UNIT - III
BOILER CONTROL – I

Combustion of fuel and excess air – Firing rate demand – Steam temperature control– Control of deaerator – Drum level control: Single, two and three element control – Furnace draft control – implosion – flue gas dew point control – Trimming of combustion air – Soot blowing

WHY BOILER CONTROL?
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.

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.

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.

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.

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PURPOSE

- The drum-type watertube boiler is the fundamental steam generator for both industrial and utility applications.
- The steam generated by a boiler may be used as a heat transfer fluid for process heating, or it may be expanded in steam turbines to drive rotating machinery such as fans, compressors, or electric generators.
- Figure 1 is a schematic representation of a drum-type boiler.
- The steam drum and mud drum are mounted in a furnace and are interconnected with watertubes called risers and downcomers.
- The furnace includes one or more burners for the combustion of an air and fuel mixture.
- The heat of combustion is transferred to the watertubes to generate steam.
- Steam bubbles form in the tubes (risers) closest to the burner and rise to the steam drum where they are separated from the water.
- The steam in the risers is replaced by water in the downcomers to provide natural circulation in the watertubes.
- A continuous supply of feedwater is necessary to replace the steam leaving the boiler.
- In most cases, the saturated steam leaving the steam drum is returned to the furnace for superheating as shown in Figure 1.

![Figure 1: Basic Mud-Drum Boiler](image)

- A forced draft (FD) fan provides combustion air to the windbox from which it is delivered to the burners.
- An induced draft (ID) fan draws the flue gases from the furnace and drives them up the stack.
- Heat from the flue gas is used to preheat the combustion air to improve efficiency.
- 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 feedwater and the correct mixture of air and fuel for safe and economical combustion.
This document shows the basic boiler control diagrams that are common to nearly all boiler control systems.

STEAM PRESSURE CONTROL (Firing rate demand)

Plant Master Control

- Steam pressure is the key variable that indicates the state of balance between the supply and 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 setpoint.
- Plants may experience fluctuations in demand due to batch processes or other process changes.
- In this case, a steam flow feedforward signal is used with steam pressure control.
- The term Plant Master is most applicable to the situation in which more than one boiler supplies a common steam header.
- In this case, there are multiple boiler masters but only one plant master.
- The plant master generates the master firing rate demand signal that drives the individual boilers in parallel.
- With multiple boilers, the Plant Master is typically configured with a variable gain, based on the number of boilers in automatic mode.

Boiler Master Control

- With several boilers supplying a common header in parallel, it is generally desirable to provide a way to adjust the load distribution among the boilers.
- Depending on the load and the performance of the individual boilers, the most efficient operation may be achieved with some boilers shut down, some boilers base loaded (constant firing rate), and the remaining boilers allowed to swing with the load (variable firing rate).
- Figure 3 shows a boiler master control diagram to provide these adjustments.
- Each boiler master provides a bias adjustment and an auto/manual transfer switch.
In manual, the operator can reduce the firing rate to a low fire condition for shutdown, or hold the firing rate at any appropriate base loading condition.

In auto, the boiler master follows the master firing rate demand signal except as altered by the bias adjustment.

The operator can adjust the boiler master bias up or down to increase or decrease its share of the load.

COMBUSTION CONTROL

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.

**Single Point Positioning Control**

The simplest combustion control system which 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**.

A single-point positioning system 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 air damper positioners 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.

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 damper are positioned based on this signal.

Figure 4 shows the simple feedback control scheme used in single-point positioning.

**Parallel Positioning Control**

The parallel positioning control system uses a similar strategy as single point positioning for combustion control.

However, parallel positioning refers to two outputs used in parallel to control the fuel valve and the air damper.

It is commonly used on **package boilers**.

In a parallel positioning control strategy, only one measurement is used.
- 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 valve are positioned based on this signal.
- 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.

