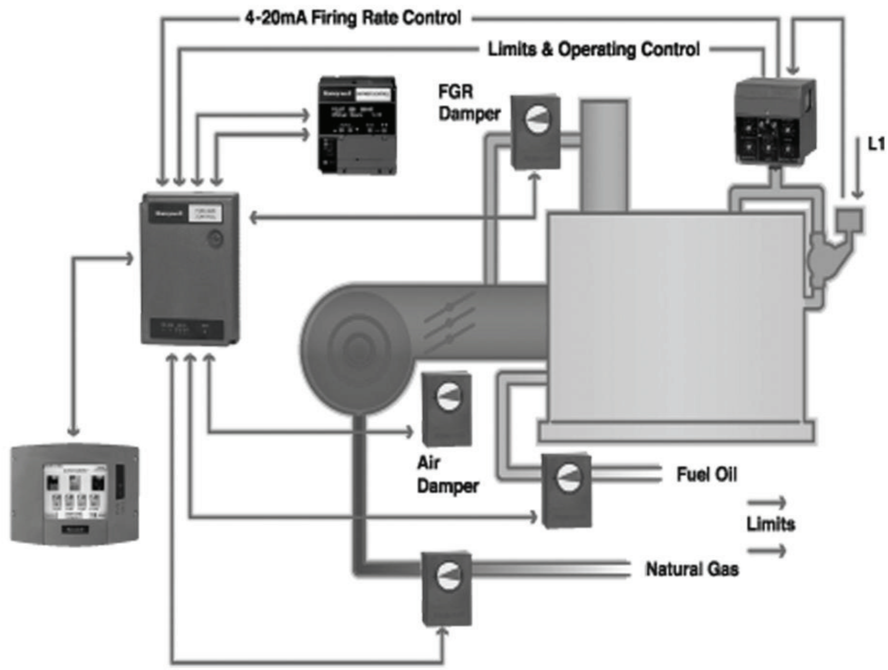
Controlling Technology

Fuel-Air Ratio Control

Boiler Application — ControLinks Fuel Air Ratio Control System



Air-fuel ratio (AFR)

- Is the mass ratio of air to fuel present during combustion. If exactly enough air is provided to completely burn all of the fuel, the ratio is known as the <u>stoichiometric</u> mixture (often abbreviated to stoich). AFR is an important measure for anti-pollution and performance tuning reasons.
- A fuel-air metering control system is essential for efficient combustion in boilers, furnaces, and other large fuel fired heating processes.

- There are three basic types of Fuel-Air Ratio control systems:
  a) Series metered system, b) parallel metered system, c) and cross limiting system.

  As show in the figure (E-1)

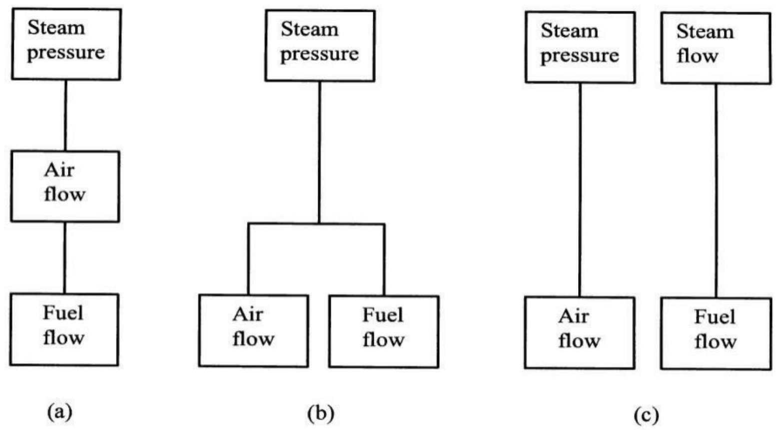


Figure (E-1)

a) The ***Series Metered System*** is fairly common where load changes are not large or common. Both fuel and air are metered. The steam pressure controller regulates the fuel flow which is measured, linearized and then is ratioed and used as the remote set point to the air flow controller. This positions an air damper to maintain the specified ratio between the fuel and air. This system is adequate for near steady state conditions. However lags in response to load changes can result in temporary smoking, incomplete combustion and fuel-rich conditions.
b) The ***Parallel Metered System*** operates the fuel and air control controllers in parallel from a set point generated by the steam pressure controller. The set point signal is ratioed before being used as the set point to the air controller to establish the fuel-air proportions. This

system relies on similar responses from both controllers to prevent improper fuel-air mixtures. This system is best applied to processes which experience relatively slow load changes.

c) The ***Cross Limiting System*** is used when large or frequent load changes are expected. This is a dynamic system which helps compensate for the different speed of response of the fuel valve and air damper. It prevents a “fuel-rich” condition and minimizes smoking and air pollution from the stack. The system is also known as a *lead-lag* system. When demand increases, a low selector blocks then increase forcing the air flow signal to become the set point to the fuel flow controller. A high selector passes the increase to the air flow controller’s set point. This means fuel flow cannot increase until air flow has begun to increase, i.e. **air increase leads fuel increase**. When demand decreases, the low selector passes the signal to the fuel flow controller set point, while the high selector passes the fuel flow signal to the air flow controller set point. This means flow cannot decrease until the fuel flow begins to drop hence **air decrease lags fuel decrease**. This means a fuel rich condition is avoided, regardless of the direction of load change.

- The Fuel Air Ratio Control System shall utilize signal inputs from the firing rate control, stack or water temperature sensor and the burner management control to control the relationship between fuel, air flow and flue gas recirculation (if used) on a full modulation power burner. Up to four (4) independently controlled positioning actuators shall be commanded by the control. Actuators control damper positioning for air and flue gas and valve positioning for the primary and secondary fuels

COMBUSTION STRATEGIES

1) Fixed Position Parallel Control

Fixed position parallel control (FPC), also known as direct of jack-shaft control, is perhaps the simplest

Form of combustion control found on power burner boilers. This control strategy incorporates a single positioning motor, which drives both the fuel and air positioning devices via an interconnected single mechanical linkage, the jack-shaft. The simplicity of the FPC strategy makes it a very economical choice for small burners with modest firing rate changes. However, the fact that the fuel and air are fixed means that the fuel-air ratio is also fixed. Because of this fixed position arrangement the burner has no way to compensate for environmental changes such as combustion air temperature or fuel pressure. Additionally, the FPC strategy has no feedback to the control element to insure that the fuel and air end devices are actually functioning and in the correct position. This could lead to a crossover condition in which the fuel crosses over the air flow and results in a fuel rich furnace or other burner efficiency loses.

To help prevent a fuel rich furnace the FPC system is setup to allow additional excess oxygen to the furnace, in the range of 4.5 to 8 percent. In practice the excess oxygen is normally set at 6-7 percent to compensate for seasonal air temperature changes. This excess air results in lower thermal efficiency by burdening the burner with unnecessary air, which only serves to cool the furnace and increase NO_x production. Show figure (E-2)

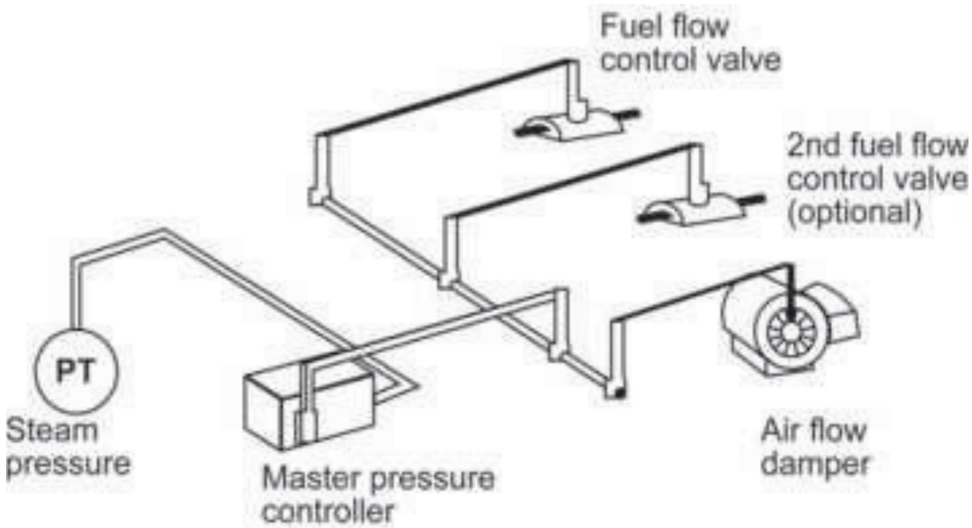


Figure (E-2)

2) Parallel Positioning Control Systems

Parallel positioning control (PPC) systems function very much like a Fixed Position Parallel system except that the fuel and air end devices are separated and driven by their individual positioners. Modern electronic PPC systems incorporate an end-device-positioning signal, which ensures the fuel and air positioners have moved to their pre-specified positions for a specific firing rate. This signal, while not actually proving final end device position and true fuel-air ratio flow, is a market improvement over FPC systems. The new systems are gaining wide acceptance with many users who have traditionally used FPC systems and are seeking an economic means to improve overall combustion efficiency. The modern PPC system is suitable for boilers ranging from 100 through 900 boiler horsepower operating with relatively stable loads. Larger systems are also becoming more prevalent. Modern electronic positioning PPC systems can hold excess oxygen levels to within 3-4 percent on many applications. It should be noted however, that when holding excess oxygen levels to these minimums the PPC control strategy should be used with caution in applications with extremely fast load swings. Controllers and positioners, which might be set too tight may not properly respond and still maintain a safe fuel-air ratio on large and very fast upsets. This is due in part to the lack of process variable feedback in the fuel-air system. And like the FPC system, it is impossible for the PPC system to compensate for any changes in fuel or combustion air characteristics. Thus, issues such as fluctuations in fuel pressure, air temperature or humidity will have adverse effects on combustion processing using this system. Show figure (E-3)

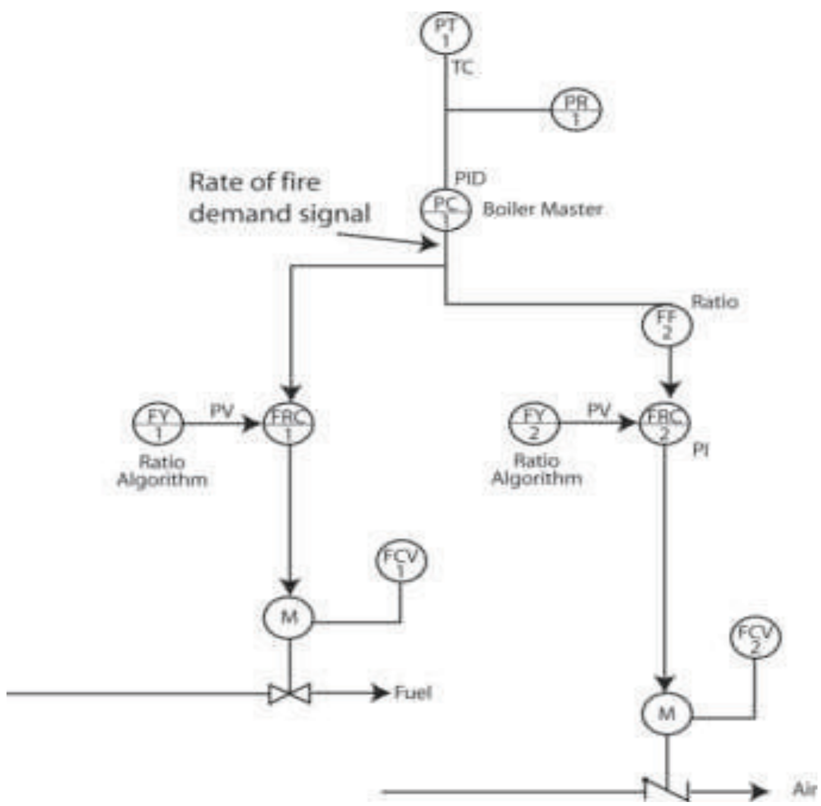


Figure (E-3)

