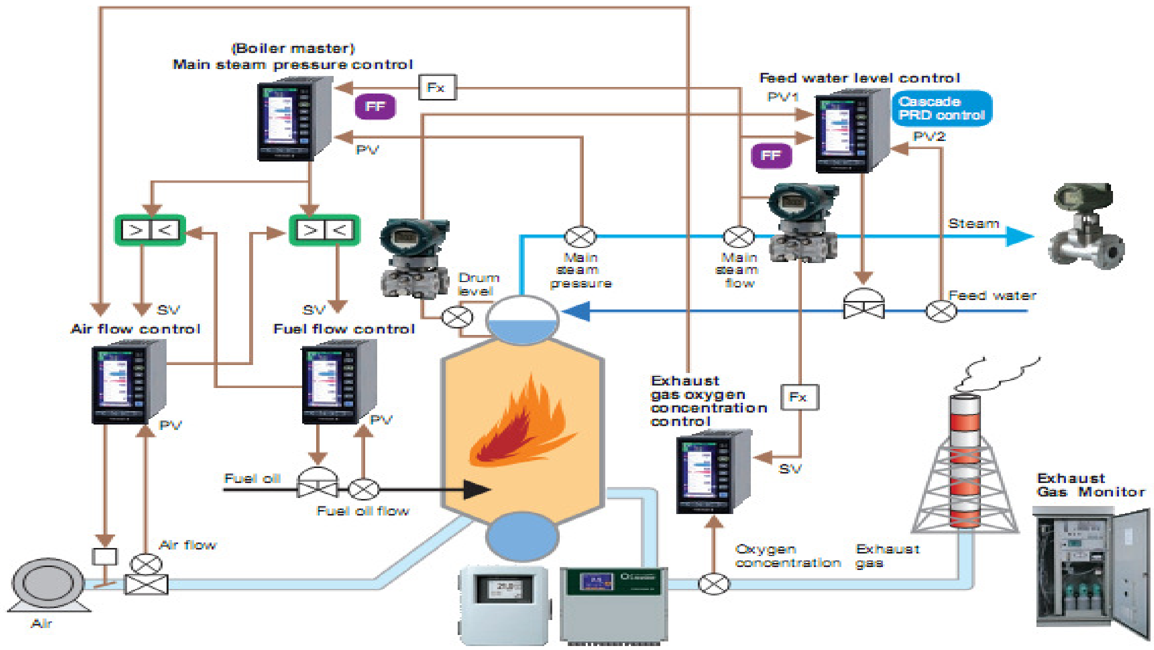
1- WHY BOILER CONTROL?

The primary purpose of any boiler control system is to manipulate the firing rate so that the supply of steam remains in balance with the demand for steam over the full load range. In addition, it is necessary to maintain an adequate supply of feed water and the correct mixture of air and fuel for safe and economical combustion. Boiler control is required to achieve the following.



1-1- Increase uptime and availability.

The primary objective of most boiler operations is maintaining availability, or uptime. Many facilities have more than one boiler on-site running in parallel. It is essential to maintain and upgrade the boiler control systems to assure steam availability. Modern controls are more reliable and can readily adjust to load swings caused by varying overall plant operations.

1-2- Reduce flue gas emissions.

Failure to comply with current emissions regulations can be as costly as lost utilities. Government mandates enforced by fines, threat of closure, or imprisonment will usually provide sufficient incentive to comply with the regulations and modernize controls if necessary. Improved combustion efficiency reduces unwanted combustion by-products. Anything that goes into the manufacture of a product (raw materials, fuel, air, water, etc.) that is not in the final product is wasted cost. This can also create added waste disposal problems. By accurately controlling oxygen, fuel flow, and stack temperature, you will see reductions in plant emissions.

1-3- Maintain boiler safety.

A modern control system will provide tight integration with the flame safety or burner management system to improve safety. Having access to field data, diagnostics, and alarms, coupled with modern electronic controls, can achieve the desired level of safety and security. Password security of configuration software also assures no unintended changes are made which could endanger your personnel or equipment.

1-4- Control operating costs.

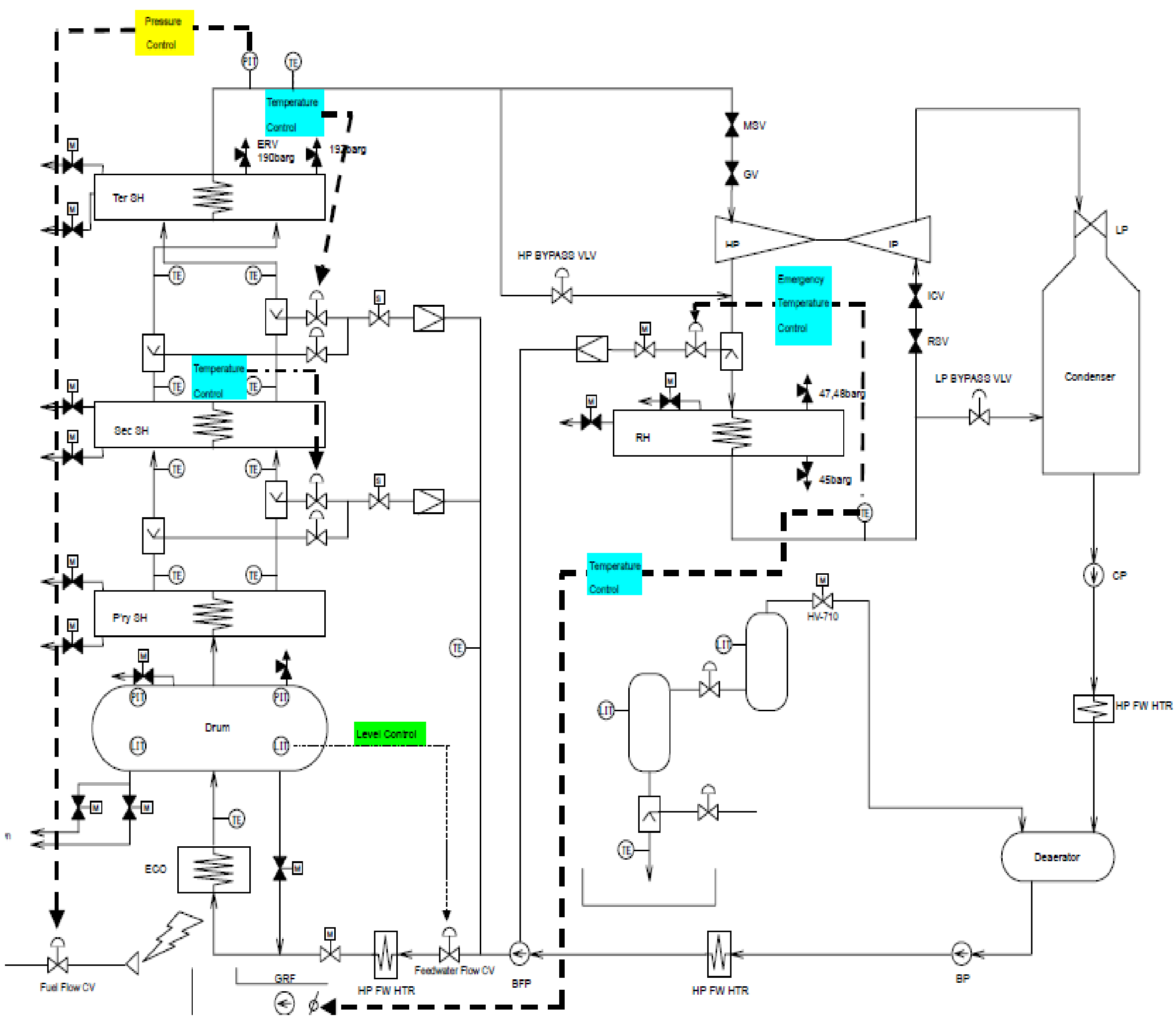
A modern boiler control system will:

- Improve combustion efficiency to reduce fuel consumption by reducing excess air
- Reduce engineering, installation, and start-up costs
- Reduce maintenance costs associated with older, less reliable equipment.
- Reduce manpower requirements by automatically responding to load changes
- Provide a flexible control strategy to reduce or eliminate process upsets
- Readily make data available for remote monitoring to determine process unit optimization, boiler efficiency, and load allocation.

2- HIGHLIGHTS

Boiler control systems generally include a number of subsystems. This document includes the following

- Plant Master
- Boiler master control
- Combustion control (air to fuel ratio control)
- Furnace pressure control
- Drum level (feedwater) control
- Steam temperature control



2-1- Plant Master This is a controller that compares the pressure with an operator selected set point and computes a firing rate demand signal (output) to the combustion controls: {boiler master(s) and the fuel/air controllers}.

Steam pressure is the key variable that indicates the state of balance between the supply of steam and the demand for steam. If supply exceeds demand, the pressure will rise. Conversely, if demand exceeds supply, the pressure will fall. Figure 2 shows a single loop control diagram that manipulates the firing rate demand to control steam pressure at the desired set point.

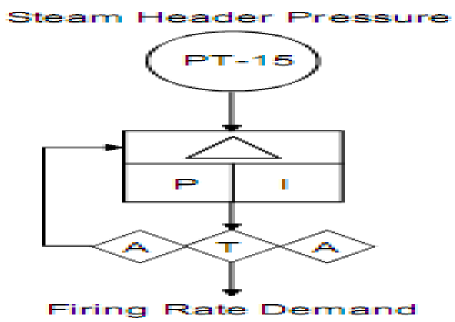


Figure: Plant Master Controller

2-2- BOILER MASTER This controller accepts the firing rate demand signal from the Plant Master controller as the process variable. The output of boiler master provides the firing rate demand signal and operator applied bias to the fuel and air controllers for that specific boiler. This bias station allows the operator to select higher firing rates and therefore higher steam production from the more efficient boilers in a multiple unit configuration Additionally; discrete outputs from the fuel and air controllers' provide mode status to the boiler master controller.