![Figure 4: Single Positioning Control](image1)

**Figure 4**
Single Positioning Control

![Figure 5: Parallel Positioning Control](image2)

**Figure 5**
Parallel Positioning Control

**Full-Metered, Cross-Limited Control**

- The full-metered, cross-limited control scheme is sometimes referred to as the standard control arrangement.
- For metered, cross-limiting control, the fuel and combustion air flows are used to improve control of the air to-fuel-ratio.
- The benefits of this control scheme are:
  - 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 fuel/air mixture.
- These are the steam header pressure, the fuel flow, and the 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.
- The characterizer on the air flow measurement scales the air flow signal relative to the fuel flow signal to provide the optimum air/fuel ratio.
- The characterizer points are determined empirically by testing the boiler at various loads and adjusting the fuel relative to the air at each test load as needed to achieve optimum combustion.
- This allows the air and fuel flow setpoints to be driven by the same firing rate demand signal.
- The cross-limiting (or lead-lag) circuit assures an air-rich mixture since the air flow setpoint will always lead the fuel on an increasing load and lag when the load is decreasing.

![Figure 6 Full-Metered, Cross-Limited Combustion Control](image)

**O₂ Trim Control**
- Automatic air/fuel ratio adjustment is generally based on the percentage of excess oxygen (O₂) in the flue gas.
- If 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 incomplete mixing, however, it is always necessary to provide more air than the theoretically correct mixture.
- This results in a small percentage of excess O₂ 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.
- The controller output is clamped by high and low limits to prevent driving the air/fuel ratio beyond unsafe or inefficient limits.
STEAM TEMPERATURE CONTROL:

- Accurate steam temperature control is necessary for avoiding the over stressing of superheater tubes and turbine front stages and to maintain overall efficiency as high as possible.
- Heating the steam further from saturation temperature is called superheating.
- Saturated steam from the boiler is passed through superheaters, where the heat energy from combustion gases is added to it to generate superheated steam.
- Water side steam temperature control
  - Desuperheater
  - Attemperator
  - Diverting part of the feed water through attemperator for condensing partially saturated boiler steam
- Fire side steam temperature control
  - Excess air control
  - Flue gas bypass control
  - Adjustable / tilting burner control

Water side steam temperature control

- Desuperheater action is just reverse of superheater action.
- The temperature and heat content of steam is reduced here unlike the superheater which increases the temperature and heat content of steam.
- Desuperheater may be located either between two successive sections of the superheater or at superheater outlet.
- Contact type or spray type one are called desuperheaters and the non contact shell type ones are sometimes called attemperators.
Desuperheater:
- A separate line is drawn from the main feed water pipe before it enters economizer.
- The water flowing through this separate line is sometimes called injection water.
- Injection water flow is manipulated variable for controlling the temperature, the process variable.
- FCE are installed in this line to regulate the amount of spray water as per demand.
- The injected water joins the main steam flow and evaporates.
- By absorbing latent heat of steam the injection water cools the steam.
- By varying the amount of injection water, the steam temperature control can be made possible.
- Figure 9 shows the arrangement of desuperheater.

![Figure 9: Temperature Control – Spraying Cold Water](image)

Attemperator; diverting part of the steam:
- Part of steam is diverted with the help of dividing plate with orifice plate and a control valve in the diverted line.
- This arrangement is shown in figure 10.
- The diverted steam flow is passed through an attemperator, shell and tube heat exchanger, before mixing up with the rest of the main steam.
- The diverted steam flow becomes manipulated variable.

