# History of Steam Generation & Types of Boilers

Hero of Alexandria probably in the first century A.D. had described a boiler and reaction turbine but he made no suggestions for the usual application of the device. In fact, there is no record of steam's practical usage until the 17th century although there was descriptive publication in the late 16th century. The most common source of steam at the beginning of the 18th century was the shell boiler, little more than a kettle filled with water and heated on the bottom .This in turn, was followed by early versions of the firetube boiler. Both types were subject to disastrous explosions because of the direct heating of the pressure slid containing a large volume of water at saturated steam temperature.

**Fire-tube boilers**

In l800 Trevithick made an engine for 65 psi pressure, having a 25-inch cylinder and a l0ft stoke. The engine's high working pressure was possible only because of the successful construction of a high pressure boiler. Built in 1804, the boiler had a cast-iron cylindrical shell and dished end. The boiler and engine were mounted together.

**Water-tube boilers**

A patent granted to William Blakey in 1766, covering an improvement in Savery's engine, includes a form of steam generator, this probably was the first step in the development of the water-tube boiler. However, the first successful user of the water-tube boiler was James Rumsey. In 1788 Rumsey patented several types of boilers, some of which were water-tube designs. John Stevens, also invented a water-tube boiler consisting of a group of small tubes closed at one end and connected at the other to a central reservoir. In 1822, Jacob Perkins built a water-tube boiler which is the predecessor of the once-through steam generator.

**The B&W boiler**

Stephen Wilcox proposed in 1856 what was to be a significant design for water-tube boilers. In 1866, George Herman Babcock became associated with Stephen Wilcox and the first Babcock and Wilcox boiler was patented a year later, and modified in 1877.

**Bent-tube boilers**

In 1880, Allan Sterling developed a design connecting the steam generating tubes directly to a stern separating drum and featuring low head room above the furnace. Merits of bent-tube boilers for special applications were soon recognized by Babcock & Wilcox, and what had become the Sterling Consolidated Boiler Company was purchased by B&W in 1906. After the problems of internal tube cleaning were solved, the bent-tube boiler replaced the straight-tube B&W boiler.

**Integral-Furnace boilers**

In the early thirties a new concept was born in which the furnace water cooled surface and the boiler surface were arranged together so that each was an integral part of a boiler unit.

**Package boilers**

The increasing need for industrial and heating boilers combined with increasing costs of field assembled equipment led to the development of the shop assembled package boiler.

**Universal-pressure boilers**

The universal-Pressure boiler, so named because it can be designed for subcritical or supercritical operation, is capable of rapid load pick up. Increase load at rates up to 5 % per minute, insofar as the boiler is concerned, is easily attained. In an emergency, the Universal-Pressure boiler is capable of increasing load from 25 to 90% of full load in four minutes, and from 90 to 100% of full load in another three minutes.

**Marine boilers**

The water-tube boiler was successfully applied to the propulsion of naval and merchant vessels in 1890's. An improved design modified in 1899.

## Boiler Control Objective

For proper control application, it is necessary to understand the objective of the control system. In the case of steam boilers, there are three basic objectives:

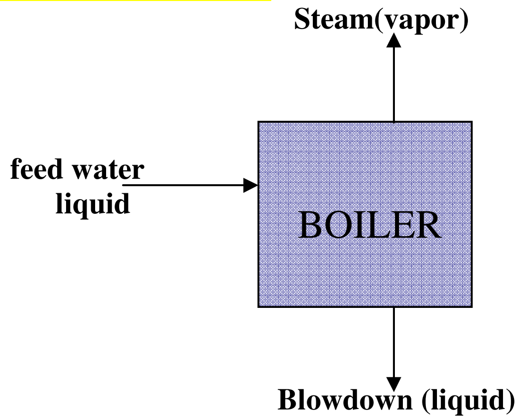
1. To cause the boiler to provide a continuous supply of steam at the desired condition of pressure and temperature.
2. To continuously operate the boiler at the lowest cost for fuel and other boiler inputs. Consistent with high levels of safety and full boiler design life
3. To safely start up, shut down, monitor on-line operation, detect unsafe condition, and take appropriate actions for safe operation at all time.

## Input / Output

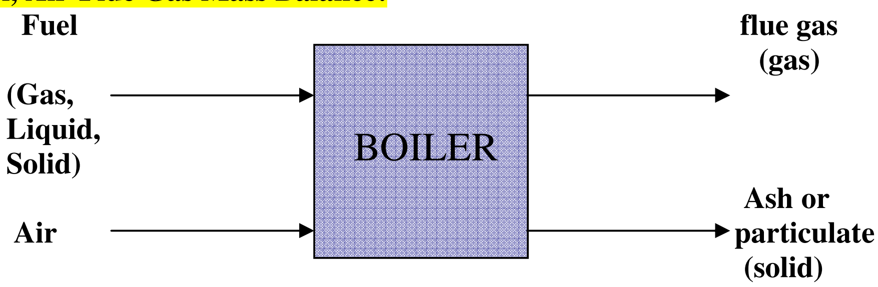
Before we begin the design of a boiler control system, we need to specify the input and outputs of the system, this is done after performing mass and energy balance, obviously this has to be done for any process control to be able to determine the manipulated variables, an interesting point is what one considers to be input / output of a plant can be the output / input of the control system as in our case.