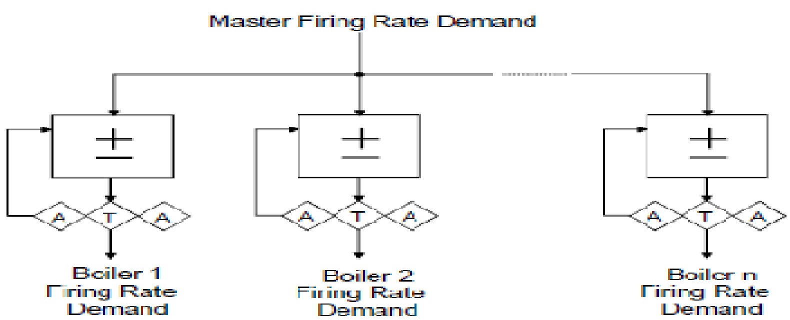


Figure: boiler master control

1 . Boiler Master (Firing Rate Demand) logic

Boiler Master (basic firing rate demand) computation is dependent on the current operating mode like coordinated mode Boiler Follow mode, Turbine Follow mode or Manual mode.

This demand is transmitted in parallel to the fuel and air control sub -loops.

(1) Unit Start up

During the unit start up , Boiler Master is determined as a fixed demand with the rate to obtain the optimum boiler steam temperature rising and steam flow until HP turbine bypass control valve is fully closed. This demand will be adjusted manually o r automatically according to the unit start up mode. During this period, main steam pressure is controlled by HP turbine bypass control valve. During the unit s tart up, the operating mode will be Manual Mode both turbine governor and Boiler Master manual.

(2) Normal opera t ion

After HP turbine bypass control valve is fully closed , the operating mode will be normally transferred to Coordinated Control Mode. In case of Coordinated Control Mode, the turbine governor controls MW and Boiler Master controls the main s team pressure. In case of Boiler Follow Mode, Boiler Master also controls the main steam pressure. In case of Boiler Master manual or load runback, the operating mode become Turbine Follow Mode and turbine governor controls the main steam pressure .

(3) Boiler Input Rate (BIR) for firing rate

Boiler Input Rate (B IR) for the firing rate compensates for the change in boiler storage energy at different load levels. B IR signal is provided from the unit load demand during the load change. The firing rate to accommodate stored energy change is almost proportional to both the load demand and the load change rate. BIR are also applied for other controls such as air flow control , SH spray control , GRF control and RH spray control as the dynamic feed forward compensation signal .

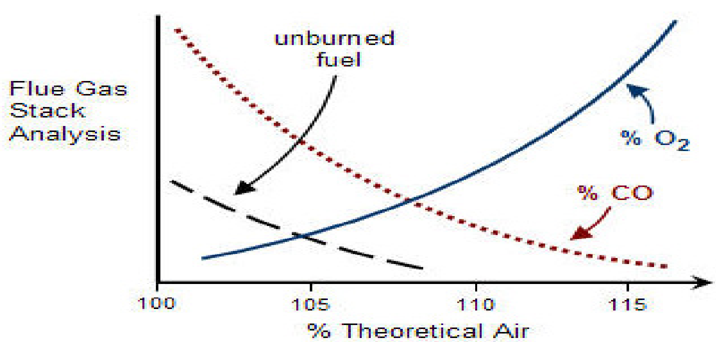
2-3- Combustion Control Process

The primary function of combustion control is to deliver air and fuel to the burner at a rate that satisfies the firing rate demand and at a mixture (air/fuel ratio) that provides safe and efficient combustion. Insufficient air flow wastes fuel due to incomplete combustion and can cause an accumulation of combustible gases that can be ignited explosively by hot spots in the furnace. Too much air flow wastes fuel by carrying excess heat up the stack. Combustion controls are designed to achieve the optimum air/fuel ratio, while guarding against the hazard caused by insufficient air flow.

Air to fuel ratio control

- Why Air/Fuel Ratio is Important

In combustion processes, air/fuel ratio is normally expressed on a mass basis and air/fuel ratio is very important for these reasons.



a- Too Little Air Increases Pollution and Wastes Fuel A too-small air/fuel ratio leads to incomplete combustion of our fuel. As the availability of oxygen decreases, noxious exhaust gases including carbon monoxide will form first. As the air/fuel ratio decreases further, partially burned and unburned fuel can appear in the exhaust stack. incomplete combustion also means that we are wasting expensive fuel. Fuel that does not burn to provide useful heat energy,

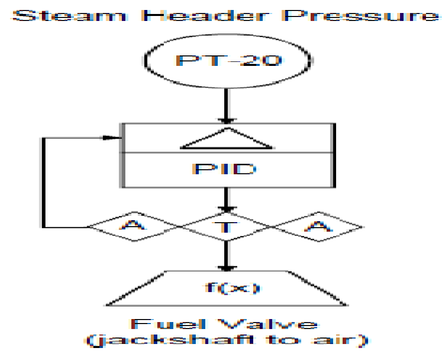
b- Too Much Air Wastes Fuel As the air/fuel ratio increases above that needed for complete combustion,the extra nitrogen and unneeded oxygen absorb heat energy, decreasing the temperature of the flame and gases in the combustion zone. As the operating temperature drops, we are less able to extract useful heat energy for our intended application.

c- Theoretical (Stoichiometric) Air The relationship between the air/fuel ratio, pollution formation and wasted heat energy provides a basis for control system design.we could determine the precise amount of air required to just complete the conversion of a hydrocarbon fuel to carbon dioxide and water. This minimum amount is called the “theoretical” or “stoichiometric" air.

2-3-*-combustion control methods

2-3-1-Single Point Positioning Control

The simplest combustion control strategy that can be applied to boilers is single-point positioning, often referred to as jackshaft control. It is commonly used on firetube and small watertube boilers. Figure 4 shows the feedback control scheme employed.



Single-point positioning uses a mechanical linkage to manipulate the fuel control valve and the combustion air flow damper in a fixed relationship. The alignment of the fuel valve and the air damper ositioners is critical for this type of control. Because fuel valves and air dampers have different flow characteristics, it is necessary to linearize these flow characteristics.

Typically, the air flow characteristic is linearized first, and then the fuel flow characteristic is linearized to match the air flow. When properly aligned, the percentage of fuel and air flow will match the percentage demanded by the single control output. In a single-point positioning control strategy, only one measurement is used: steam header pressure or hot water outlet temperature, depending on the type of boiler. Both the fuel control valve and the air damper are positioned based on this signal.

2-3-2-Parallel Positioning Control

To regulate the firing rate, parallel positioning control employs a strategy that is similar to single-point positioning. Once again, only one measurement is used and this is either the steam header pressure or the hot water outlet temperature, depending upon the type of boiler. Both the fuel control valve and the air control damper are positioned based on this signal. Unlike single-point positioning, parallel positioning has two control outputs. One controls the fuel valve, the other controls the air damper position. Since both fuel flow and air flow are non-linear, the fuel flow is mechanically linearized using a cam. Air flow is linearized within a digital electronic controller. Parallel positioning permits the optimum air/fuel ratio to be maintained across the entire firing rate. This control scheme is commonly used on package boilers

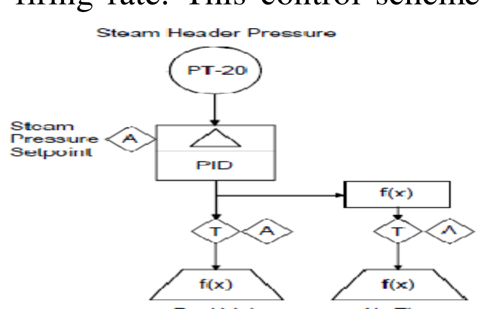


Figure 5: shows the parallel positioning control scheme. The two controller outputs go to the fuel valve and the air damper. The jackshaft used in single-point positioning is replaced by a characterizer within the controller.

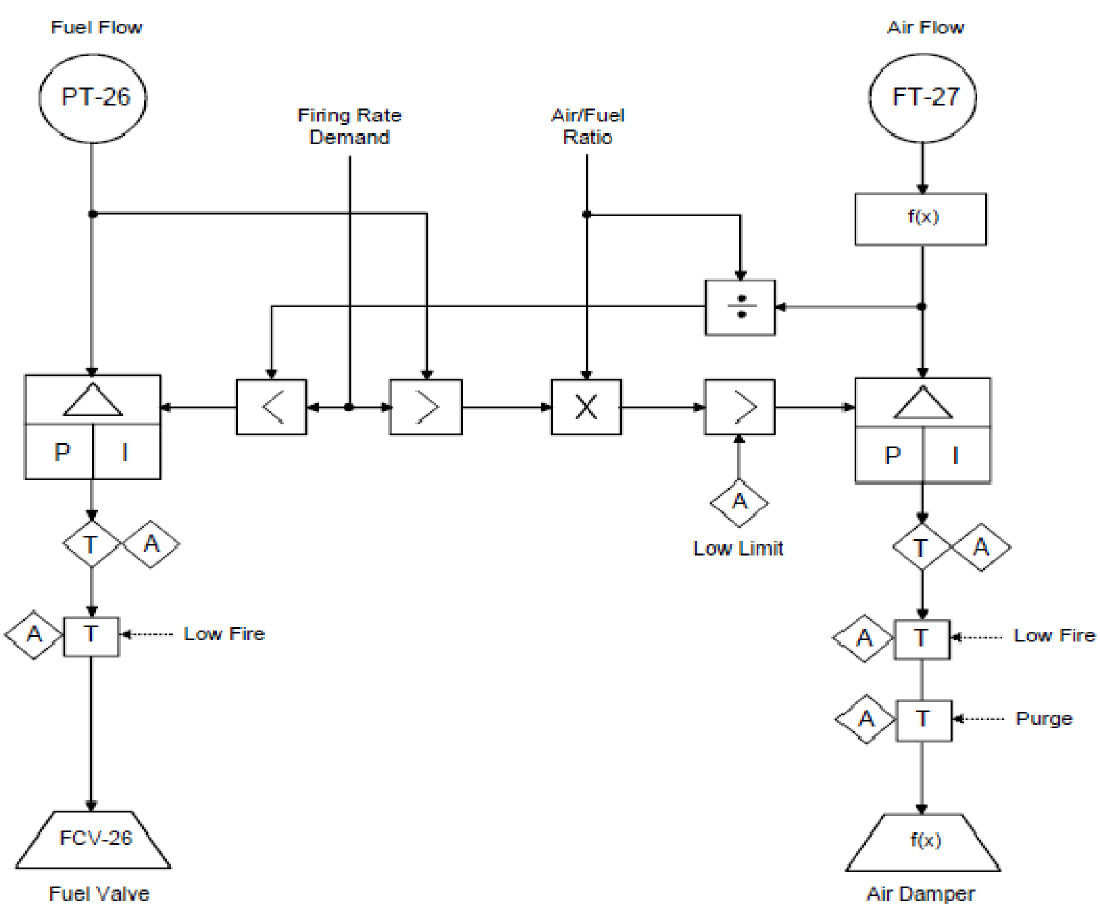
2-3-3-Full-Metered, Cross-Limited Control