![Figure 10: Attemperator Diverting Part of the Steam](image)
Attemperator: diverting part of feed water:
- Part of the feed water is diverted to an attemperator (a shell and tube heat exchanger) to remove variable amount of the latent heat and control the final steam temperature.
- The outlet feed water from the attemperator joins back the main feed water coming out of economizer and before entering the boiler drum.
- This arrangement is shown in figure 11

![Figure 11 Attemperator Diverting Part of the Feed Water](image)

Fire side steam temperature control:
Excess Air control:
- One of the methods of fire side temperature control is the raising and lowering of the percentage of excess air in order to control steam temperature.
- This method tends to improve the overall heat rate of power generation equipment though the thermal efficiency of boiler itself may be lowered.
- This method may be used on a boiler that was not specifically designed for temperature control.
- Although increasing excess air flow increases boiler stack heat losses, turbine thermal efficiency will be increased thus providing greater economic benefit.
- Figure 12 shows the excess air control

![Figure 12 Excess Air Control](image)

Flue gas bypass Control:
- The flow stream of the flue gas passing through the superheater can be split, so that the mass of flue gas in contact with superheater can be varied.
- Such a mechanism is called a superheater bypass damper as shown in the figure.
The required position of damper as a function of load variation is well established for any boiler design. Therefore it is a common practice to program their position as a function of load. Controller output varies directly with load and this tends to cancel the inversely varying process gain. This arrangement is shown in figure 13

Figure 13 Super heater Bypass Damper Control

Adjustable / Tilting Burner Control:
- Burners mounted in the furnace corners are arranged so that the flame can be tilted up/down from horizontal.
- By this arrangement the temperature of the flue gas entering the superheater can be changed.
- Burner flame is aimed at a tangent to an imaginary circle in center of furnace and the burners in four corners tilted at same angle results in a fire ball in centre of the furnace which can be lowered / raised in the furnace by tilting the burners
- Lowering fire ball increases furnace heat absorption, which lowers the flue gas temperature as it enters the superheater.
- Raising fireball decreases heat absorption, with opposite effect on the temperature of flue gases entering the superheater
- Burners in fixed wall of the furnace can be elevated to higher or lower
- By varying the ratio of the fuel in the upper row of burners to that of in the lower row of burners, the furnace heat absorption can be modified, thereby changing the temperature of the flue gases entering the superheater.
- Figure 14 (a) shows the arrangement of tilting burner and Figure 14 (b) shows the Adjustable burner arrangement.
Combination of both Water side and Fire side control:

- Temperature control by desuperheater can be used to supplement the gas manipulation or burners position tilting.
- This effectively changes the furnace heat transfer area, resulting in temperature changes of flue gases leaving the boiler.
- Spray is frequently used with these systems as an override control.
- Following figure 15 shows the Combination of both Water side and Fire side control.

CONTROL OF DEAERATOR:

- It is highly recommended to eliminate the entrained or dissolved gases like Oxygen and Carbon-dioxide (CO\textsubscript{2}) from the feed water before entering the boiler.
- If Carbon-dioxide remains in the water, it will be carried along with steam and get converted into corrosive carbonic acid.
- Heat exchangers that use the steam and the steam carrying pipelines will get corroded.
- The dissolved oxygen, if not removed, can corrode the boiler seriously.
- The process of elimination of such dissolved gases from the feed water before allowing it to the boiler is called Deaerator (Deaeration)
- Water can hold the dissolved gases in greater amounts at low temperature.
- Vigorous boiling and venting the gases to atmosphere helps remove the dissolved gases.
- Water is directly heated with steam (Extracted from turbine) to form an intimate mixture of steam and water at boiling point.
- The entrained or dissolved gases get released from the water.
- The released gases are then vented out to atmosphere.
- The deaeration process eliminates them as efficiency as possible.
- The remaining traces of dissolved gases can be further removed by scavenging chemicals.
- The water leaving the deaerator heater is deposited into an integrated heated water storage tank which is connected to the section of the boiler feed pumps.

**Types of Deaerator is**
- Tray Type
- Spray Type

![Diagram of Spray Type](image)

Spray Type:
- As shown in above figure 16.a, the typical spray-type deaerator is a horizontal vessel which has a preheating section (E) and a deaeration section (F).
- The two sections are separated by a baffle (C).
- Low-pressure steam enters the vessel through a sparger in the bottom of the vessel.
- The boiler feedwater is sprayed into section (E) where it is preheated by the rising steam from the sparger.
- The purpose of the feedwater spray nozzle (A) and the preheat section is to heat the boiler feedwater to its saturation temperature to facilitate stripping out the dissolved gases in the following deaeration section.
- The preheated feedwater then flows into the deaeration section (F), where it is deaerated by the steam rising from the sparger system.
- The gases stripped out of the water exit via the vent at the top of the vessel.
The deaerated boiler feedwater is pumped from the bottom of the vessel to the steam generating boiler system.

