetted boiler surfaces. These materials are susceptible to chloride anion **stress corrosion cracking**, and will fail under pressure. Finally, consider a cast iron water column with a maximum allowable working pressure of 1035 kPa. This fitting will fail if attached to a boiler with a MAWP of 1720 kPa. Therefore, to ensure valves and fittings are of the proper strength and material for the particular service for which they are used, it is necessary that they be clearly marked or identified. Fittings that are improperly identified must never be placed in pressure service.

The markings on fittings must be legible. As a minimum, the markings must show the:

- Manufacturer name or its identifying trademark.
- Service for which the fitting is designed (e.g. pressure, temperature).
- Material designation (e.g. steel, cast iron, malleable iron, ductile iron, ASTM number).

ASME Code References

Power Engineers must know what code, and what code section, to consult when pressure components are to be replaced or repaired. This is so that the proper design methods are followed to ensure the piping system is safe and durable. These codes dictate acceptable materials, provide design calculations for thicknesses and pressures, and direct builders on acceptable fabrication methods. If the wrong code is followed, the resulting designs and installations will likely be unsafe.

The **ASME** codes contain most of the code references pertinent to power plant design and construction. **ASME BPVC I Power Boilers** and **ASME B31.1 Power Piping Code** address design and fabrication requirements for high-pressure plant piping installations. **ASME BPVC IV Heating Boilers, ASME BPVC VI Recommended Rules for the Care and Operation of Heating Boilers**, and **ASME B31.9 Building Services Piping Code** address design and fabrication requirements for low-pressure plant piping installations.

ASME BPVC I and **ASME B31.1** divide high-pressure plant piping into three categories:

1. **Boiler proper piping.** This is the piping that is a part of a boiler, such as piping between the drum and superheater.
2. **Boiler external piping.** This is the piping that connects the boiler proper to fittings, such as water columns, safety valves, and blow off valves. Boiler external piping terminates at the isolation valves required by the code, such as the feedwater isolation valve located at the drum, or the steam piping that leads to the main steam stop valve.
3. **Nonboiler external piping.** This is the piping that extends beyond the isolation valve required by **ASME BPVC I**. For example, the steam piping downstream of the main steam stop valve is nonboiler external piping. The blowoff piping between the bottom blowoff valves and the blowoff tank is also nonboiler external piping. As well, the majority of the feedwater piping from the boiler feed pumps to the boiler feedwater isolation valve is nonboiler external piping.

When existing piping systems need repairs, or new piping systems are installed, the designers, installers, and repair agencies must follow the correct code. For high-pressure steam and high-pressure high-temperature hot water plants, **ASME BPVC I** is the code with jurisdiction over the materials, design, fabrication, installation, and testing of boiler proper piping. The **ASME B31.1** code covers boiler external piping, and nonboiler external piping. For low-pressure steam and hot water installations, **ASME B31.9** has jurisdiction.

ASME B31.1 Power Piping Code

Part 122.1: Boiler External Piping

The **ASME BPVC I** has administrative jurisdiction over boiler external piping. However, **ASME B31.1** has technical jurisdiction. This means that the design and fabrication rules for boiler external piping are found in **B31.1**. This includes:

- **Steam piping** from the boiler shell to, and including, the main steam stop valve.
- **Feedwater piping** from the boiler shell to the feedwater regulator and feedwater bypass valves.
- **Blowoff piping** from the boiler shell to the second blowoff valve.
- **Blowdown piping** from the boiler shell to the continuous blowdown, or surface blowoff isolation valve.
- **Boiler drain** lines.
- **Miscellaneous systems:** piping from the boiler shell to water level indicators, water columns, gauge cocks, and pressure gauges.
- **Installed valves and fittings:** steam, feedwater, blowoff, and miscellaneous valves installed on boiler external piping systems.

Part 122.2: Blowoff and Blowdown Piping in Nonboiler External Piping

The **ASME B31.1** code has administrative and technical jurisdiction over the design and fabrication of all nonboiler external piping. **Part 122.2** covers:

- Blowoff piping, located between the blowoff valves and the blowoff tank.
- Blowdown piping, downstream of the boiler blowdown isolation valve.

Part 122.6: Pressure Relief Piping

The **ASME B31.1** code has administrative and technical jurisdiction over the design and fabrication of piping for pressure relief devices. **Part 122.6** covers:

- Piping to pressure-relieving valves and devices.
- Discharge piping from pressure-relieving valves and devices.

Other Important Sections of the ASME B31.1 Code

ASME B31.1 also covers the piping for the following power plant components that are of interest to the Fourth Class Power Engineer:

- **Part 122.3 Instrument, Control, and Sampling Piping**
- **Part 122.5 Pressure-Reducing Valves**
- **Part 122.11 Steam Trap Piping**
- **Part 122.13 Pump Discharge Piping**

ASME BPVC Boiler Fittings

ASME BPVC covers the materials of construction and installation of many of the fittings required to ensure the integrity of the boiler proper. These include water columns, water level indicators, pressure gauges, and safety valves.

Power Boilers

Power boilers generate steam, or other vapour, at a pressure of more than 100 kPa (15 psi). Boilers designed to **ASME BPVC I** may be sub-categorized as:

- High-pressure steam boilers
- High-pressure, high-temperature hot water boilers
- Electric boilers
- Miniature boilers
- Organic fluid vaporizers

Of these, the first three are of greatest interest to the Fourth Class Power Engineer.

The construction and design requirements for all types of power boilers are found in **ASME BPVC I Part PG General Requirements for All Methods of Construction**. Specific rules for watertube, firetube, electric, miniature, welded, and riveted designs are included in their respective sections. When researching a code reference for a specific design element of a boiler (such as the location of a gauge glass, or the number of safety valves required), first consult **Part PG**. Then, check the specific part of the code for the type of boiler under consideration.

Table 1 – ASME BPVC I Specific Code References in Part PG

Reference	Part
Boiler Outlets and External Piping	PG-58
Requirements Common to Steam, Feedwater, Blowoff, and Drain Systems	PG-59.1
Requirements for Feedwater Connections	PG-59.2
Requirements for Blowoffs	PG-59.3
Requirements for Drains	PG-59.4
Requirements for Valves and Fittings	PG-59.5
Requirements for Miscellaneous Pipe, Valves, and Fittings, including Water Level Indicators, Water Columns, and Pressure Gauges	PG-60
Boiler Overpressure Protection Requirements	PG-67
Superheater and Reheater Overpressure Protection Requirements	PG-68
Capacity of Pressure Relief Valves	PG-70
Mounting of Pressure Relief Valves	PG-71
Operation of Pressure Relief Valves	PG-72
Minimum Requirements for Pressure Relief Valves	PG-73

Other parts of the code have more specific references related to boilers of particular designs. A good example can be seen with **Part PEB**. Note that these power boilers have specific requirements that may not be fulfilled by the general requirements in **Part PG.**

Table 2 – ASME BPVC I Special Code References for Electric Boilers

Reference	Part
Blowoff pipes	PEB-12.2
Water level indicators	PEB-13
Pressure relief valves	PEB-15

Many of the **ASME BPVC** code sections, as well as **ASME B31.1**, are in the **PanGlobal ASME Academic Extracts**. Review these code sections in detail.

Heating Boilers

Heating boilers generate:

- Steam or other vapour at a pressure not exceeding 100 kpa
- Hot water at a pressure not exceeding 1100 kpa, or
- Hot water at a temperature not exceeding 120°C

ASME BPVC IV rules covers the design and construction of:

- Steam heating boilers
- Hot water heating boilers
- Hot water supply boilers
- Hot water heaters

The following tables show the code references for many items of interest for Fourth Class Power Engineers.

Table 3 – ASME BPVC IV Instruments, Fittings, and Controls for Steam Heating Boilers

Reference	Part
Safety Valve Requirements for Steam Boilers	HG-400.1
Minimum Requirements for Safety and Safety Relief Valves	HG-401
Steam Gauges	HG-602
Water Gauge Glasses	HG-603
Water Column and Water Level Control Pipes	HG-604
Pressure Control	HG-605
Automatic Low-Water Fuel Cutoff and/or Water Feeding Device	HG-606

Table 4 – ASME BPVC IV Instruments, Fittings, and Controls for Hot Water Heating Boilers

Reference	Part
Safety Relief Valve Requirements for Hot Water Boilers	HG-400.2
Minimum Requirements for Safety and Safety Relief Valves	HG-401
Pressure or Altitude Gauges	HG-611
Thermometers/Temperature Sensors	HG-612
Temperature Control	HG-613
Low-Water Fuel Cutoff	HG-614

Objective 2

Describe the code requirements for pressure gauges on steam boilers.

Steam Pressure Gauges

Boilers are designed strong enough to withstand a certain amount of internal pressure. Excessive pressure may cause a pressure vessel explosion, especially if a boiler is nearing the end of its useful service life, or has been poorly maintained. Therefore, each steam boiler must be equipped with an accurate pressure gauge to indicate the boiler's internal pressure. The bourdon tube gauge is commonly used for this purpose.

ASME BPVC I: High-Pressure Steam Boilers

ASME BPVC I Part PG-60.6.1

ASME BPVC I Part PG-60.6.1 states:

> *Each boiler shall have a pressure gauge so located that it is easily readable. The pressure gauge shall be installed so that it shall at all times indicate the pressure in the boiler.*

It also says:

> *The dial of the pressure gauge shall be graduated to approximately double the pressure at which the safety valve is set, but in no case to less than 1 ½ times this pressure.*

This is important for three reasons:

1. When the pressure gauge is calibrated to double the safety valve setting, the operator can tell at a distance if the boiler is at its normal operating pressure. The gauge pointer will be nearly vertical.
2. When a pressure gauge is reading at mid-span, it is most accurate.
3. The pressure gauge will be suitable for use during a hydrostatic test, which is performed at 1 ½ times the maximum allowable working pressure of the boiler.

Part PG-60.6.1 also says the pressure gauge must be connected "*to the steam space or to the water column or its steam connection.*" This reduces the likelihood of blockage in the piping connection, due to the accumulation of sediment or corrosion products, which would render the gauge inoperative. As well, at this location, the pressure indication will not be affected by the boiler's hydrostatic head.

Part PG-60.6.1 requires a shutoff "*valve or cock… placed in the gauge connection adjacent to the gauge*," and prohibits the installation of any other shutoff valve between the gauge and the boiler. The shutoff valve is important for two reasons:

1. It permits the replacement of the pressure gauge while the boiler is in operation.
2. It permits the installation of a master test pressure gauge, to verify the accuracy of the boiler pressure gauge.

Because the pressure gauge must be attached to the steam space of the boiler, it must be protected from the action of high pressure and high temperature steam. Steam can reduce the elasticity of the Bourdon tube, and weaken its brazed joints. These conditions will affect the accuracy of the gauge and reduce its service life. For this reason, **Part PG-60.6.1** states:

> *For a steam boiler, the gauge or connection shall contain a syphon or equivalent device that will develop and maintain a water seal that will prevent steam from entering the gauge tube.*

Figure 1 shows a pigtail siphon.

Figure 1 – Pigtail Siphon

(Courtesy of Winters Instruments)

The "equivalent device" is usually a piping arrangement that traps condensate in its lower parts, keeping steam away from the pressure gauge. This piping arrangement must be equipped with tees, cross-tees, and plugs so that the pressure piping can be inspected and cleaned on a regular basis.

To ensure the siphon or the equivalent device does not plug off, the piping must be of adequate cross-section. **Part PG-60.6.1** requires piping or siphons of the following minimum dimensions:

> *The connections to the boiler, except the syphon, if used, shall not be less than NPS ¼ (DN 8) but where steel or wrought iron pipe or tubing is used, they shall not be less than ½ in. (13 mm) inside diameter.*
>
> *The minimum size of a syphon, if used, shall be ¼ in. (6 mm) inside diameter.*

Figure 2 shows a finned siphon. This design builds condensate in a small internal reservoir to protect the pressure gauge. This siphon also acts as a snubber.

Figure 2 – Finned Siphon on a Steam Pressure Gauge

ASME BPVC I Part PG-60.6.3

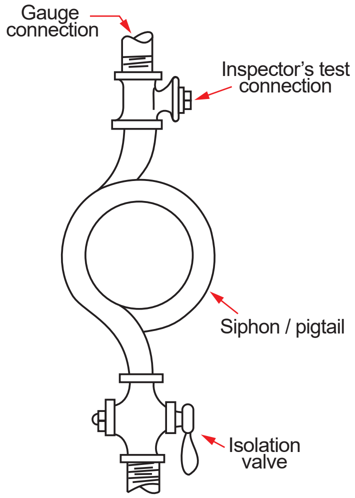
ASME BPVC I Part PG-60.6.3 requires that:

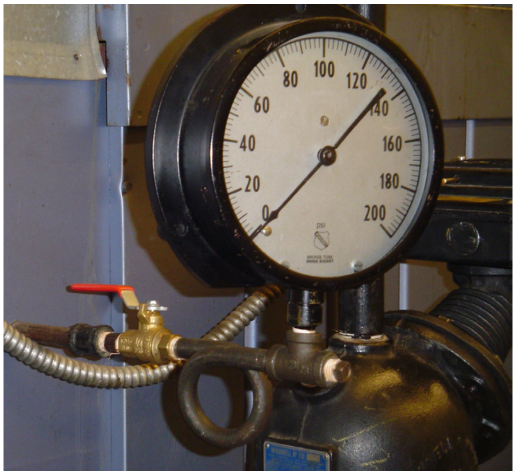
> *Each boiler shall be provided with a valve connection at least NPS ¼ (DN 8) for the exclusive purpose of attaching a test gauge when the boiler is in service, so that the accuracy of the boiler pressure gauge can be ascertained.*

This is usually accomplished by installing a tee with an NPS ¼ (DN 8) plug between the siphon and boiler pressure gauge. This is shown in Figure 3.

For the inspector to connect the test gauge, it is necessary to shut off the lever-handle cock, and remove the plug from the tee. The inspector's test gauge is a master gauge used to verify the pressure shown on the boiler gauge, while it is in operation.

Figure 3 – Pigtail Siphon with Inspector Test Connection and Isolation Valve

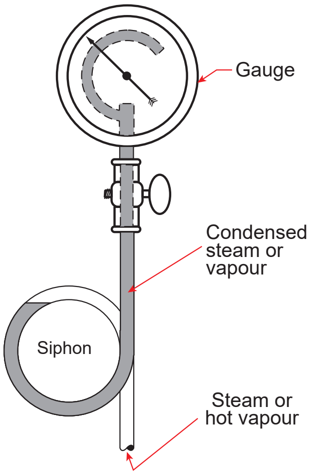




Pigtail siphons are liquid seals, shaped in a spiral pattern or a "U". Regardless of the shape, siphons all work the same way. Steam enters the body of the siphon, and gives off heat. As it loses heat, the steam condenses. The condensate becomes trapped in the lower portion of the pigtail or U. This trapped condensate keeps steam away from the pressure-sensing device, while still permitting the pressure to be transmitted to the gauge.

Because of the damaging effects of steam on pressure sensors, siphons should be filled with distilled water prior to installation. This ensures the pressure-sensing device is protected as soon as steam is admitted to the siphon.

Figure 4 – Operation of a Pigtail Siphon



Siphons are also used to protect pressure limit controls, modulating pressure controllers, and electronic pressure sensors.