3) Series Metered Control System

The series metered control (SMC) is common on larger boilers (above 750 boiler horsepower) where load changes are neither large nor frequent. In this application both the fuel and the air are metered. The Boiler Master regulates combustion air flow by setting the air flow set point. The air flow controller then cascades the air flow signal to the fuel controller as its remote set point. A ratio algorithm is applied to the remote set point signal sent to the fuel controller to adjust the fuel-air ratio. The ratio algorithm compares the remote set point cascaded to the fuel controller by the air flow and positions the fuel flow control valve to maintain the specified ratio between the two. This ratio algorithm has an inherent lag in it due to the fact that the air controller is always directing the fuel controller's function; air always leads fuel. This lag provides a desirable lean furnace on demand rise, as the air controller must respond to the Boiler Master before sending a remote set point to the fuel controller. However on a fast-falling demand the lag between the air controller and fuel controller can result in the air flow overshooting the fuel flow resulting in a crossover fuel rich furnace. Because of this lag characteristic, the series control system is only adequate for near steady state conditions due to its inability to react to fast falling load swings. To compensate for these possible overshoots and lag times, excess oxygen levels in series control systems are normally set at 5- 8 percent. The use of an oxygen trim system is then incorporated to adjust the excess oxygen levels down to 3-4 percent during steady state operation. Significant improvements in the accuracy of the flowing process variables fuel and air may be made using SMART temperature and pressure compensated transmitters, thus improving the overall accuracy of this and subsequent metered systems. Show figure (E-4)

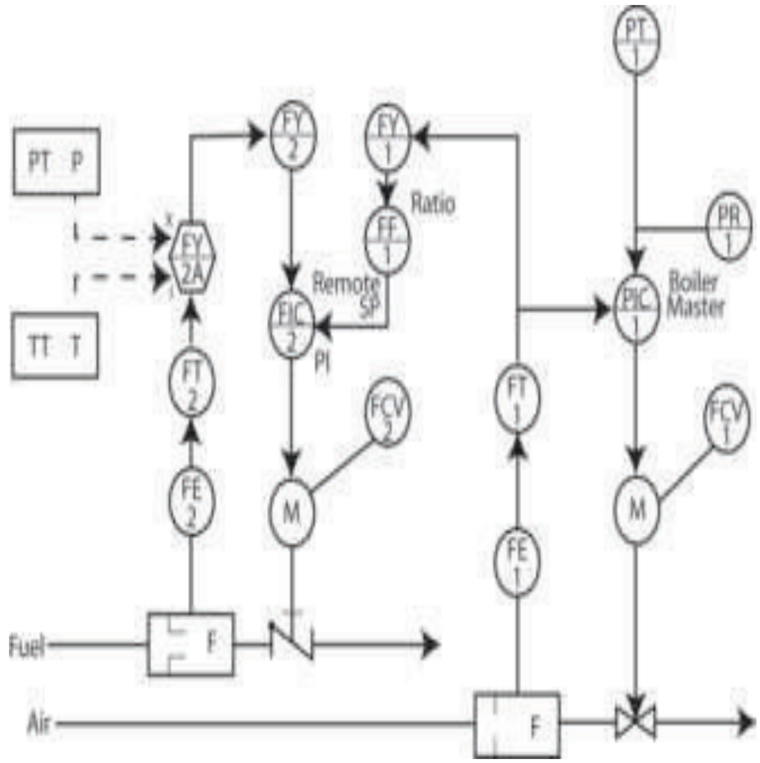


Figure (E-4)

4) Metered Parallel Positioning Control

Boilers operating at 1,000 boiler horsepower and above commonly incorporate the metered parallel positioning control system. The metered parallel positioning control (MPPC) operates the fuel and air control loops in parallel (as opposed to series) from a single set point generated by the boiler master controller. The combustion air set point is ratioed which establishes the fuel-air proportions. By allowing for customization of the fuel-air ratio the amount of excess oxygen in the exhaust gases may be reduced to about 3-4 percent as opposed to the 5-8 percent normally found in the series metered control strategy. In practice however, the excess air is set at about 4.5-5 percent to compensate for barometric changes in air density. The use of an oxygen trim system is then incorporated to adjust the excess oxygen levels down to 2.5-3 percent during steady state operation. The MPPC system relies on near identical response from both the air and fuel control loops to prevent fuel rich or air rich mixtures in the furnace. The difficulty in maintaining this near identical response limits the application of the MPPC system to applications with modest demand swings.

Like the Series system, the traditional MPPC system does not have any feedback to the opposing flow controllers, i.e., fuel does not recognize air and air does not recognize fuel. This absence of feedback can result in a combustion imbalance on large or very fast load swings, resulting in either a fuel-rich or lean furnace. To compensate for the lack of feedback found in the MPPC, these systems are normally set-up with additional excess air to over compensate for fuel flow during set point excursions, thus maintaining an air-rich furnace on transition. Show figure (E-5)

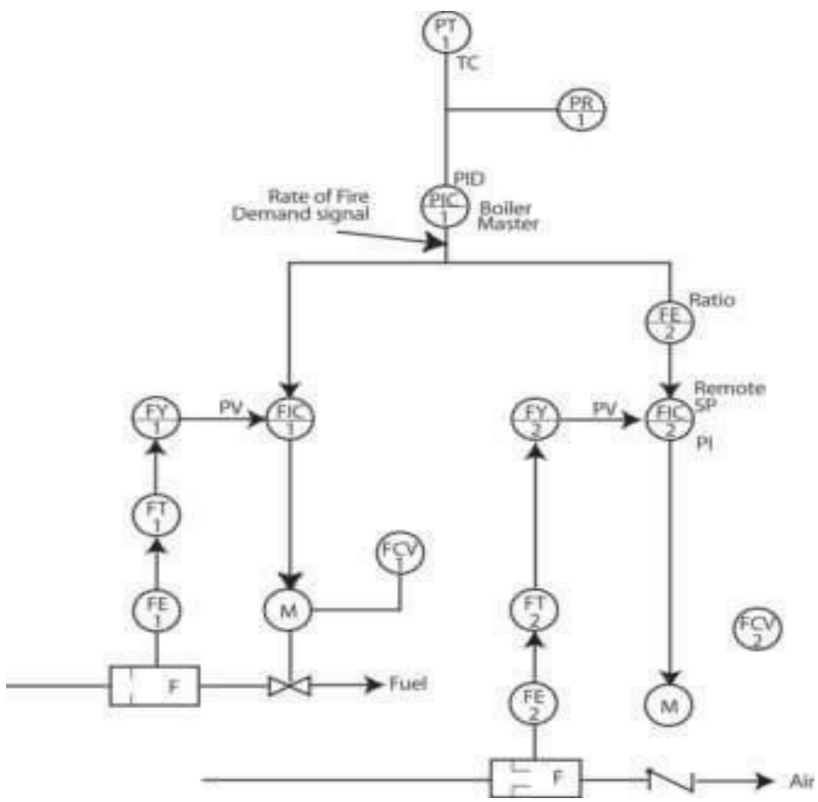


Figure (E-5)

5) **Cross-Limited Metered Control**

Cross-limited metered parallel positioning control, (a.k.a. cross-limited control (CLC) or lead lag control (LLC)), improves on the MPPC strategy by interlocking the fuel-air ratio control through high and low selectors. This interlock function prevents a fuel-rich furnace by forcing the fuel to follow air flow on a rising demand, and forcing air to follow fuel on a falling demand. The CLC system is a dynamic system, which easily compensates for differences in response times of the fuel and air end devices. This flexibility allows its use in systems that experience sudden and large load swings, as well as very precise control at steady state operation. The CLC operates as follows. In steady state, the steam demand signal, fuel flow and air flow signals to the high and low selectors are equal. Upon a demand increase the **low** selector applied to the fuel loop forces the fuel flow to follow the lower of either the air flow or steam demand set point. Conversely on a falling demand the **high** selector applied to the air controller forces the air flow to follow the higher or either the fuel flow or demand set point. This high/low selector function insures that the burner transitions are always air rich/fuel lean thus preventing a fuel rich furnace environment. The cross-limited control system can easily maintain excess oxygen levels in gas burners to 3-4 percent and 2.5-3 percent in No. 2 oil systems. Additionally, since fuel flow cannot increase (cross limited) until air flow has begun to increase, fuel cannot overshoot air flow. The use of an oxygen trim system is then incorporated to adjust the excess oxygen levels down to 2-2.5 percent during steady state operation. Because of the CLC system's capability for close tolerance control, it is suited for all sizes of boilers, which can support the systems cost economically. Additionally the

CLC system is readily adapted to oxygen trim control as well as being suited for low NO_X burner applications.

Show figure (E-6)

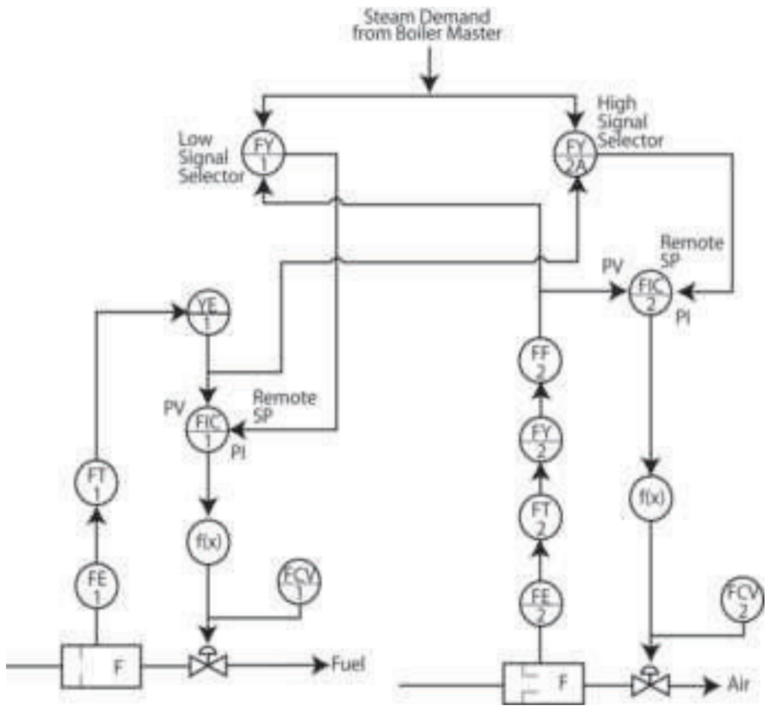


Figure (E-6)

Component Model Description

R7999A, B (ControLinksTM Fuel Air Ratio Controller)

The R7999 is a microprocessor-based control that simultaneously directs up to four UPPAs (Universal Parallel Positioning Actuators), based on input from the Firing Rate Control, Limit and Operating Controls, Primary Flame Safeguard Control and/or the S7999B System Display. Provides for two independent fuel profiles. The control generates fault messages and annunciations, stores operating history and shows status of power, alarm and UPPAs via LEDs. The ControLinks. Controller, along with the UPPAs, maintains optimal burner Fuel Air Ratio to maximize burner efficiency and minimize fuel usage and emissions.

R7999A: Meets North American and international approvals. 100-120Vac.

R7999B: Meets international approvals. 200-240Vac.

ML7999A (Universal Parallel Positioning Actuator (UPPA))

Drives combustion air dampers, gas valves, oil valves and flue gas recirculation system dampers based on input from the R7999 ControLinks. Control Provides fuel and air in proper proportion and varies burner firing rate to meet the load demand.

Q7999A (Wiring Subbase)

Provides terminals for field wiring. Line voltage and low voltage wiring is separated on the wiring subbase and prevents the incorrect installation of the ControLinks. Control.

Burner Controls

Integrating a boiler control system is one of the highest-impact, lowest-cost solutions for increasing boiler efficiency. Boiler controls eliminate costly on-off cycles and improve turndown ratios, saving you money and increasing the life of your boiler.