**Tray Type:**

- The typical tray-type deaerator in shown in figure 16.b, has a vertical domed deaeration section mounted above a horizontal boiler feedwater storage vessel.
- Boiler feedwater enters the vertical deaeration section above the perforated trays and flows downward through the perforations.
- Low-pressure deaeration steam enters below the perforated trays and flows upward through the perforations.
- Some designs use various types of packed bed, rather than perforated trays, to provide good contact and mixing between the steam and the boiler feed water.
- The steam strips the dissolved gas from the boiler feedwater and exits via the vent valve at the top of the domed section.
- The deaerated water flows down into the horizontal storage vessel from where it is pumped to the steam generating boiler system.
- Low-pressure heating steam, which enters the horizontal vessel through a sparger pipe in the bottom of the vessel, is provided to keep the stored boiler feedwater warm.
- External insulation of the vessel is typically provided to minimize heat loss.

**Control:**

- The figure 17 shows the various control schemes in deaerator control.
- The pressure in deaerator shouldn’t exceed the turbine pressure at the point of extraction; a pump (Main Boiler Feed Water Pump) must follow the deaeration heater.
- The confluence of steam and water flows makes possible the efficient removal of noncondensables as well as the heating of the feedwater.
- The deaerator heater is usually positioned in the feedwater line at a pressure to prevent air inleakage and at a temperature at which Oxygen retention is least likely.
- Most deaerator heaters are designed for Oxygen concentration in the outlet feedwater below 0.005 cm$^3$/L
- The deaerator outlet feedwater is at or near saturation.
Pumping saturated water results in cavitation because of the pressure drop below saturated pressure, thus causing flashing on the back side of pump vanes. The deaerator heater is therefore usually positioned in the powerplant steam-generator house high above its pump by perhaps 60 ft. This provides sufficient pump inlet pressure to render the saturated water compressed (or subcooled) and prevents cavitations.

**BOILER DRUM LEVEL (FEEDWATER) CONTROL**

- **Benefits**
  - Maximizes steam quality
  - Maintains proper drum level to prevent damage to boiler

- The cylindrical vessel where the water-steam interface occurs is called the boiler drum.
- Boiler drum level is a critical variable in the safe operation of a boiler.
- A low drum level risks uncovering the watertubes and exposing them to heat stress and damage.
- High drum level risks water carry over into the steam header and exposing steam turbines to corrosion and damage.
- The level control problem is complicated by inverse response transients known as shrink and swell.
- Simply put, shrink and swell refer to a decreased or an increased drum level signal due to the formation of less or more vapor bubbles in the water, and no change in the amount of water in the drum.
- This condition produces level changes during boiler load changes in the opposite direction of what is expected with a particular load change.
- Although only temporary, this can cause severe control system overshoot or undershoot.

**Single-Element Drum Level Control**

- The single-element system is the simplest type used for controlling packaged firetube and watertube boilers.
- In this strategy, control is based on the boiler drum level measurement only.
- This does not allow for compensation of any shrink or swell and, therefore, is only an acceptable control strategy for small boilers with slow load changes.
- Figure 18 shows the single element control.

**Two-Element Drum Level Control**

- In two-element control, steam flow is measured along with boiler drum level.
- The steam flow signal is used in a feedforward control loop to anticipate the need for an increase in feedwater to maintain a constant drum level.
- This strategy requires the differential pressure across the feedwater control valve to remain constant, as well as the control valve signal vs. flow profile.
- Boilers with moderate load changes can usually be controlled with this strategy.
- Figure 19 shows the two element control.