ASME BPVC IV: Low-Pressure Steam Boilers

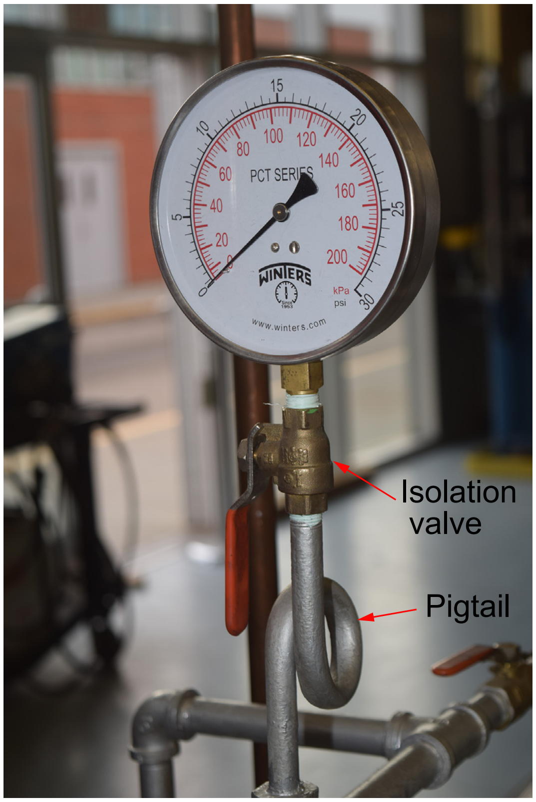
ASME BPVC IV Part HG-602 states the requirements for pressure gauges used on low-pressure steam heating boilers. These include the following points:

- *Each steam boiler shall have a steam gauge or a compound steam gauge connected to its steam space or to its water column or to its steam connection.*
- *The gauge or piping to the gauge shall contain a siphon or equivalent device that will develop and maintain a water seal that will prevent steam from entering the gauge tube.*
- *The piping shall be so arranged that the gauge cannot be shut off from the boiler except by a cock placed in the pipe at the gauge and provided with a tee- or lever-handle arranged to be parallel to the pipe in which it is located when the cock is open.*
- *The gauge connection boiler tapping, external siphon, or piping to the boiler shall not be less than DN 8 (NPS ¼). Where steel or wrought iron pipe or tubing is used, the boiler connection and external siphon shall be not less than DN 15 (NPS ½).*
- *The scale on the dial of a steam boiler gauge shall be graduated to not less than 200 kPa (30 psi) nor more than 414 kPa (60 psi).*
- *The travel of the pointer from 0 kPa to 200 kPa (0 psi to 30 psi) pressure shall be at least 75 mm (3 in.).*

Figure 5 shows an installation compliant with these rules.

Though an inspector gauge connection is not mandatory for low-pressure boilers, it is a good idea to install a connection anyway, for the ability to verify the reading of the boiler gauge during operation.

Figure 5 – Pressure Gauge Mounted on a Low Pressure Boiler



Objective 3

Describe the code requirements for the boiler connections and valves on steam boilers.

Boiler Outlet Connections

Outlet connections are tappings in a boiler drum or shell, for connecting external piping and fittings. They connect the boiler to various controls, instruments, or fittings, such as:

- Safety valve
- Main steam stop valve
- Drum vent
- Water column and gauge glass
- Feedwater inlet
- Pressure controls
- Bottom blowoff
- Continuous blowdown
- Surface blowoff
- Chemical feed

These fittings and piping stubs may be welded directly to the drum or shell. Fittings and piping can also be attached to the boiler with threaded fittings screwed directly into the drum or shell, and with flanged connections.

ASME B31.1 Boiler Connections

Outlets and External Piping

The piping that leads to and from a boiler up to the first valve (or sometimes, the second valve) is boiler external piping, and falls under technical jurisdiction of **ASME B31.1 Power Piping Code.** However, **ASME BPVC I** also contains direction about the required configuration of boiler piping systems. Therefore, it is often necessary to consult both codes.

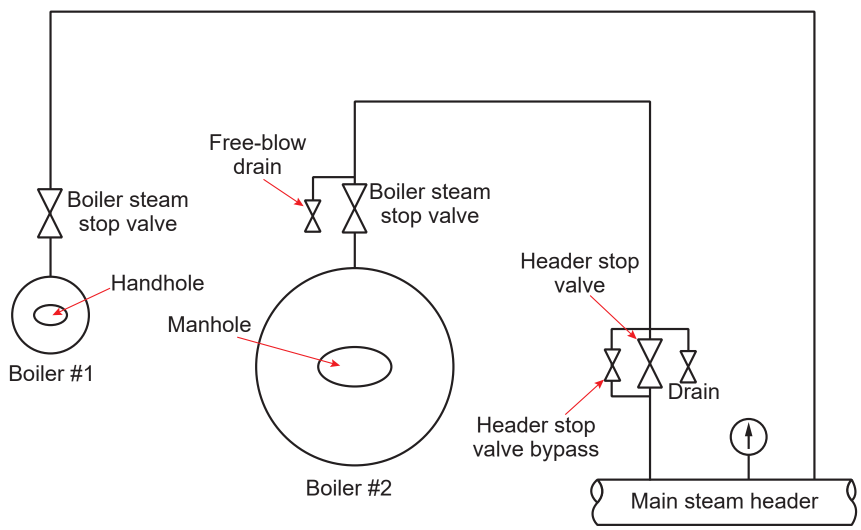
Steam Piping

ASME B31.1 122.1.7 (A3) states:

> *When two or more boilers are connected to a common header, or when a single boiler is connected to a header having another steam source, the connection from each boiler having a manhole opening shall be fitted with two stop valves having an ample free-blow drain between them.*

Figure 6 shows these requirements. Boiler #1 has a small steam drum, and is only equipped with a handhole. Boiler #2 has a larger shell, and requires a manhole for inspections and maintenance. Because both boilers are connected to a common steam header, the boiler with the manhole requires block and bleed valves in the steam line. If the small boiler also had a manhole, it too would require a block and bleed system.

Figure 6 – ASME BPVC I Requirements for Steam Line Stop Valves and Drains



The required steam shut-off valves must be equipped with a position indicator, to show from a distance whether the valve is open or closed. Outside screw and yoke, rising stem valves are preferred.

Feedwater Piping

ASME B31.1 Power Piping Code Part 122.1.7 (B.1) covers feedwater piping requirements for power boilers. It states:

> *The feedwater piping for all boilers… shall be provided with a check valve and a stop valve between the check valve and the boiler.*

The purpose of the check valve is to prevent the boiler from draining through the feedwater line when a boiler feedwater pump is not running. The stop valve permits isolation of the feedwater line for maintenance and repair without draining the boiler.

CAUTION

Feedwater components must not be repaired or replaced when the boiler is hot and under pressure. Follow plant lockout and tagout procedures.

Part 122.1.7 (B.10) states:

> *Wherever globe valves are used within feedwater piping for either isolation or regulation, the inlet shall be under the disk of the valve.*

In this way, if the valve disk becomes detached from the valve stem, it will not block the feedwater flow.

Some boilers are equipped with multiple feedwater inlets. To address this, **Part 122.1.7 (B.3)** states:

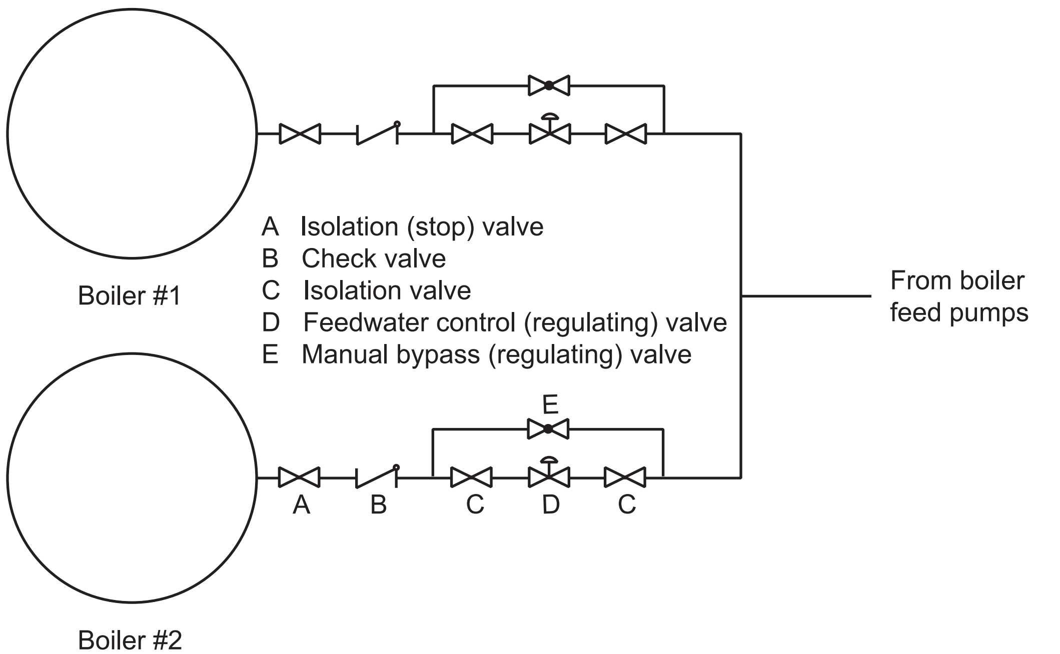
> *If a boiler is equipped with a duplicate feed arrangement, each such arrangement shall be equipped as required by these rules.*

Power plants with multiple boilers are often fed with a single feedwater pump. Each boiler has independent feedwater needs, depending on the capacities of the boilers and their firing rates. To address this, **Part 122.1.7 (B.5)** states:

> *When two or more boilers are fed from a common source, there shall also be a globe or regulating valve in the branch to each boiler located between the check valve and the source of supply.*

Figure 7 shows a typical feedwater arrangement that meets the criteria of **B31.1.**

Figure 7 – Feedwater Valve Arrangement for Multiple Boilers



Blowoff Piping

ASME B31.1 Power Piping Code Part 122.1.7 (C.4) requires all boilers with allowable working pressures over 100 psig (690 kPag) to have two slow-opening blowoff valves, or one quick-opening valve at the boiler nozzle, followed by a slow-opening valve. A slow-opening valve requires at least five 360-degree turns of the operating mechanism to change from fully closed to fully opened.

The rationale for this rule is:

- Slow-opening valves help the operator reduce thermal shock with a gradual, controlled warmup of the blowoff line, before subjecting it to high-pressure high-temperature liquid.
- With a two-valve system, one valve operates in non-moving fluid, preserving its integrity for shut-off purposes. The other valve experiences the wear.

Certain boilers are exempt from the two-valve rule:

- Electric steam boilers with a normal water content of 380 L (100 US gallons) or less.
- Boilers in traction service, including those used in steam traction engines and steam locomotives.
- Portable steam boilers.

For these boilers, other rules apply:

- According to **Part 122.1.7 (C.11)**, traction and portable boilers require only one blowoff valve, which may be either slow-opening or quick-opening.
- According to **Part 122.1.7 (C.12)**, forced circulation and electric steam boilers with a normal water content of 380 L (100 US gallons) or less require only one blowoff valve, which must be of a slow-opening type.

Ordinary globe valves have dams or pockets where sediment can collect. Because of this, **Part 122.1.7 (C.1)** prohibits them from blowoff service. Rather, **122.1.7 (C.2)** requires Y-type globe valves, because they do not trap sediment.

When the boiler MAWP is greater than 1725 kPa, the blowoff valves must be at least cast steel Class 300 valves. When the boiler MAWP is less than 1725 kPa, the blowoff valves may be Class 250 bronze, cast iron, ductile iron, or steel.

Miscellaneous Piping

ASME B31.1 Part 122.1.6 covers the miscellaneous piping, such as water level indicators, water columns, gauge cocks, and pressure gauges.

ASME BPVC IV Steam Heating Boiler Connections

The various fittings attached to a low-pressure steam boiler include:

- Steam outlet stop valve
- Feedwater inlet stop and check valves
- Blowoff valves
- Vent valve
- Water level controls
- Water level indicators
- Low water fuel cut-off
- Pressure limit controls
- Pressure gauge

Pressure gauges, pressure limit controls, low water cut-offs, water level indicators, and water level controls have already been discussed.

Steam Outlet and Stop Valve

The steam produced in the boiler leaves through the steam outlet, and flows through the main header to the branch lines, which distribute the steam to the various parts of the system.

ASME BPVC IV Part HG-710.1 *covers the steam stop valve requirements for installations with only a single steam boiler.* **Part HG-710.3** covers installations with multiple boilers.

> **Part HG-710.1** *When a stop valve is used in the supply pipe connection of a single steam boiler, there shall be one used in the return pipe connection.*
>
> **Part HG-710.3** *A stop valve shall be used in each supply and return pipe connection of two or more boilers connected to a common system.*

The two types of valves commonly used on the steam outlet of a boiler are the gate valve and the globe valve. The connections may be threaded, flanged, welded, or brazed. The gate valve is more likely to be used since it offers the least resistance. It will be wide open during operation, and no throttling is involved.

ASME BPVC IV Part HG-710.4(b) requires that all stop valves be suitably pressure and temperature rated.

> *The minimum pressure rating of all valves or cocks shall be at least equal to the pressure stamped upon the boiler, and the temperature rating of such valves or cocks, including all internal components, shall be not less than 120°C.*

When the steam outlet is DN 50 (2" NPS) or larger, it is recommended to use outside screw and yoke valves with rising spindles. These valves enable the operator to see, even from a distance, whether the valve is open or closed. Also, since the threaded part of the spindle is outside the valve body, it is not exposed to corrosive action by steam or water, and can be easily lubricated.

Feedwater Connection and Check Valves

The feedwater connection is the point at which the water enters the boiler. It should be arranged so that the water does not discharge directly against surfaces exposed to hot combustion gases or radiant heat from the fire. Frequently, an internal pipe is used to direct the feedwater to a suitable point within the boiler.

ASME BPVC IV Part HG-705(a) states that:

> *Feedwater shall not be introduced through openings or connections provided for inspection or cleaning, safety valve, water column, water gage glass, or pressure gage.*

Feedwater to the water column or safety valve connections could adversely affect the operation of feeders, cut-offs, or the safety valve.

ASME BPVC IV Part HG-705(a) also states:

> *The feedwater pipe shall be provided with a check valve near the boiler. A stop valve or cock shall be installed either upstream or downstream of the check valve.*

In pumped return systems, the check valve keeps the boiler from draining when the boiler feedwater pump is off. The stop valve boiler allows the feedwater system components to be isolated for repairs without draining the boiler. The check valve used in the feedwater line may be a swing, or a lift check type.

In addition to the feedwater check valve, **ASME BPVC IV Part HG-703.2** requires the installation of a return (or Hartford) loop. This piping configuration prevents boiler pressure from lowering the boiler water level to below the lowest permissible water level, if the feedwater check valve fails.

Bottom Blowoff Valves

ASME BPVC IV Part HG-715(a) requires all steam heating boilers to have bottom blowoff connections connected to the lowest water space practicable. This is to ensure:

- The boiler can be completely drained.
- Blowoff can discharge all the sediment that accumulates.

The size of the blowoff line varies with the boiler steam production capacity. The sizes are shown in Table 5. The blowoff discharge piping must be full size to the point of discharge.

Table 5 – Size of Bottom Blowoff Piping and Valves, According to ASME BPVC IV HG-715

Minimum Required Safety Valve Capacity, kg/hr	Blowoff Piping and Valve Size, DN (NPS)
Up to 225	20 (3/4)
225 to 550	25 (1)
550 to 1200	32 (1 ¼)
1200 to 2700	40 (1 ½)
2700 and larger	50 (2)

Packaged firetube boilers have the blowoff connection at the bottom of the shell close to the back end. Boilers with water legs, such as firebox boilers, have a blowoff connected at the lowest point of each water leg.

The minimum pressure rating of valves used to blowoff or drain low-pressure steam boilers must be at least 200 kPa (30 psi). The temperature rating must not be less than 120°C (250°F).

Blowdown valves are installed for the testing of, and intermittent removal of, sediment from the water column, gauge glass, and low water fuel cutoff. Again, these valves must be temperature and pressure rated.

Objective 4

Describe the code requirements for fittings on hot water heating boilers.