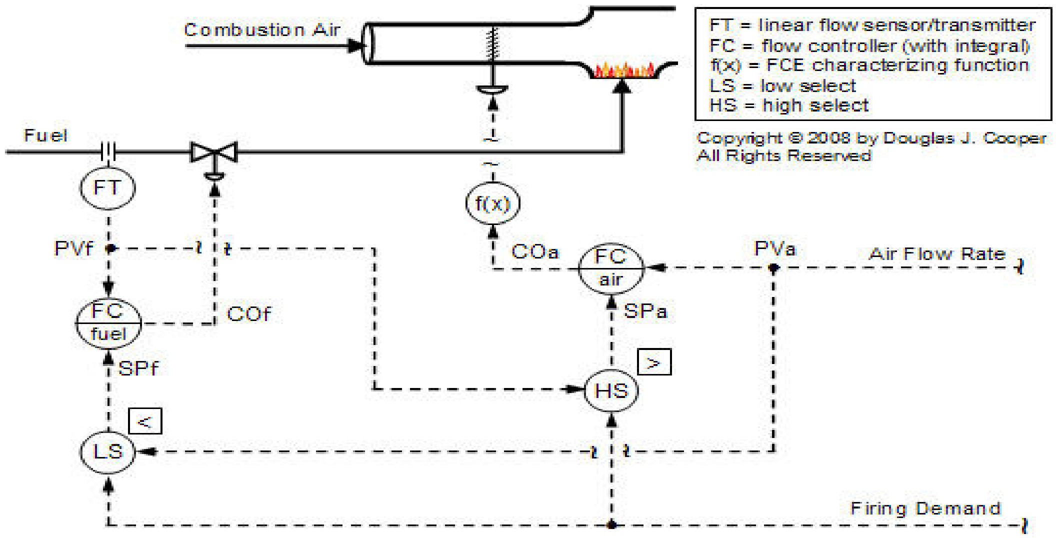
The full-metered, cross-limited control scheme is sometimes referred to as the standard control arrangement. Full metered control measures both the fuel and air flows in order to improve control of the air to fuel ratio. This control scheme:

- Compensates for fuel and combustion air flow variations
- Provides active safety constraints to prevent hazardous conditions in a metered control system, three measurements are used to balance the air/fuel mixture: steam header pressure, fuel flow, and air flow. As shown in Figure 6, the combustion controls consist of fuel flow and air flow control loops that are driven by the firing rate demand signal.

2-3-4-Certain assumption are used in the presentation that follows:

1. Air/fuel ratio is normally expressed as a mass flow ratio of air to fuel.
2. The air and fuel flow transmitter signals are linear with respect to the mass flow rate and have been scaled to range from 0-100%.
3. The flow transmitters have been carefully calibrated so that both signals at the design air/fuel ratio are one to one. That is, if the fuel flow transmitter signal, PVf, is 80%, then an airflow signal, PVa, of 80% will produce an airflow rate that meets the design air/fuel mass ratio. This enables us to implement the ratio strategy without using multiplying relays.





As shown above, the firing demand signal enters the high select override for the set point of the airflow controller (SPa). In this cross-limiting strategy, the same firing demand signal enters the low select override for the set point of the fuel flow controller (SPf).

As discussed in assumption 3 above, the flow transmitters have been calibrated so that when both signals match, we are at the design air/fuel mass flow ratio. Thus, because of the high select override, SPa is always the greater of the firing demand signal or the value that matches the current fuel flow signal. And because of the low select override, SPf is always the lesser of the firing demand signal or the value that matches the current airflow signal.

The result is that if firing demand moves up, the high select will pass the firing demand signal through as SPa, causing the airflow to increase. Because of the low select override, the fuel set point, SPf, will not match the firing demand signal increase, but rather, will follow the increasing air flow rate as it responds upward.

And if the firing demand moves down, the low select will pass the firing demand signal through as SPf, causing the fuel flow to decrease. Because of the high select override, the air set point, SPa, will not match the firing demand signal decrease, but rather, will track the decreasing fuel flow rate as it moves downward.

In short, the control system ensures that during sudden operational changes that move us in either direction from the design air/fuel ratio, the burner will temporarily receive extra air until balance is restored (we will be temporarily lean). While a lean air/fuel ratio means we are heating extra air that then goes up and out the stack, it avoids the environmentally harmful emission of carbon monoxide and unburned fuel.

2-3-5-Variable Air/Fuel Ratio

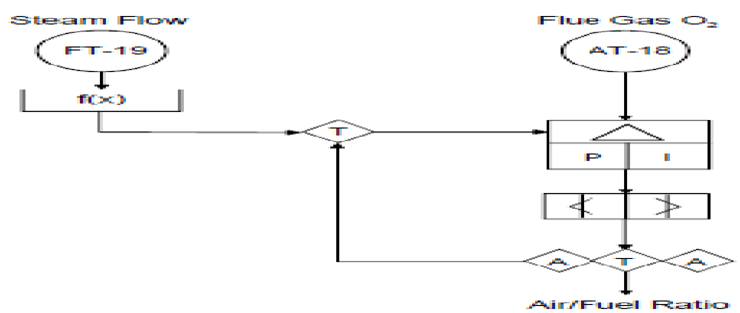
The basic cross-limiting strategy we have described to this point provides no means for adjusting the air/fuel ratio. This may be necessary, for example, if the composition of our fuel changes, if the burner performance changes due to corrosion or fouling, or if the operating characteristics of the burner change as firing level changes.

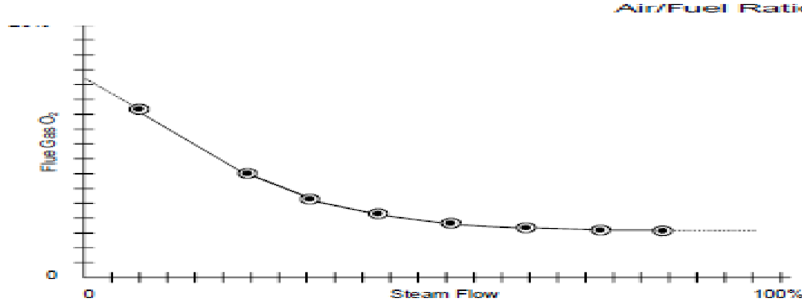
2-3-6-O2 Trim Control

The basic cross-limiting strategy we have described to air to fuel ratio control provides no means for adjusting the air/fuel ratio. This may be necessary, for example, if the composition of our fuel changes, if the burner performance changes due to corrosion or fouling, or if the operating characteristics of the burner change as firing level changes.

Automatic air/fuel ratio adjustment is often based on the percentage of excess oxygen (O2) in the flue gas. If the air and fuel are mixed in chemically correct (stoichiometric) proportions, the theoretical products of combustion are carbon dioxide and water vapor. Under ideal conditions, all of the oxygen supplied with the air would be consumed by the combustion process. Due to the dynamic nature of combustion, it is necessary to provide slightly more air than is theoretically required for the complete combustion of the fuel. This insures complete combustion an minimizes the formation of carbon monoxide. The result is a small percentage of excess oxygen in the flue gas. A flue gas oxygen analyzer supplies feedback on the combustion process and is the basis for trimming the air/fuel ratio to maintain optimum combustion.

Figure 7: shows one method of trimming the air/fuel ratio based on O2 control. The optimum percentage of O2 in the flue gas depends on the type of fuel and varies with load. Therefore, the O2 setpoint is characterized as a function of steam flow, which provides an index of the boiler load. Figure 8 shows a plot of excess O2 as a function of steam flow for a particular application. Controller output is restricted by high and low limiters to prevent driving the air/fuel ratio beyond safe and efficient operating points.





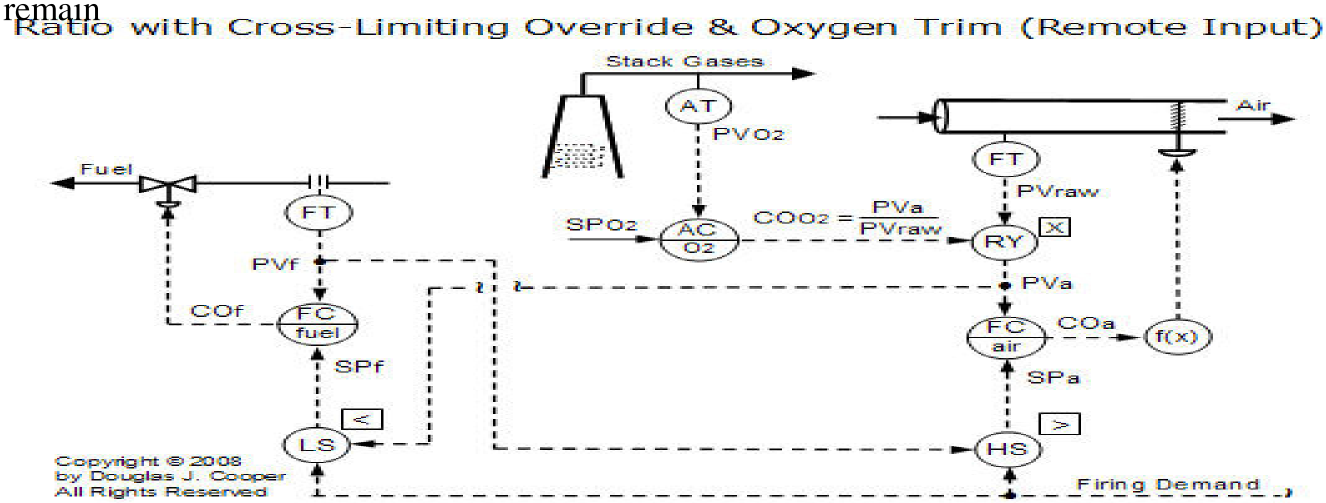
As shown in the diagram, the signal from the airflow transmitter, PVraw, is multiplied by the output of the analyzer controller, COO2, and the product is forwarded as the measured airflow rate process variable, PVa.