## Mass and Energy Balance Involved

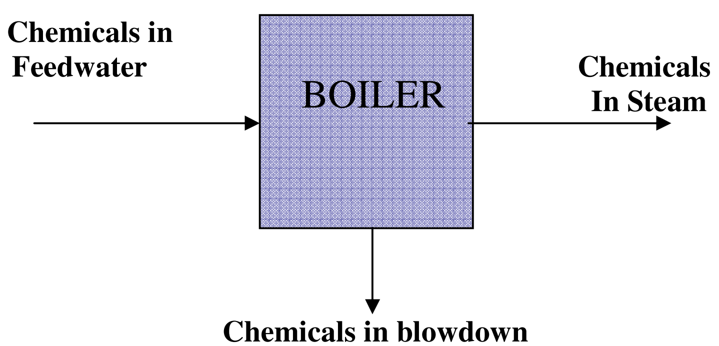
- **Steam-water mass balance:**




- **Fuel, Air-Flue Gas Mass Balance:**

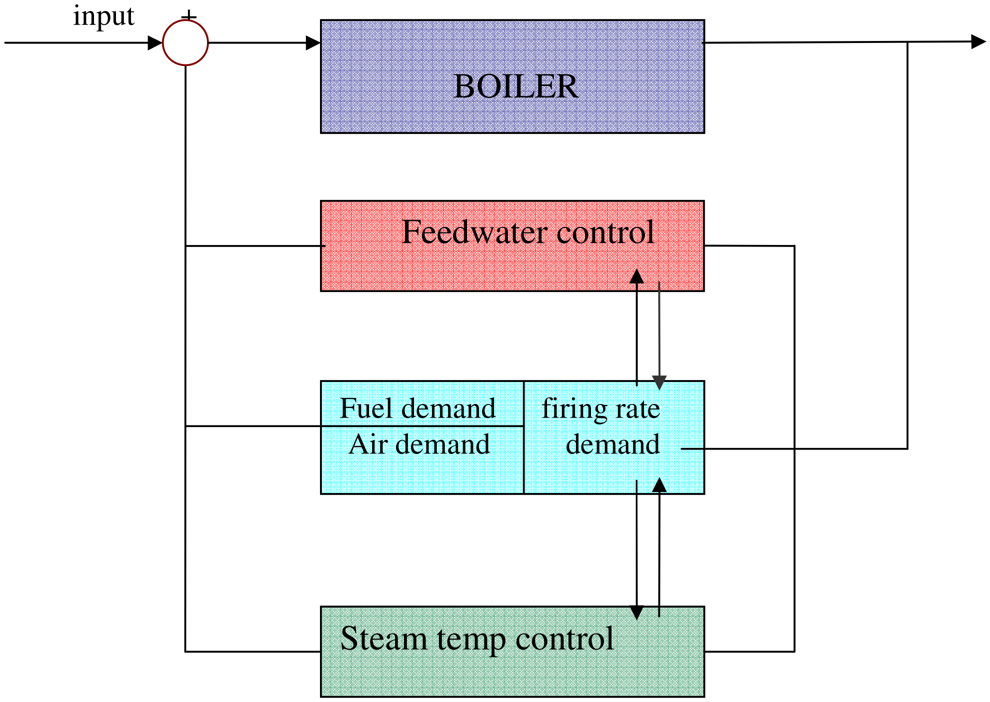



- **Water Side Chemical Mass Balance**



## Boiler Control-The Process of Managing the Energy and Mass Balances

The boiler control system is the vehicle through which the boiler energy and mass balances are managed. All the boiler energy and mass inputs must be regulated in order to achieve the desired output conditions. The measurements of the output process variables furnish the information to the control system intelligence unit figure below is a block diagram showing how the parts of the overall control system are coordinate into the overall boiler control system. For the energy input requirement, a firing rate demand signal must be developed. This firing rate demand creates the separate demand for the mass of fuel and combustion air the mass of the water-steam energy carrier must also be regulated, and the feedwater control regulates the mass of the water in the boiler. The final steam temperature condition must also be regulated. The effects of the input control actions interact, since firing rate also affects steam temp and feedwater flow affects the steam pressure, which is the final arbiter of the firing rate demand.




## Basic definitions and boiler classifications:

**1- Steaming process**:

It is the conversion of water from it's liquid phase to it's vapour phase

**2- Boilers:**

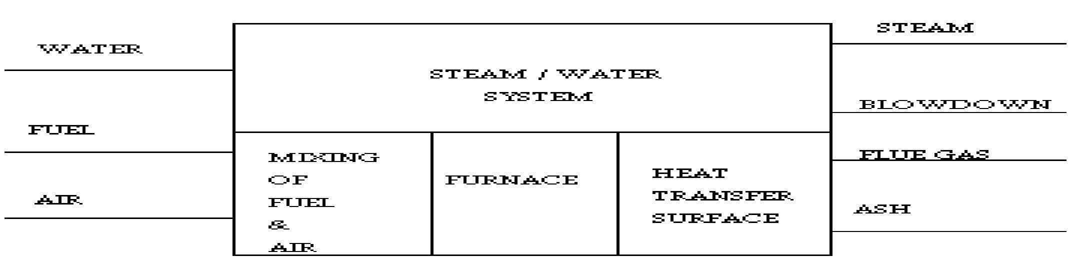
a boiler is basically a pressure vessel designed to transfer heat to water, which is used to produce hot water ,saturated steam or super heated steam

**3- The basic boiler:**

A boiler comprises two different systems which are

*Water side*: water is introduced and converted into steam due to the heat transferred to it through heating surface

*Fire side*: it is the system which provides heat needed to be transferred to water side



**4-Boiler Classifications :**

Boilers can be classified according to many points of views.

**4.a- According to operation type:**

- Utility boilers: used in electric utility generating
- Industrial boilers: used in smaller scale industrial applications
- Hot water boilers: actually not boilers by definition as it doesn't reach boiling temperature but same operating principles as boilers

**4.b-According to air draft type:**

- Forced draft fan boilers
- Induced draft fan boilers
- Balanced draft fan boilers

**4.c-According to heating surface type:**

- Fire tube boilers
- Water tube boilers
- Once through water tube boilers (super critical boilers)

**4.d-According to fuel type:**

- Solid fuel
- Liquid fuel
- Gaseous fuel
- Mixed fuel

**4.e-According to number of burners**

- Single burner
- Multiple burner

Typical boiler:

The boiler that we will going to work with is a water tube utility boiler, forced draft fan type, liquid or gaseous fuel type with a single burner and a superheater ,boiler capacity is 100ton/hr. and a drum size 1.6m diameter and 8m length. Steam is superheated to 400 degrees Celsius.

# Part II

This part is mainly dedicated to the description of basic boiler control loops and the explanation of the various elements and instrumentations used, also a dynamic simulation of control circuits is included.

## 2.1 Basic Control Loops:-

Basic control systems of the boiler chosen will be discussed showing the different strategies used in each loop and explaining the mostly used methods for the three basic control circuits.

The basic circuits are:-

1- Level circuit (water side circuit)
2- Fire circuit
3- Super heating circuit
4- Burner management system (B.M.S.)

### 2.1.1 Level Circuit (Water Side Circuit):-

This section is dedicated to the explanation and design of level system.

As seen in the schematic drawing of water side (FIG.2.1), a level control system is supposed to maintain the water level in the boiler drum to a set value in steady state and changing of demand conditions.

To achieve this we shall explain the basic idea that a control system should satisfy which is simply the continuity equation which states that;