**Three-Element Drum Level Control**

- Three-element drum level control adds a feedwater flow signal to the steam flow and boiler drum level signals used in two-element feedwater control.
The drum level controller manipulates the feedwater flow setpoint in conjunction with feedforward from the steam flow measurement.

The feedforward component keeps the feedwater supply in balance with the steam demand.

The drum level controller trims the feedwater flow setpoint to compensate for errors in the flow measurements or any other unmeasured load disturbances (e.g. blowdown) that may effect the drum level.

Three-element control is used in boilers that experience wide, fast load changes, and is the most widely used control strategy.

Figure 20 shows the single element control.

During startup or low load operation, the flow measurements used in the three-element control strategy may fall well below the rangeability limits of these flowmeters.

In that situation, three-element drum level control becomes erratic, and it is better to control the drum level with a single loop (one-element) control strategy.

As shown in Figure 21, drum level control switches automatically from three-element to one-element when steam flow falls below an adjustable low limit.

Separate level controllers are used to allow different controller tuning for one-element versus three-element control and to provide appropriate controller tracking strategies to provide for bumpless transfer between these two control modes.
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.
- Figure 22 shows the furnace arrangement.
**Natural Draft**
- A natural draft furnace uses the stack (chimney) effect.
- Gases inside the stack are less dense than those outside 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.

**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.

**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.

**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 23, 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 there is a corresponding change to the flow out of the furnace.
- An impulse feedforward connection couples the two dampers to minimize the furnace pressure disturbance on a change in air flow.
- As the impulse decays, external reset feedback to the furnace pressure controller drives the integral component to maintain the new steady state ID damper position.
- The furnace pressure controller trims the feedforward compensation as required to control the pressure at setpoint.
IMPLOSION:
- Explosion: It is a violent release of energy with large increase in volume and pressure of the substance invariably accompanied by loud sound.
- Implosion: it is the opposite of explosion. Instead of a positive pressure, a large negative pressure builds up in the boiler under certain conditions of maloperation leading to the inward collapse of draught plant and furnace in particular.
- In the large high efficiency modern balanced draught utility boilers, the suction heads of ID fans are very high because of large back end gas cleaning equipments.
- The design draught of ID fan can exceed the structural design pressure of furnace and ducts.
- If there is a sudden
  - Loss of air from FD fans
  - Flame by the burners
  - Control on ID fan inlet vanes
  there can be a runaway increase in the draught causing an inward collapse.
- The resultant damage can be considerable needing a few months to rebuild.
- Recognizing this aspect the furnaces and flues and ducts in boilers are strengthened with sufficient stiffening.
- The buck stays and stiffeners are designed for both positive and negative pressure excursions matching the heads of ID fans.
- The furnace implosion protection system has to comply with the guidelines established by NFPA 85G. These guidelines are
  - Redundant furnace pressure transmitters and transmitter monitoring system
  - Fan limits or run-backs on large furnace draft error
  - Feed-forward action initiated by a main fuel trip
  - Operating speed requirements for FCE and interlock systems
TRIMMING or (OPTIMISATION) OF COMBUSTION AIR

- Optimisation of combustion control is aimed at improved efficiency and economy of operation of a power plant
- It may require some additional instruments, analysers and controllers
- Even minor improvements in efficiency of operations will compensate for the expenditure made for those additional units
- In power plant operation, the optimisation of combustion control uses two main techniques. They are
  - Excess air optimisation
  - Stack temperature optimisation

**Excess air optimisation**

- If combustion air supply is in deficient, proper combustion of fuel may not take place and hence loss due to unburned fuel will be more.
- If combustion air supply is in excess, loss due to unburned fuel is negligible; whereas heat loss due to heat energy carried away by flue gases will increase.
- Furnace losses are mainly divided into three parts.
  - Loss due to unburned fuel or incomplete combustion loss
  - Loss due to heat energy carried away by flue gases or flue gas loss
  - Loss due to radiation and wall losses

**Incomplete combustion loss**

- When air deficiency is there, the fuel atoms do not find enough oxygen atoms to get burned.
- Then some combustibles are left unburned.
- This unburned fuel quantity gets reduced when enough or excess combustion air is supplied.
- The loss due to incomplete combustion will be almost negligible in the excess air region.