Industrial Boiler and Mechanical is home to the complete line of Fir eye Integrated Controllers and Siemens Burner Controls. IB&M provides installation, commissioning, and servicing for all burner control systems, flame detectors, and control actuators.

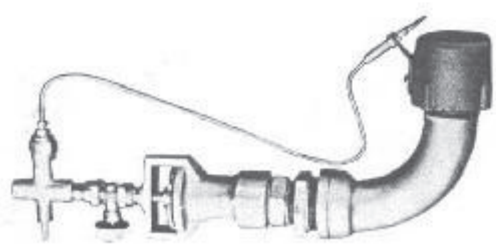
Both Fir eye and Siemens controllers offer fully integrated control in a single module, saving valuable floor space over non-integrated systems. Each system is designed to meet or exceed the reliability and safety requirements of the industrial heating industry.

With independent flame detection for up to 30 boilers, our burner control systems provide the ultimate in flame control and supervising capabilities for gas, oil, combination, and forced-draft burners.

ATMOSPHERIC (VENTURI) BURNERS

These are burners that operate on gas only. The velocity of the gas stream flowing through an orifice entrains atmospheric air for combustion from a venturi throat. The resultant mixture burns at a specially designed tip, of which there are a wide variety, known as a flame retention head. For hot glass glory-hole, tank and pot furnaces, atmospheric burners generally use

L.P. Gas at high pressure as the pressure of reticulated natural gas is usually too low to inspirate sufficient air to generate a hot, short flame with any forward velocity. Atmospheric natural gas burners are used successfully on ceramic kilns.



There is a definite ratio between the burner port area and the venturi throat. Typically, depending on the kiln or furnace back pressure, gas pressure and burner head design, the venturi throat area should be approx. 40-50% of the total burner port area. Mismatching may result in a decrease in mixture velocity producing inadequate burning or at worst "flash back".

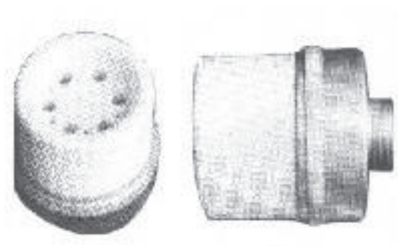
Low rates can be achieved by using a preheat pilot.

This method of firing is the cheapest in terms of equipment costs but is also the least economical. Attention should be paid to obtaining as neutral (correct mixture of atmospheric air and gas) a flame as possible as either oxidising (more air then gas) or reducing (less air) flames or atmospheres are wasteful. Special process or glaze firings are of course excluded. Although some secondary air (air entrained around the burner tip) is necessary for complete combustion, try to keep it to a minimum by correctly sized burner ports and flue outlets. It is possible to check the furnace conditions by restricting the flue exit and checking for slight reduction. This will indicate the settings are close to perfect.

It is difficult to achieve sufficient temperature in higher temperature furnaces with these burners. The greatest limitation, due to the low mixture pressure produced, is the volume of combustion products that can be introduced to the furnace combustion area. Simply increasing the combustion space size will not achieve results as losses will increase proportionally. Obviously there is a fine balance. In some cases better results have been attained by using several smaller burners rather than a single, large burner. Smaller burners with smaller gas orifices and higher gas pressure would develop higher mixture pressures allowing more combustion products into the space in a shorter time. A better alternative is to increase the pressure the combustion products are forced into the space by using a forced air supply. Please contact for more advice on this option.

Flame safety systems for these burners are usually the thermoelectric type that can be used with or without a separate pilot burner. The pilot burner can serve as a low-fire setting. Mount the pilot and/or safety probe well away from the furnace back heat. It is always better and safer to purchase the burners assembled and pre-tested with the appropriate controls.

Automatic ignition and quick lockout safety systems are readily available as an option for these burners.



PRE-MIX OPEN AND SEALED BURNERS

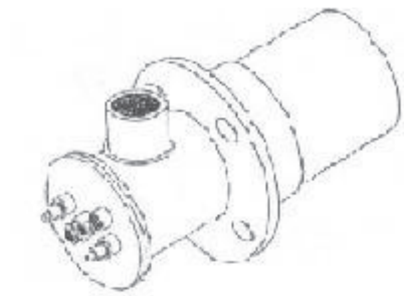
These are burners using a machined mixing set and forced air from a blower or compressor. Open burners use a suitable cast iron or steel flame retention tip and the sealed type utilise a R.I. castable tunnel or MP multiport tip (illustrated) mounted into the furnace wall. Natural gas or L. P. Gas may be used at low pressure as the forced air induces the gas and produces a blast-type flame. These burners are more efficient than atmospheric burners as greater control is available over the air and gas mix, a hotter flame is produced and the sealed burner requires no wasteful secondary air. The open burner will need secondary air for cooling purposes to prolong the tip's life and to complete combustion. Some operators have traded tip life for lower noise and lower capacity by sealing the tip in the furnace port with fibre.

The higher mixture pressures developed by this burner style enable greater combustion volumes into the available furnace combustion space. Some careful preheating of the combustion air may be possible but is not recommended, as there is a risk of flashback or damage to the controls through heat conduction.

Premix burners generally have a shorter flame length than comparable nozzle mix burners, the air/gas ratio is easier to control and the burner overall generally easier to set up. Special flow regulators can be fitted to simplify adjustment enabling alteration of air flow only to raise or lower the temperature. This lends itself to simple, accurate temperature control. Again, care must be taken to correctly size the mixer as a definite ratio exists between the size of the mixer chambers and the burner orifice for proper operation. It is possible to construct a simple mixer from pipe pieces but extra care should be taken to ensure it is not possible for the air to flow into the gas line if the burner or feed pipe is blocked. As a minimum, a light flap safety check valve should be fitted to the gas line. If accurate mixing and turn down are required, use the correct mixer.

State gas regulations concerning forced draft (premix, nozzle mix) burners tend to differ, with some States demanding full sequence electronic flame failure while others may allow glory hole burners without safety if the burner is constantly supervised. All enclosed kilns, pot or tank furnaces should have quick lock out safety as these burners can produce large amounts of unignited mixture in a short period of time.

NOZZLE-MIX BURNERS



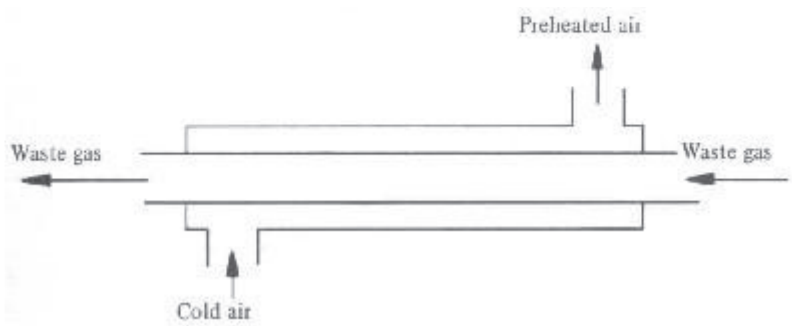
These types of burners accomplish the mixing of the air and gas after they leave the burner port. Up to the burner head the air and gas are kept separate, lower gas and air pressures (unless high velocity is required) may be used and there is no chance of flash back. They generally have greater turn down than other burner types by controlling the gas only and can use preheated air. As the preheated combustion air is kept separate there is no chance of over-heating the gas controls.

Basic cast nozzle-mix burners can handle low preheat temperatures providing some fuel savings but deterioration may result if these burners are exposed to high temperatures for a period of time. Nozzle mix burners that will provide high preheat temperatures and maximum fuel savings are constructed from stainless steel internals or in some special cases ceramic materials. Various types of flame shapes and capacities can be designed to suit the customers' requirement including flat flame burners. This type of burner has a specially designed burner tip and refractory quarl to produce a spinning flat flame that spreads at 90 degrees to the mixture outlet. They have been used in industry where little forward flame travel is desirable and efficient radiant heat is best.

Air and gas controls and safety equipment are similar to premix burners

RECUPERATION

Recuperation is the process of preheating the combustion air by utilising the waste flue products. Although recuperation has been used in industry in various forms for many years, its use in small production situations has only recently become viable due to high fuel costs. Fuel savings of up to 40% can be achieved through properly designed and implemented systems. A simple counter flow design is illustrated.



A simple and effective recuperator uses a stainless steel tube on the flue outlet with a larger tube sited around it. The area between the inner and outer tubes must be adequate to allow for free circulation of the cold combustion air but sufficiently restricted to enable the heat conducted through the inner tube to heat the air to the desired preheat temperature by the time the air exits the recuperator and flows to the burner head. The passage of the hot combustion products flowing through the inner tube must similarly be restricted to allow sufficient heat penetration. Baffles may be added to the inner tube or the single inner tube exchanged for multiple tubes to increase the available surface area. It is important not to exceed the working temperature of the steel and a refractory base or longer section may need to be used to take the initial heat. Experience has shown that over a period of time a coating of products produced by the glass making process tend to accumulate on the inner tube surface. Provision must be made for periodic cleaning of the inside tube and it is a good idea to have a small reservoir underneath the flue outlet to gather these products rather than allow them to block the furnace outlet. Refractory recuperators can be made to increase the preheated air temperature to the burner and prolong life.

Air piping from the recuperator to the burner head should have a large cross sectional area to cope with the expansion of the cold air as it is heated. This can be up to 40% at typical temperatures.

FIRING LOW TEMPERATURE OVENS

There are many functional ovens in use including some with well-designed features such as adjustable combustion spaces for varied throughput's and automatic doors for hands free loading. An efficient oven will have many capabilities including even heat distribution, the ability to maintain a set temperature and fire down over a period of time at an accurate rate if required.

Gas ovens work best using a down draft design (the flue outlet near the base of the oven) and burners that have a short, clean flame with good turndown characteristics (high flame to low flame). The burners usually fire through the base, on either side of the loading area, however higher gas pressure burners can fire horizontally along a base channel. Better ovens have been constructed using high pressure burners firing around the top of the space, creating a circular swirl, for even temperature gradients.

Insulation materials are a matter for personal preference with many people maintaining that R.I. brick ovens can virtually cool down (with all openings closed) at the required rate without any added heat input. Against this it must be remembered that it takes extra energy to heat a brick oven than a light-weight fibre type.

Low gas pressure burners suitable for these ovens are atmospheric and can be pipe-type burners with either a row of drilled holes, slots or newer designs that incorporate a mixer with many fine slots in the burner casing. The newer types are generally cheaper, more efficient and have a better turndown. Safety controls are usually thermoelectric.

As temperature control is such an important consideration, programmable units are available to accurately maintain and control the temperature gradient. Accurate electronic digital units are available up to 8 or 12 stages and control the burners using solenoid valves according to demand. Electric kilns are easily controlled with programmers, the contactor coil or relay substituted for the solenoid valve.

HIGHER TEMPERATURE FURNACES

These furnaces fire to higher temperatures (more than 700^{o}C) but can employ similar burners. Downdraft designs are effective for general work but it is also possible to fire high pressure smaller burners across the product. This method relies not only on convection heat input but also, to a degree, on radiation from the flame. It is important if using this method that sufficient draw is available from the fluing system particularly in the early stages of a firing. It may be necessary to preheat the flue but in any case pressure drops across the flue pipe and exit port must be minimised. Sealed burner tips are better.

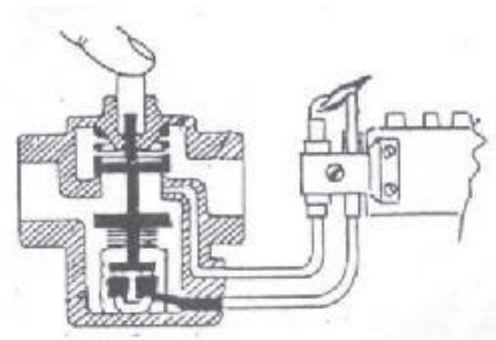
Larger, more industrial kilns should use higher pressure forced draft burners firing across, under or through the load. These use an air fan/blower with the appropriate mixing mechanism to deliver sufficient velocity for even heat distribution.