BPVC IV Hot Water Heating Boiler Fittings

ASME BPVC IV distinguishes between hot water heating and hot water supply boilers. The followings fittings are required by **ASME BPVC IV**, on every hot water heating boiler:

- Pressure or altitude gauge
- Thermometer
- Safety relief valve
- Temperature controls
- Low water fuel cut-offs
- Stop valves
- Blowoff or drain connections
- Expansion tanks

Safety relief valves, temperature controls, low water fuel cut-offs, and expansion tanks have been covered elsewhere in detail. However, they deserve some brief mention here.

Pressure or Altitude Gauges

ASME BPVC IV Part HG-611 covers the requirement for pressure indicators for hot water heating boilers. This section includes the following:

> *Each hot water heating boiler shall have a pressure or altitude gage connected to it or to its flow connection in such a manner that it cannot be shut off from the boiler except by a cock with tee or lever handle, placed on the pipe near the gage. The handle of the cock shall be parallel to the pipe in which it is located when the cock is open.*

The design and operation of pressure and altitude gauges is the same as that of steam pressure gauges. However, in hot water service, no siphon is required between the gauge and the boiler. This is because hot water boilers are completely filled with water, and generate no steam.

The term "altitude" gauge refers to pressure gauges that are calibrated in terms of height of water. These gauges indicate whether the hot water system is full. An altitude gauge has one pointer that is operated by the bourdon tube assembly, and another that is manually placed in a fixed position, to show the normal height of water in the system. In closed hot water heating systems, the pressure should always be greater than the altitude. If the pressure is less, the system is not full.

As with steam heating boilers, the scale on the dial of the pressure or altitude gauge must be graduated to between 1 ½ and 3 ½ times the safety relief valve set pressure.

Pressure gauges are also found before and after hot water circulation pumps. These gauges can be filled with a liquid that dampens the needle movement in the gauge.

Thermometer

ASME BPVC IV Part HG-612 requires all hot water heating boilers to have an easily read thermometer or temperature sensor (with display). The thermometer or sensor must indicate the hot water temperature at or near the boiler outlet. The thermometer must have a minimum reading of at least 20°C, and a maximum reading of at least 160°C, but not more than 205°C.

Pressure and temperature gauges are commonly combined into a single gauge, as shown in Figure 8. These gauges are available for numerous combinations of temperature and pressure. The gauge shown is designed for a hot water boiler with a normal operating pressure near 900 kPa, and a normal operating temperature of around 90°C. During normal operations, both needles are vertical. If the gauge includes an altitude scale, it is commonly referred to as a **tridicator** gauge.

Figure 8 – Combination Temperature and Pressure Gauge

Safety Relief Valves

Safety relief valves have been covered extensively in **Chapter 1 Pressure Relief Valves.** However, hot water heating boilers have some unique requirements worthy of further discussion.

ASME BPVC IV Part HG-400.2 covers the safety relief valve requirements for hot water boilers. Each hot water heating boiler must have at least one automatic reseating type safety relief valve, set to relieve at or below the maximum allowable working pressure of the boiler. However, when more than one safety relief valve is used, the additional valves may be set to higher than the MAWP. The higher set safety relief valve must not exceed the MAWP by:

- 40 kPa, for boilers up to and including 400 kPa, or
- 5%, for boilers exceeding 400 kPa

Safety relief valves must be between DN 20 and DN 100 (NPS ¾ and NPS 4) in size.

When a single safety relief valve is used, it must have sufficient relief capacity so that, with the fuel burning equipment operated at maximum capacity, the pressure cannot rise more than 10% above the MAWP. If two safety relief valves are installed, the overpressure cannot go higher than 10% above the set pressure of the highest set valve.

Stop Valves

ASME BPVC IV Part HG-710.2 states that stop valves must be placed in the supply and return pipe connections on all hot water heating boilers. This allows the boiler to be drained without emptying the entire piping system. However, in down feed hot water systems, it is possible to drain only the boiler, without draining the system. Therefore, **Part HG-710.2** says that when the boiler is located above the system, and can be drained without draining the system, stop valves are not required.

For multiple boilers connected to a common system, **Part HG-710.3** requires a stop valve in the supply and return pipe connection of each boiler, regardless of whether the system is up feed or down feed.

Type of stop valves is covered under **HG-710.4.** The minimum pressure rating of all valves must be at least equal to the pressure stamped on the boiler. The temperature rating must not be less than 120°C.

During operation, the stop valves in the supply and return pipes should be wide open, and offer a minimum of resistance to the circulating water. A full port opening valve, such as the gate valve, ball valve, or butterfly is suitable for this purpose.

Drain Valves

Each hot water heating boiler must have a bottom connection fitted with a drain valve. This permits draining of the boiler for maintenance or extended layup.

Expansion Tank

The purpose of the expansion tank is to provide storage space for excess water (due to expansion) in the heating system. When the system is heated, the water expands. Excessive pressure buildup is prevented by allowing the excess water to flow into an expansion tank. When the water in the system cools down and decreases in volume, the water in the expansion tank flows back into the system again, keeping the system filled and under the correct pressure.

ASME BPVC IV Part HG-709 covers the provisions for thermal expansion in hot water systems.

Open Expansion Tanks

Open expansion tanks are rarely used today. They were limited to systems with a maximum water temperature of 80°C. They were, by necessity, installed above the highest point of the piping system.

Closed Expansion Tanks

Closed expansion tanks can be used in systems with high operating temperatures and pressures. They may be located anywhere in the heating system, but are often located in the boiler room. Expansion tanks are connected to the supply main, or directly to the top of the boiler.

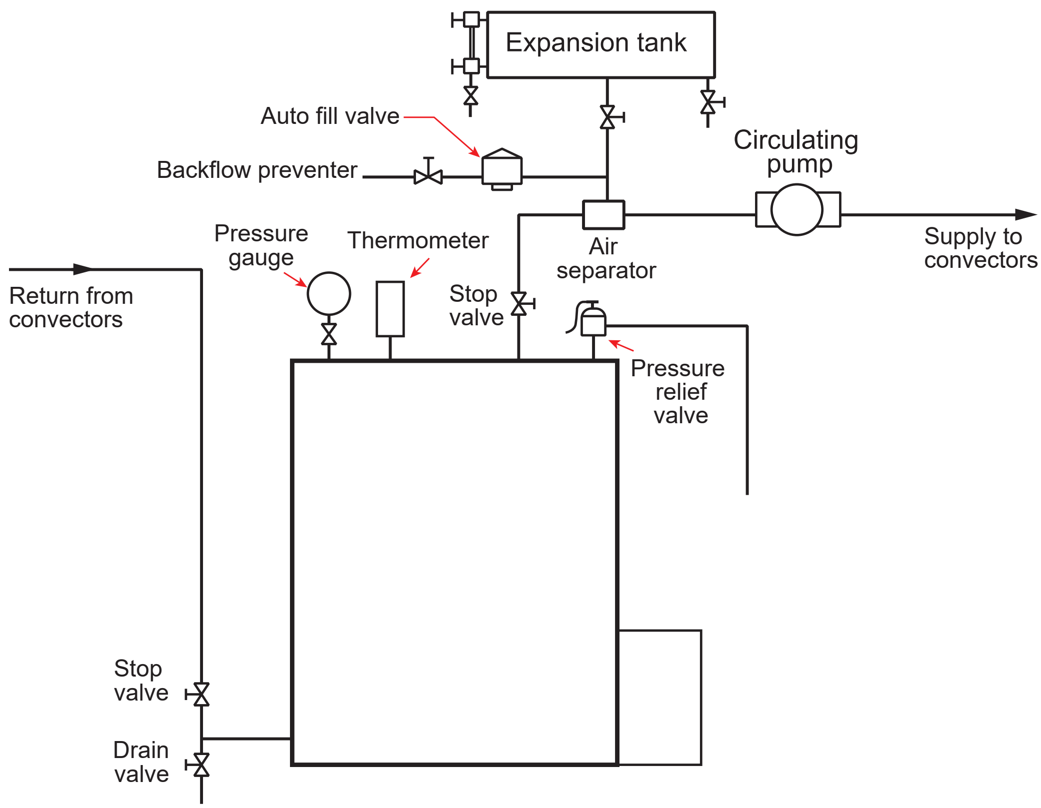
When the water in the boiler and system increases in temperature, it expands. The expanding water moves into the tank, compressing the air cushion inside the tank. For this reason, expansion tanks are also called cushion or compression tanks.

ASME BPVC IV Part HG-709.2 addresses expansion tanks. It states that "*an expansion tank shall be installed that will be consistent with the volume and capacity of the system.*" **HG-709.2** includes calculations for determining the required volume of the expansion tank, given the system volume, operating pressure, and operating temperature. If the system is designed for a working pressure of 200 kPa or less, the tank must be designed for a minimum hydrostatic test pressure of 520 kPa. This permits hydrostatic testing of the system without damaging the tank. Expansion tanks for systems designed to operate above 200 kPa must be pressure vessels, designed and constructed in accordance **ASME BPVC VIII, Division 1.**

Provisions must be made for draining the tank without emptying the system, except for pre-pressurized (bladder-style) tanks. Though not a requirement, installing isolation and drain valves in the piping to a bladder-style expansion tank is good practice. This permits servicing, replacing, and repairing the expansion tank without draining the heating system.

Figure 9 shows an arrangement of a closed expansion tank. This tank is connected to the supply main by means of an air separator, which separates air bubbles from the water flow, and directs them into the tank.

Figure 9 – Required Fittings and Controls for Hot Water Heating Boilers



The expansion tank shown is equipped with a gauge glass and a drain valve. A shutoff valve is placed in the connecting line between the tank and the hot water supply header. This allows the tank to be drained without draining the system.

Side Track

Expansion tank operation and maintenance is covered extensively in **Part B, Unit 4, Chapter 3 Operational Checks.**

Non-bladder style expansion tanks bring air into direct contact with the water. Over time, oxygen dissolves into the water in the expansion tank. When the heating system temperature drops, some oxygenated water enters the heating system as the water contracts. This can cause corrosion of steel piping and heating units. Bladder-style tanks and nitrogen-charged tanks eliminate this problem.

Objective 5

Describe the non-code fittings used on boilers.

Non-Code Fittings for Hot Water Heating Boilers

Figure 9 shows a hot water heating boiler equipped with all the code required fittings. It also shows other fittings and components beneficial for proper system operation. The air separator in the supply line to the heating system, the circulating pump, and the automatic fill valve are desirable, but not required. Note that a hot water boiler does not require a gauge glass since the boiler is completely filled with water during normal operations. A gauge glass is usually fitted on the expansion tank.

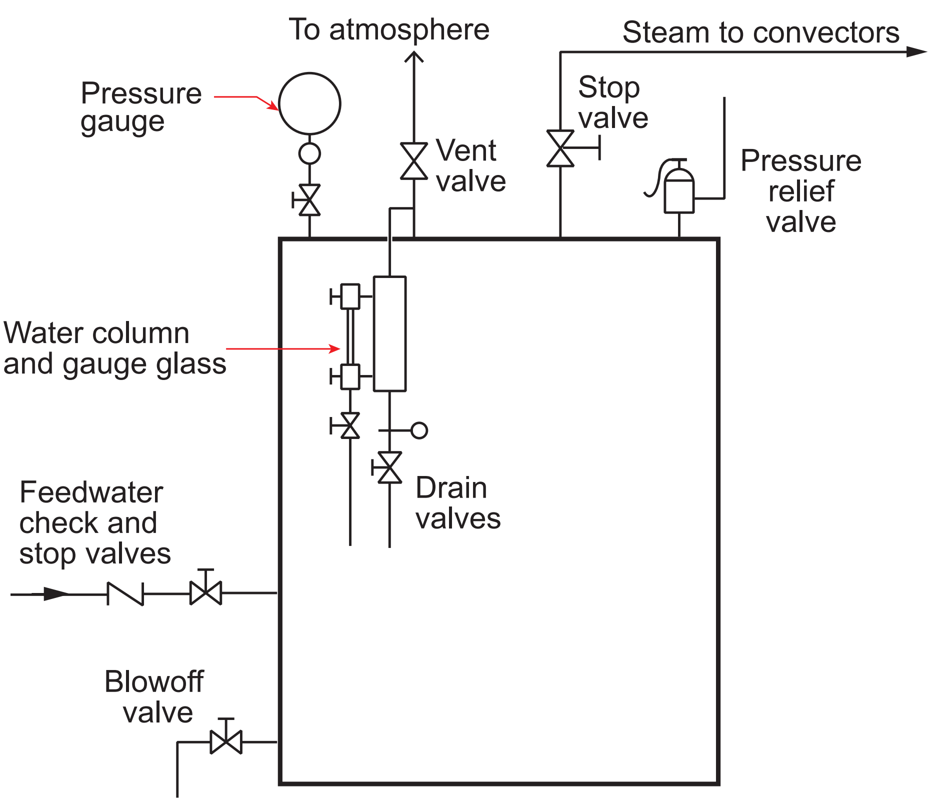
Non-Code Fittings for Steam Heating Boilers

Figure 10 shows a diagram of a low-pressure steam heating boiler equipped with many of the fittings required by **ASME BPVC IV.**

Feedwater regulators are not required by **ASME BPVC IV.** However, by maintaining a consistent water level, feedwater regulators can reduce fuel consumption, thermal shock, carryover, and the possibility of low water conditions.

For single steam heating boiler systems, **ASME BPVC IV** does not require a stop valve in the steam outlet. However, if one is installed, there must be a stop valve installed in the return pipe connection as well.

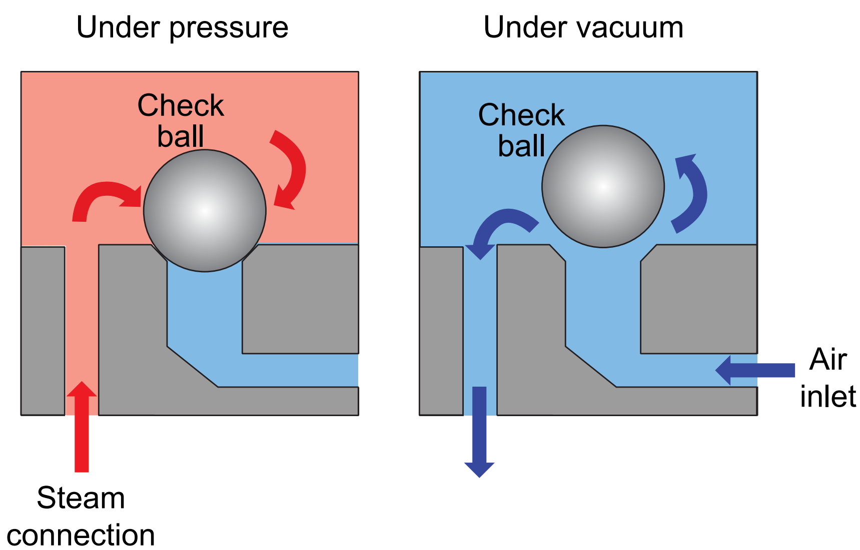
Figure 10 – Required Fittings and Controls for Steam Heating Boilers



Low-pressure steam heating boilers, when controlled by an outside air temperature sensor, may remain off for several hours, or even days, during the spring or fall months. During the off cycle, these boilers cool off so that an internal vacuum will form. This will draw water into the boiler from the feedwater system, and will flood the boiler. To prevent this from occurring, vacuum breakers are often installed.

A vacuum breaker is a small fitting that contains a stainless steel check ball. The fitting has connections for a steam inlet and an air inlet. When the boiler is operating, steam pressure holds the ball on its seat. When the boiler cools off, and its pressure drops below atmospheric, air is automatically drawn into the boiler to prevent a vacuum. A vacuum breaker is shown in Figure 11.

Figure 11 – Vacuum Breaker Operation



Non-Code Fittings for Steam Power Boilers

Although not required by **ASME BPVC I**, most boilers are equipped with a drum vent valve. This may be located on top of the shell, on top of the water column, or on the water column steam piping connection to the boiler.