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

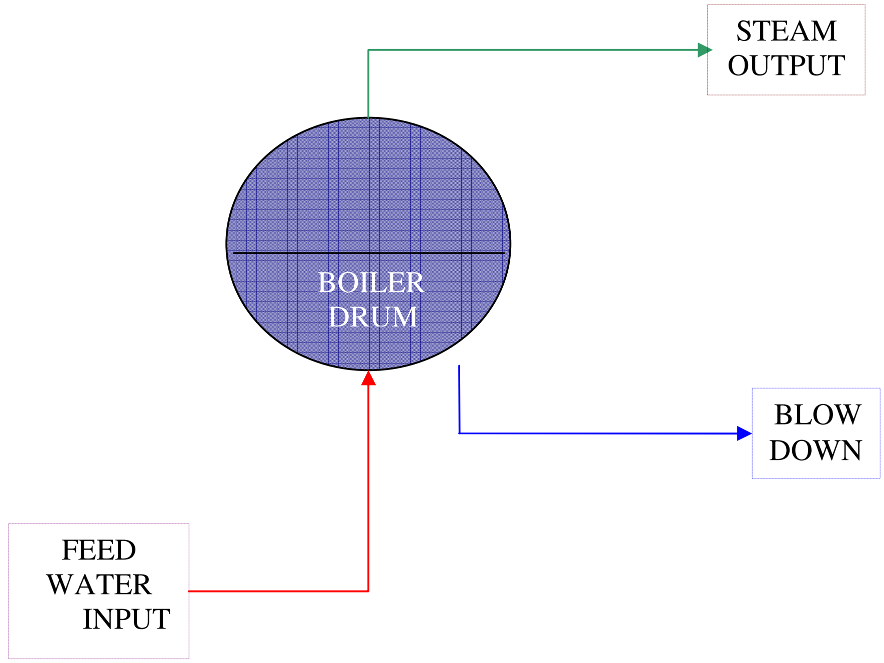



**Fig 2.1**

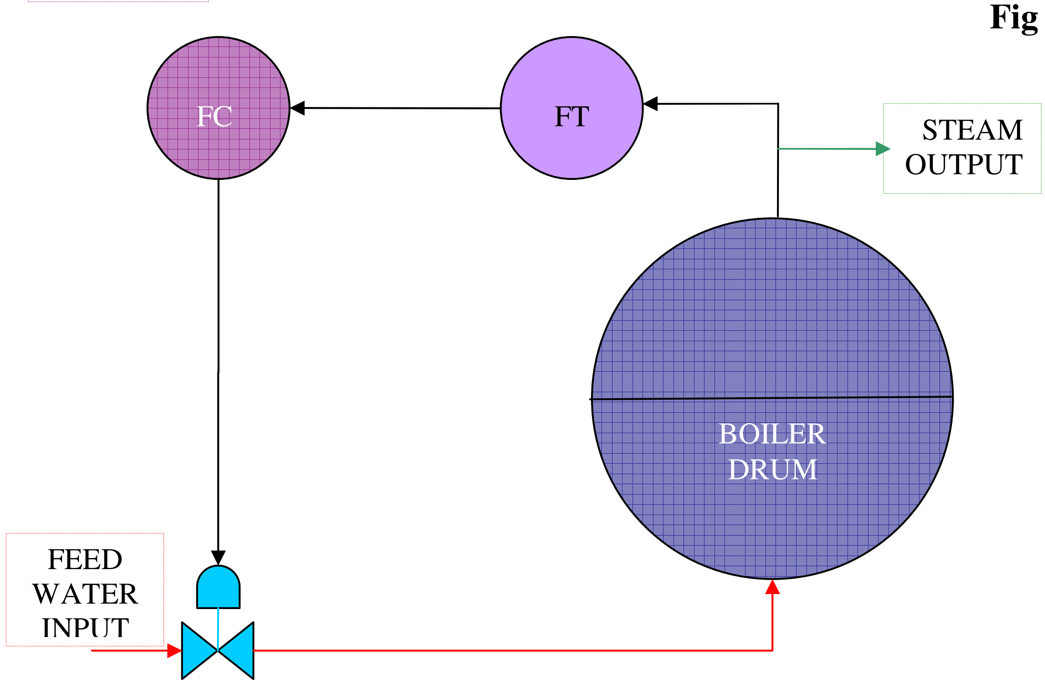



**Fig 2.2**

Considering a control system as shown in fig (2.2) , such a system checks the output flow conditions and feeds it to a flow controller that operates a control valve so this system satisfies the continuity equation that states that ( ***output flow = input flow*** )……… ***but this is not proper level control system :-***

1- This system operates only in steady operating conditions of demand.
2- No account has been made for blow down.
3- Although the output flow has been measured but the basic value to be measured **(which is the level)** has not been measured.
4- There is nowhere in the loop for the operator to state his required level set point.

For the above reasons we shall consider such a loop invalid and discuss the loops available which are:-

**Basic Level Control Loops:-**

We have three basic level control loops namely:-

a- Single element loop
b- Double element loop
c- Triple element loop

## A) Single Element Loop:-

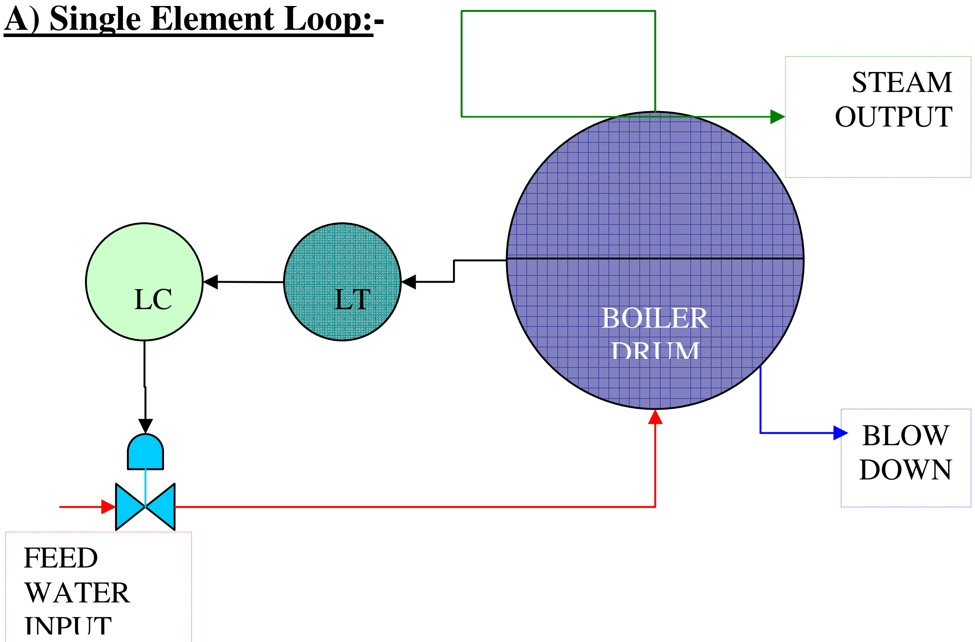



**Fig 2.3**

Figure (Fig 2.3 ) shows the design of a single element loop, obviously this single element is the one which was taken into consideration ***(level position),***this control action does not show problems during steady operating demand but it's main defects are:-

1- The system doesn't take into account changes in the feed water input caused by the pump.
2- The system doesn't take into account any sudden changes in the steam demand caused by the user which makes it's response to changing conditions rather slow.

This shall make us shift to the second technique namely the double element loop.

## B) Double Element Loop:-

Figure ( FIG 2.4 ) shows the double element loop, the two elements taken into consideration are the level position and the feed water flow delivered by the pump, this type of control action is called ***(cascade system control )*** in which two controllers are involved, namely the flow controller and the level controller, the level controller is termed the ***(master controller)*** because it's set point in defined by the operator, while the flow controller is termed ***(slave or sometimes secondary controller)*** because it's set point is the output of the master controller.

This system works well in steady state, and also takes into consideration the changes caused by the pump action but it is still not aware of the changes in demand.

This leads us to the last type or triple element loop.