**Flue gas loss**

- The heat losses occurring due to the heat energy carried away by flue gases is called flue gas loss.
- After combustion the hot flue gases transfer heat energy to feed water in the boiler tubes to saturated steam in the superheater, to cold feedwater in the economiser and to cold combustion air in the air preheater.
- After transferring heat in the air preheater, flue gases are let into atmosphere through ID fan chimney.
- They are sometimes called as waste gases because no more heat energy is extracted from flue gases after air preheater unit.
- Under air deficient conditions the unburned fuel carries heat energy along with flue gases and in air excess conditions the heat loss is due to unused oxygen and the accompanying nitrogen carrying away heat energy when discharged into atmosphere.
- There is always a trend of steady increase in flue gas loss as the air combustion goes up.
**Radiation and wall losses**
- These losses depend mainly on the combustion chamber temperature and the refractory wall conditions.
- Radiation and wall losses are relatively constant throughout the operating region except when the excess air allowed is much more than required.
- In that case the combustion chamber will have a tendency to cool down and hence the reduction in losses.

![Diagram](image.png)

**Figure 24 Furnace Losses Vs Excess Air**
- Figure 24 shows the plot for different losses in furnace as a function of excess air.
- The purpose of optimisation control is to determine the minimum total loss point at the operating load condition and adjunct the excess air accordingly.
- As no burner is capable of cent percent effective mixing, minimum loss point ia always in the excess air region.
- Due to excess air each carbon molecule is converted into CO2 whereas not all oxygen molecules would find corresponding carbon molecule.
- That is why theoretical and practical deviation is different.

**Stack temperature optimisation**
- Stack temperature has to be minimised to keep the total losses at a minimum point.
- The trend of fuel saving potential against stack temperature and percentage excess oxygen in flue gas is shown in figure 25.
- By optimisation techniques the temperature of the stack can be brought down to minimum level so as to achieve maximum fuel saving.
Using oxygen analyser in flue gas for combustion trimming further fuel saving is possible by reducing the percentage oxygen in flue gas for the minimum stack temperature.

The best operating point for the boiler under analysis with a particular design using a particular fuel is at 200 °C stack temperature and 2% oxygen in the flue gas.

Optimisation

- **Air-Fuel Ratio Control With O2% Trimming**
  - Depending on the steam load %O2 set point is generated for the oxygen trim controller ARC.
  - Comparing this set value with actual %O2 signal from the analyser AT, the controller generates trimming signal which can be added or subtracted from the set value applied to the existing air/fuel ratio control. (Figure 26)

- **Air-Fuel Ratio Control based on CO**
  - A control system with %O2, CO and steam flow for trimming is shown in figure 27.
- This control system utilizing the measurement of both %O2 and %CO can optimize boiler efficiency even if load, ambient conditions, or fuel characteristics vary.
- The final trimming signal is always clamped by high and low limits to prevent driving the air/fuel ratio beyond inefficient limits.

![Figure 27 Fine Trimming Based on %CO](image-url)

**FLUE GAS DEW POINT CONTROL**

**Dew Point Temperature**
- The dew point or dew point temperature of a gas is the temperature at which the water vapor contained in the gas is transformed into the liquid state.
- This transition is called condensation, the formed liquid is called condensate.
- Below the dew point temperature humidity (moisture) exists as liquid, above the dew point as gaseous component of the gas.
- An example for that is the formation and decomposition of fog or dew as a function of the temperature.
- The dew point temperature is a function of the moisture content of the gas: The dew point of air with 30% moisture content is at appr. 70 °C, while dry air with only 5% moisture content has a dew point at appr. 35 °C, is shown in the figure 28.
Flue Gas Dew Point Temperature