The vent valve is used for the following purposes:

1. It allows air to escape from the boiler when it is being filled with water.
2. It allows air into the boiler when it is being drained or cooled, which prevents the formation of a vacuum.
3. It releases air and non-condensable dissolved gases (such as oxygen and carbon dioxide) from the boiler during warm up. If these gases enter the main steam system, they cause return line corrosion, and possible air binding.

Chapter Summary

This chapter covered fittings that are needed for proper boiler operation. Fittings must comply with **CSA B51** and **ASME Codes.** In terms of design and construction, boilers are classified as either power or heating boilers. Objective 1 began with a high-level overview of these code requirements.

Pressure gauges are essential for the safe operation of boilers. Equally important are safety valves, main steam outlet valves, water columns, and feedwater related fittings. These fittings are covered in **ASME BPVC I** and **IV,** and **ASME B31.1.**

The latter part of the chapter covered the non-code required fittings, and other accessories that are found on boilers, such as automatic make-up water valves, vacuum breakers, and feedwater regulators. These fittings aid in every day boiler operation.

It is important to select fittings that are registered designs, and suitable for the service conditions they will encounter. Improper selection and application of fittings can result in hazardous operating conditions that can even lead to fatalities. Because of its numerous code references, this chapter is a valuable resource for Power Engineers over the duration of their careers.

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Chapter 5

Firing Rate Controls

Learning Outcome

When you complete this chapter you should be able to:

Describe the operating and safety controls found on boilers.

Learning Objectives

Here is what you should be able to do when you complete each objective:

1. *Describe basic boiler firing rate controls.*
2. *Discuss various operating controls for steam and hot water boilers.*

Chapter Introduction

Boiler-firing circuits are the primary focus of this chapter. It builds upon the **Instrumentation** topics covered in **Part A, Unit 9**, and other chapters related to boilers. There are numerous references made to **ASME CSD-1 Controls and Safety Devices for Automatically Fired Boilers. CSD-1** is the code that most suitably addresses automatic firing rate controls, for both heating and power boilers.

Firing rate controls may automatically respond to temperature or pressure set points, or they may be manually operated. Firing rate controls must be able to adjust to varying load demands, while maintaining the proper air to fuel ratio, whether operated manually or automatically. In the event of an operating control failure, high limit controls must be able to shut off the burner to prevent unsafe operating conditions.

Firing rate controls must also be able to maximize boiler operating efficiency. This chapter explores firing rate control strategies, sensing elements, controllers, safety limit devices, and final control elements used in firing rate controls.

Objective 1

Describe basic boiler firing rate controls.

Boiler Firing Rate Control

The energy output of a boiler must always equal the energy demand. This is true for steam heating boilers, power boilers, or hot water boilers.

Steam Boilers

Boilers produce a mass of steam, at a particular rate, under certain conditions of temperature, pressure, and quality. For example, a boiler may produce 5000 kg of 98% dry and saturated steam per hour, at 1725 kPa. The energy in this mass of steam must equal the energy required by the equipment using the steam. When the energy output and the energy demand are equal, the boiler pressure remains constant at 1725 kPa. The pressure rises when there is greater heat energy entering the boiler than required by the equipment. The pressure falls when there is less heat energy entering the boiler than required by the equipment.

If a steam boiler continues to fire at an excessive rate, and this condition goes unchecked, the boiler will over-pressurize and may explode. For this reason, steam boilers are equipped with pressure limit controls to reduce or stop the energy input, and safety valves should the pressure limit controls fail.

In steam boiler control systems, the measured variable is the steam pressure. The manipulated variables are the fuel flow and the airflow. The final control elements are the combustion air dampers and the firing rate control valve. The automatic control system changes the firing rate as required to maintain a steam pressure set point.

Hot Water Boilers

Hot water boilers produce a mass of hot water, flowing at a particular rate, at a particular temperature. For example, a boiler may produce 110 litres per second of hot water at 85°C. The energy in this mass of water must equal the energy needed by the equipment using it. When the energy output and the energy demand are equal, the boiler temperature remains constant at 85°C. The temperature rises when there is more heat energy entering the boiler than needed by the equipment. The temperature falls when there is less heat energy entering the boiler than needed by the equipment.

If a hot water boiler continues to fire at an excessive rate, and this condition goes unchecked, the boiler will produce supersaturated hot water, and will over-pressurize due to liquid expansion. This can produce explosions every bit as devastating as those caused by steam boilers. So, hot water boilers are equipped with temperature limit controls to reduce or stop the energy input, and safety relief valves should the temperature limit controls fail.

In hot water boiler control systems, the measured variable is the outlet water temperature. The manipulated variables are the fuel flow and the airflow. The process variable is the hot water supply temperature. The final control elements are the combustion air dampers and the firing rate control valve. The automatic control system changes the firing rate as required to maintain a hot water temperature set point.

Note that in both of these systems the final control elements manipulate the fuel and airflow. Two elements are used, because fuel and air must be kept in a constant ratio, in order to ensure combustion is complete and efficient. The major difference between the two systems is in the primary sensing elements: steam boilers require pressure-sensitive sensors, and hot water boilers require temperature-sensitive sensors.

Side Track

For a review of instrumentation and control systems, refer to **Part A, Unit 9, Chapter 1 (Introduction to Energy Plant Controls and Instrumentation)**, and **Chapter 2 (Introduction to Process Measurement)**.

Firing Rate Control Strategies

In **Part A, Unit 9, Chapter 3 (Basic Control and Instrumentation Components)**, several control strategies were covered:

- Two-position
- Multi-position
- Fully modulating

Each of these control strategies apply to packaged boiler firing rate control.

On Track

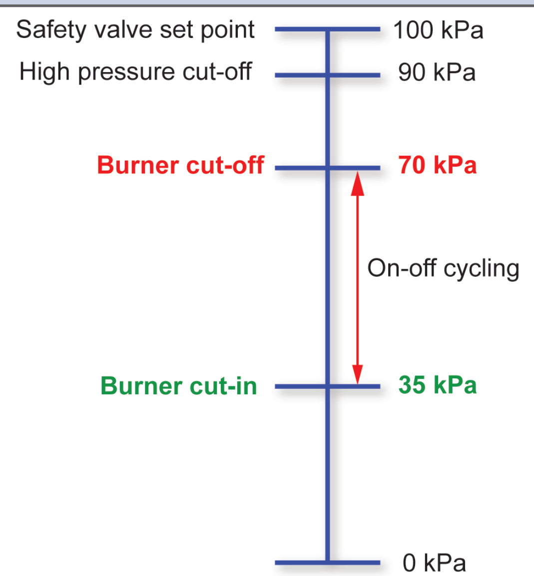
The pressure and temperature set points for the operating controls used in this objective are examples. Actual boiler set points vary from plant to plant, in accordance with the plant design requirements.

Two-Position (On-Off) Firing Rate Control

With two-position control, the burner is either on or off. When on, the burner fires at its maximum heat rating (in kW or Btuh). A two-position burner cannot fire at an intermediate rate.

To meet a steady energy demand that is somewhere between the maximum firing rate and zero, the burner must cycle on and off. When firing, the burner generates too much heat for the load demand. When off, the burner generates too little heat. Over a period of time, the average heat input of the burner will equal the average heat requirements of the process. However, due to the cycling of the burner, the pressure (or temperature) swings above and below the desired set point. This can be seen in Figures 1 (steam) and Figure 3 (hot water).

Figure 1 – Two-Position Control of Low-Pressure Steam Boiler



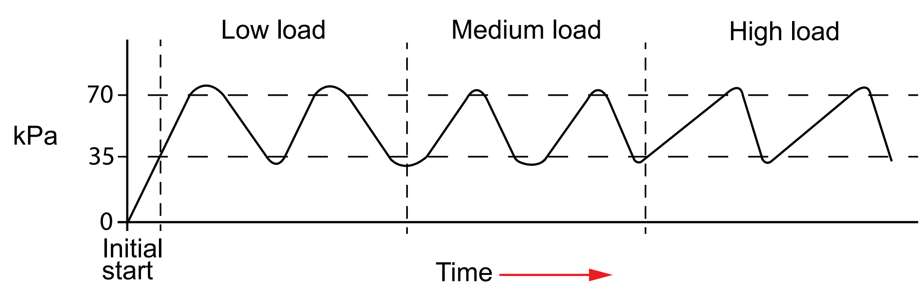
In this case, the cut-in point of the burner is set to 35 kPa (Figure 1). This means that at any pressure below 35 kPa, the burner will fire. The burner continues to fire until the boiler pressure reaches 70 kPa. At this point, the burner shuts off. It remains off until the boiler pressure drops below 35 kPa. Such a wide swing in pressure may be acceptable in some applications, such as in steam heating plants.

An operating cycle consists of all the steps necessary to start the burner, and all the steps necessary to shut it off. As discussed, this includes pre-purge, trials for ignition, run, and post purge periods.

Each time the boiler cycles off, it must undergo a purge. This results in significant loss of heat from the boiler, as the furnace draft carries heat away from the boiler and up the chimney. On low loads, on-off boilers cycle more often, resulting in inefficient operation. For greater efficiency, boilers (regardless of the firing rate control system used) should operate continuously.

Figure 2 shows how an on-off boiler cycles with response to load changes. Note that when the load is low, the boiler cycles more often. When the load is high, the boiler cycles less frequently.

Figure 2 – On-Off Boiler Control at Low, Medium, and High Load



On Track

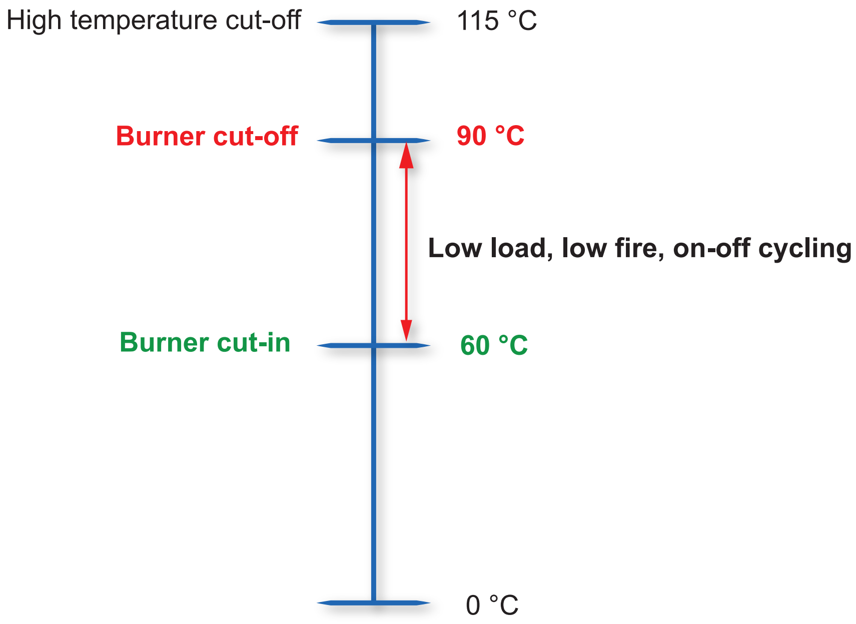
Figures 1 and 2 refer to steam heating boilers. The same operating principles apply to steam power boilers. However, the pressures of the safety valve, high-pressure cut-off, and cut-in/cut-out points vary from boiler to boiler.

Side Track

Refer to **Unit B4, Chapter 3 (Boiler Operation)** for more information on the correct setting of boiler pressure controls.

Figure 3 shows how these same principles apply to hot water boilers. Instead of cycling based on pressure, though, hot water boilers cycle based on temperature. Again, increased cycling rates reduce the boiler efficiency.

Figure 3 – Two-Position Control of Hot Water Boiler



Two-position control, then, is only used in smaller capacity boilers. This is because:

a) Temperature and pressure swings are unacceptable in larger plants with more stringent pressure and temperature requirements.

b) Energy losses due to frequent cycling have less economic impact for small capacity boiler plants than for large capacity plants.

Multi-Position (High-Low-Off) Firing Rate Control

Like on-off control, multi-position control is non-modulating. This permits finer control of the boiler steam pressure or temperature, and reduces heat losses caused by repeated purging.

High-low boilers require more complex controls than on-off boilers. Instead of having one operating pressure control (pressuretrol), high-low boilers require two. Sometimes, these controls are combined in a single device.

High-low boilers require multiple burners, or a single burner with a two-stage SSOV, or firing rate control valve. If multiple burners are used, each burner starts in sequence, depending on the load on the boiler. One burner is the low-fire burner, and the other is the high-fire burner. If two-stage SSOVs are used, they are shut, open at a low-fire setting, or open at a high-fire setting.

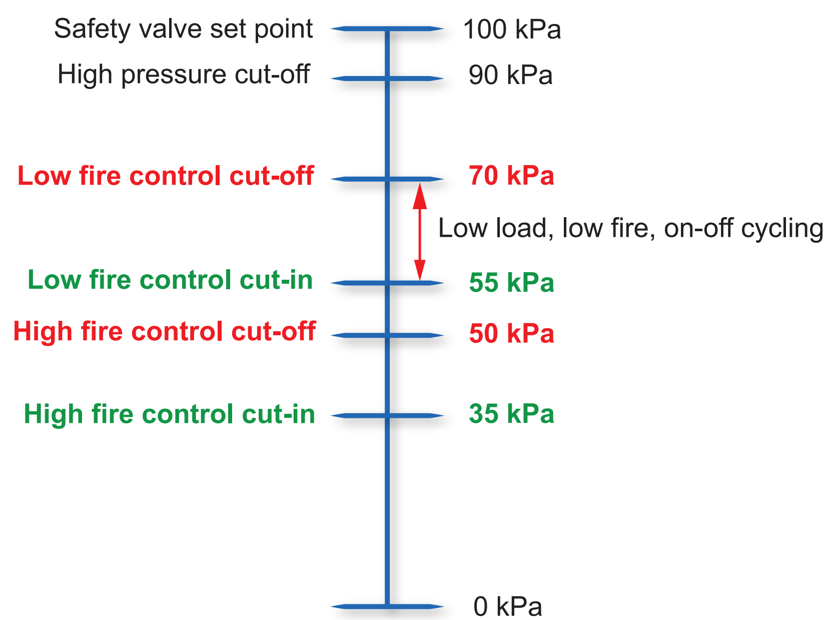
Figure 4 shows multi-position firing rate control applied to a low-pressure steam heating boiler. Note that instead of a single operating pressure control, there is one for both high-fire and low-fire. Each of these is a pressure-operated switch, with its own cut-in and cut-out pressure.

The low-fire control cut-in is set to 55 kPa. This means that at any pressure below 55 kPa, the low-fire burner circuitry is energized. It remains energized until the boiler pressure reaches 70 kPa.

The high-fire control cut-in is 35 kPa. This means that at any pressure below 35 kPa, the high-fire burner circuitry is energized. It remains energized until the boiler pressure reaches 50 kPa.

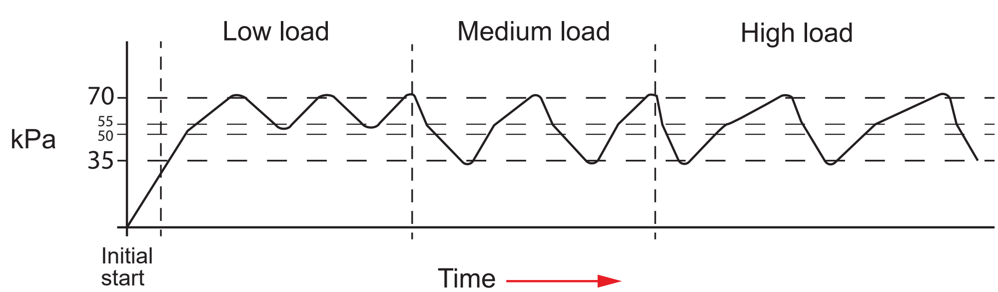
At low loads, the low-fire burner may produce more heat than the load demand requires. In this situation, the burner cycles on and off, like a two-position control. When load demand increases, the low-fire burner cannot satisfy the load demand, and the boiler pressure continues to drop. If the boiler pressure falls to 35 kPa, the high-fire burner starts. Both high- and low-fire remain on until the pressure reaches 50 kPa. At this pressure, the high-fire burner shuts off, but the low-fire burner stays on. If the low firing rate is insufficient for the load, the pressure will once again drop until the high-fire burner starts again.