Automatic temperature programmers are important and can be effectively connected with any gas burner system. Multiple tips commonly utilise a ladder type pilot arrangement on either side, modulating the main burners to relight from the pilot for accurate temperature control. Flame safety is simply fitted to the ladder pilot with manual or automatic spark ignition an option.

SAFETY CONTROLS

Safety controls for gas appliances vary from over-temperature controls to sophisticated automatic start-up and flame failure controllers. Flame safety controls are recommended for all types of burners where there is the risk of a build-up of unignited gas should the flame be extinguished. Flame rectification or UV units are required on all forced air burners and gas will not be connected unless they are fitted. The regulations cover natural gas and L.P. Gas. In some instances the authorities may also insist on over temperature protection or explosion relief. Explosion relief is simply a panel fitted to the furnace of the correct dimensions of a material with less resistance to an explosion than the furnace itself. Non-return check valves may also be required in the gas main to prevent air flowing back to the meter. A regulator is always required on either natural gas or L.P. gas installations to monitor the gas flow and provide the correct pressure outlet. All valves and fittings must be approved and pipe fittings particularly must be suitable for gas. Safety valves should be listed in the gas association bulletin and the burners and controls installed by a licensed person.

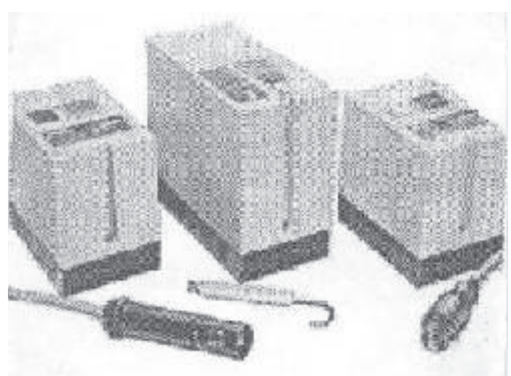
We can advise on any of the above safety considerations and recommend suitable components.



THERMOELECTRIC SAFETY

This is the simplest form of flame safety and is permitted on atmospheric burners with a capacity under 500 MJ/hour. These operate on an electromagnetic principle and require no power. A small current is generated when the tip of a thermocouple probe is heated by the flame. This current excites an electro-magnet located in a safety valve and attracts a plate allowing gas to flow. Shut off time, should the probe cool, can be up to 20 seconds.

ELECTRONIC QUICK-LOCKOUT



These units require power and are usually fitted to forced air burners or safer atmospheric burners. They shut down on a flame failure in approx. one second by closing a solenoid valve fitted into the gas line. Two main types are available; the flame rectification type and the ultra-violet type. Flame rectification relies on the ability of ionised gases in the flame to rectify on AC current from the control unit. A flame sensing rod made from special high temperature material is used and must be situated near the edge of the main flame. A micro-amp meter may be used in series with the rod to check the best position and minimise nuisance shutdowns. The wire must be sturdy enough to resist drooping or deterioration at high temperatures and the porcelain insulators must be kept clean or replaced if cracks develop. For reliable operation the earthing point on the burner must have at least four times the area of the rod in the flame.

UV monitors are sensitive to the ultra violet radiation produced by flames. They also sense the arc of a spark so must be sited away from any automatic spark igniters fitted to the burner. Their main advantage in high temperature situations compared to flame rods is that they can be mounted away from the heat zone. They are protected and see through a protective cover such as ultra violet transmitting fused quartz glass. In some situations cooling air should be blown across the UV cell face to remove dust and protect from excessive back-heat.

NOTES ON FIRING HIGH TEMPERATURE FURNACES

Nozzle mixing and premix furnace burners can be oversized to reduce the ambient noise level providing control is not compromised. Ideally furnaces should be commissioned using combustion analysers, however in the absence of these tools, a slightly reducing gas/air mix with the air rate kept at a minimum will achieve the temperature required. The open type premix burners can have the primary air reduced further as a percentage is entrained as secondary air. The ideal open flame has slight yellow tips; sealed burners should be blue without hard, defined cones. Furnace pressures should be slightly positive to ensure the flue is not drawing excessively and there is no possibility of wasteful ingress of secondary air. This can be tested in a basic fashion by using a hollow tube fitted through a gap in the door. Seal the rest of the door opening completely with ceramic fibre and fit a balloon on the other end of the tube. A slight inflation of the balloon indicates slight positive pressure.

Furnace pressure is controlled by the flue and flue exit size assuming the gas and air flows are at the most efficient settings. If burners have been undersized, more capacity is possible by increasing the flue height and the draw to allow greater furnace gas inputs. Furnaces take longer to reach operating temperatures during the initial heat up phase. Allow this time to slowly heat castables or furnace parts that may not have been fired past critical temperatures previously. Check the heat up rate recommended by the manufacturer to be safe and use a pilot or small torch as a low rate if necessary.

Refer to specific instructions on setting up and adjusting burners. Nozzle mixing burners usually require special proportionators in the gas line for accurate high to low control of the flame although some furnaces require models that are able to modulate the gas only for better turn down and even temperatures. Premix burners have a gas adjusting valve under the aluminium cap located on the mixing chamber. Loosen the locknut and turn the brass screw anti-clockwise for more gas. If a zero type regulator is used on the gas line for single (air) valve control of the burner output, the adjustment of the gas valve will alter the air/gas ratio only. i.e. if more gas is supplied there will be a gas rich flame over the entire range. If manual control is preferred, this screw may be set for maximum gas only and the manual air and gas valves adjusted to alter the flow.

It is possible to reduce the noise on an open type premix burner by sealing the burner in the open port (cutting the secondary air) with ceramic fibre. The trade off will be a shortened life for the cast iron tip as the cooling secondary air is not available. The tip/s should be cleaned frequently with particular attention given to the small retention ports around the main port. They should be replaced if there is excessive corrosion or the outer casting has burnt away. Of course, a better option is to use the MP ceramic tip.

<u>Drum water level control</u>

Why do I need boiler water controls and alarms?

To achieve a steam output matched to the varying requirements of the average steam plant, good control of boiler water level is necessary. With the small steam spaces now common in modern boilers, a quick and accurate response to variations in water level is essential.

drums separate water and steam. Drums are different in structure, but all are the same in operation. The mixture of water and steam enters the separator. Then centrifugal force. and circular movement will separate them After passing the drier plates and finally conducts to water wall tubes by down comers, steam losses its water completely. Drum is like a reserve for boilers Too. It reserves water or steam in itself and keeps it for boiler critical condition .Once water inside the boiler or steam generator, the process of adding the latent heat of vaporization or enthalpy is underway. The boiler transfers energy to the water by the chemical reaction of burning some type of fuel The water enters the boiler through a section in the convection pass called the economizer. From the economizer it passes to the steam drum.

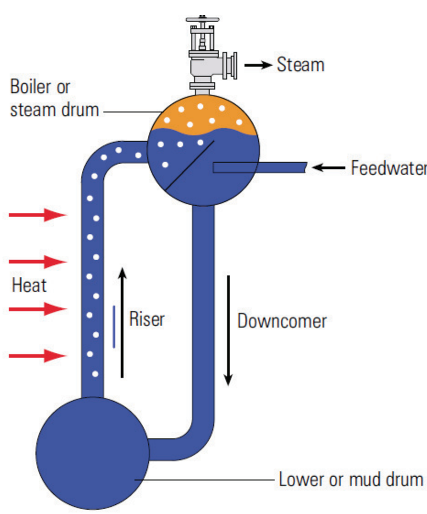


Fig. 3.3.2
Natural water circulation in a water-tube boiler

Drum Level and Feed water Control

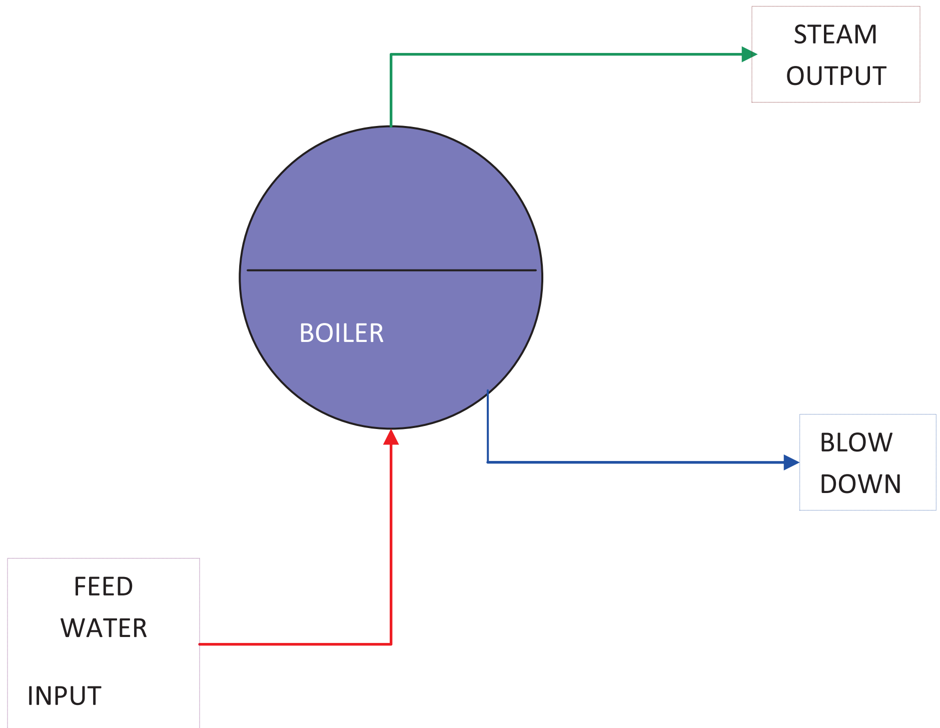
A very common control problem, and one used in many examples elsewhere, is that of controlling the level in a boiler drum. Many industrial plants have boilers for generating process steam, and of course boilers are central to thermal power generation. can run dry resulting in mechanical damage of the drum and boiler piping. If the level becomes too high, water can be carried over into the steam pipe work, possibly damaging downstream equipment. The design of the boiler drum level control strategy is normally described as single-element, two-element, or three-element control.

feed water is controlled to keep the drum level .

Water-level controls continuously monitor the level of water in a steam boiler in order to control the flow of feed water into the boiler and to protect against a low water condition which may expose the heating surfaces with consequent damage. The control may be float operated but modern plant will have conductivity probes. The probes will be fitted in pads or standpipes on the crown of the shell or drum and enclosed in a protection tube which will extend to below the lowest water level. With water tube boilers the control of the water level needs to be precise and sensitive to fluctuating loads due to the high evaporative rates and relatively small steam drums **and** a small water content

Level Circuit (Water Side Circuit):-

Feed water input flow = steam flow + blow down + f (level)