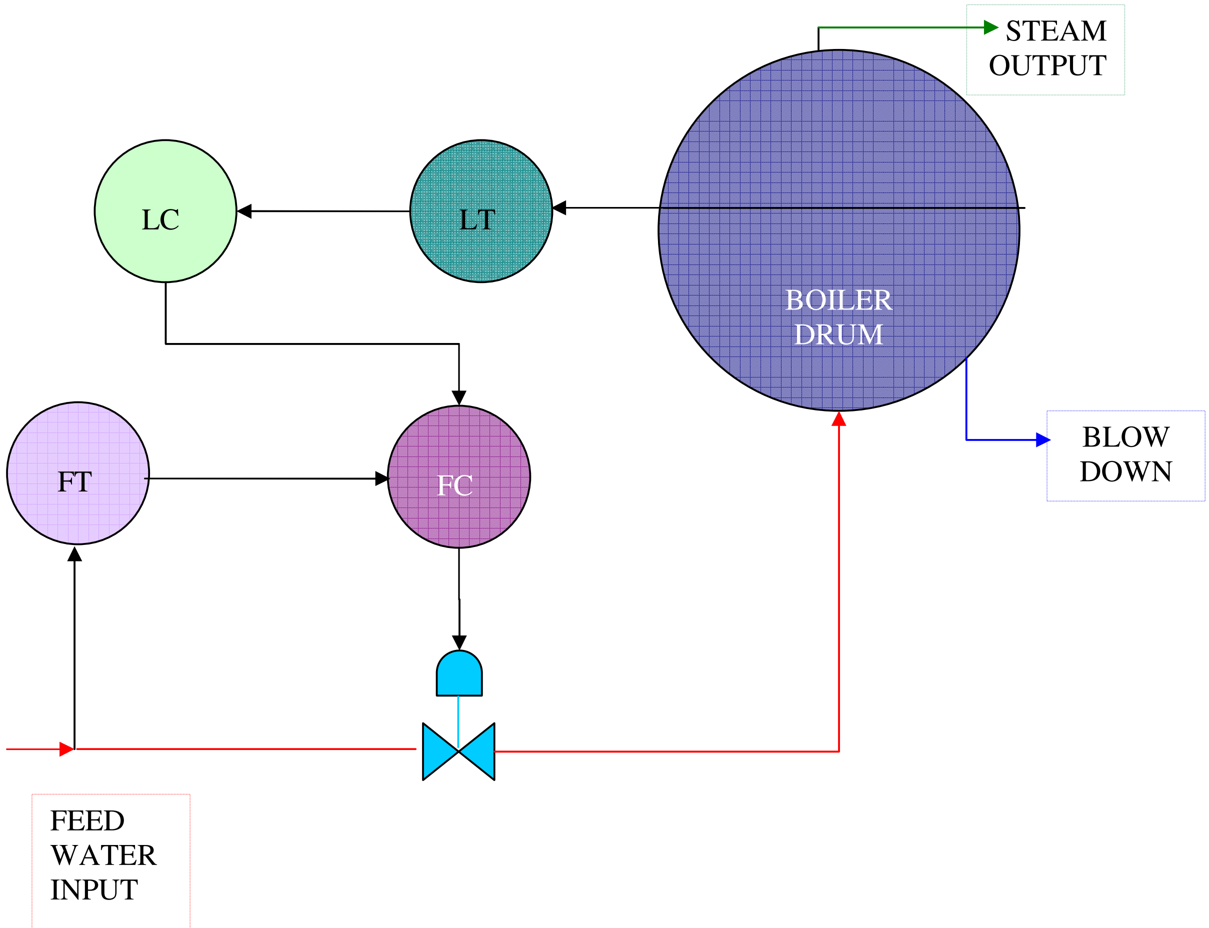



**Fig 2.4**

## C)<u>Triple Element Loop</u>:-

Figure (FIG. 2.5) shows triple element loop.

As it is shown in (FIG.2.5) the three element loop takes into account the most important elements of level control which are the level position , the flow conditions from pump discharge and the demand flow conditions and it also satisfies the continuity equation, as seen the demand output flow is summed at the summation point to equal the flow rate.

An important adjustment is made for this loop which is the bias of 50% of the level controller's signal is subtracted from the summation point this is to keep a signal when the level is maintained at set point instead of giving a zero signal, this gives the controller the space to give signals greater or lesser than the zero.

Another important adjustment is the blow down system, it is a system which is taken into consideration indirectly because it affects the level…….this systems works in three ways:-

1- periodically blowing down an amount of water
2- constantly blowing down a certain percentage of the input
3- finally by blowing down a certain percent which is decided by a water analyzer.

The modified loop will look like as in figure (Fig 2.6)