Figure 4 – Multi-Position Control of Low-Pressure Steam Boiler



Multi-position firing rate is illustrated in Figure 5. When the boiler load is low, the average steam pressure is higher. As the load increases, the average steam pressure decreases.

Figure 5 – Multi-Position Control of Steam Boiler at Low, Medium, and High Load



The same operating principles apply to hot water boilers with multi-position firing rate control (see Figure 6). As in the steam boiler, two operating temperature controls (aquastats) must be used to control high and low firing rates. Compare this diagram with Figure 4.

Figure 6 – Multi-Position Firing Rate Control of Hot Water Boiler

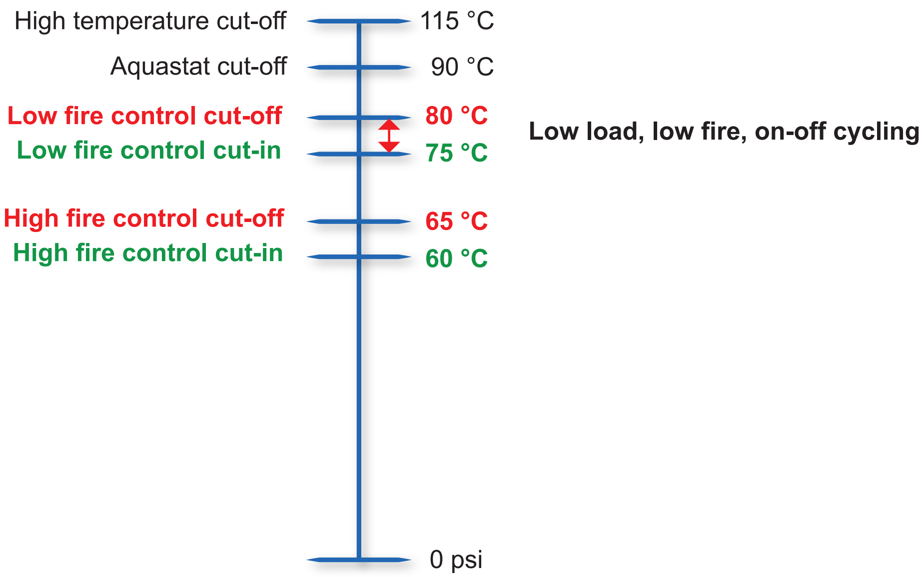
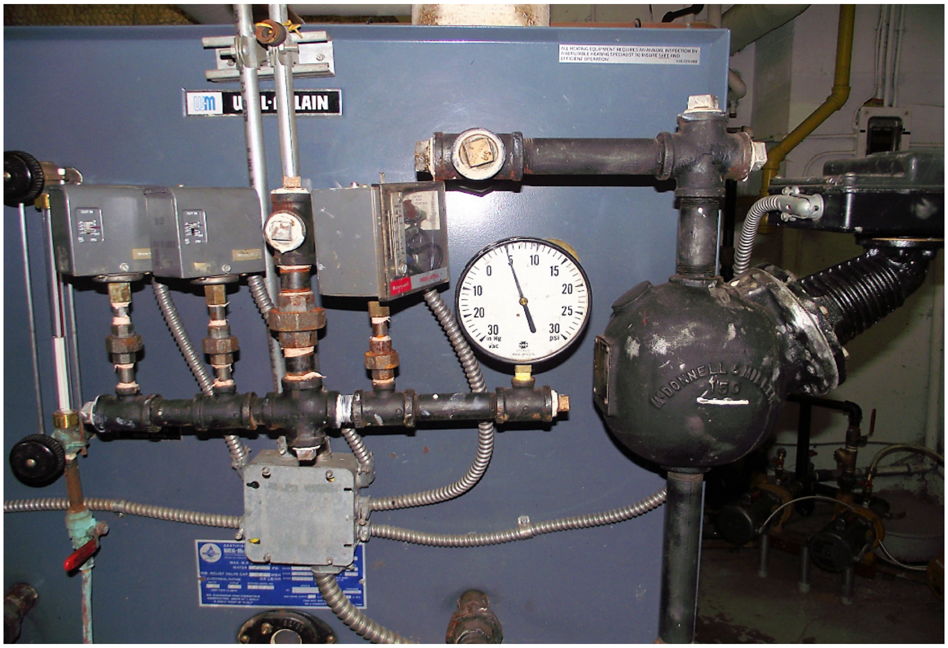


Figure 7 shows a low-pressure steam boiler equipped for high-low firing rate control. Note that there are two operating pressure controls. The one on the left is the high-fire control. The one in the middle is the low fire control. The pressure control on the right is a high-pressure cut-off with manual reset.

On this boiler, the high- and low-fire controls are used to directly actuate the modulating motor that drives the combustion air damper. When the programming controller is in the **RUN** mode and the damper is in the high-fire position, an end switch in the modulating motor places the SSOV into high-fire. This maintains both fuel flow and airflow in the correct ratio. The air damper linkage is adjusted to maximize combustion efficiency at both low and high firing rates.

Figure 7 – Steam Heating Boiler with Multi-Position (High-Low) Firing Rate Control



When a cold steam boiler is first started, its internal pressure will be below the high-fire cut-in point. Similarly, for a hot water boiler, its water temperature will be below the high-fire cut-in temperature.

When the programming controller enters **RUN** mode, the boiler will immediately go to high-fire. This will create uneven thermal expansion, and excessive stress on the boiler. Therefore, when starting up a cold boiler with a high-low firing rate control, it must be limited to low fire until sufficiently warm. This may be accomplished with a manual firing rate limit switch. During warm-up, the manual limit switch is placed on **LOW**. The boiler can be placed in **AUTO** or **HIGH** after warming the boiler according to the manufacturer warm-up instructions.

Fully Modulating Firing Rate Control

Modulating firing rate control provides the highest efficiency and closest set point adherence of the three control strategies. Fully modulating burners can operate at high-fire, low-fire, or any one of an infinite number of firing rates between these two extremes. On low-fire, some can turn down to 10% of the maximum firing rate (or even less), while still maintaining flame stability.

Steam boilers with fully modulating firing rate control require three pressure controls:

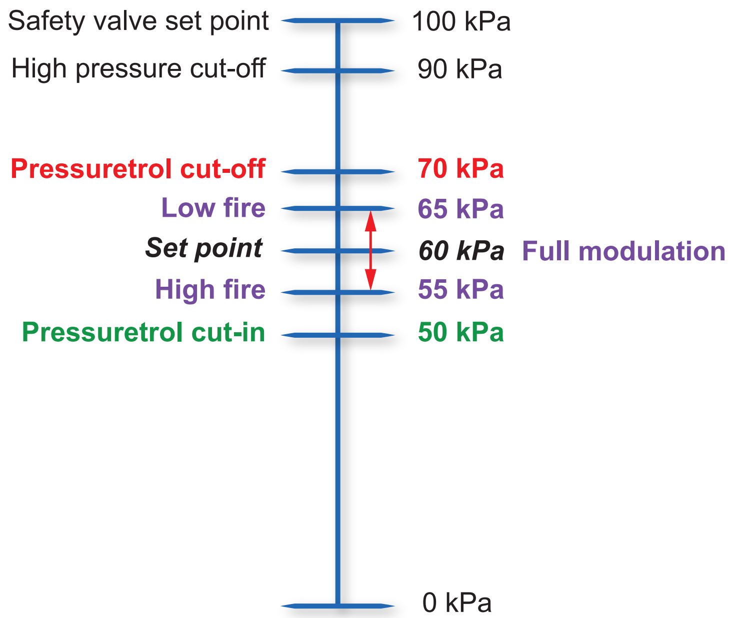
1. An operating pressure control that activates a call for heat.
2. A resistance slide-wire pressure control that positions a modulating motor.
3. A high-pressure cut-off control.

Refer to Figure 8. The operating pressure control (pressuretrol) is set to cut in at any pressure less than 50 kPa. It cuts out when the boiler pressure reaches 70 kPa. When the pressuretrol calls for heat and the programming controller is in RUN mode, the resistance slide-wire control positions the modulating motor in response to the error between the control set point and the boiler pressure. The modulating motor positions the combustion air damper and the firing rate control valve simultaneously, in order to maintain the air-to-fuel ratio.

When the programming controller is in RUN and the boiler pressure is below 55 kPa, the modulating motor places the air and fuel in high-fire. As the boiler pressure rises to 65 kPa, the firing rate gradually drops to its minimum. If the boiler pressure should again drop, the firing rate will increase accordingly.

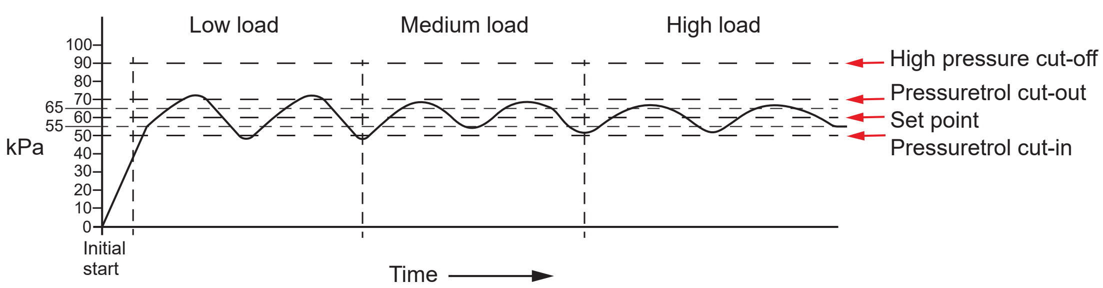
If the heat input at low-fire exceeds the load demand, the pressure will continue to rise until it reaches 70 kPa. Above 70 kPa, the burner will turn off. The burner will restart when the pressure drops below 50 kPa.

Figure 8 – Steam Heating Boiler with Modulating Firing Rate Control



Fully modulating firing rate control is shown in Figure 9. Note that the boiler pressure varies above and below the set point, but not as dramatically as with two-position and multi-position control. Also, note that the burner does not cycle off very often. This increases plant efficiency by reducing purge losses.

Figure 9 – Modulating Firing Rate Control of a Steam Boiler



The same operating principles apply to hot water boilers with fully modulating firing rate control (see Figure 10). Like the steam boiler, hot water boilers with fully modulating firing rate control require three controls:

1. An operating temperature control (aquastat) that activates a call for heat.
2. A resistance slide-wire temperature control that positions a modulating motor.
3. A high-temperature cut-off control.

Compare Figure 10 with Figure 8.

Figure 10 – Modulating Firing Rate Control for Hot Water Boiler

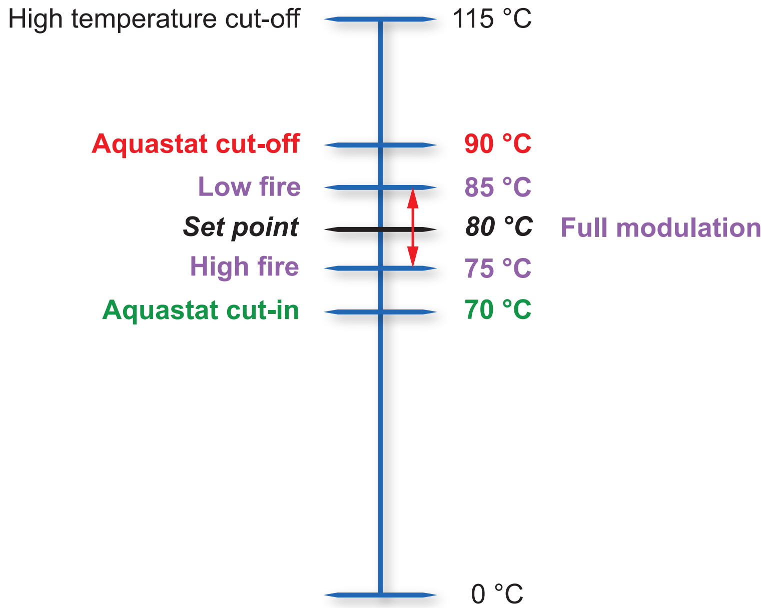
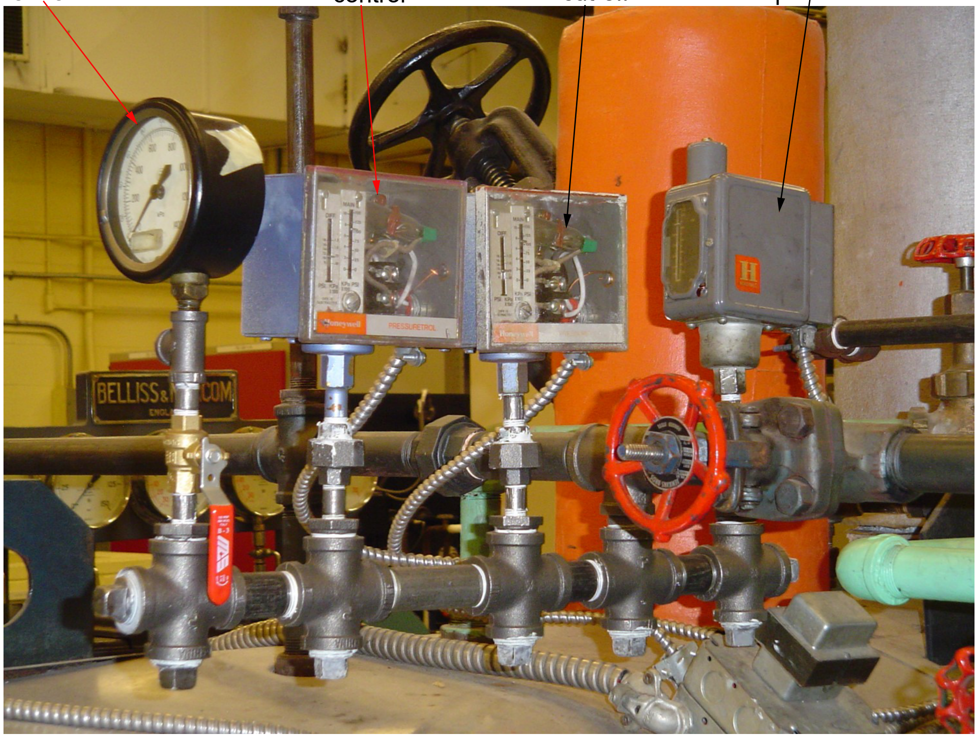


Figure 11 shows a high-pressure steam boiler equipped for fully modulating firing rate control. There are two operating pressure controls. The one on the left is the operating pressure control (pressuretrol). The one in the middle is the high-pressure cut-off. The pressure control on the right is a resistance slide-wire pressure control that positions a modulating motor.

On this boiler, the resistance slide-wire pressure control is used to directly actuate the modulating motor that drives the combustion air damper and the firing rate control valve. Modulation only happens when the programming controller is in the RUN mode. The firing rate control valve is adjusted throughout the firing range for maximum combustion efficiency.

Figure 11 – High-Pressure Steam Boiler with Fully Modulating Firing Rate Controls



When first starting a cold boiler, it will immediately go to high-fire as soon as the programming controller enters **RUN** mode. This will create uneven thermal expansion, and excessive stress on the boiler. Therefore, when starting up a cold boiler with a fully modulating firing rate control, it must be limited to low-fire until the boiler is sufficiently warm.