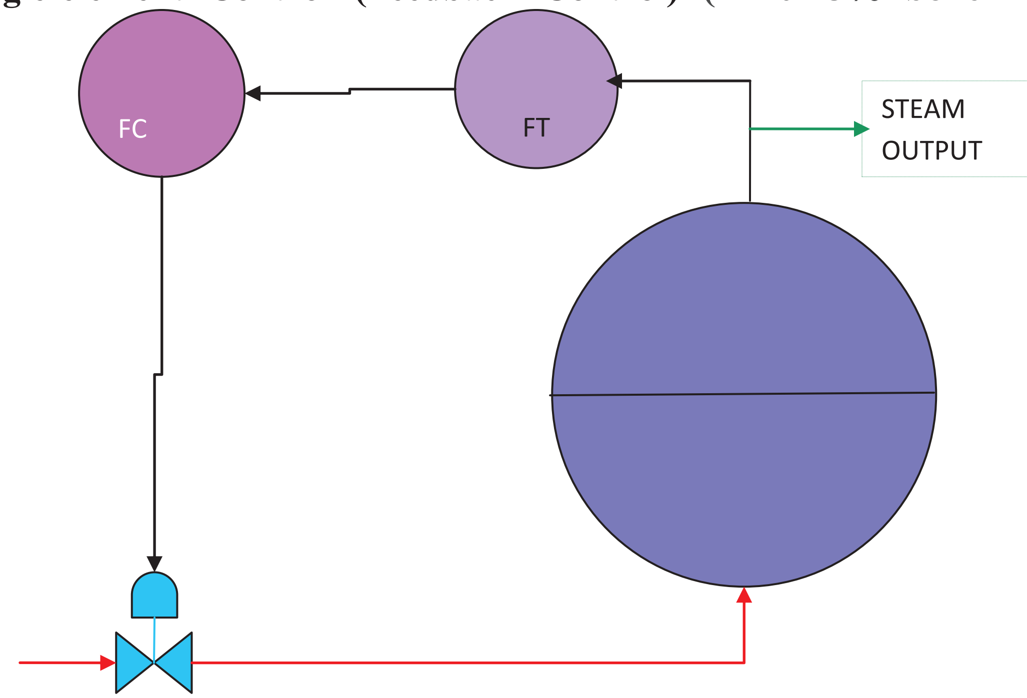


Level control circuit

This section is dedicated to the explanation and design of level system .As seen in the schematic drawing of water side a level control system is supposed to maintain the water level in the boiler drum to a set value in steady state and changing of demand conditions. To achieve this we shall explain the basic idea that a control system should satisfy which is simply the continuity equation which states that;

Feed water input flow = steam flow + blow down + f (level)

Single-element Control (Feedback Control) (< 20-25% boiler load)



Single-element Control

The single-element control is the basic boiler level control strategy. The drum level is measured using a single measurement device and provides a control signal to the feed water regulator in direct relation to the current operating drum level. This system is used in both the on/off and modulating feed water control strategies. One or more boiler feed water pumps push water through one or more feed water control valves into the boiler drum. The water level in the drum is measured with a pressure and temperature-compensated level transmitter. The drum level controller compares the drum level measurement to the set point and modulates the feed water control valves to keep the water level in the drum as close to set point as possible. Variable-speed boiler feed pumps are sometimes used to control the level instead of valves.

In a conventional one-element control strategy the output of a level controller cascades into a flow controller. Consider now the use of a conventional one-element control strategy to control the steam drum level. As the drum level increases the controller reduces the feed water supply. And similarly, if the drum level decreases the controller increases the feed water supply. Let us assume that the steam consumption increases suddenly. Due to the swelling effect the steam drum level will rise initially and then decrease. The controller will initially reduce the feed water supply. This will in effect reduce the water inventory and after the swell effect the water drum level will drum significantly

<u>Disadvantages of Single-element Control:</u>

(SHRINK and SWELLING)

Which is happened at boiler drum whenever you start firing the boiler:- To illustrate the shrink and swell effect in a steam drum let us consider a sharp increase of steam consumption. With the sudden increase in the steam consumption the steam drum pressure drops immediately. With the sudden drop in the pressure the steam bubbles in the water wall and the drum swell and results in a sharp momentary increase in the drum level. After the pressure stabilizes the drum levels behaves in a conventional manner. This initial increase in the level is called swell and it is unique to the steam drum Similarly, when the steam consumption reduces suddenly the drum pressure rises immediately and the steam bubbles in the water shrink. This leads to a sharp momentary decrease in the drum level. This initial decrease in the steam drum level is called shrink

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This will in effect reduce the water inventory and after the swell effect the water drum level will drum significantly This is a disadvantage of one element control system , therefore we use only this system structure at (20 to 25 % load) , and we have to take care of drum level by controlling the start up blow off valves. So, to eliminate such this problem , another control scheme is applied to eliminate the drawbacks of one-element control at high loads

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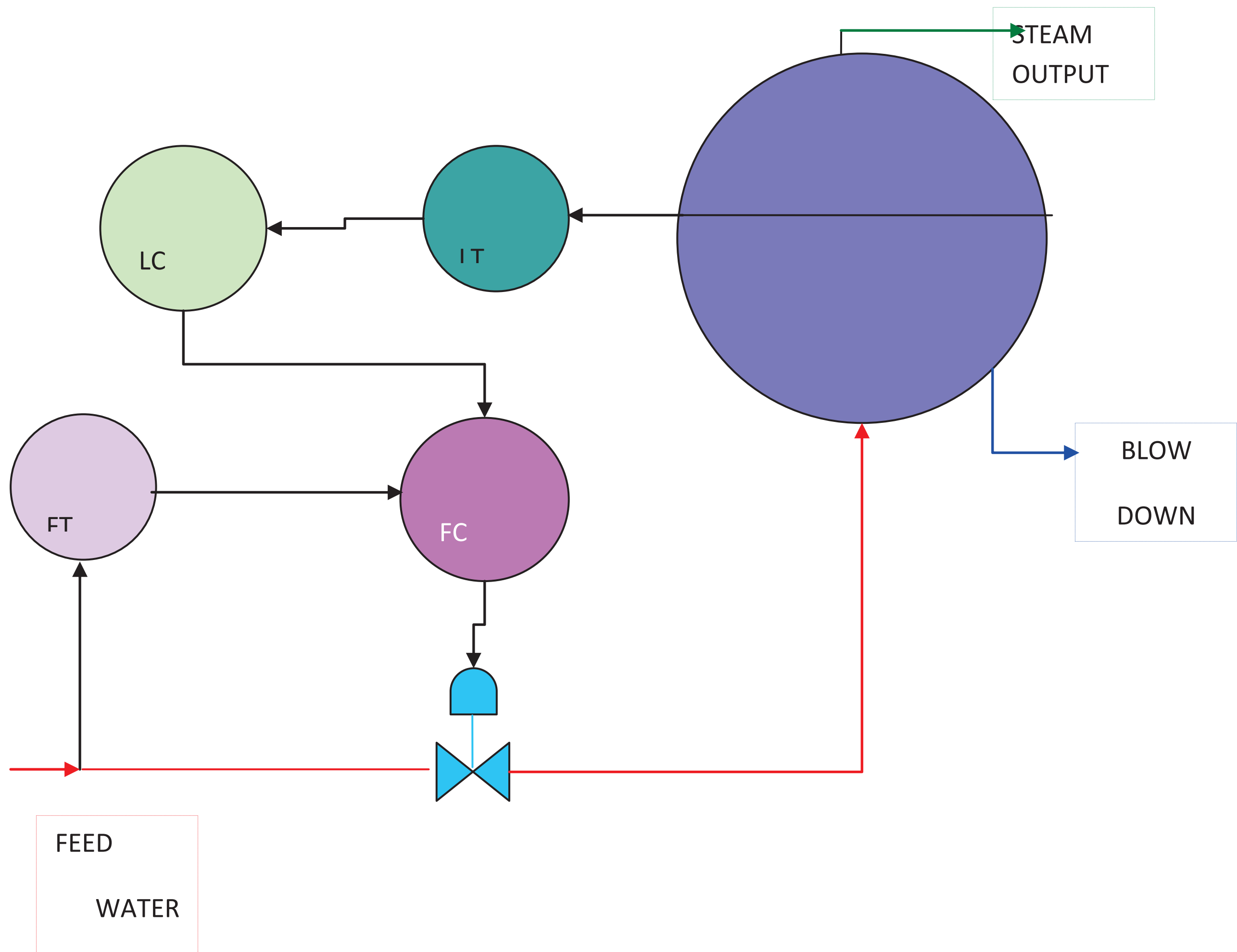
Two-element Control (Cascade Control)

The two-element drum level strategy is suitable for processes that have moderate load swings and speeds, and it can be used on any size of boiler. This system uses the two variables, drum level and Feed water flow delivered by the pump, which balances the feed water demand. Many boilers have two or three feed pumps that will be switched on or off depending on boiler load. If a feed pump is started up or shut down, the total feed water flow rate changes. This causes a deviation in drum level, upon which the drum level controller will act and change the feed water control valve position to compensate. As explained above, the level controller's response is likely very slow, so switching feed pumps on and off can result in large deviations in drum level. A faster control action is needed for dealing with changes in feed water flow rate. This faster action is obtained by controlling the feed water flow rate itself, in addition to the drum level. To control both drum level and feed water flow rate, cascade control is used. The drum level controller becomes the primary controller and its output drives the set point of the feed water flow controller, the secondary control loop. This arrangement is also called two-element control, because both drum level and feed water flow rate are measured and used for control.



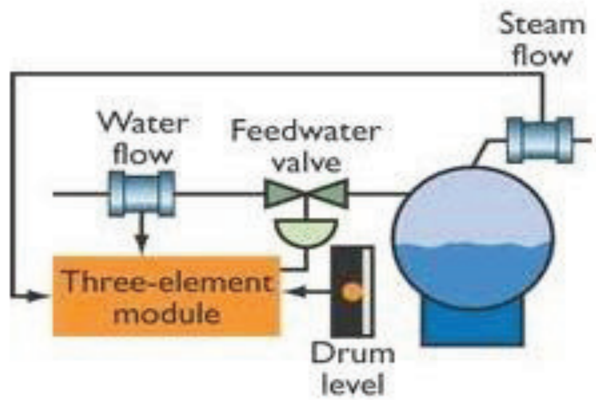
Two-Element Drum Level Control

Three-element Control (Cascade + Feed forward Control)

Drum level

Feed water flow

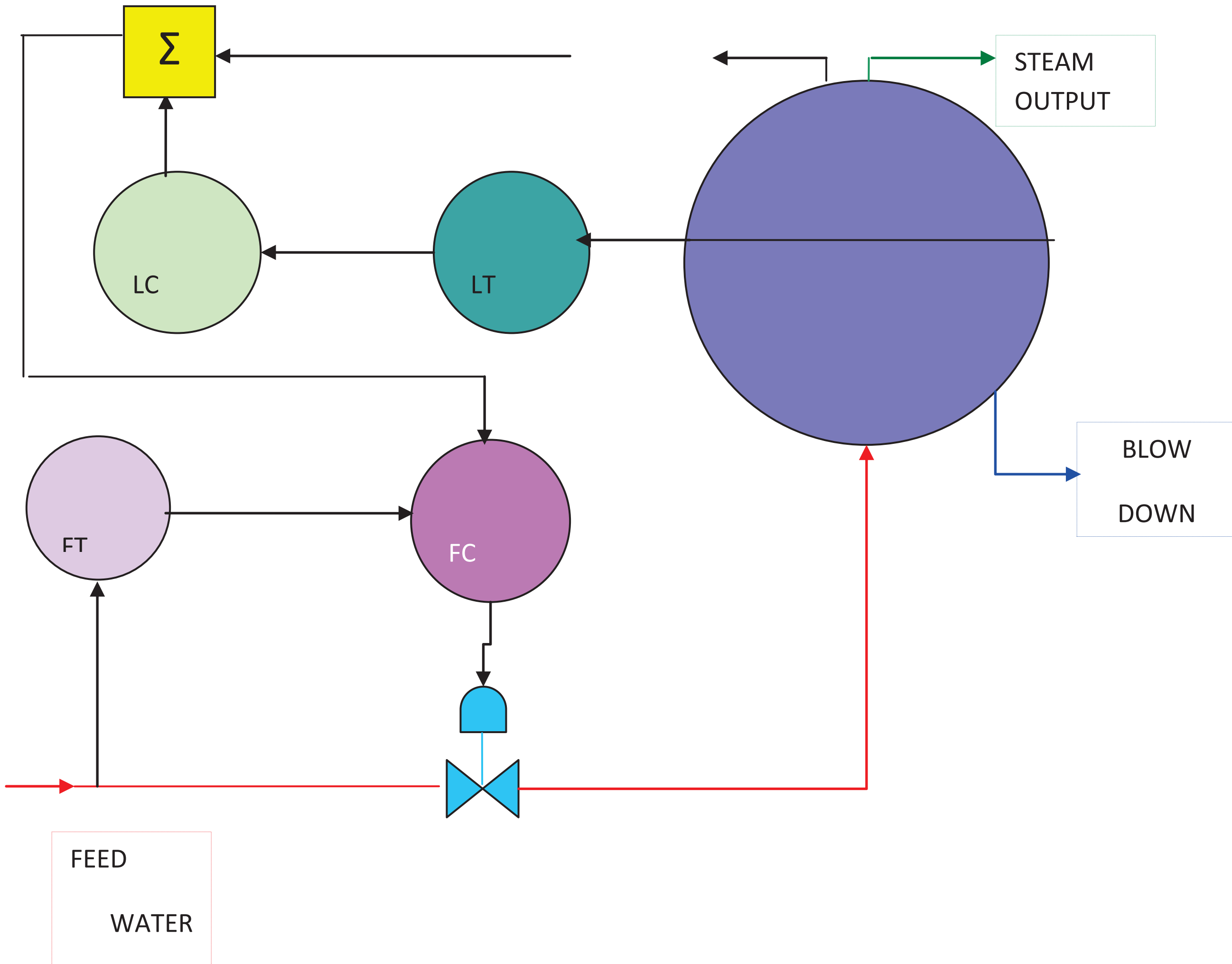
Main steam flow



In order to handle the situation, the steam flow rate should also be considered for drum level control. It can be done by adding the steam flow rate as a feed forward signal to the output of the level controller. Hence, the supply of the feed water flow is compensated for changes in the steam flow rate demand. With this strategy as the steam flow rate changes the demand for the feed water flow rate also changes in the right direction and minimizes the effect of shrink and swell on the drum level.