- Most flue gases produced by the combustion of fuels contain contaminants that can condense into sulfuric, sulfurous, or hydrochloric acid droplets.
- Flue Gas Dew Point Corrosion occurs when these aggressive acids condense on carbon and stainless steels in convection sections (Air Pre Heater or Economizer), flue ducts, and stacks.
- The amount of contaminants in the fuel is directly correlated with the concentration of the acid droplets, and therefore with the degree of corrosion.
- There are several ways in which flue gas dew point corrosion can be avoided.
- Normally the flue gas temperature is maintained above dew point temperature to avoid corrosion at the cold end of air pre heater.
- At the cold end of an air pre-heater if the air temperature is 80ºF and the flue gas temperature is 300 ºF, the average metal temperature in contact with the flue gas is considered to be 190 ºF, the average of the flue gas and combustion air temperatures.
- With a dew point temperature of 200 ºF, acid moisture would collect on the metal surface and corrosion would take place.

Controlling Dew Point

- This can be avoided through use of a control method that raises the incoming combustion air temperature so that the average cold end metal temperature is above dew point.
- In the example above, raising the incoming air temperature to 120 ºF would cause flue gas temperature to shift upward to approximately 320 ºF.
- The average metal temperature would then be 230 ºF, well above a 200 ºF dew point temperature.
- If the dew point temperature were 230 ºF, then the combustion air temperature would have to rise still higher than the 120 ºF point.
- A control method that accomplishes is shown in below figure 29.
An air heater, with steam as the heating medium, is placed in the combustion air stream ahead of the flue gas heat recovery air pre-heater.

The steam is controlled to this heater in order to develop the desired combustion air temperature.

The control loop controlling the steam flow is shown in below diagram (Figure 30).

A simple feedback control loop is usually adequate.

The average of the flue gas and air temperature, shown in feedback is considered a pseudo metal surface temperature.

Figure 29 Dew Point Control Process Arrangement

Figure 30 Flue Gas Dew Point Control
**Prevention Methods Based on Construction:**

- More resistant materials can be used in the construction of flues, which can prevent corrosion.
- Also, limiting the number contaminants in heater and boiler fuels is another good way to prevent corrosion from occurring.
- Although, it should be noted that the latter method is far more difficult to accomplish, since most fuels contain sulfur compounds and some are contaminated with chlorides.
- Another way to prevent corrosion is to maintain the surface metal temperatures of exposed equipment above the dew point.
- Finally it is possible to protect cooler surfaces by applying a coating that is resistant to the acidic condensate and will withstand the temperatures to which it is exposed.

**SOOT BLOWING**

- The fuel used in thermal power plants causes soot and this is deposited on the boiler tubes, economizer tubes, air pre heaters, etc.
- This drastically reduces the amount of heat transfer of the heat exchangers and increases fuel consumption.
- A reduction in heat transfer efficiency is indicated by an increased flue gas temperature.
- Therefore the cleaning of these heat exchanger surfaces during service is essential.
- Soot blowers controls the buildup of soot and ash deposits that create corrosive environment.
- This is very essential particularly during low load operation when acid dew point of the fuel being fixed could be reached.
- The types of soot blowers are:
  - **Fixed type** has nozzles that blow steam or compressed air in lane or mass pattern
    - **Lane Type**: Nozzle in the space between each tube to be cleaned, element rotate in prescribed arc to remove deposits between the tubes.
    - **Mass Blowing**: Larger nozzles in few numbers and are positioned upto 40-50 cm from the face of the tube banks. (Figure 31)
Retractable soot blower: The advantages are that they are placed far away from the high temperature zone, they concentrate the cleaning through a single large nozzle rather than many small nozzles and there is no concern of nozzle arrangement with respect to the boiler tubes.

Soot blower for Economiser

REFERENCE:

- Arora Domkundwar, “A Course in Power Plant Engineering”