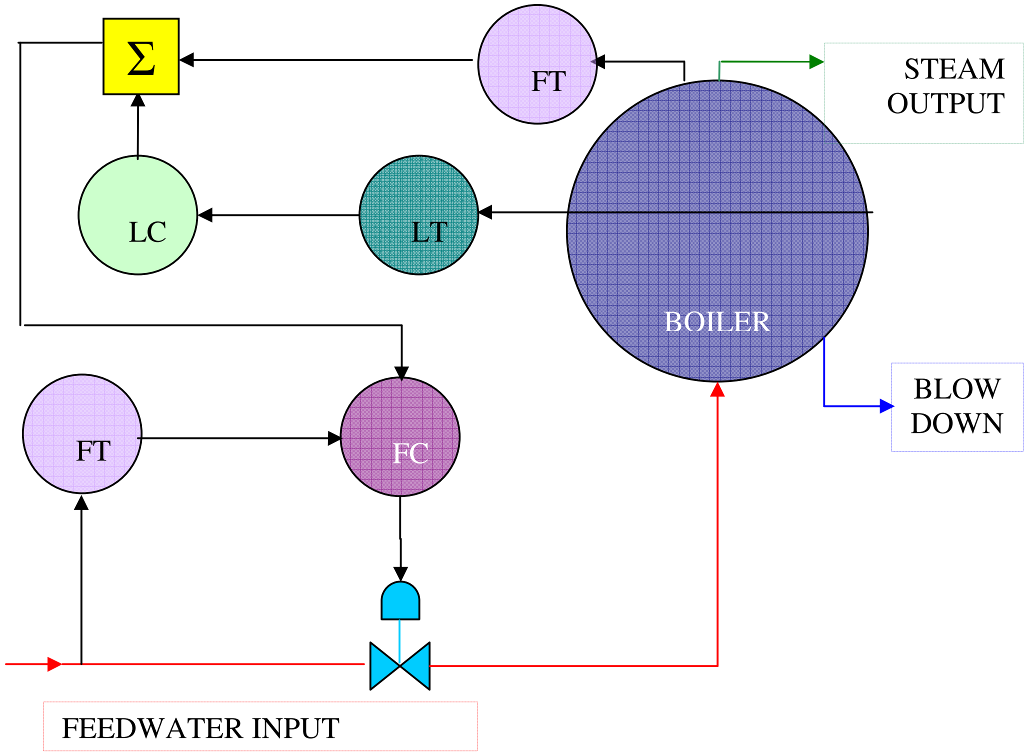



**Fig 2.5**

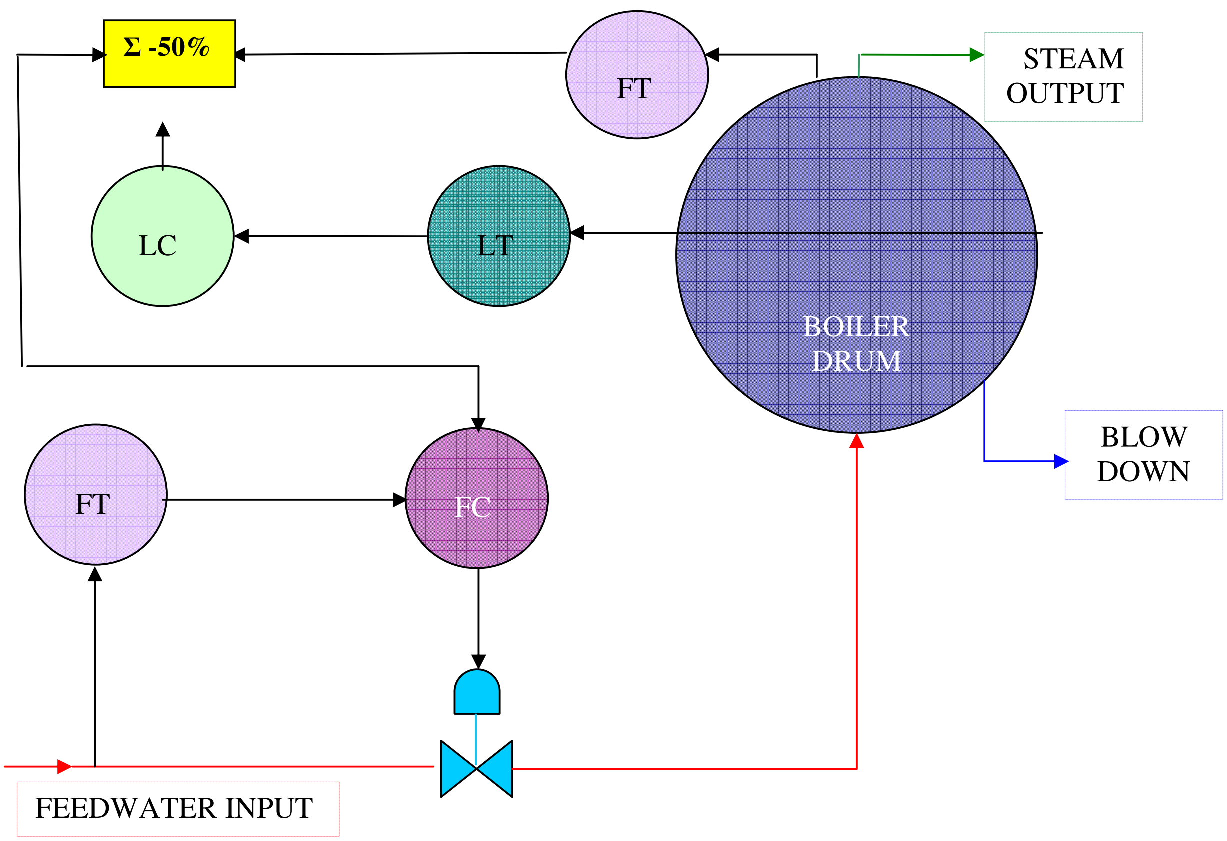



**Fig 2.6**

### 2.1.2 Fire Side Circuit:-

The aim of this circuit is to maintain the steam exit conditions and the pressure inside the drum, and to supply the required amount of fuel and air in correct ratios maintaining correct fuel to air ratio, and assuring excess air.

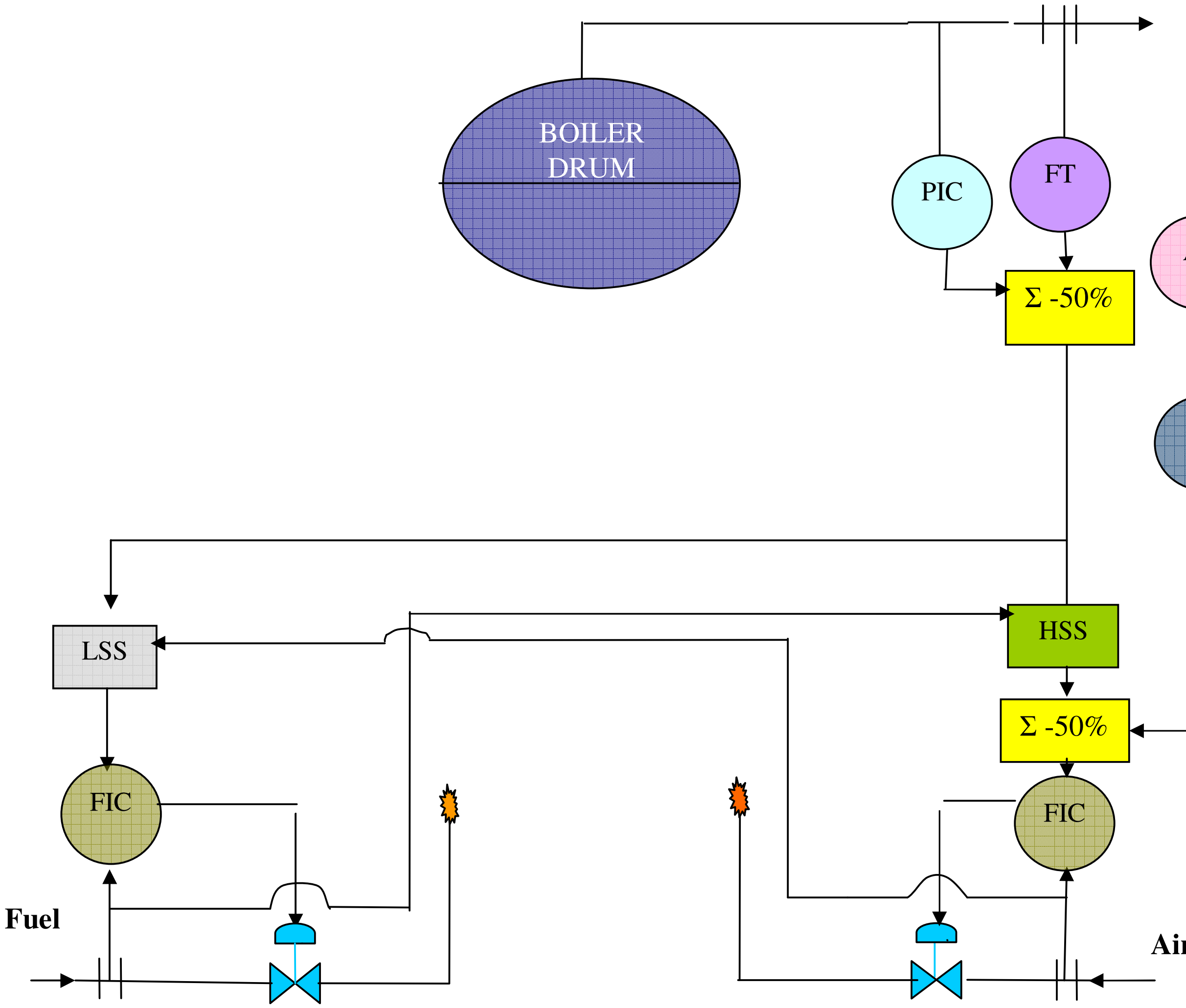



**Fig 2.7**

- ## How it Works

  The steam flow and the pressure are measured by the flow transmitter and the pressure controller respectively and collected in a bias adder (which is explained in the level loop). They are directly proportional to the energy required to be liberated from the combustion room, where the mixture of the fuel and air are burned. The gas analyzer signals the oxygen emitted from the stack of the combustion room, where it is placed. All these signals (from the flow transmitter, pressure control, and the gas analyzer) are directed to the controller to give the suitable flow rates of air and fuel.

- ## Unsteady Conditions

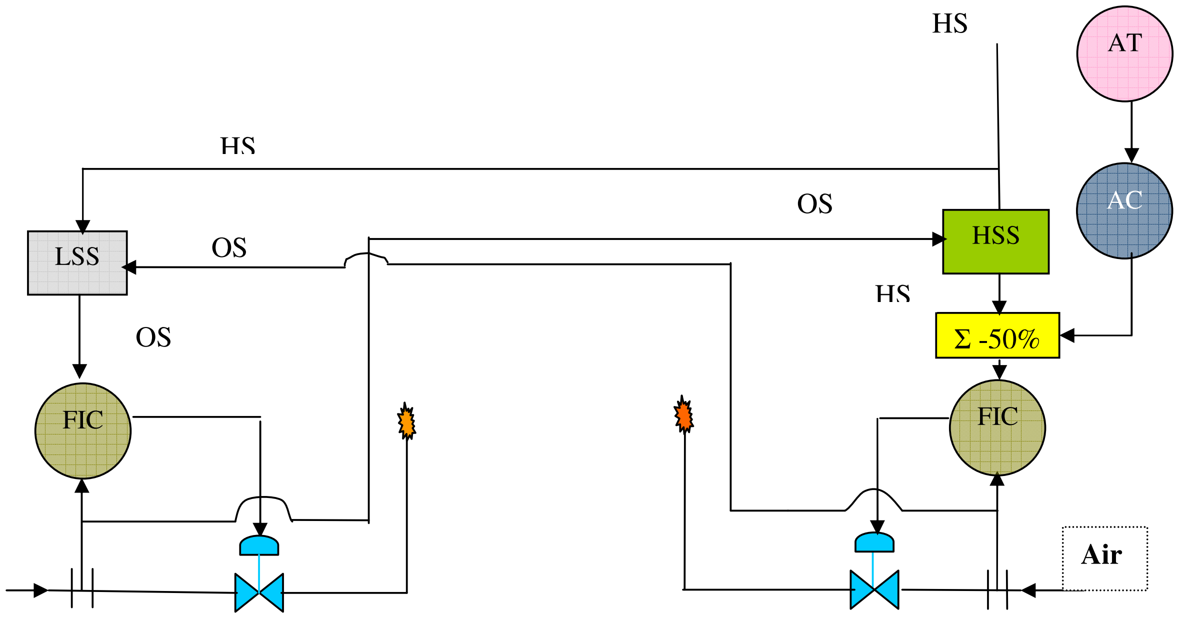
  To obtain safe combustion, the increased air required should be introduced to the combustion room before introducing the increased fuel, in case of increasing of the heat required, but in case of decreasing of the heat required, we should reduce the fuel flow before reducing air flow. To these two conditions the HSS (high signal selector) and the LSS (low signal selector) are used in the circuit to achieve the first and second condition respectively.