Now, let us assume that the steam consumption increases suddenly. As the steam consumption increases the feed forward signal increases the feed water supply to the steam drum. Due to the swell effect the level controller reduces the feed water supply. The net effect of the three-element level control scheme changes the feed water supply appropriately and reduces the effect of swell on the drum level. Thus, the three-element level control strategy provides a more stable drum level control.
To address the issues of phasing still present in the two-element control strategy, a third element, feed water flow is added to the drum level control

strategy. In this system the math summer output of the two-element controller is cascaded down to a second feed water flow controller that acts as a remote set point. Similar to feed flow, changes in steam flow can also cause large deviations in drum level, and could possibly trip the boiler. Changes in steam flow rate are measurable and this measurement can be used to improve level control very successfully by using a feed forward control strategy. For the feed forward control strategy, steam flow rate is measured and used as the set point of the feed water flow controller. In this way the feed water flow rate is adjusted to match the steam flow. Changes in steam flow rate will almost immediately be counteracted by similar changes in feed water flow rate. To ensure that deviations in drum level are also used for control, the output of the drum level controller is added to the feed forward from steam flow. The combination of drum level measurement, steam flow measurement, and feed flow measurement to control boiler drum level is called three-element control.



Three-Element Drum Level Control

Advantages of control of water level in drum :

constant water level can be maintained

Excess water level can be avoided by high alarm signal

Low water level can be avoided by low alarm signal

Continuous steam & water flow is possible

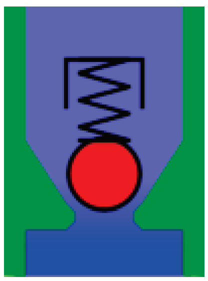
Smooth & efficient working of the boiler

Variation in steam pressure, temp & flow is minimized.

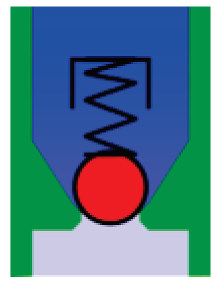
Controlling valves

Check valve

A **check valve**, **clack valve**, **non-return valve** or **one-way valve** is a mechanical device, a valve, which normally allows fluid (liquid or gas) to flow through it in only one direction.



Open



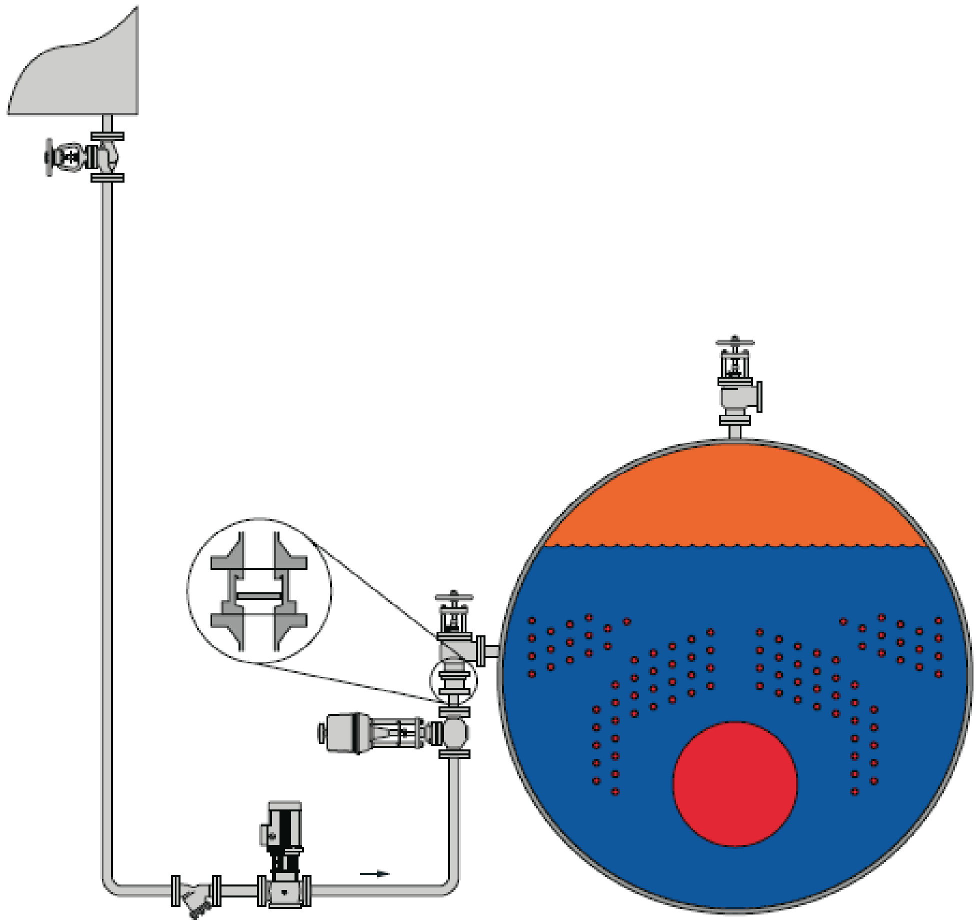
closed

Check valves are two-port valves, meaning they have two openings in the body, one for fluid to enter and the other for fluid to leave. There are various types of check valves used in a wide variety of applications. Check valves are often part of common household items. Although they are available in a wide range of sizes and costs, check valves generally are very small, simple, and/or inexpensive. Check valves work automatically and most are not controlled by a person or any external control; accordingly, most do not have any valve handle or stem. The bodies (external shells) of most check valves are made of plastic or metal.

An important concept in check valves is the cracking pressure which is the minimum upstream pressure at which the valve will operate. Typically the check valve is designed for and can therefore be specified for a specific cracking pressure.

Check valve in boilers:

Check valves are used feed line to make sure that the water inside boiler won't return back to the feed line.

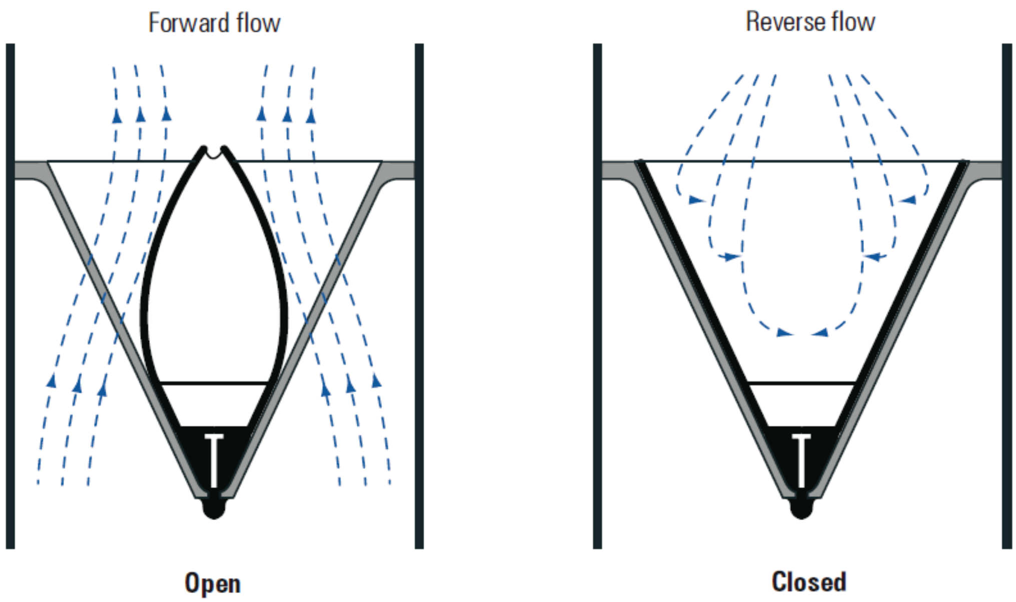


Boiler feedline applications

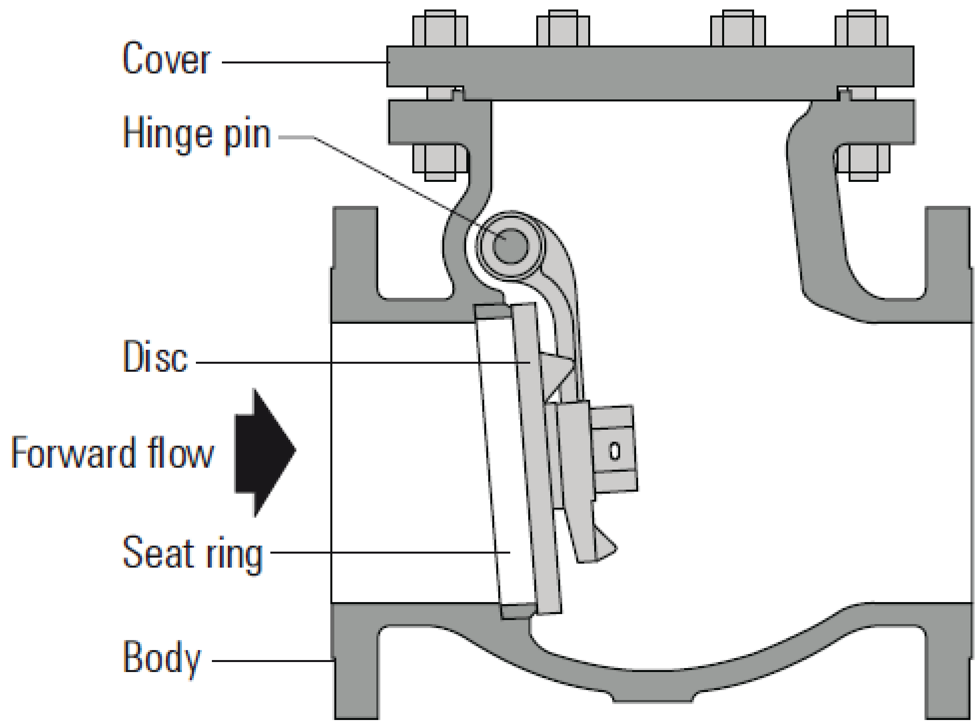
Types of check valves:

ball check valve: is a check valve in which the closing member, the movable part to block the flow, is a spherical ball. In some (but not all) ball check valves, the ball is spring-loaded to help keep it shut. For those designs without a spring, reverse flow is required to move the ball toward the seat and create a seal.

diaphragm check valve uses a flexing rubber diaphragm positioned to create a normally-closed valve. Pressure on the upstream side must be greater than the pressure on the downstream side by a certain amount, known as the pressure differential, for the check valve to open allowing flow. Once positive pressure stops, the diaphragm automatically flexes back to its original closed position.



swing check valve or **tilting disc check valve** is check valve in which the disc, the movable part to block the flow, swings on a hinge or trunnion, either onto the seat to block reverse flow or off the seat to allow forward flow. The seat opening cross-section may be perpendicular to the centerline between the two ports or at an angle. Although swing check valves can come in various sizes, large check valves are often swing check valves. The flapper valve in a flush-toilet mechanism is an example of this type of valve. Tank pressure holding it closed is overcome by manual lift of the flapper. It then remains open until the tank drains and the flapper falls due to gravity. Another variation of this mechanism is the clapper valve, used in applications such firefighting and fire life safety systems. A hinged gate only remains open in the inflowing direction. The clapper valve often also has a spring that keeps the gate shut when there is no forward pressure.