With this construction, if the measured exhaust oxygen, PVO2, matches the oxygen set point, SPO2, then the analyzer controller (AC) output, COO2 will equal one and PVa will equal PVraw.

But if the oxygen level in the stack is too high, COO2 will become greater than one. By multiplying the raw airflow signal, PVraw, by a number greater than one, PVa appears to read high. And if the oxygen level in the stack is too low, we multiply PVraw with a number smaller than one so that PVa appears to read low.

The ratio strategy reacts based on the artificial PV values, adjusting the air/fuel ratio until the measured oxygen level, PVO2, is at set point SP02.

This manipulation to the air/fuel ratio based on measured exhaust oxygen is commonly called oxygen trim control. By essentially changing the effective calibration of the airflow transmitter to a new range, the signal ratio of the carefully scaled air and fuel transmitters can remain



Fuel flow control logic The boiler is initially fired with warm up oil . At alater stage during start up, it is fired with natural gas or fuel oil .

(1) Fuel demand

The firing rate demand from Boiler Master forms the basic demand for fuel . The firing rate demand is cross limited with the measured air f low, the lower being selected. This is to prevent significant mismatch between air and fuel (Fuel demand > air f low).

2-4- Oil /Gas Ratio

The fuel demand is distributed to oil and gas fuel according to the oil /Gas Ratio setting by the operator. Oil /Gas Ratio setting by the operator is effective only on both fuel oil flow and main gas flow control AUTO.

The oil demand is calculated from fuel demand times the ratio setting . The gas demand is calculated from fuel demand less the oil demand. In case of main gas flow control manual, the oil flow demand is determined from total fuel demand less the measured gas flow. In case o f oil f low control manual, the gas f low demand is determined from total fuel demand less the measured fuel oil flow on fuel oil f low control manual.

2-4-1- Fuel oil flow control

The fuel oil flow is controlled by regulating opening of the fuel oil flow control valve to follow the oil flow demand**.** The control provides the minimum header pressure limitation .

2-4-2- Fuel gas flow control

The fuel gas flow is controlled by regulating opening o f the fuel gas f low control valve to follow the gas flow demand. The control provides the minimum / maximum header pressure limitation .

2-4-.3 Warm up oil flow control

The warm up oil flow is controlled by regulating opening of the warm up oil flow control valve to follow the fuel oil flow demand. Each of fuel oil flow and warm up oil flow control AUTO is only allowed.

2-4-4-Air flow control logic

Combustion air is supplied by Forced draft Fan. Fan output is controlled by regulating Fan inlet vane control drive . The firing rate demand forms the basic demand for air flow. The signal is subject to the following modifier.

(1) Boiler Input Rate (B IR) for air flow during load changing The purpose of this function is to ensure that the air flow is always in excess of requirements when the firing rate is being changed.

(2) Excess air cor reaction (O2 control) In order to ensure complete combustion, the amount of air supplied needs to be in excess o f that theoretically required to burn all the fuel . This additional component is called “excess air ”. The actual amount o f excess air can be determined by measuring the oxygen [O2] in flue gas . The desired oxygen setpoint is calculated by the function generator and the oxygen controller output is multiplied by the basic air flow demand.

(3) Minimum air flow The air demand is subject to a minimum limit (normally 30%MCR).

(4) Cross limit The cross limit prevents a serious deficiency o f air by ensuring that the air demand is not less than the fuel f low.

(5) Equalizing function The vane control has the equalizing logic between A and B. When a second FDF is started, the other operating FDF vane is automatically decreased according to the in crease of s tar ted FDF vane position to equalize both positions. When one FDF is t ripped, the other FDF vane position is immediately in creased in reverse for the decrease of the tripped FDF vane position to maintain the total air f low.

(6) AAP Inlet Air Damper Control AAP inlet air control damper is used for two stage combustion to reduce Nox. The position of these control dampers is determined by the separate function generator from the air flow demand.

2-5-FURNACE PRESSURE CONTROL

A basic boiler has a steam water system and a fuel-air-flue gas system. In the fuel-air-flue gas system, the air and fuel are mixed and ignited in the furnace. Air and fuel flow into the furnace and flue gas flows out. The force driving this flow is the differential pressure between the gases inside the furnace and those outside the furnace. Furnace pressure is commonly referred to as draft or draft pressure. The draft is maintained slightly negative to prevent the combustion products and ash from being discharged from the furnace into surrounding areas through inspection ports, doors, feeders, etc. For greatest efficiency, the controlled pressure should be as close as possible to atmosphere, thereby minimizing the ingestion of "tramp air" or excess air drawn through the openings in the furnace duct work that cool combustion gases. Furnaces are classified by the method for moving air and other gases through the system.

2-5-1-Natural Draft

A natural draft furnace uses the stack (chimney) effect. Gases inside the stack are less dense than those out-side the chimney. The gases in the stack will rise, creating a vacuum (suction) which will draw the combustion air into the furnace and combustion gases or flue gas out of the furnace. Natural draft furnaces naturally operate below atmospheric pressure.

2-5-2-Induced Draft

An induced draft fan draws the gases through the furnace and the combustion air into the furnace. An induced draft fan makes high stacks unnecessary. Control is accomplished by regulating the fan speed or damper operation. An induced draft furnace is operated slightly below atmospheric pressure.

2-5-3-Forced Draft

A forced draft furnace uses a fan or blower to force combustion air through the system. Control is accomplished by regulating the fan speed or damper operation. This type of furnace is operated slightly above atmospheric pressure.

2-5-4-Balanced Draft

Furnaces equipped with both FD and ID fans are called balanced draft systems. To control furnace pressure, it is necessary to maintain a balance between the flow in and flow out of the furnace. Balanced draft furnaces operate at slightly negative pressures to prevent flue gas leakage to the surroundings. However, too low a pressure must also be avoided to minimize air leakage into the furnace and, in the extreme, to prevent furnace implosion. As shown in Figure 10, the FD fan damper is generally manipulated by the air flow controller, and the ID fan damper is manipulated by the furnace pressure controller. When the air flow controller manipulates the flow into the furnace the pressure will be disturbed unless

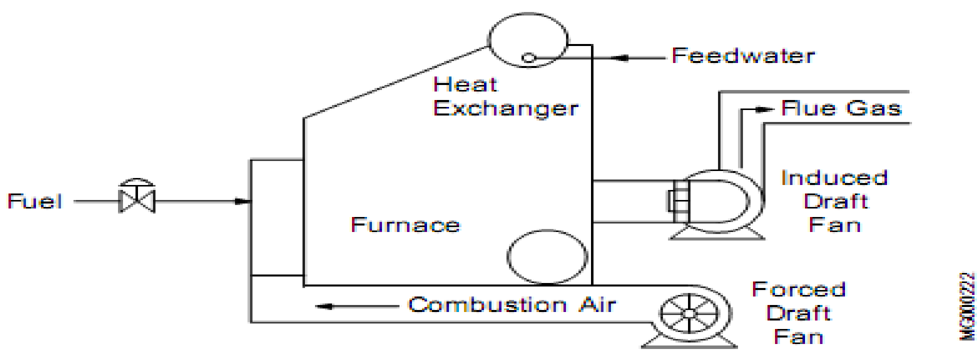


FIGURE 9 Typical Single Burner Boiler

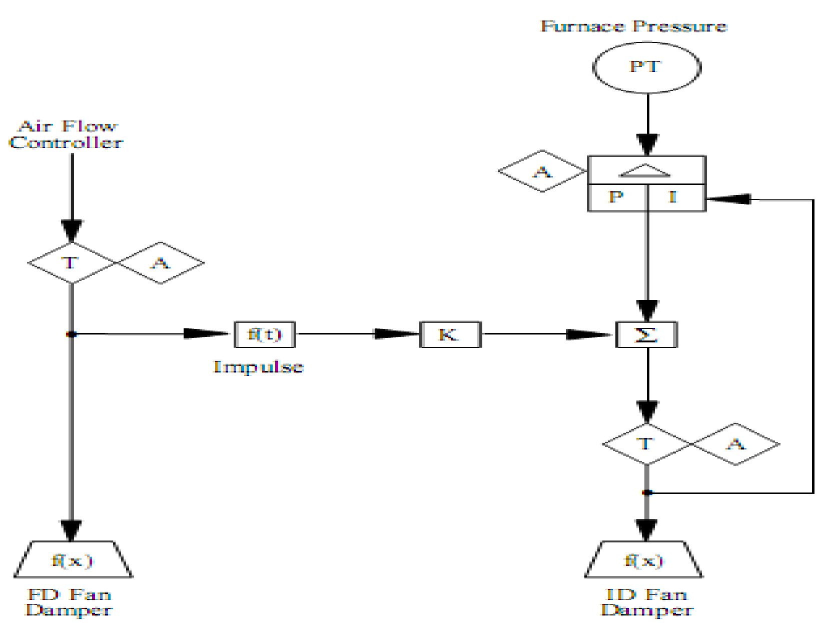
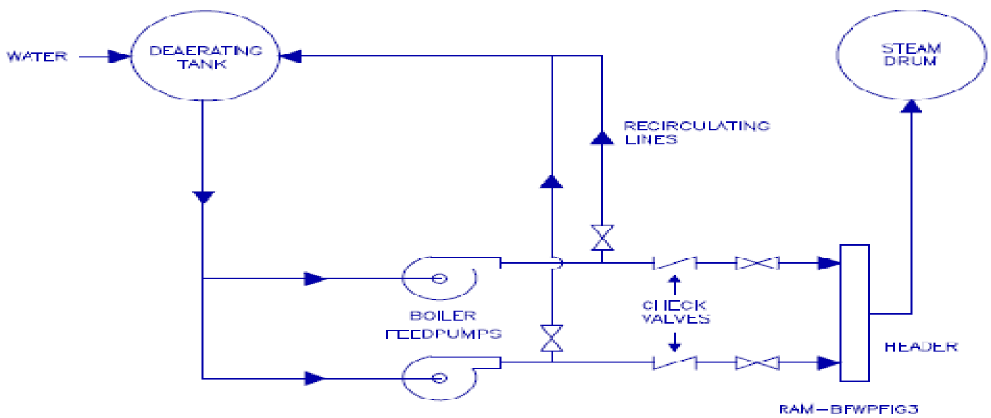


FIGURE 10 Furnace Pressure Control

2-6-BOILER DRUM LEVEL CONTROL

Boiler drum level control is critical for both plant protection and equipment safety and applies equally to high and low levels of water within the boiler drum.