Like with the multi-position control, the burner can be limited to low-fire with a manual firing rate limit switch, or a potentiometer. During warmup, the manual limit switch is placed on **LOW** or the potentiometer is turned to its lowest setting.The boiler can be placed in **AUTO** or **HIGH** after warming the boiler according to the manufacturer warm-up instructions.

Firing Rate Control Devices

Firing rate control devices include sensing elements and final control elements.

Steam boilers use pressure-actuated two-position single-pole, single-throw switches as operating pressure controls, low-fire controls, high-fire controls, and high-pressure cut-offs. They use variable resistance pressure-actuated sensors to control the firing rate of fully modulating burners.

Hot water boilers use temperature-actuated two-position single pole, single throw switches as operating temperature controls, low fire controls, high fire controls, and high temperature cut-offs. They use variable resistance temperature-actuated sensors to control the firing rate of fully modulating burners.

Two-position (on-off) boilers do not modulate, so they do not require modulating motors to position fuel valves or combustion air dampers. Multi-position and fully modulating boilers, when equipped with power burners, use modulating motors, linkages, jackshafts, jackshaft arms, and cams to position both fuel and air at different firing rates.

Two-Position (On-Off) Control Devices

Steam Boilers

A two-position pressure control device is a pressure-actuated, single-pole, single-throw (SPST) switch. They are used on all steam boilers as operating pressure controls, high and low firing controls, and high-pressure cut-offs.

ASME CSD-1 Part CW-310 Requirements for Pressure Controls for Steam Boilers states the requirements for pressure controls for automatically fired heating or power boilers. The following is a summary.

a) *"Each automatically fired steam boiler or system of commonly connected steam boilers shall have at least one steam pressure control device that will shut off the fuel supply to each boiler … when the steam pressure reaches a preset maximum operating pressure."* Hi-low fired boilers require two of these operating pressure controls to satisfy this requirement.

b) In addition to the pressure control in a), each automatically fired steam boiler must have a high steam pressure limit control that will:
   - Prevent generation of steam pressure above the maximum allowable working pressure.
   - Cause safety shutdown and lockout when it activates.
   - Require manual reset.
   - Indicate when it is activated.

c) Each limit and operating control shall have its own sensing element and operating switch.

d) No shutoff valve of any type shall be placed in the steam pressure connection between the boiler and any steam pressure control device.

e) Each pressure control device shall be protected with a siphon, or equivalent water seal, to prevent steam from entering the control. The minimum size of a siphon shall be DN 8 (NPS ¼). When a mercury switch is mounted on the siphon, the loop of the siphon shall be on a plane 90 degrees from the plane of the mercury switch.

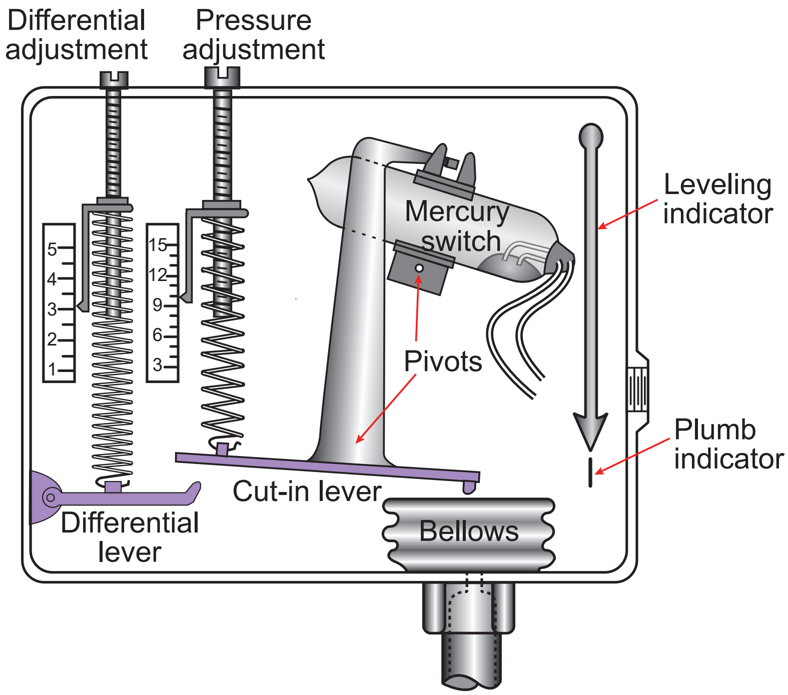
Operating Pressure Control (Pressuretrol), High-Fire Control, or Low-Fire Control

Older two-position controls have mercury switches, operated by a bellows. Increasing boiler pressure causes the bellows to expand and tilt the mercury switch, against the opposing force of a pressure adjustment spring.

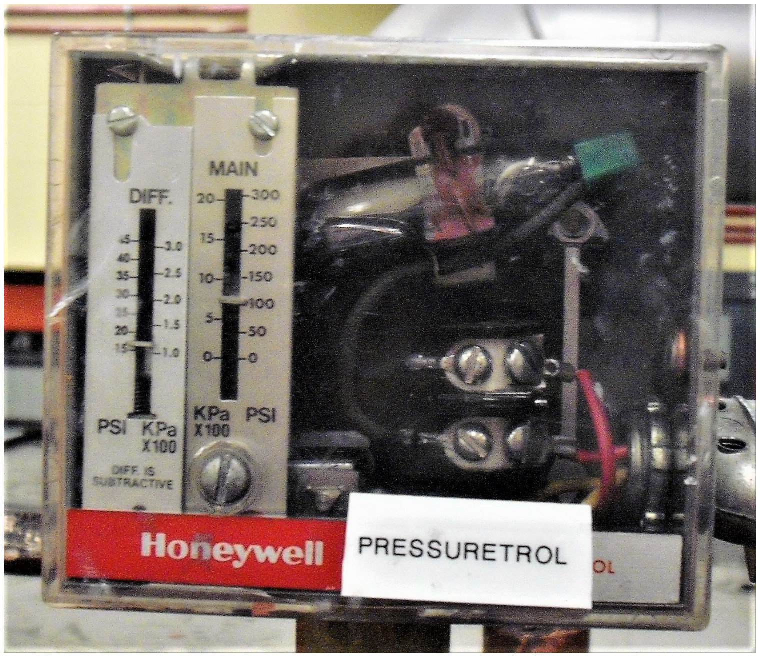
When the desired cut-off pressure is reached, the glass tube tilts far enough to cause the mercury to flow to the opposite end of the tube. This opens the electrical circuit for the combustion system, and closes the SSOVs. The boiler pressure then drops. This causes the bellows to contract. Then, the pressure adjustment spring tilts the mercury switch back to its original position, which closes the firing circuit. The difference between the cut-out and cut-in points is called the differential. A second adjustable spring determines the control differential.

Figure 12(a) shows a mercury switch pressure control suitable for low-pressure boiler service. Figure 12(b) shows a pressure control suitable for high-pressure boiler service.

Figure 12 – Two-Position Mercury Controls for Steam Boilers



(a)



(b)

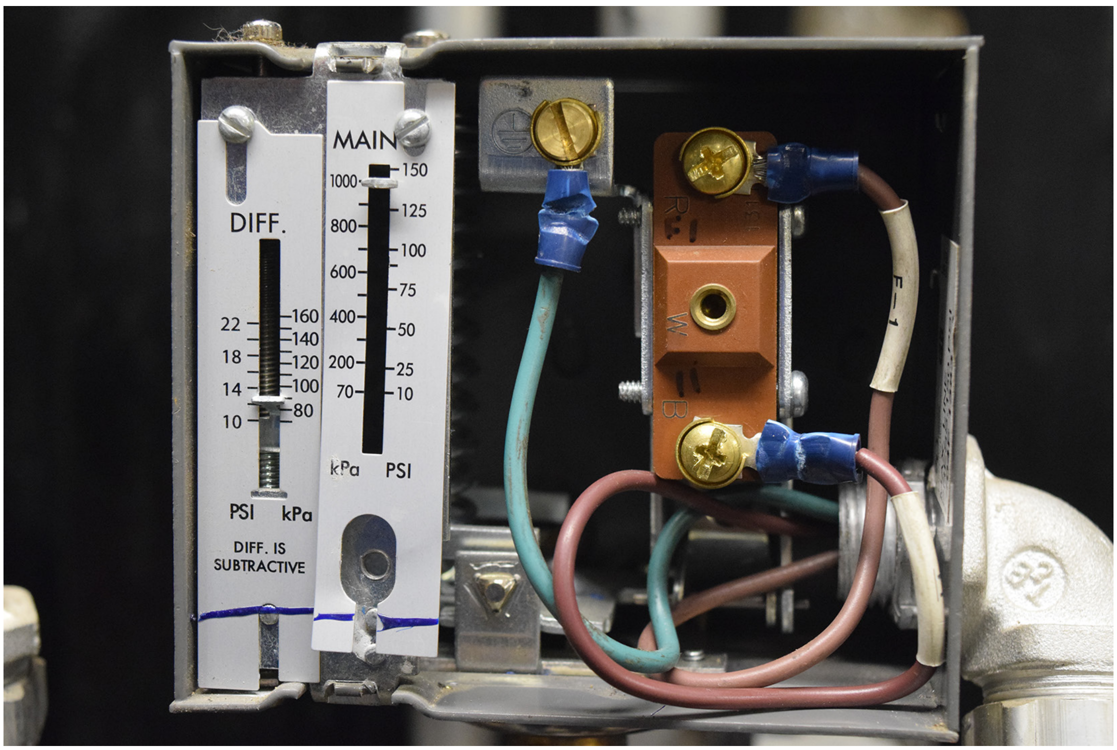
Though highly reliable, mercury switches occasionally fail. Small cracks in the glass permit oxygen to enter and oxidize the mercury. When this occurs, the mercury loses its lustre, and may appear rusty. It no longer flows properly, and will fail to close or open the switch contacts. At this point, the control must be replaced.

Mercury switches are no longer manufactured. Instead, purely mechanical switches are used. These types have a pressure capsule which moves levers and activates the switch, according to the spring tension on the pressure adjustment. Figure 13 shows a mechanical switch pressure control suitable for high-pressure boiler service.

CAUTION

Treat mercury as a hazardous material. Wear the correct personal protective equipment to replace a control that contains mercury. Dispose of the mercury according to environmental regulations.

Figure 13 – Mechanical Two-Position Control for Steam Boilers



High-Pressure Cut-Off (HPCO)

The high-pressure cut-off is similar in operation to the operating pressure control. A bellows or pressure capsule operates a SPST switch to open the firing circuit. The high-pressure cut-off is set higher than the operating pressure control, the high-low fire controls, and the modulating pressure control. It shuts off the burner when the operating pressure controls fail to stop the burner. In this regard, the high-pressure cut-off is the last line of defense before the safety valve operates.

The HPCO is different from the operating pressure control in two significant ways:

1. The HPCO does not have a differential adjustment.
2. The HPCO has a manual reset button.

When the HPCO activates, its switch locks in the open position. When the boiler pressure decreases, it does not automatically reset. Instead, operator intervention is required. This alerts the engineer that the operating pressure control has failed and needs replacement. Figure 14 shows a high-pressure cut-off suitable for a high-pressure boiler. Note the lack of a differential adjustment, and the manual rest button on top of the housing.

Figure 14 – High-Pressure Cut-Off with Manual Reset

The cut-out pressure of the HPCO must be sufficiently above the cut-out pressure of the operating limit control to avoid unnecessary lockouts.

The **National Board of Boiler and Pressure Inspectors** recommends the following HPCO set points:

a) For steam heating boilers, the HPCO set point should not exceed 90 kPa.

b) For steam power boilers:

   i. Up to 2100 kPa MAWP, the HPCO setting should be at least 10% lower than the setting of the safety valve, or 50 kPa lower than the setting of the safety valve, whichever is greater.

   ii. Over 2100 kPa to 6890 kPa, the HPCO setting should be at least 7% lower than the setting of the safety valve, or 200 kPa lower than the setting of the safety valve, whichever is greater.

   iii. Over 6890 kPa to 13800 kPa, the HPCO setting should be at least 5% lower than the setting of the safety valve, or 480 kPa lower than the setting of the safety valve, whichever is greater.

This will ensure the safety valves are not damaged from simmering and weeping.

Hot Water Boilers

A two-position temperature control device is a temperature-actuated, single-pole, single-throw (SPST) switch. They are used on all hot water boilers, as operating temperature controls (aquastats), high- and low-firing controls, and high-temperature cut-offs.

ASME CSD-1 Part CW-410 Requirements for Temperature Controls for Hot-Water Heating and Supply Boilers states the requirements for temperature controls for automatically fired heating or power boilers.

a) Each automatically fired hot water boiler shall have at least one temperature-actuated control to shut off the fuel supply when the system water reaches a preset operating temperature. Hi-low fired boilers require two of these operating temperature controls to satisfy this requirement.

b) In addition to the temperature control in item a) above, each automatically fired hot water boiler shall have a high-temperature limit control that will:

    i. Prevent the water temperature from exceeding the maximum allowable water temperature.

    ii. Cause safety shutdown and lockout when it activates.

    iii. Require manual reset.

    iv. Indicate when it is activated.

c) Each limit and operating control shall have its own sensing element and operating switch.

Operating Temperature Control (Aquastat), High-Fire Control, or Low-Fire Control

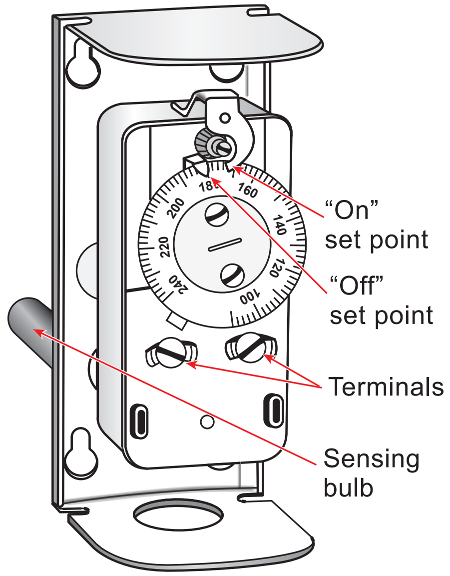
The operating temperature control combines a filled system thermometer with a bellows-operated SPST switch. The pressure inside the thermometer increases when boiler water temperature increases. This expands the bellows, and activates the switch at the controller set point. The opposite occurs when the temperature drops.

The thermometer-sensing bulb is inserted in a thermowell located at the boiler hot water outlet. If equipped with a capillary tube, the controller may be mounted separately, at a more easily accessible location.

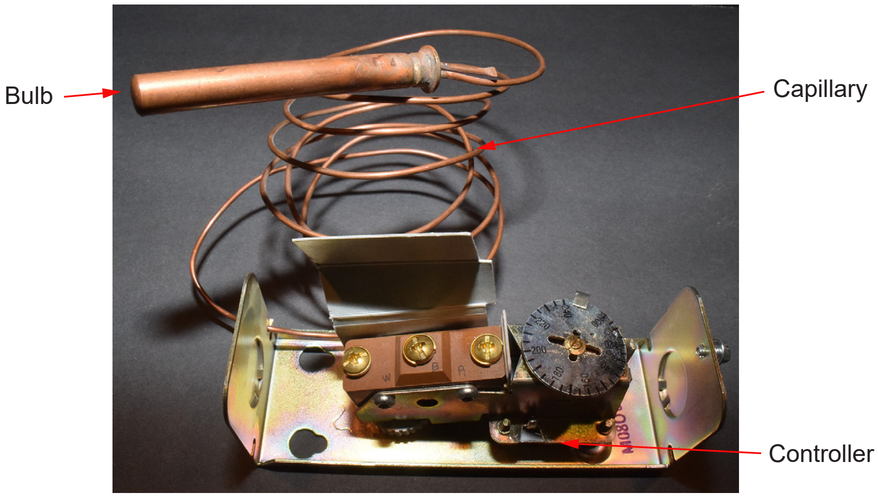
Figure 15 shows two-position controls used for hot water boilers. Figure 15(a) has its thermal element mounted directly to the back of the controller. Therefore, this control must be mounted where the water temperature is sensed. Note the control has set points for “on” and “off.” It cannot be set above 115°C (240°F), because this control is designed for hot water heating boilers.