  The HSS passes the higher signal, while the LSS passes the lower signal.

**Case (A): Increase of Heat required**

**1st Step:**

**The HSS will select the high signal sending it to the FIC which send the signal to the air valve (inlet guide vanes) which increases the airflow first.**




Note: HS (high signal)> OS (original signal)> LS (low signal)

**Fig 2.8**

**<u>2nd Step</u>: Then Fuel will increase.**

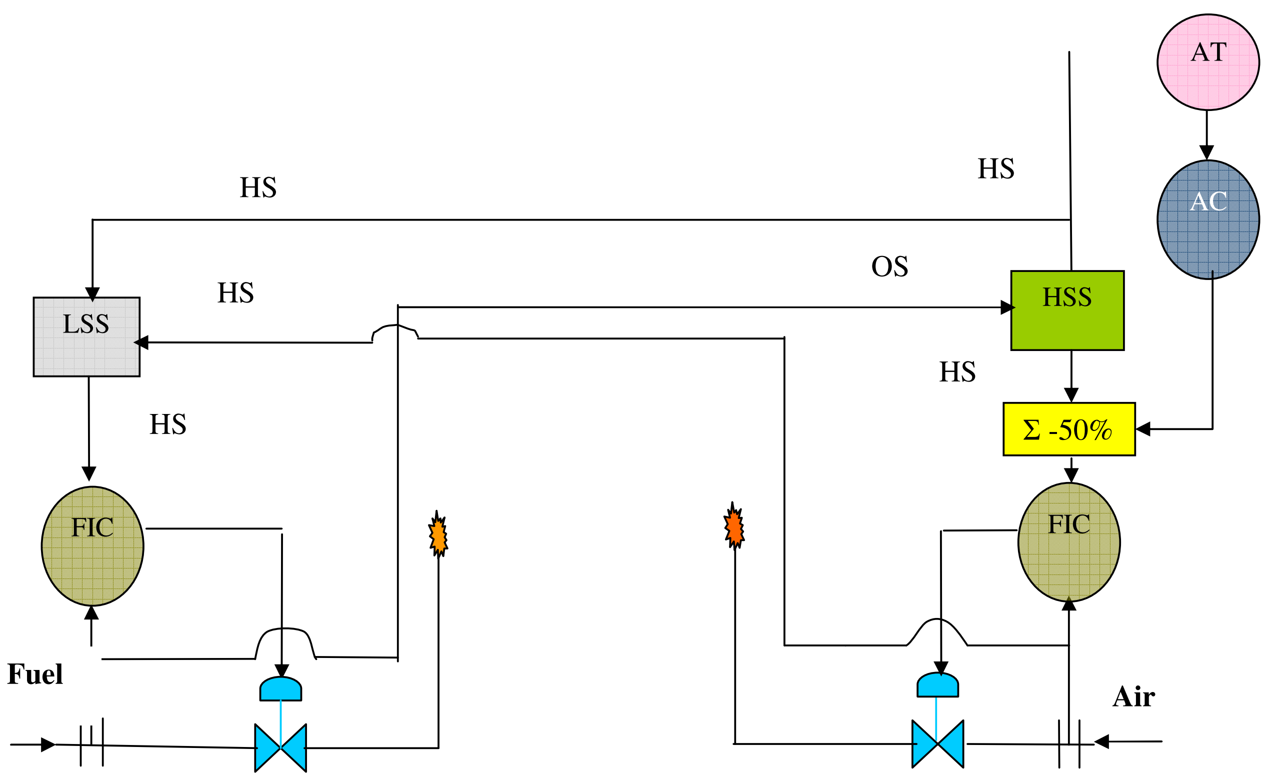



**Fig 2.9**

**Case (B) : <u>Decrease of Heat Required</u>**

**<u>1st step:</u>**

**The LSS will select the low signal sending it to the FIC which send the signal to the fuel valve which start to reduce the flow**