The purpose of the drum level controller is to bring the drum up to level at boiler start up and maintain the level at constant steam load. A dramatic decrease in this level at constant steam load. A dramatic decrease in this level may uncover boiler tubes, allowing them to become overheated and damaged. An increase in this level may interfere with the process of separating moisture from steam within the drum, thus reducing boiler efficiency and carrying moisture into the process or turbine.



Water level indication and boiler water levels

Water level indication applies to steam boilers where the water level can be detected. It includes most steam boilers, the exception being those of the 'once through' or coil type, where there is no steam drum. In such cases, steam outlet temperatures exceeding a pre-set value are taken to indicate insufficient water input. In most cases, the simple gauge glass on the steam / water drum or boiler shell is used as the indicator. Many standards stipulate the provision of two gauge glasses. Arrangements are usually required to prevent a breakage from causing a hazard to the operator. The most common form of protection is a toughened glass screen to the front and sides of the water gauge glass. Water gauge glass constructed from flat or prismatic glass may be required for high-pressure boilers. The gauge glass device, which has stood the test of time, is used on the vast majority of boilers and is usually arranged to give a visible range of water level above and below the normal water level.

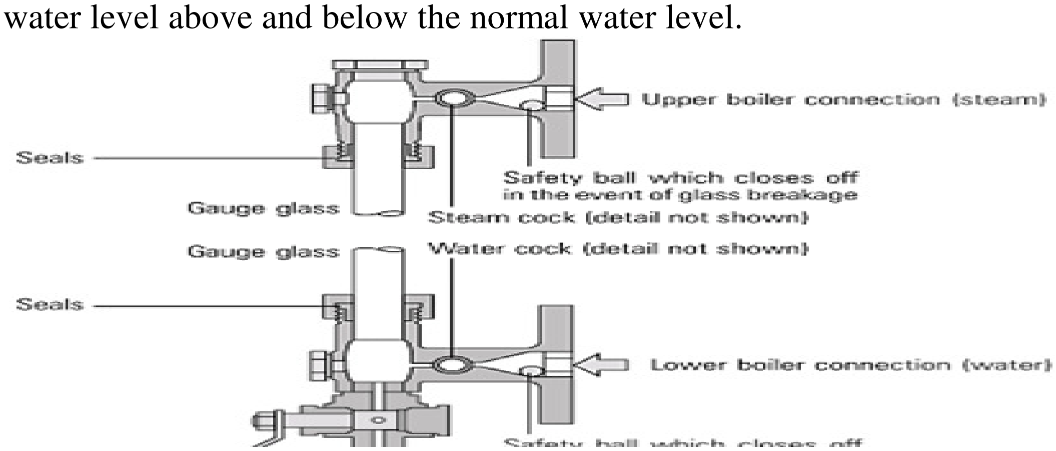


Fig. 3.15.2
Water gauge glass and mountings

It is essential to understand what is seen in a boiler gauge glass. The following Section explains some of the factors which will influence the level of water indicated in the gauge glass.

It is not possible to define the exact water level in a steaming boiler, because the water surface is made up of a mass of bubbles with a strong horizontal circulation. There are therefore, level variations both across and along the boiler shell. Conversely, the gauge glass contains water which:

- Is not subject to current and agitation
- Does not contain steam bubbles
- Is cooler than the water in the boiler

This means that the water in the gauge glass (and other external fittings) is denser than the water within the boiler shell. This in turn, means that the level gauge glass will show a lower level than the average water surface level in the boiler shell.

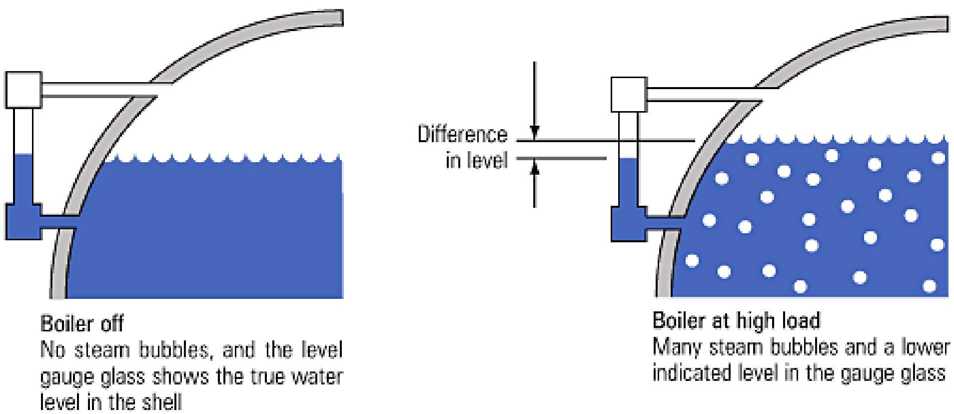


Fig. 3.15.3
Water level difference in the gauge glass

The difference between the level in the gauge glass and the level in the boiler shell at high steaming rates, depends on such factors as:

- The boiler steam generation rating
- The height of the gauge glass water connection into the boiler
- The TDS and chemical analysis of the boiler water
- The size of the boiler shell

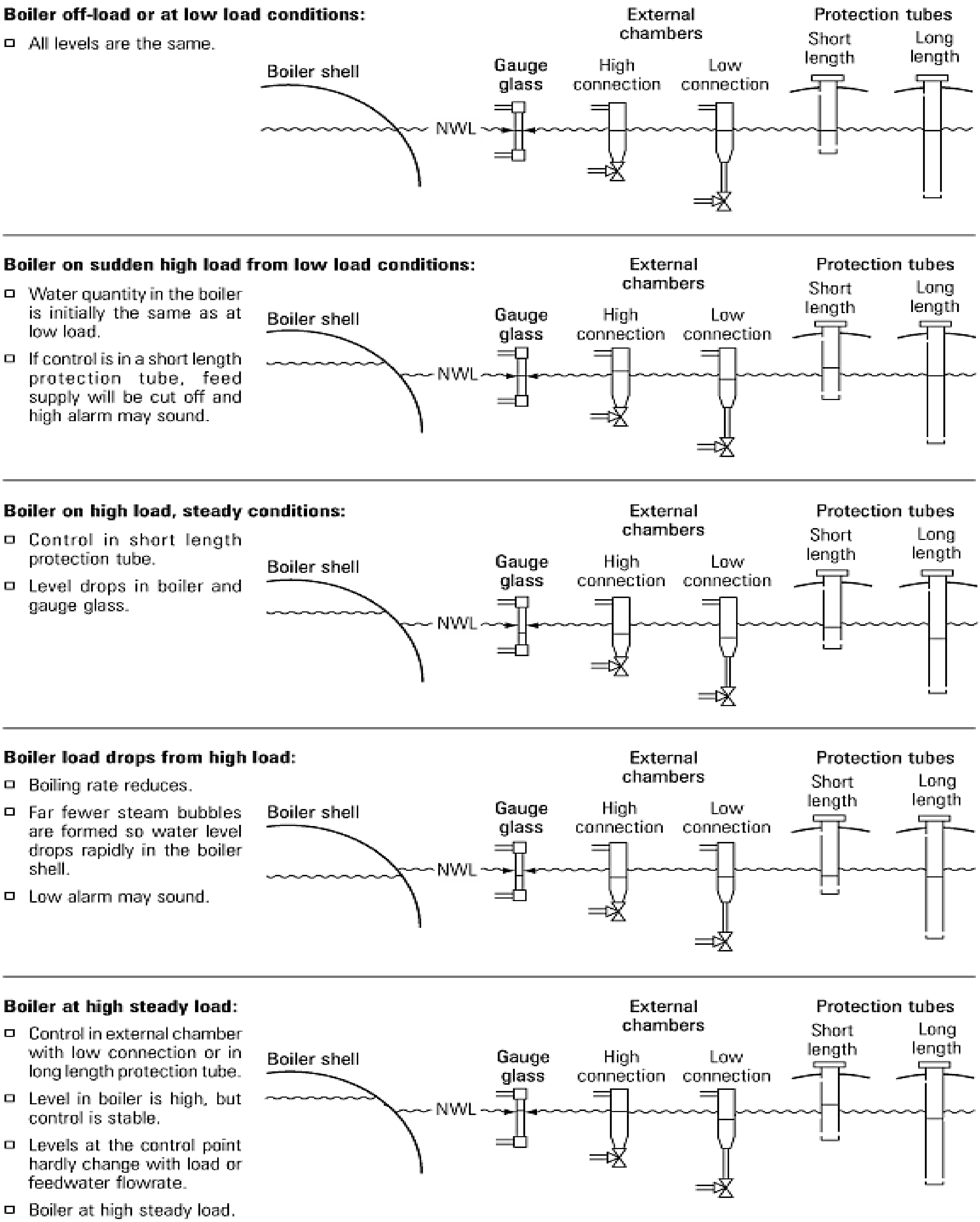
2-7-Level changes due to boiler circulation

With a boiler on high load, the strong circulation of the boiler water will cause the water level to vary along the length of the boiler. These circulation currents are normally considered to be upwards along the front and back of the boiler, and upwards along the centreline over the furnace.