Figure 15(b) uses a remote temperature-sensing element. There is a differential setting wheel located behind the switch for establishing the cut-in and cut-out points.

Figure 15 – Two-Position Control for Hot Water Boilers



(a)



(b)

Similar controllers are specialized for multi-position (high-low) firing. These controls will have two SPST switches operated by the same thermal element. A special differential switch is used to adjust the inter-stage temperature differential.

High-Temperature Cut-Off (HTCO)

The high temperature cut-off is similar in operation to the operating temperature control. A bellows or pressure capsule, attached to a filled system thermometer, operates a SPST switch to open the firing circuit. The high temperature cut-off is set higher than the operating temperature control, the high-low fire controls, and the modulating temperature control. It shuts off the burner when the operating temperature controls fail to stop the burner.

The HTCO is different from the operating temperature control in two significant ways:

1. The HTCO does not have a differential adjustment.
2. The HTCO has a manual reset button.

When the HTCO activates, its switch locks in the open position. When the boiler temperature decreases, the HTCO requires operator intervention. This alerts the engineer that the operating control has failed and needs replacement. Figure 16 shows a high-temperature cut-off suitable for a heating boiler. This control is factory set to 121°C, and has a fixed 11°C differential. Because of this, the temperature must drop to below 110°C before it can be reset.

Figure 16 – High-Temperature Cut-Off with Manual Reset

The cut-out temperature of the HTCO must be sufficiently above the cut-out temperature of the operating limit control to avoid unnecessary lockouts.

Modulating Controllers

Steam Boilers

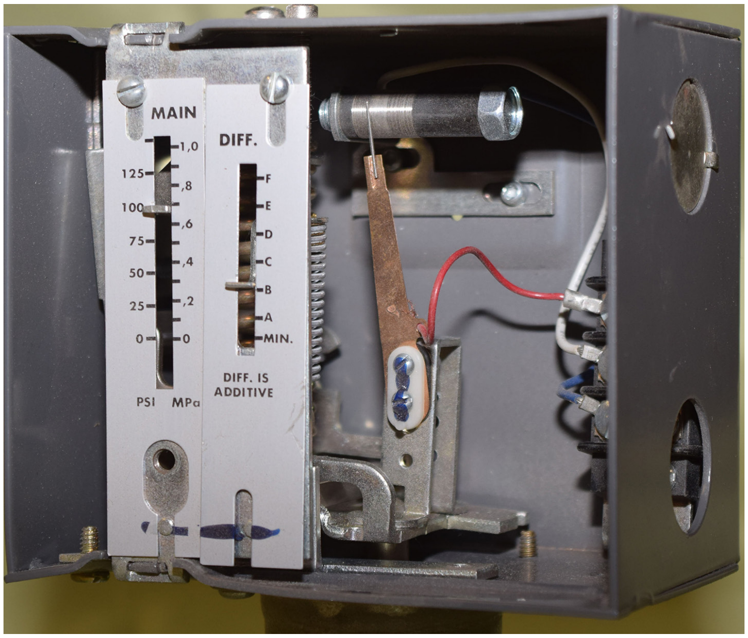
Steam boilers with fully modulating burners require a modulating pressure control, in addition to the operating pressure control and the high-pressure cut-off. The operation of a modulating pressure control is quite similar to that of an on-off pressure control. However, boiler pressure variations cause the bellows to operate a potentiometer, in the form of a resistance slide wire.

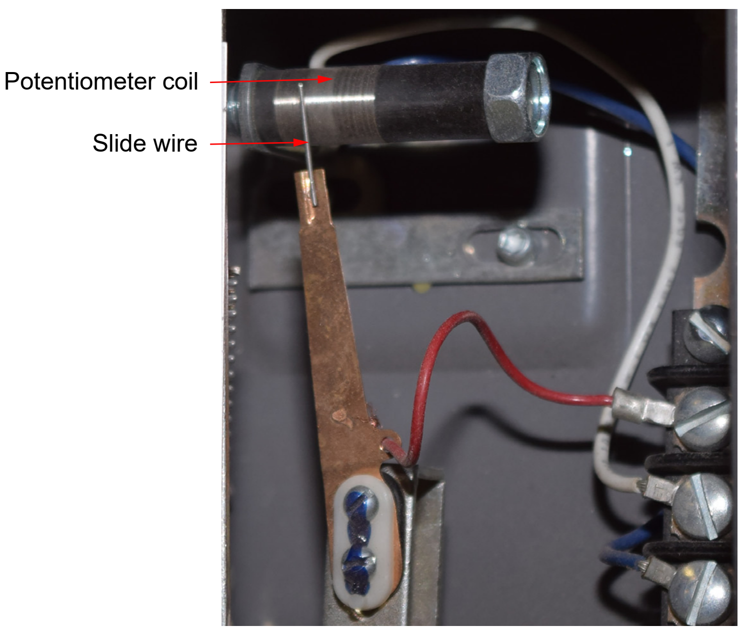
To permit low-fire operation when the boiler is cold, the boiler control panel must include a **MANUAL-AUTOMATIC** switch and a manual flame control potentiometer. The modulating controller is enabled when the programming controller is in **RUN**, and the **MANUAL-AUTOMATIC** switch is in **AUTOMATIC**.

While in **AUTOMATIC**, the firing rate is continuously adjusted to match the boiler load as it varies. Placing the switch in **MANUAL** transfers the control of the modulating motor to the manual flame control potentiometer. This allows the firing rate to be kept at low-fire during warm-up periods, and can modulate when up to normal pressure.

Figure 17 shows a modulating pressure control with its cover removed. This controller has two settings: set point and differential. The differential setting is used to control how closely the boiler pressure tracks the set point. The **MIN** setting tracks the set point the closest, to provide the finest pressure control. In other words, the **MIN** setting has the smallest proportional band.

Figure 17 – Modulating Pressure Controller





Hot Water Boilers

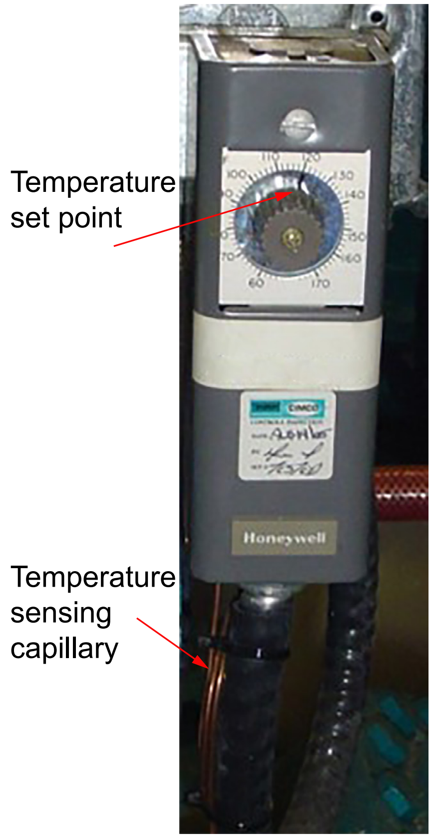
Hot water boilers with fully modulating burners require a modulating temperature control, in addition to the operating temperature control and the high-temperature cut-off. The operation of a modulating temperature control is quite similar to that of an on-off temperature control. However, boiler water temperature variations cause the bellows to operate a potentiometer, in the form of a resistance slide wire.

To permit low-fire operation when the boiler is cold, the boiler control panel must include a **MANUAL-AUTOMATIC** switch and a manual flame control potentiometer. The modulating controller is enabled when the programming controller is in **RUN**, and the **MANUAL-AUTOMATIC** switch is in **AUTOMATIC**.

While in **AUTOMATIC**, the firing rate is continuously adjusted to match the boiler load as it varies. Placing the switch in **MANUAL** transfers the control of the modulating motor to the manual flame control potentiometer. This allows the firing rate to be kept at low-fire during warm-up periods, and can modulate when up to normal temperature.

Figure 18 shows a modulating temperature control used with hot water heating boilers. This controller has two settings: set point and proportional range. The proportional range setting is used to control how closely the boiler pressure tracks the set point.

Figure 18 – Modulating Temperature Controller



Modulating Motors

Modulating motors are used in electrical control systems to position dampers and valves. In the case of boilers, they position the combustion air damper and the firing rate control valve.

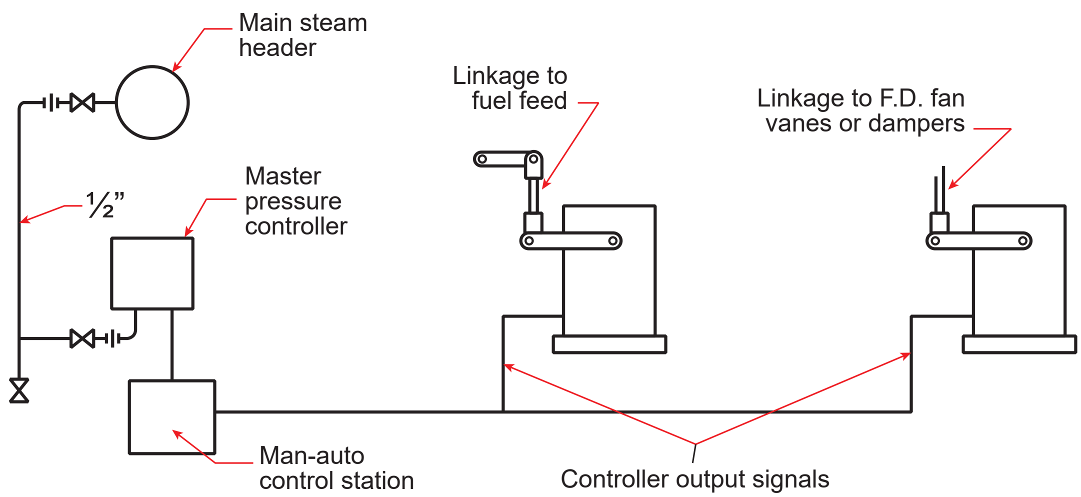
The modulating motor has a bridge circuit and a balancing relay connected to the modulating controller. When the steam pressure (or water temperature) is at the controller set point, the circuit is balanced (i.e. all relay contacts are open). When this occurs, the modulating motor does not run. The air and fuel flows remain unchanged.

If the steam pressure or water temperature rises, the resistance of the slide wire controller changes. This unbalances the circuit, so a larger current flows through one side of the balancing relay. Then, a set of contacts in the relay closes, causing the modulating motor to drive to the closed position. As the motor runs, a feedback potentiometer, inside the modulating motor, moves to balance the circuit. When the circuit is again balanced, the balancing relay contacts open, and the modulating motor stops. This reduces the firing rate and restores the pressure or temperature to the set point.

If the steam pressure (or water temperature) falls, the opposite sequence occurs.

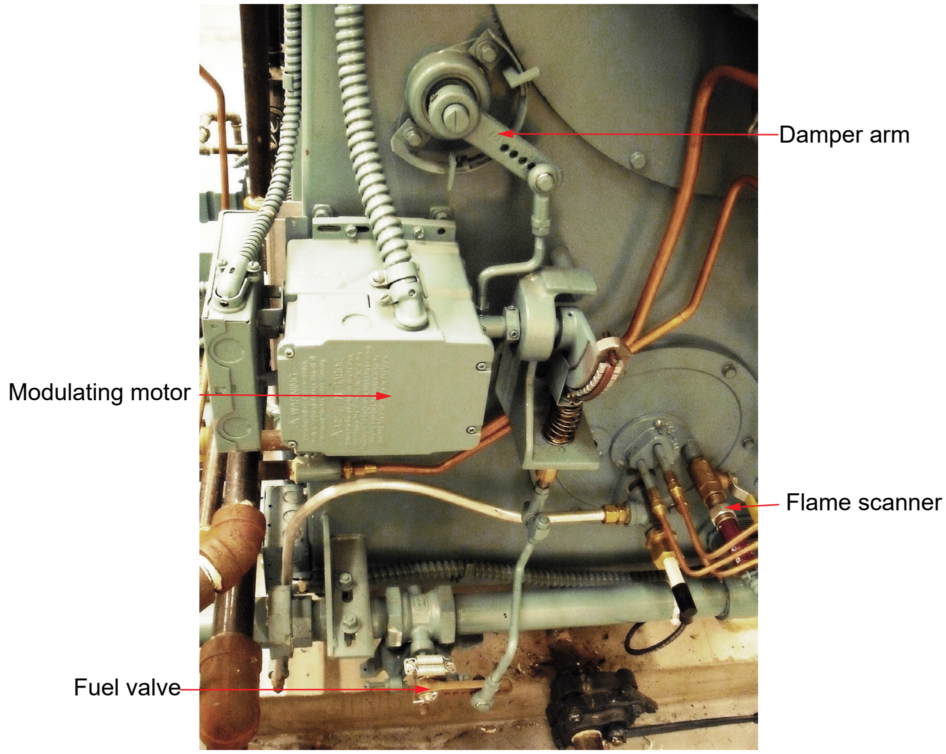
Some larger boilers may use two modulating motors to control the air and fuel flow (see Figure 19). Each modulating motor receives the same signal from a single master pressure or temperature controller. The fuel flow is adjusted for optimum combustion efficiency across the firing range. A **MAN-AUTO** control station is provided to interrupt the control signal, so that the boiler can be kept at low-fire for warm up, or base loaded.

Figure 19 – Modulating Control



Smaller packaged boilers commonly use a single modulating motor that operates both the combustion air damper, and the firing rate control valve, in unison. This is done with a jackshaft, crank arms, and a fuel cam. Figure 20 shows a common arrangement. As the modulating motor shaft turns, both the combustion air damper and firing rate control valve crank arms turn. The crank arm for the fuel valve has an adjustable cam to fine-tune the combustion conditions.

Figure 20 – Modulating Motor, Jackshaft, Crank Arms, and Cam



Objective 2

Discuss various operating controls for steam and hot water boilers.

Control Switches

Depending on the type of operating control used on automatically fired heating boilers, the control panel is equipped with one or more of the following switches:

- Burner On-Off switch
- Damper positioning switch (Hi-Low-Auto)
- Manual-Automatic switch
- Manual flame control potentiometer

The following discussion refers to the types of controls found on one particular make of packaged dual-fuel boiler. These boilers are fully modulating when firing on gas, but are multi-position when firing on oil. Figure 21 shows the controls discussed below.

Burner Switch (On-Off)

All boilers are equipped with a manually operated On-Off switch to start and stop the boiler.

Damper Positioning Switch (Hi-Low-Auto)

The boiler's modulating motor will position the air damper and firing rate control valve, according to the load on the boiler. The modulating motor also has internal switches that successively energize oil nozzles, in accordance with load. The load is determined by the error between the set point of the modulating pressure control and the boiler steam pressure. For hot water boilers, the load is determined by the error between the set point of the modulating temperature control and the boiler hot water outlet temperature.

When the damper positioning switch is set to **LO**, the modulating motor remains in the low-fire position. The manual-auto switch and the manual flame control potentiometer have no effect on the position of the modulating motor. When firing on gas, both the air damper and firing rate valve remain in low-fire, regardless of the boiler load. When firing on oil, a switch in the modulating motor permits only one oil nozzle to fire. This permits slow warm-up, and continuous low-load operation.

When the damper positioning switch is set to **HI**, the modulating motor drives to high-fire. Again, the manual-auto switch and the manual flame control potentiometer do not affect the modulating motor. When firing on gas, both the air damper and firing rate valve remain in high-fire, regardless of the boiler load. When firing on oil, the switches in the modulating motor energize the remaining oil nozzles. The boiler remains on high-fire regardless of the set point of the pressuretrol.