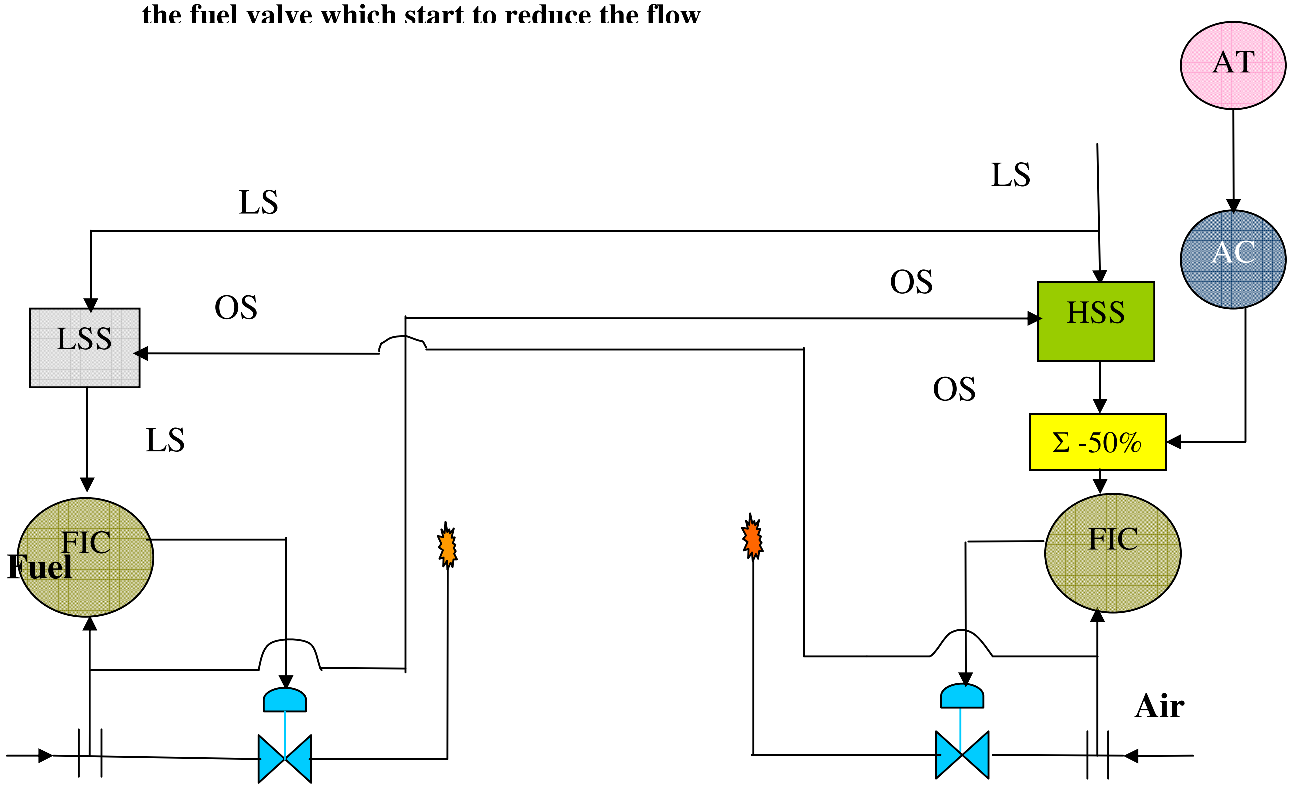



**Fig 2.10**

**<u>2nd Step</u> Air will be reduced after fuel**

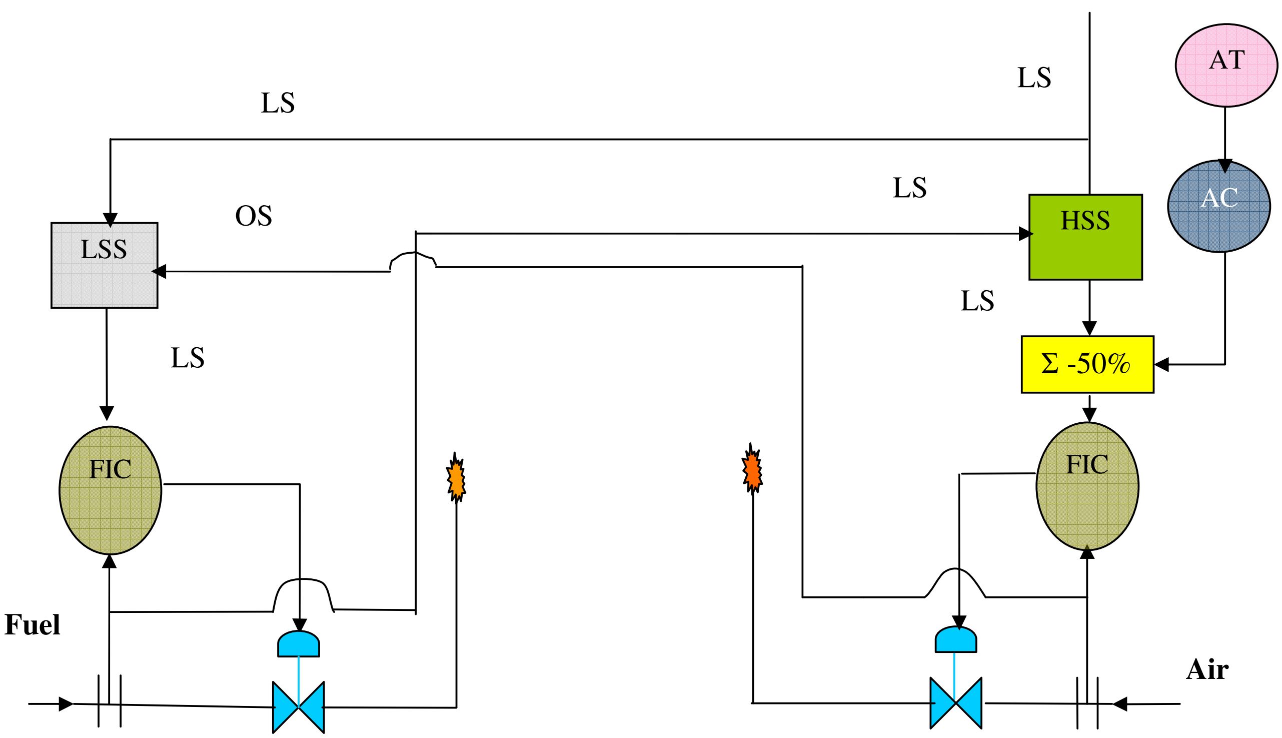



**Fig 2.11**

### 2.1.3 Superheat Circuit:

As the name suggests this loop is involved with controlling the superheated steam temperature. Although there are many methods of controlling superheated steam temperature such as flame tilting, heat exchange with a colder fluid, the method used here is one of the most common, which is desuperheating , such a method involves heating the steam to a temperature above the required the desuperheating it by spraying water until it reaches the required temperature. This method has a low time constant within a few seconds, besides it provides accepted tolerances within ±$10^0$C.