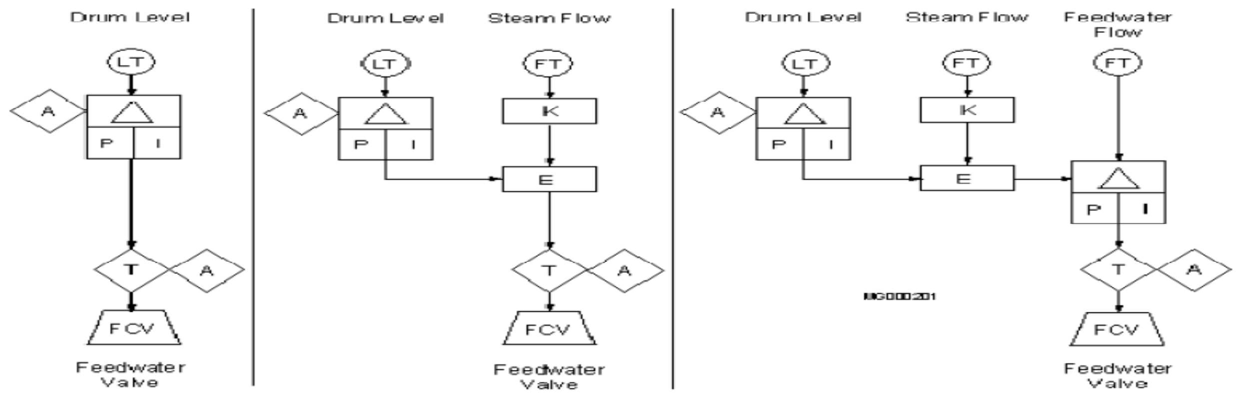
The downward circulation must therefore be at the sides, in the centre section of the boiler. There could also be a 'drawing' effect from the steam off-take connection which will tend to raise the water locally.

During sudden load changes there is also the possibility of waves developing in the boiler, which can often be seen in the level gauge glass, but should ideally be ignored by the water level controls.

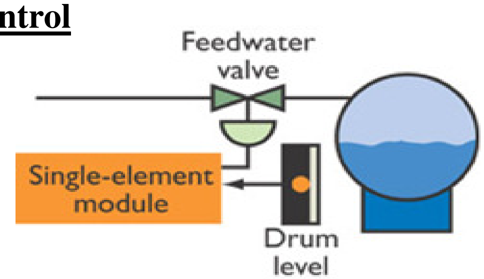
A summary of the level changes to be expected under various boiler conditions is illustrated in Figure 3.15.4.



The Three main options available for drum level control are



<u>2-7-1-Single element drum level control</u>

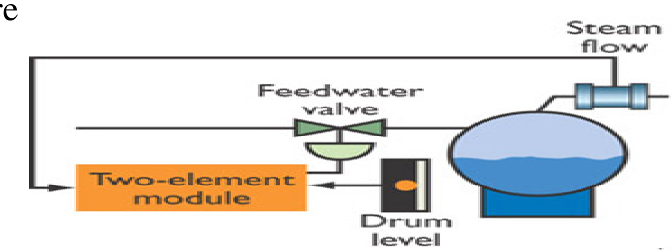


This consists of proportional signal or process variable (PV) coming from the drum level transmitter. This signal is compared to a set point and the difference is a deviation value.

This signal is acted upon by the controller which generates corrective action in the form of a proportional output. The output is then passed to the boiler feed water valve, which then adjusts the level of feed water flow into the boiler drum

2-7-2-Two elements drum level control

The two-element drum level controller can best be applied to a single drum boiler where the feed water is at a constant pressure



The two elements are made up of the following:

Level Element: a proportional signal or process variable (PV) coming from the drum level transmitter. This signal is compared to a set point and the resultant is a deviation value. This signal is acted upon by the controller which generates corrective action in the form of a proportional value.

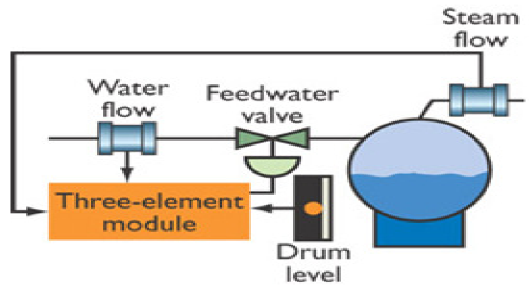
Steam Flow Element: a mass flow rate signal (corrected for density) is used to control the feed water flow, giving immediate corrections to feed water demand in response to load changes.

Any imbalance between steam mass flow out and feed water mass flow into the drum is corrected by the level controller.

This imbalance can arise from

- Blow down variations due to changes in dissolved solids
- Variations in feed water supply pressure
- Leaks in the steam circuits

2-7-3-Three-element drum level control



The three-element drum level control is ideally suited where a boiler plant consists of multiple boilers and multiple feed water pumps or where the feed water has variations in pressure or flow.

The three-elements are made up of the following:

Level Element & Steam Flow Element: corrects for unmeasured disturbances within the system such as:

- Boiler blowdown
- Boiler and superheater tube leaks

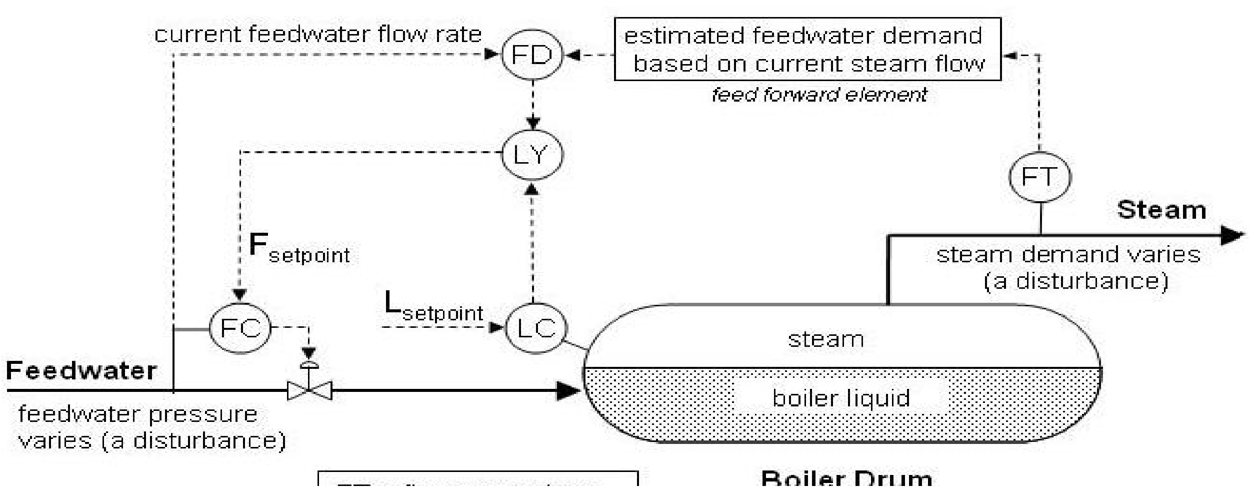
Feedwater Flow element: responds rapidly to variations in feedwater demand, either from :

- Steam flow rate feedforward signal
- Feedwater pressure or flow fluctuations

<u>2-8-Cascade, Feed Forward and Boiler Level Control of 3-element strategy</u>

As shown below, most boilers of medium to high pressure today use a “3-element” boiler control strategy. The term “3-element control” refers to the number of process variables (PVs) that are measured to effect control of the boiler feedwater control valve. These measured PVs are:

- liquid level in the boiler drum,
- flow of feedwater to the boiler drum, and
- flow of steam leaving the boiler drum.



Maintaining liquid level in the boiler steam drum is the highest priority. It is critical that the liquid level remain low enough to guarantee that there is adequate disengaging volume above the liquid, and high enough to assure that there is water present in every steam generating tube in the boiler. These requirements typically result in a narrow range in which the liquid level must be maintained.

The feedwater used to maintain liquid level in industrial boilers often comes from multiple sources and is brought up to steam drum pressure by pumps operating in parallel. With multiple sources and multiple pumps, the supply pressure of the feedwater will change over time. Every time supply pressure changes, the flow rate through the valve, even if it remains fixed in position, is immediately affected.

So, for example, if the boiler drum liquid level is low, the level controller will call for an increase in feedwater flow. But consider that if at this moment, the feedwater supply pressure were to drop. The level controller could be opening the valve, yet the falling supply pressure could actually cause a decreased flow through the valve and into the drum.

Thus, it is not enough for the level controller to directly open or close the valve. Rather, it must decide whether it needs more or less feed flow to the boiler drum. The level controller transmits its target flow as a set point to a flow controller. The flow controller then decides how much to open or close the valve as supply pressure swings to meet the set point target.

This is a “2-element” (boiler liquid level to feedwater flow rate) cascade control strategy. By placing this feedwater flow rate in a fast flow control loop, the flow controller will immediately sense any variations in the supply conditions which produce a change in feedwater flow. The flow controller will adjust the boiler feedwater valve position to restore the flow to its set point before the boiler drum liquid level is even affected. The level controller is the primary controller (sometimes referred to as the master controller) in this cascade, adjusting the set point of the flow controller, which is the secondary controller (sometimes identified as the slave controller).

The third element in a “3-element control” system is the flow of steam leaving the steam drum. The variation in demand from the steam header is the most common disturbance to the boiler level control system in an industrial steam system.

By measuring the steam flow, the magnitude of demand changes can be used as a feed forward signal to the level control system. The feed forward signal can be added into the output of the level controller to adjust the flow control loop set point, or can be added into the output of the flow control loop to directly manipulate the boiler feedwater control valve. The majority of boiler level control systems add the feed forward signal into the level controller output to the secondary (feedwater flow) controller set point. This approach eliminates the need for characterizing the feed forward signal to match the control valve characteristic.

Actual boiler level control schemes do not feed the steam flow signal forward directly. Instead, the difference between the outlet steam flow and the inlet water flow is calculated. The difference value is directly added to the set point signal to the feedwater flow controller. Therefore, if the steam flow out of the boiler is suddenly increased by the start up of a turbine, for example, the set point to the feedwater flow controller is increased by exactly the amount of the measured steam flow increase.

Simple material balance considerations suggest that if the two flow meters are exactly accurate, the flow change produced by the flow control loop will make up exactly enough water to maintain the level without producing a significant upset to the level control loop. Similarly, a sudden drop in steam demand caused by the trip of a significant turbine load will produce an exactly matching drop in feedwater flow to the steam drum without producing any significant disturbance to the boiler steam drum level control.

Of course, there are losses from the boiler that are not measured by the steam production meter. The most common of these are boiler blow down and steam vents (including relief valves) ahead of the steam production meter. In addition, boiler operating conditions that alter the total volume of water in the boiler cannot be corrected by the feed forward control strategy. For example, forced circulation boilers may have steam generating sections that are placed out of service or in service intermittently. The level controller itself must correct for these unmeasured disturbances using the normal feedback control algorithm.