A full-bodied, swing check valve

stop-check valve is a check valve with override control to stop flow regardless of flow direction or pressure. In addition to closing in response to backflow or insufficient forward pressure (normal check-valve behavior), it can also be deliberately shut by an external mechanism, thereby preventing any flow regardless of forward pressure.

lift-check valve is a check valve in which the disc, sometimes called a *lift*, can be lifted up off its seat by higher pressure of inlet or upstream fluid to allow flow to the outlet or downstream side. A guide keeps motion of the disc on a vertical line, so the valve can later reseat properly. When the pressure is no longer higher, gravity or higher downstream pressure will cause the disc to lower onto its seat, shutting the valve to stop reverse flow.

A lift check valve

duckbill valve is a check valve in which flow proceeds through a soft tube that protrudes into the downstream side. Back-pressure collapses this tube, cutting off flow.

Applications:

Check valves are often used with some types of pumps. Piston-driven and diaphragm pumps such as metering pumps and pumps for chromatography commonly use inlet and outlet ball check valves. These valves often look like small cylinders attached to the pump head on the inlet and outlet lines. Many similar pump-like mechanisms for moving volumes of fluids around use check valves such as ball check valves.

Check valves are used in many fluid systems such as those in chemical and power plants, and in many other industrial processes.

Check valves are also often used when multiple gases are mixed into one gas stream. A check valve is installed on each of the individual gas streams to prevent mixing of the gases in the original source. For example, if a fuel and an oxidizer are to be mixed, then check valves will normally be used on both the fuel and oxidizer sources to ensure that the original gas cylinders remain pure and therefore nonflammable.

Blowdown valve

The blow down valve is a very popular category of pipe valves, used in a wide variety of applications. They are used for operation in open position. The main function of blow down valve is mainly to control a continuous flow of steam /fluid under high differential pressure. The outstanding feature of this type of valve is that it can maintain fluid tightness and it is easily operated without the help of any wedging action.

How does a blowdown valve operate?

-At start-up, the valve closes. This leads the separator pressure to build up.

-At shut-down the valve opens to bleed the separator to atmosphere or to the tank in case of boiler(our case). This is when a pressure is applied. The valve can also be used as a by-pass valve to bleed air with the help of the compressor at start-up.

The blowdown valve in boiler:

It has two functions:

-Removing Suspended solids from the bottom of the boiler.

-act as a safety valve to blowdown water if the pressure of the boiler became so high.

How does it work?

-At start-up, the valve is closed. This leads the boiler to work normally.

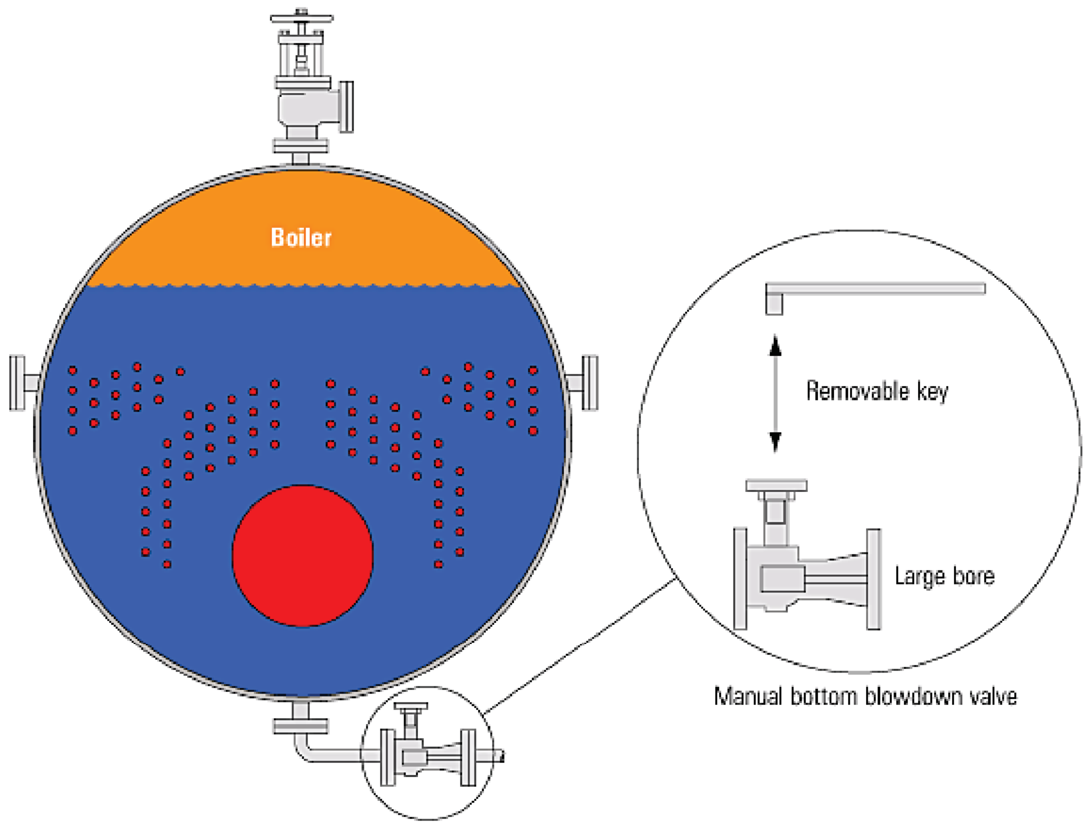
-when blow down is necessary the valve opening performed.

there are two methods to control(on/off) the blowdown valve:

1-manualy.

-Using removable key as shown below ,the valve is opened and closed manually using the key shown.

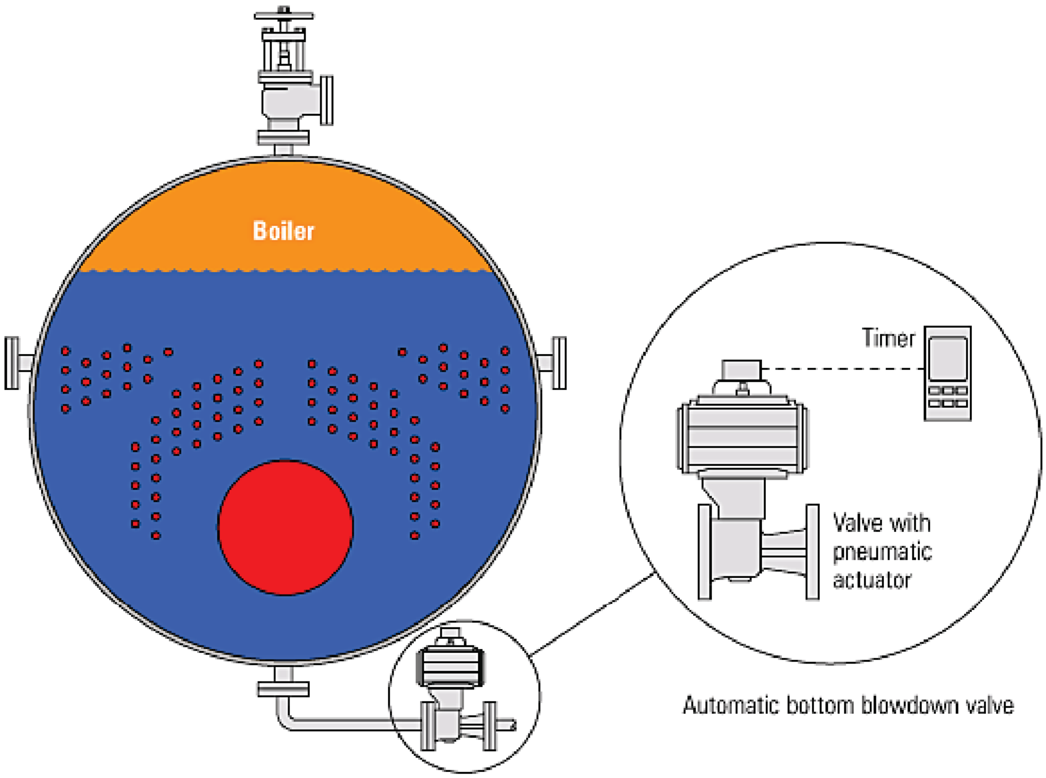
-There is no other control method except the human action.



2-**Timer controlled automatic bottom blowdown:**

-using a proprietary timer linked to a pneumatically operated ball valve, The timer should be capable of opening the valve at a specific time, and holding it open for a set number of seconds.

The use of automatic bottom blowdown ensures that this important action is carried out regularly and releases the boiler attendant for other duties.



<u>Relief valve</u>

The **relief valve** (RV) is a type of valve used to control or limit the pressure in a system or vessel which can build up by a process upset, instrument or equipment failure, or fire.

How does a relief valve operate?

The pressure is relieved by allowing the pressurised fluid to flow from an auxiliary passage out of the system. The relief valve is designed or set to open at a predetermined set pressure to protect pressure vessels and other equipment from being subjected to pressures that exceed their design limits. When the set pressure is exceeded, the relief valve becomes the "path of least resistance" as the valve is forced open and a portion of the fluid is diverted through the auxiliary route. The diverted fluid (liquid, gas or liquid-gas mixture) is usually routed through a piping system known as a *flare header* or *relief header* to a central, elevated gas flare where it is usually burned and the resulting combustion gases are released to the atmosphere. As the fluid is diverted, the pressure inside the vessel will drop. Once it reaches the valve's reseating pressure, the valve will close.

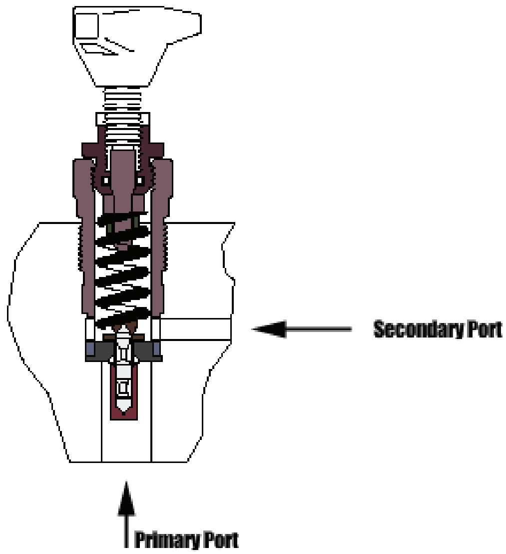
<u>There are two methods of actuating of relief valve:</u>

Direct acting:

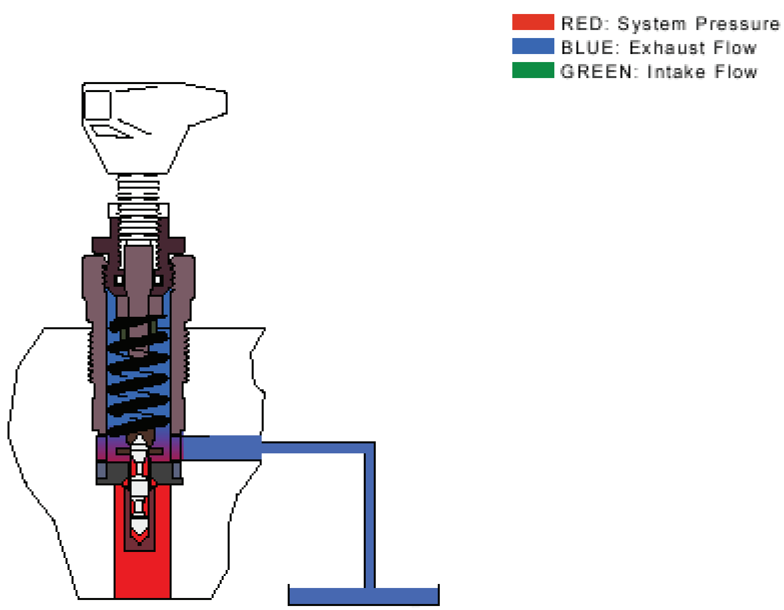
It has two ports:

-first port is connected to the system pressure.