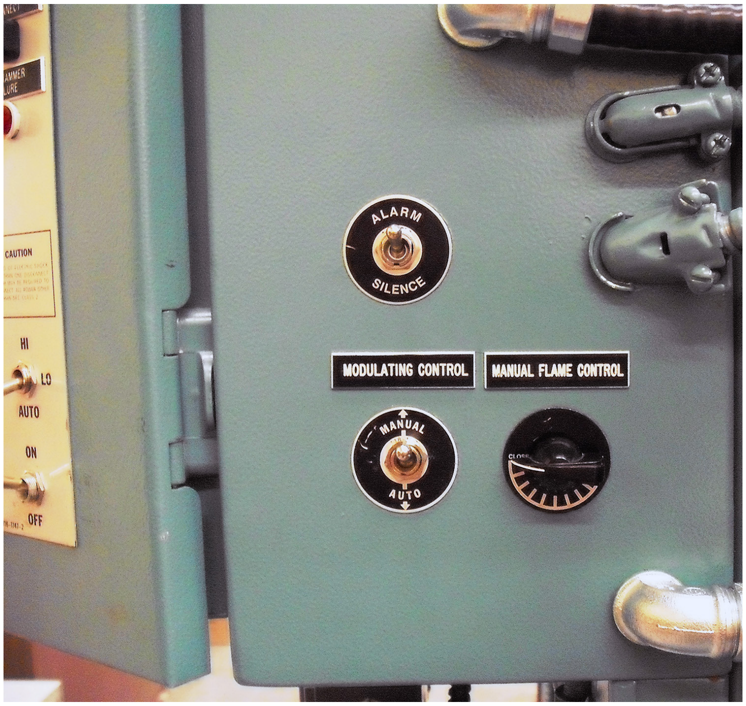
When the damper positioning switch is set to **AUTO**, the error between the boiler pressure (or temperature) and the set point of the pressuretrol (or aquastat) determines the position of the modulating motor. The burner will fully modulate, as long as the manual-automatic switch is also set to **AUTO**.

Manual-Automatic Switch and Manual Flame Control Potentiometer

When the damper positioning switch is set to **AUTO**, and the manual-automatic switch is set to **AUTO**, the modulating controller signal positions the modulating motor.

When the damper positioning switch is set to **AUTO**, and the manual-automatic switch is set to **MANUAL**, the manual flame control potentiometer controls the firing rate of the boiler, independent of the pressuretrol signal. This permits base loading of the boiler at any desired output. Also, it permits cold boilers to be warmed on low-fire, which reduces harmful stress caused by uneven thermal expansion.

Figure 21 – Boiler Control Switches



Chapter Summary

This chapter built upon the **Instrumentation** topics covered in **Part A, Unit 9**, and other chapters related to boilers. There were numerous references made to **ASME CSD-1 Controls and Safety Devices for Automatically Fired Boilers**.

Firing rate controls may automatically respond to temperature or pressure set points, or they may be manually operated. Firing rate may be controlled with two-positon, multi-position, or fully modulating strategies. Of these, the least efficient and coarsest control is the two-position. The most efficient and finest control system uses full modulation.

Hot water boilers use temperature sensitive controls to control firing rate. These include temperature actuated switches and variable resistors. Steam boilers use pressure-actuated controls. Firing rate controls maintain the proper air to fuel ratio, whether operated manually or automatically. Multi-position and fully modulating controls must be able to limit the firing rate during boiler warm-up periods. In the event of an operating control failure, high limit controls must be able to shut off the burner to prevent unsafe operating conditions.

Many automatically fired packaged boilers use modulating motors, or multi-stage fuel valves, to control the firing rate. The same modulating motor can be used to control both combustion airflow and fuel flow.

Unit Summary

The efficient operation of boiler and pressure vessel systems is important to ensure that unplanned maintenance for the facility and plant is kept to a minimum. Integral to an efficient operation, by both design and regulation, is the care and proper use of the appropriately designed safety devices. This unit has discussed a number of devices critical to plant safety. These devices focus on monitoring and control of those conditions that system upsets can create including pressure, liquid level, and combustion.

Pressure relief valves protect equipment from damage due to over pressurization. Pressure relief valves are installed on all pressure equipment. These valves prevent explosions due to over-pressurization. Some of these valves also provide over-temperature protection.

The first failure of a single combustion safeguard control can cause a devastating explosion. For this reason, combustion systems are engineered extensively, and designed with safety in mind. Firing rate controls respond to temperature or pressure set points, either automatically or manually.

Low water conditions are the most common cause of boiler pressure vessel explosions. Power Engineers rely on various boiler water level instruments to measure and prevent this condition.

Boiler fittings such as pressure gauges and safety valves must comply with the rules in the **CSA Standard B51** and the requirements of **ASME Code**. The improper use of both code and non-code required fittings may result in boiler inefficiency, but more importantly can lead to fatal accidents.

The boiler's safety devices are designed to help protect the boiler from damage should an over pressure or firing upset condition occur. As such, they are the last line of defense in the tools that a Power Engineer uses to keep the plant operating efficiently, and the workplace a safe environment. Proper use, maintenance, and testing of these devices ensures that they operate as intended.

A self-assessment tool is available on MyPower LMS. Login using the unique user ID and password found on the inside front cover of Unit 1.

Notes

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UNIT B-3

Knowledge Exercises and Unit Glossary

Knowledge Exercises – Chapter 1

Name: ______________________ Date: ______________________

Instructor: ______________________ Course: ______________________

Objective 1

1. Define the following terms:

   a) Pressure relief valve

   b) Temperature and pressure relief valve

   c) Safety valve

   d) Safety relief valve

   e) Safety valve blowdown

Chapter 1 (Cont.)

2. Explain why a superheater safety valve is set to open before, and to close after, a drum safety valve.

3. A safety valve blowdown adjusting ring is moved so that it covers the huddling chamber escape ports. After this change, the safety valve will reseat at _________________ drum pressure.
   a) A higher
   b) A lower
   c) The same

Objective 2

4. What is the purpose of a safety valve body drain opening? When should it be plugged off?

5. Compare the design and operation of the pressure relief valves used for hot water heating boilers to the valves used for steam boilers.

Chapter 1 (Cont.)

6. What causes the safety relief valve to open frequently on hot water boilers?

Objective 3

7. A hot water heating boiler has a safety relief valve set to 207 kPa. How often should it get a try lever test?

8. What test determines a safety valve opening pressure, closing pressure, and blowdown?

Objective 4

9. At what temperature does a T&P valve open?

10. What is the maximum allowable pressure permitted by ASME BPVC IV for a potable hot water tank?

11. Name two differences between a T&P valve and a fusible plug.

Knowledge Exercises – Chapter 2

Name: ______________________________ Date: ________________________________

Instructor: ___________________________ Course: ______________________________

Objective 1

1. Sketch a gas fuel train that is compliant with CSA B149.3 code, suitable for boilers over 3000 kW output. Label the components.

2. Why is the input flow control valve of a gas train located downstream of the low gas pressure cut-off?

Chapter 2 (Cont.)

3. Identify the CSA B149.3 code requirements for high and low gas pressure cut-off switches.

4. What are proof-of-closure switches, and how are they applied to burner systems?

5. What fuel delivery systems require low fuel temperature cut-off switches, and why are they required?

Chapter 2 (Cont.)

Objective 2

6. Why are thermocouples and thermopiles only used to supervise the flames of boilers with less than 120 kW input?

7. A new thermocouple develops between _______ and _______ millivolts in an open circuit.

8. Explain how a flame rectification system works.

9. Which type of flame scanner can be fooled by an ignition spark?

Objective 3

10. How does a BMS detect high combustion airflow?

Chapter 2 (Cont.)

11. Describe the CSA B149.3 code requirements for high-fire purge.

12. Why is it unacceptable to put fine mesh screen over combustion air inlets?

Objective 4

13. What are the differences between a primary controller and a programming controller?

14. How long does a pilot flame trial for ignition period last?

15. What is the maximum flame failure response time for a burner with greater than 120 kW input, as stipulated in CSA B149.3?

Objective 5

16. What does a BMS check during a safe start check?

Chapter 2 (Cont.)

17. List 6 causes of safety shutdown and lockout during the burner run period.

18. What should be done before resetting a programming controller lockout? Why is this important?

Knowledge Exercises – Chapter 3

Name: ______________________ Date: ______________________

Instructor: ______________________ Course: ______________________

Objective 1

1. Make a simple sketch of a float-type low water cut-off, and describe how it works.

2. Explain the operation of a low water cut-off with a magnetically operated switch.

Chapter 3 (Cont.)

3. What are the restrictions on the location of a hot water boiler low water cut-off?

Objective 2

4. What kinds of boilers are permitted to have flow switches rather than low water fuel cut-offs?

5. Why are test and check valves installed in LWCO hot water boilers?

6. Why can two low water fuel cut-offs share a steam connection to the boiler drum, but not a water connection?

Objective 3

7. What is the difference between ASME BPVC I and IV regarding the location of the lowest visible part of a gauge glass?

Chapter 3 (Cont.)

8. What determines the pressure rating of gauge glass material?

9. What causes the failure of many new gauge glasses installed on high-pressure boilers?

10. What happens when the water connection to a steam boiler gauge glass is closed, and the steam connection is left open, while the boiler is in operation?

Knowledge Exercises – Chapter 4

Name: ______________________ Date: ______________________

Instructor: ______________________ Course: ______________________

Objective 1

1. Explain the identification requirements for boiler fittings.

2. List the kinds of boiler external piping that fall under the jurisdiction of ASME B31.1 Power Piping Code.

3. A hot water boiler operates at 115°C. Its safety relief valve is set to 1350 kPa. Is this a power boiler or a heating boiler? Explain your answer.

Chapter 4 (Cont.)

Objective 2

4. Why must the dial of a power boiler pressure gauge be graduated to between 1 ½ and 2 times the boiler MAWP? List three reasons.

5. The scale on the dial of a steam heating boiler gauge shall be graduated to not less than _________ kPa, and not more than _________ kPa.

6. How is the installation of a steam pressure gauge different for steam heating boilers, as compared to steam power boilers?

Objective 3

7. With a simple diagram, illustrate an acceptable steam piping arrangement for two high-pressure steam boilers connected to a common header, with each boiler having a manhole opening.

Chapter 4 (Cont.)

8. Why are outside screw and yoke (OS&Y) valves preferred as steam shut-off valves?

9. Why must power boilers have either two slow-opening blowoff valves, or one fast and one slow opening blowoff valve?

10. A low-pressure steam boiler produces 950 kg of steam per hour. By design, its blowoff connection and blowoff piping should be DN _________ or __________ NPS.

Objective 4

11. List the boiler fittings required by ASME BPVC IV for all hot water heating boilers.

12. What is a tridicator gauge?

13. ASME BPVC IV Part ________________ covers the provisions for thermal expansion in hot water systems.

Chapter 4 (Cont.)

Objective 5

14. Why are vacuum breakers installed on steam heating boilers?

15. Why are drum vents installed on high-pressure steam boilers?

16. Make a simple sketch of a low-pressure steam boiler, showing all necessary code fittings.

Knowledge Exercises – Chapter 5

Name: ______________________ Date: ______________________

Instructor: ______________________ Course: ______________________

Objective 1

1. Explain why frequent boiler cycling is inefficient.

2. What are the construction differences between an operating pressure control and a high-pressure cut-off?

3. Why do fully modulating boilers require manual firing rate potentiometers?

Chapter 5 (Cont.)

4. A ____________________________ firing rate control does not use a modulating motor.

5. According to ASME CSD-1, what are the functions of a high steam pressure limit control?

6. How can an operator tell if a mercury switch is defective?

Objective 2

7. Under what operating conditions would a manual firing rate potentiometer be used?

8. When would a damper positioning switch be placed in **LO**?

9. What is the concern if a high-low boiler is started from cold, with the **HI-LO-AUTO** switch in **AUTO**?

Unit B-3 Glossary

Term	Definition
Austenitic stainless steel	Steel alloys high in nickel and chromium, used in some superheater and reheater construction, due to their high temperature creep and corrosion resistance.
Blowdown (pressure relief valve)	In a pressure relief valve, the difference between the actual popping pressure and the actual reseating pressure. It is expressed as either a percentage of the set pressure, or in units of pressure.
Brownout	A period of high electrical demand that results in a reduction of system voltage.
Cad cell	A sensor responsive to visible light given off by a flame.
Call for heat	A load demand signal to which heat-generating appliances respond.
Combination gas valve	A safety shutoff valve that combines several functions within the valve body.
Flame out	The unintentional extinguishing of a burner flame. Also called flame failure.
Flame relay	An electromechanical relay that responds to a flame signal, to energize or de-energize burners as required.
Flame rod	A flame detection component of a flame rectification circuit, that responds to the existence of a flame.
Flame signal	An electrical signal that indicates the existence of a flame.
HGPCO	See *high gas pressure cut-off switch*.
High gas pressure cut-off switch (HGPCO)	A switch to stop the burner if the gas pressure is too high.
Huddling chamber	In a pressure relief valve, the annular pressure chamber between the nozzle exit and the disc that produces a “pop action” lifting force.
LGPCO	See *low gas pressure cut-off switch*.
Low gas pressure cut-off switch (LGPCO)	A switch to stop the burner if the gas pressure is too low.
Main flame establishing period	See *main flame trial for ignition period*.
Main flame trial for ignition period	A timed interval when, with the ignition means proved, the main valve is permitted to remain open. If the main burner is not ignited during this period, the main fuel valve and ignition means are cut off.
Millivolt system	A control system for gas burners powered by a millivolt signal generated by a thermopile.
Number 6 fuel oil	Residual fuel oil of high viscosity (also called Bunker C). Commonly used in marine and stationary steam power plants.
Pilot flame establishing period	See *pilot flame trial for ignition period*.
Pilot flame trial for ignition period	A timed interval when the pilot valve is held open and an attempt made to ignite and prove it If the presence of the pilot is proved at the termination of the interval, the main fuel valve is energized; if not, the pilot and ignition are cutoff followed by a safety lockout.
Pilotstat	A sensitive relay that detects a millivolt flame signal to energize or de-energize a low voltage safety shutoff valve, as appropriate.

Term	Definition
Potable	Water that is safe to drink.
Pressure relief valve	A safety device designed to protect a boiler, pressure vessel, or pressure piping system against pressure in excess of design pressure. This category of devices includes safety valves, safety relief valves, and relief valves.
Relief valve	An automatic pressure-relieving device designed for liquid-filled vessels, such as hot water tanks. The valve opens proportionally to the vessel's increase in pressure.
Safe start check	The period during which a burner management system looks for a flame or flame simulating condition prior to commencement of a purge.
Safety relief valve	An automatic pressure-relieving device characterized by rapid opening or pop action, or by gradual opening proportional to the pressure increase, depending on the application. It may be used either for vapour or liquid service.
Safety valve	An automatic pressure-relieving device actuated by the static pressure upstream of the valve. It is characterized by full-opening pop action. It is used for gas or vapour service including steam.
Safety vent valve	A solenoid operated gas valve used to bleed gas pressure from between safety shutoff valves in a double block and bleed system.
Simmer	In a pressure relief valve, the audible or visible escape of fluid between the seat and disc, at an inlet pressure below the popping pressure of the valve.
Stress corrosion cracking	A form of progressive intergranular fracture caused by a combination of stress, elevated temperature, and a corrosive environment.
Super-saturated liquid	Liquid at a saturation temperature greater than the saturation temperature at atmospheric pressure.
Temperature and pressure (T&P) relief valve	A safety valve installed on potable hot water tanks and heaters.
Thermopile	A grouping of several thermocouples in series, used to generate higher flame signals in a millivolt flame detection system.
Tridicator	A gauge used on hot water heating systems that indicates water pressure, water height or "head", and water temperature.
Try lever	A handle used to apply a force to the stem of a pressure relief valve, to manually open the valve at a pressure below the set pressure.