2- 9-Swell and Shrink:

When a boiler's steam flow rate changes, an energy and mass imbalance is introduced to the system. The energy imbalance causes the combustion controls to change the firing rate in response to an change in steam demand. The mass imbalance between steam leaving the drum and feedwater entering the drum causes the drum level controls to adjust feedwater flow to re-achieve balance and maintain level in the drum. Clearly, when the steam flow is increased the feedwater flow must be equally increased, and when the steam flow is decreased the feedwater flow must be equally decreased. Intuitively, it seems that the faster the feedwater flow is changed to match a change in steam flow, the better the control, but this is not the case.

The initial response of boiler drum level to a load change is called inverse response. This means that drum level does the opposite of what would be expected when the steam load changes. For example, if the steam flow from the boiler is increased, the drum level initially begins to rise even though the drum will eventually run dry if feedwater is not increased. Likewise, if the steam flow is reduced, the drum level initially begins to fall. The initial level rise upon increasing load is called "swell", while the initial drop in level upon a decreasing load is called "shrink Swell and shrink can be easily understood by example. Consider a boiler firing at steady-state. At any given load, the water within the drum, boiler tubes and mud drum coexists with the bubbles of steam that are being generated. If the demand for steam suddenly increases, the resultant increase in steam flow from the drum causes a drop in drum pressure. Since steam generation rate is a function of drum pressure, the drop in pressure instantly causes more steam to be produced. This means that more steam bubbles are coexisting within the water "inventory" of the boiler and the steam-to-water ratio below the water surface increases. Because steam has a greater specific volume than water, the drum level rises or "swells" until the new steam generation rate stabilizes.

Once the new steaming rate does stabilize, the mass flow imbalance between the feedwater and steam flows will cause the drum level to quickly drop unless the feedwater flow is increased. This makes controlling the drum level difficult. If the demand for steam suddenly decreases, a similar but opposite effect occurs. In this scenario, drum press instantly increases thus reducing the steam generation rate the new steam generating rate stabilizes. Once stabilized, the drum level will quickly begin to rise unless the feedwater flow is reduced to balance with the new steam flow rate.

The swell and shrink phenomena pose a control problem to standard level controllers because a steam load change causes the controller to initially change feedwater flow in the wrong direction. This causes greater variability and larger excursions in the drum level, and it also causes interactions with the combustion controls, thus reducing the ability of the boiler to respond to load swings. A more complex 3- element control strategy, as already discussed, includes control action based on both level and steam flow changes to help eliminate these problems. When properly adjusted, this control strategy balances the influence of level with the influence of steam flow thus eliminating incorrect response to swell and shrink and allowing time for the boiler water inventory to re-adjust gradually. Ultimately, this results in optimum drum level control with a minimum of level variation and combustion control interaction. What this means with respect to the feedwater control valve is that 3-element drum level control, by design, will not change the valve position quickly, but rather, smoothly ramp it in the proper direction allowing the water inventory to gradually change. **Figures 2A, 2B & 2C** show the response of properly and improperly adjusted 3-element drum level control strategies.

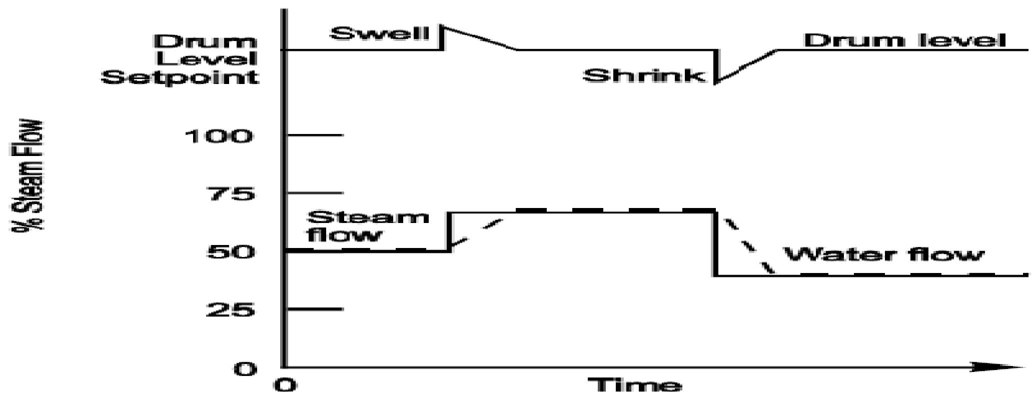
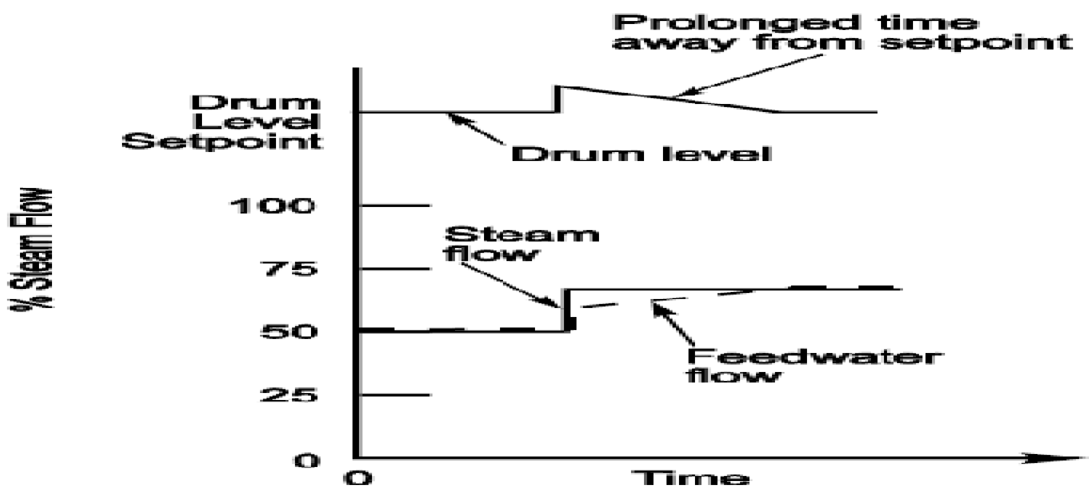
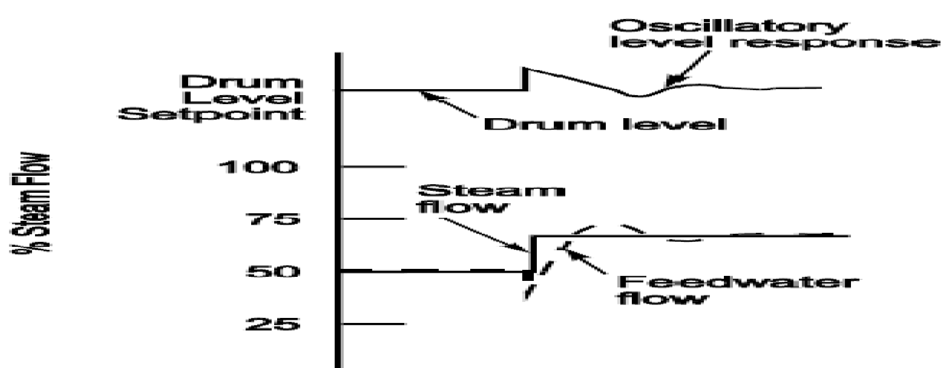


Figure 2A Proper Balance of Feedwater Control Influences





2-10-Steam Temperature Control

Steam temperature is one of the most challenging control loops in a power plant boiler because it is highly nonlinear and has a long dead time and time lag. Adding to the challenge, steam temperature is affected by boiler load, rate of change of boiler load, air flow rate

After separation from the boiler water in the drum, the steam is superheated to improve the thermal efficiency of the boiler-turbine unit. Modern boilers raise the steam temperature to around 1000F (538C), which approaches the creep (slow deformation) point of the steel making up the superheater tubing. Steam temperatures above this level, even for brief periods of time, can shorten the usable life of the boiler. Keeping steam temperature constant is also important for minimizing thermal stresses on the boiler and turbine.

Steam temperature is normally controlled by spraying water into the steam between the first and second-stage superheater to cool it down. Water injection is done in a device called an attemperator or desuperheater. The spray water comes from either an intermediate stage of the boiler feedwater pump (for reheater spray) or from the pump discharge (for superheater spray). Other methods of steam temperature control include flue gas recirculation, flue gas bypass.

This discussion will focus on steam temperature control through attemperation. The designs discussed here will apply to the reheater and superheater

2-10-1-Steam temperature control logic

SH Steam Temperature Control

5.1 SSH out let s team temperature control

SSH out let temperature is controlled by varying opening of 1st spray water control valve to keep the temperature at the setpoint value.

1) Cascade control (two controllers) is applied to obtain fast and s table control .
   - Primary controller : SSH out l e t steam temperature control
   - Secondary controller : SSH inlet steam temperature control
2) Dynamic feedforward signal (BIR) is added to SSH inlet steam temperature setpoint to improve dynamic per formance during load change.
3) The average o f SSH out let temperature is used as the feedback for the primary controller. The output of the unbalance controller which equalizes the differential temperature between the east side and west side of SSH out let temperature is added or subtracted to common SSH inlet steam temperature setpoint .
4) The saturation limit function at SSH inlet is provided.
5) 1st spray water control valve has the redundancy (100% capacity) . The transfer o f valve is allowable only on both control valves manual for the safety.

2-10-2- Main steam temperature control

Main steam temperature is controlled by varying opening of 2nd spray water control valve to keep the temperature at the setpoint value.

1) Cascade control (two controllers) is applied to obtain fast and stable control .
   - Primary controller : Boiler outlet steam temperature control
   - Secondary controller : TSH inlet steam temperature control
2) Dynamic feedforward signal (BIR) is added to FSH inlet steam temperature setpoint to improve dynamic performance during load change.
3) The average of SSH out let temperature is used as the feedback for the primary controller.
4) The saturation limit function at TSH inlet is provided.
5) 2nd spray water control valve has the redundancy (100% capacity). The transfer of valve is allowable only on both control valves manual for the safety.

RH Steam Temperature Control

The reheater steam temperature can be controlled by regulating gas recirculation flow or RH spray.