-second port is connected to the tank.



When the pressure rises more than the pressure which the valve was adjusted to-by the mean of seal and nut- the liquid pushes the spring and returns back to the tank.



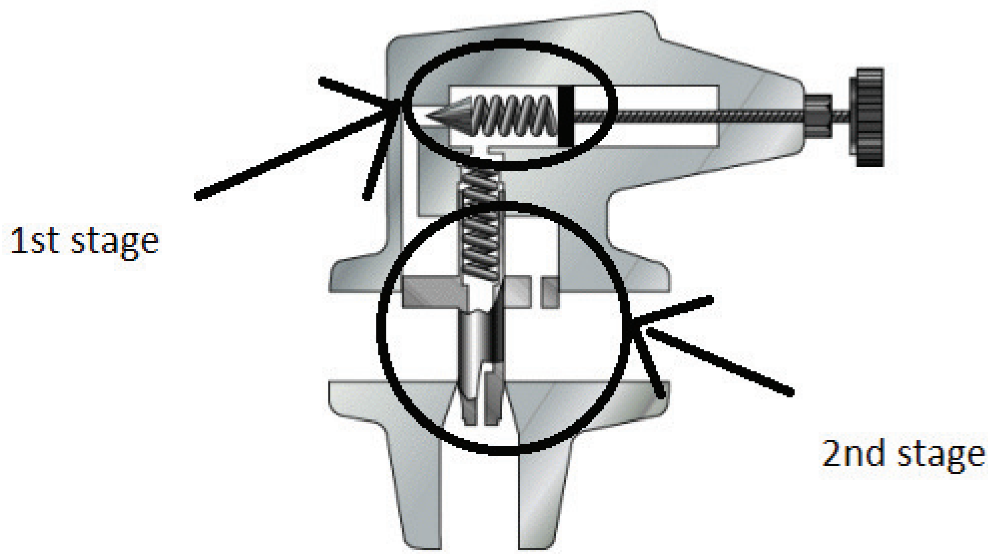
Pilot operated relief valve:

It consists of two stages:

-first stage direct acting relief valve, which adjusted to a specific pressure.

-second stage contains the main spool and subjected to the flow pipe.

When the pressure rises to a value more than the valve was set to, the poppet moves from its position, this will result to a pressure difference between the flow pressure and the pressure on the other side of the main poppet, this will make the poppet move from its seat and that will discharge some of the liquid and results on pressure correction.



Types of relief valves:

Pressure Relief Valve: (PRV) or Pressure Safety Valve (PSV). The difference being that PSVs have a manual lever to activate the valve in case of emergency. Most PRV are spring operated. At lower pressures some use a diaphragm in place of a spring. The oldest PRV designs use a weight to seal the valve.

Set Pressure: When increasing system pressure reaches this value the PRV opens. Accuracy of set pressure often follows guidelines set by the ASME.

Relief valve (RV): A valve used on a liquid service, which opens proportionally as the increasing pressure overcomes the spring pressure.

Safety valve (SV): Used in gas service. Most SV are full lift or snap acting, they pop open all the way.

Safety relief valve (SRV): A PRV that can be used for gas or liquid service. But set pressure will usually only be accurate for one type of fluid at a time (the type it was set with).

Pilot-operated relief valve (POSRV, PORV, POPRV): device that relieves by remote command from a pilot valve that is connected to the upstream system pressure. Low pressure safety valve (LPSV): automatic system that relieves by static pressure on a gas. The pressure is small and near the atmospheric pressure.

Vacuum pressure safety valve (VPSV): automatic system that relieves by static pressure on a gas. The pressure is small, negative and near the atmospheric pressure.

Low and vacuum pressure safety valve (LVPSV): automatic system that relieves by static pressure on a gas. The pressure is small, negative or positive and near the atmospheric pressure.

Calibration

Boiler (program)98i Readings:

Boiler pressure		89.1 bar
Outlet superheater pressure		87.3 bar
Inlet reheater pressure		14.6 bar
Outlet reheater pressure		12.8 bar
Feed water temperature		196 ^oC
Outlet economizer water temperature		250 ^oC
Outlet superheater temperature		513 ^oC
Inlet reheater temperature		296 ^oC
Outlet reheater temperature		513 ^oC
Air temperature		24 ^oC
Exhaust temperature		166 ^oC
Air delivery		83726.604 m^3/h
Fuel delivery		7570.5244 kg/h
Feed water delivery		94 m^3/h
Steam delivery		90 t/h
Fuel available heat	Q_d	324,886 MJ/h
Heat to economizer	Q_e	20,160 MJ/h
Heat of vaporization	Q_c	152,730 MJ/h
Superheat	Q_s	60,210 MJ/h
Reheat	Q_{rs}	42,300 MJ/h
Waste heat in the funnel	Q_f	16,853 MJ/h
Waste heat by radiation or other	Q_i	32,632 MJ/h
Efficiency	η	0.848

Boiler Calculations:

quantity of available heat in the fuel = fuel superior calorific power * fuel mass delivery

$Q_d = P_{cs} * P_g$

$= 42.07 * 7570.5244$

$= 318{,}492$ MJ/h

quantity of transferred heat into the economizer = water mass delivery * average specific heat of water * (outlwet economizer water temperature – feed water temperature)

$Q_e = P_w * C_m * (T_e – T_i)$

$= [94 * 1/.0013] * .00427 * (250 – 196)$

$= 16{,}673$ MJ/h

quantity of transferred heat in the generator = steam delivery * [heat energy kept in one kg of saturated steam – (average specific heat of water * outlet economizer water temperature)]

$Q_c = P_v * [h_v – (C_m * T_e)]$

$= 90{,}000 * [2.746 - (.00427 * 250)]$

$= 151{,}065$ MJ/h

quantity of transferred heat into the superheater = steam delivery * (heat energy of the superheated steam - heat energy of the saturated steam)

$Q_s = P_v * (h_s – h_v)$

$= 90{,}000 * (3.4221 – 2.746)$

$= 60{,}849$ MJ/h

quantity of transferred heat into the resuperheater = steam delivery * (heat energy of the resuperheated steam at the entrance - heat energy of the resaturated steam at the exit)

$Q_{rs} = P_v * (h_{ru} – h_{re})$

$= 90{,}000 * (3.5035 – 3.0311)$

$= 42{,}516$ MJ/h

quantity of lost heat in the funnel = total mass delivery * fumes average specific heats * (exhaust temperature – air temperature)

$Q_f = [(P_a * \beta) + P_g] * C_{mf} * (T_f - T_a)$

$= [(83726.604 * 1.225) + 7570.5244] * .001025 * (166 - 24)$

= 16,030 MJ/h

Quantity of lost heat for radiation and unburned is obtained for difference

$Q_i = Q_d - Q_e - Q_c - Q_s - Q_{rs} - Q_f$

= 318,492 - 16,673 - 151,065 - 60,849 - 42,516 - 16,030

= 31,359 MJ/h

Efficiency = heat gained ÷ heat paid

$\eta = (Q_e + Q_c + Q_s + Q_{rs}) \div Q_d$

= (271,103) ÷ 318,492

= .85121

Conclusions:

Selection of a boiler with "designed-in" low maintenance costs and high efficiency can really pay off by providing ongoing savings and maximizing your boiler investment. Remember, first cost is a relatively small portion of your boiler investment.

High boiler efficiency is the result of specific design criteria, including:

- Number of boiler passes
- Burner / boiler compatibility
- Repeatable air/fuel control
- Heating surface
- Pressure vessel design

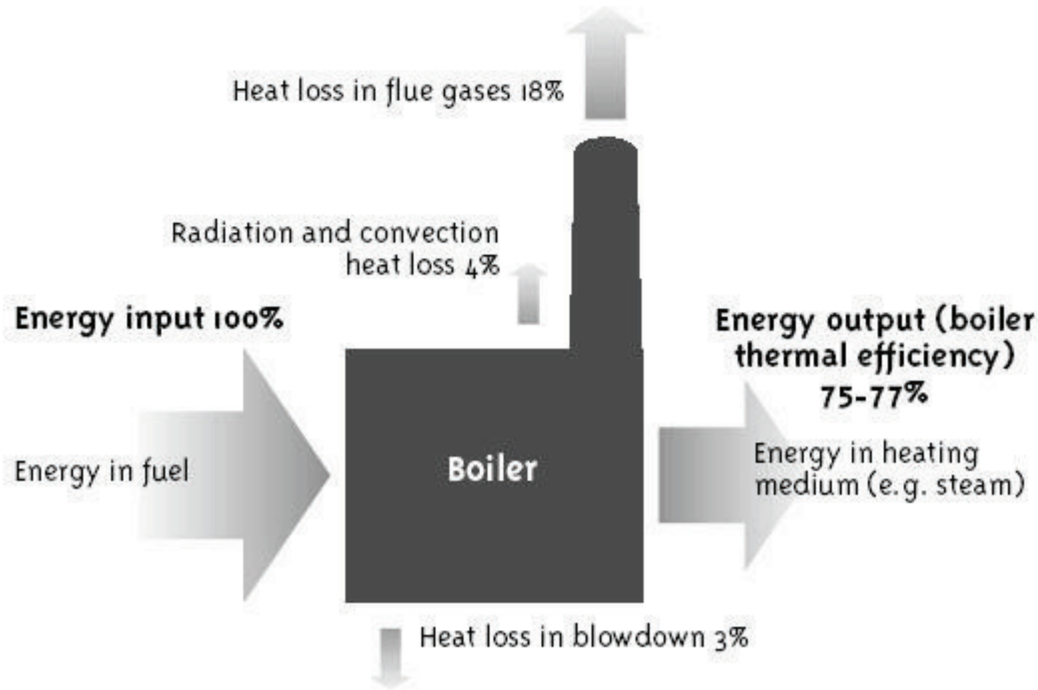
- Boiler efficiency calculations that are accurate and representative of actual boiler fuel usage require the use of proven and verified data, including:
- Proven stack temperature
- Accurate fuel specification
- Actual operating excess air levels
- Proper ambient air temperature
- Proper radiation & convection losses

When evaluating your boiler purchase, ask your boiler vendor to go through the efficiency calculation to verify it is realistic and proven. Also review the type of boiler / burner being utilized to check if the unit's performance will be consistent and repeatable. You will pay for the fuel actually used, not the estimated fuel based on the efficiency calculation. Once the boiler is installed, you can't go back and change the design efficiency of the unit.

The facts regarding boiler efficiency are clear: optimal high efficiency boiler designs are available. You will get superior performance with these premium designs. And efficiency calculations can be verified and proven. Make sure the efficiency data you are using for your boiler evaluation is guaranteed and is accurate and repeatable over the life of the equipment.

Make sure your actual fuel usage requirements of the boiler are understood before you buy.

In the end, the time spent evaluating efficiency will be well worth the effort. Insisting on a high efficiency, repeatable design firetube boiler will pay off every time your new boiler is fired, for the entire life of the equipment.



This image shows a typical boiler energy balance for a boiler in good running condition with no energy efficiency measures added. By first identifying the areas of energy loss and roughly quantifying it, it is easier to estimate the overall savings potential by taking efficiency action in that area. For example, if the blowdown loss is 3% of total input energy, it is not possible to expect a 5% savings of input energy by installing a blowdown heat recovery system.