6 .1 Gas Recirculation control:

RH outlet steam temperature is normally controlled by regulating the gas recirculation flow. Increased flue gas flow over Reheater of the convection heating surfaces increases the heat absorption and RH temperature is increased.

The amount of gas recirculation flow is controlled by positioning the inlet dampers on the two Gas Recirculation Fans (GRF).

1) During s tart up (approximately <25% boiler load) , GRF inlet damper position is control l e d by the function generator from Boiler Master. Because RH temperature feedback control is difficult during the start up due to the slow response.
2) Dynamic feedforward signa l (BIR) is added to GRF inlet damper to improve RH steam temperature control during load change.
3) High and low limit from Boiler Master for GRF inlet damper are provided. High limit is to avoid the unstable combust ion and the over current of GRF. And low limit is to protect the water wall and avoid the high Nox.
4) Equalizing function GRF inlet damper ha s the same equalizing logic as FDF inlet vane to equalize A and B.

6.2 RH spray control:

RH spray is provided for emergency case or load change if high RH outlet steam temperature occurs. The RH spray control may also be used if the GR fans are on manual control or minimum limit .

1) The RH outlet steam temperature set point bias is changed from the normal value to small value during the load change, GRF inlet damper manual or minimum limit.
2) Dynamic feedforward signal (B IR) is added to RH spray to improve RH steam temperature control during load change.
3) The saturation limit function at R H inlet is provided.

2-11-Temperature control methods

2-11-1-BASIC FEEDBACK CONTROL

The simplest method for controlling steam temperature is by measuring the steam temperature at the point it exits the boiler, and changing the spray water valve position to correct deviations from the steam temperature set point (Figure 1).

This control loop should be tuned for the fastest possible response without overshoot, but even then the loop will respond relatively slowly due to the long dead time and time lag of the superheater.

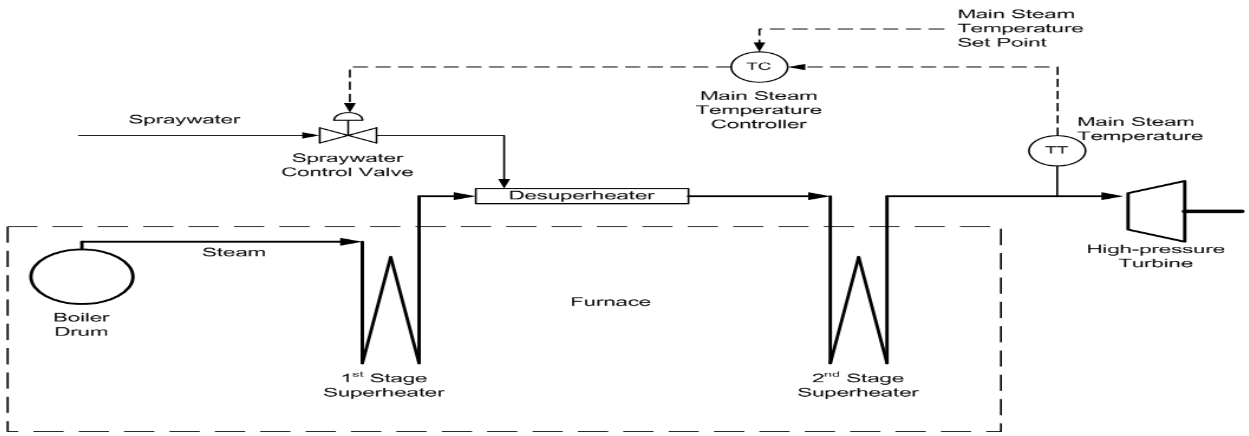


Figure 1. Simple Steam Temperature Control

2-11-2-CASCADED STEAM TEMPERATURE CONTROL

Because of the slow response of the main steam temperature control loop, improved disturbance rejection can be achieved by implementing a secondary (inner) control loop at the desuperheater. This loop measures the desuperheater outlet temperature and manipulates the control valve position to match the desuperheater outlet temperature to its set point coming from the main steam temperature controller (Figure 2).

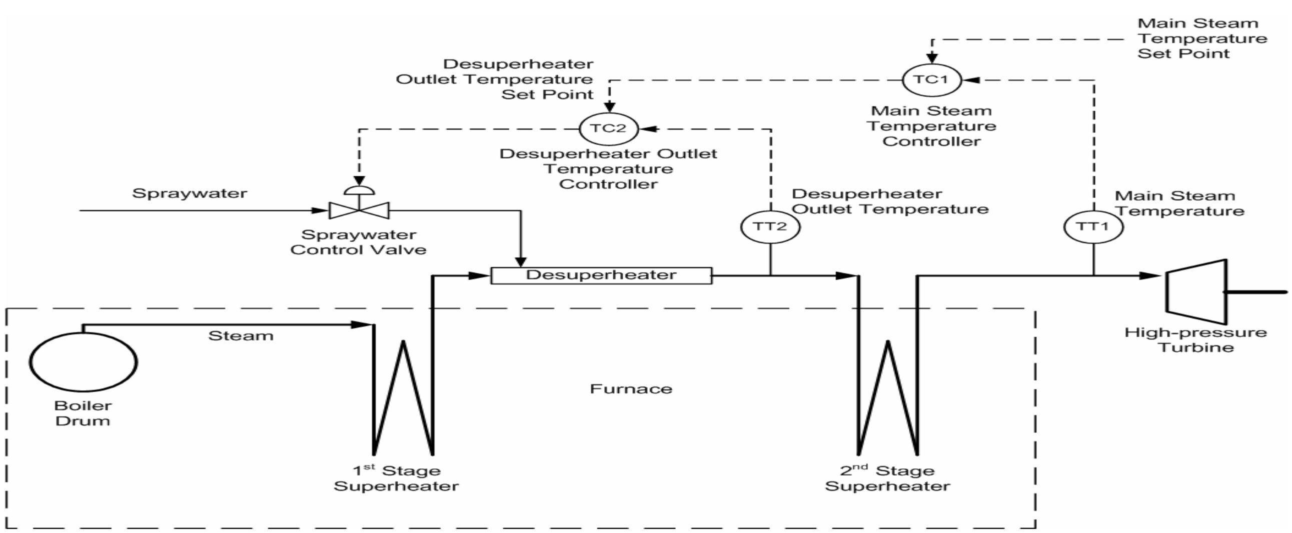


Figure 2. Cascaded Steam Temperature Controls

The spray water comes from upstream of the feedwater control valves, and changes in feedwater control valve position will cause changes in spray water pressure, and therefore disturb the spray water flow rate. The desuperheater outlet temperature control loop will provide a gradual recovery when this happens. If the spray water flow rate to the attemperator is measured, a flow control loop can be implemented as a tertiary inner loop to provide very fast disturbance rejection. However, in many cases spray water flow rate is not measured at the individual attemperators and this flow loop cannot be implemented.

2-11-3-GAIN SCHEDULING

The process dead time of the superheater increases with a decrease in boiler load because of the slower rate of steam flow at lower loads. This will have a negative impact on the stability of the main steam temperature control loop unless gain scheduling is implemented. Step tests need to be done at low, medium, and high boiler loads, and optimal controller settings calculated at each load level. A gain scheduler should be implemented to adjust the controller settings according to unit load. Because of the changing dead time and lag of the superheater, The gain of the desuperheater outlet temperature loop will be affected by steam flow rate.

Changes in steam flow rate will affect the amount of cooling obtained from a given spray water flow rate. Less cooling will occur at high steam flow rates. In addition, at high loads the pressure differential between the feedwater pump discharge and steam pressure will be lower, reducing the spray flow rate for a given spray valve position (assuming the absence of a flow control loop on the desuperheater spray flow). To compensate for these nonlinear behavior, controller gain scheduling should be implemented on the desuperheater outlet temperature loop too. Fugure 3 shows the basic design of the steam temperature controller gain scheduler (cascaded controller is not shown for clarity). Similar to tuning the main steam temperature control loop, step tests must be done at low, medium, and high boiler loads to design the gain scheduler.

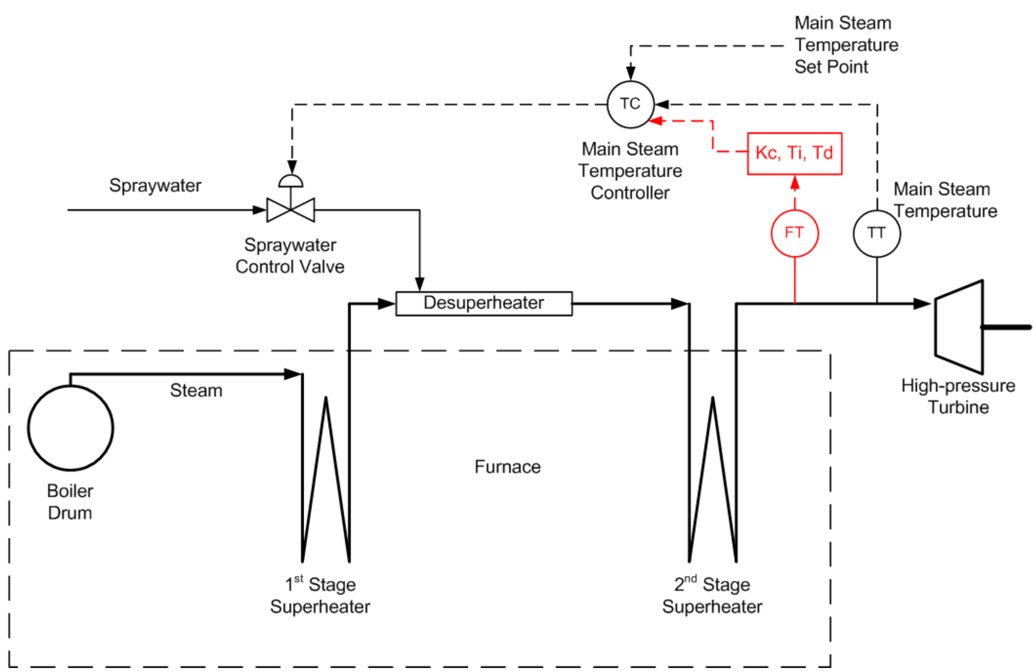


Figure 3. Steam Temperature Controller Gain

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