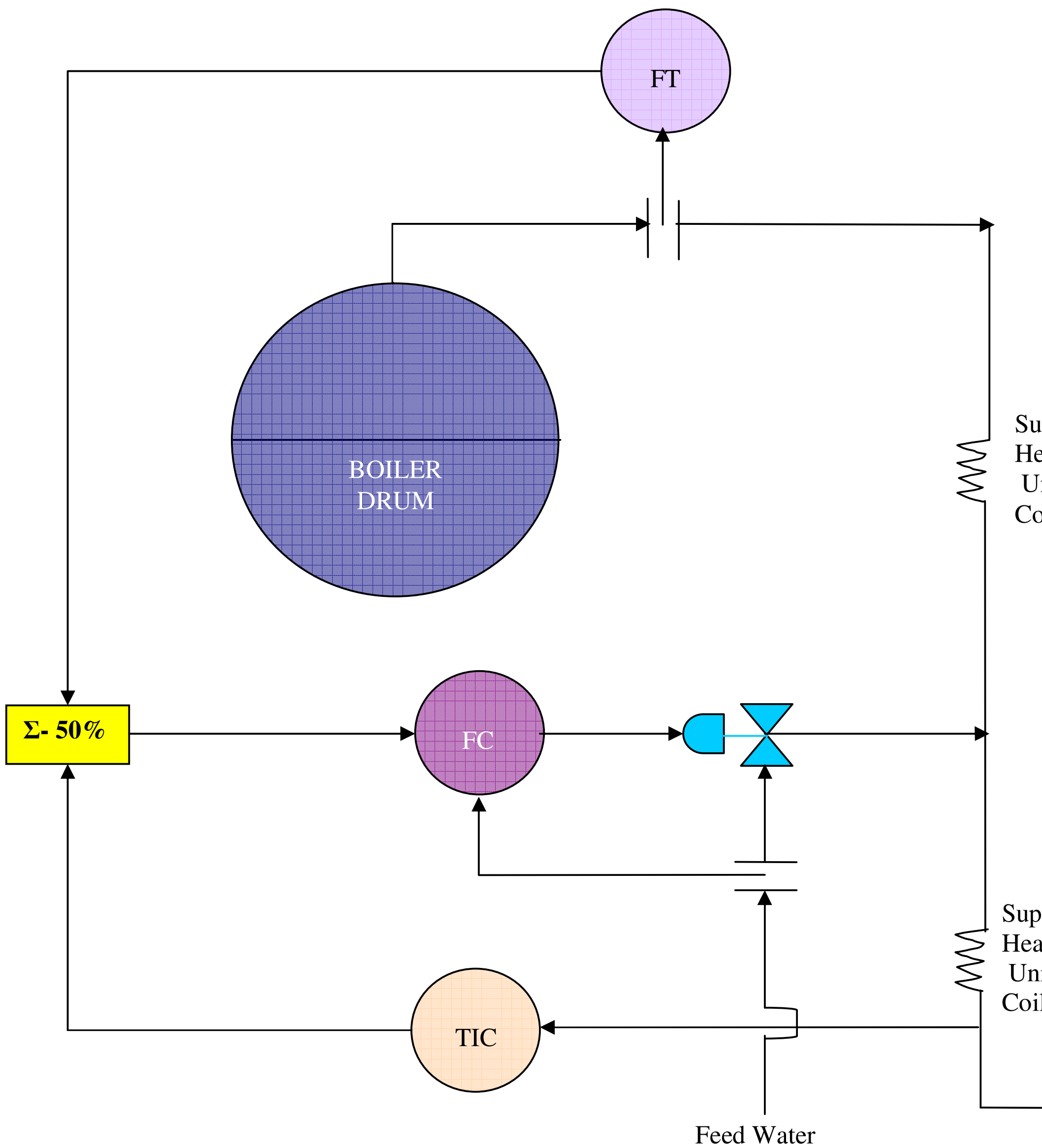



**Fig 2.12**

The control loop is a simple one involving a master temperature controller that receives the temperature signal of the steam, it the sends its signal to the biased adder in which it meets with the steam flow rate signal. The adder then signals to the slave controller which has it's set point as the biased adder signal and compares it with the desuperheating water spray flow rate, it the manipulates the desuperheating valve.

### 2.1.4 Burner Management System:-

A management system actually is not a control system, it is rather an operating and security system, but it is usually the control engineer's duty to design such a system.

- **National fire protection association( N.F.P.A. ) requirements:-**

**1.** Boiler and burner explosions and failures typically occur during the period of lighting off the boiler and other critical periods. To combat the boiler explosion and failure hazard, a group of laws regarding management and interlock systems has been developed by N.F.P.A. to reduce the hazards to a minimum. These systems are also designed to monitor the boiler operation, light off and shut down burners as necessary, and trip the fuel whenever the continued operation appeals to be unsafe.

**2.** The standard followed in selection of the proper burner management system is the N.F.P.A.8502 STANDARD, the standard will mention the following:-

1- The required functional system describing their:-
   - a- system functions
   - b- system requirements
   - c- sequence of operating the sequence

2- Alarming and interlocking system

### 2.1.4.1) Required Functional Systems

The three main systems are the purge logic system, gas burner system and the main fuel trip.

#### A) Boiler Purge Logic and Furnace Explosion Prevention System:-

This system is involved with the safety of furnace during starting up and lighting of operations.

- **Basic Cause of Furnace Explosions**

The basic cause of furnace explosions is the ignition an accumulated combustible mixture within the confined space of the furnace or the associated boiler passes, ducts, and fans that convey the gases of combustion to the stack.
This might be due to the following:-

1) Fuel leakage in to an idle furnace and the ignition of the accumulation by a spark or other source of ignition.
2) Repeated unsuccessful attempts to light-off without appropriate purging, resulting in the accumulation of an explosive mixture.
3) The accumulation of an explosive mixture of fuel and air as a result of loss of flame or incomplete combustion at one or more burners in the presence of other burners operating normally or during lighting of additional burners.
4) The accumulation of an explosive mixture of fuel and air as a result of a complete furnace flameout and the ignition of the accumulation by a spark or other ignition source.

- **Boiler Purge Logic**

A particularly critical time period is that of lighting the first burner. For this reason purging the boiler furnace of combustible gases is mandatory before any such action the Purging procedure is used only when a boiler is in the process of being started this may be when the boiler has been unused for some time period or when the main fuel has tripped and the boiler is being restarted.

#### B) Gas Burner Management Logic

This system is responsible of operating the gas-fired boiler in the following operations:-

1- cold start
2- normal operation
3- normal shut down

#### C) Main Fuel Trip

This is locking the fuel flow and shutting down the burner at any of these situations:-
(1) Forced draft fan not running.
(2) Induced draft fan not running,

(3) Boiler drum level low.
(4) Air flow below minimum
(5) Total loss of flame,
(6) Furnace pressure high or low,
(7) Gas header pressure high or low.
(8) Loss of flame detector cooling air
(9) Operator initiated trip.

**2.1.4.2) Alarms & Interlocks**

**A) Annunciators & Alarm Lights**

Annunciators and alarm lights, both visual and audible, are provided primarily for safety considerations, but also to alert an operator and give him immediate information on the status of the steam generating unit at any instant. Thus he will have an early warning in the event of malfunction of any piece of equipment or important off-limit operating variable, and he will be able to take faster corrective action to keep the unit on stream.

**Variables that frequently require alarms are:**

1. High and low steams drum water level.
2. Low feedwater pressure or loss of feedwater flow.
3. Low pressure differential between feedwater and steam drum pressures.
4. High and/or low fuel oil supply temperature. When burning heavy fuel oil.
5. High and/or low fuel oil supply pressure.
6. Atomizing media low pressure differential.
7. Low fuel gas pressure in burner header.
8. High fuel pressure.
9. Low pilot gas supply pressure.
10. Low forced draft fan differential pressure.
11. High pressure in combustion chamber.
12. Loss of air preheater drive.
13. Loss of main burner flame.
14. Loss of pilot flame.
15. Instrument air low pressure.
16. Loss of electric power.
17. Oxygen high or low.
18. Combustibles high.
19. High flue gas temperature.

**B) Safety Shutdown Systems**

Careful attention should be given to the installation of shutdown devices and associated electrical and instrument air supplies in order to ensure adequate equipment and personnel protection and to minimize nuisance shutdowns.

**Some of the variables selected for automatic trip are:**

1. Low fuel gas or fuel oil burner pressure.
2. Burner pressure high.
3. Atomizing steam low differential pressure.
4. Loss of combustion air.
5. Low water level.
6. Loss of electrical power.
7. Loss of instrument air.
8. Emergency trip switch.
9. Loss of flame.

**2.1.4.3) Degree of Burner Automation**

The procedures discussed can he implemented with either a fully automatic system or a supervised manual system. An automatic system requires an initiating push button with all purging positioning timing and valve opening and losing taken care of automatically in an supervised manual system, the operator performs the acts with a interlock at the break points along the way. Also a D.C.S. system will be introduced as a burner management system in the coming phase.

## 2.2 Elements of Control Loops:-

This section is dedicated to the elements used in control systems, elements will be considered generally or with some details according to its nature, the elements are as follows:-

1- Measuring elements
2- Controllers
3- Signals
4- Actuators
5- System

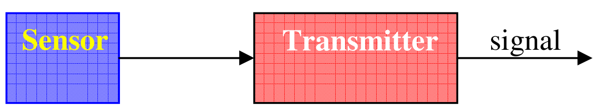
Elements are calculated according to standards which are mentioned or chosen from catalogues of certain companies, both standards and catalogues offer two types of specifications which are, specifications for the user's conditions and requirements to enable him to select or design a suitable element and these are mentioned in this section, and specifications for the user to prepare for the element to function correctly and these are included in the appendices.

### 2.2.1 Measuring Elements:-

#### A) Temperature Measurements:

The measurement of temperature is used in measuring the super heated steam temperature. There are many types of temperature measurements such as resistance thermometers, PTC (positive temperature coefficient) sensors, thermocouples, NTC (negative temperature coefficient) sensors and many more .Here we will use a thermocouple for temperature measurements chosen from the Rosemount Measurement Catalogue for temperature sensors, assemblies and accessories.

A typical temperature measurement arrangement is as in the following figure:-

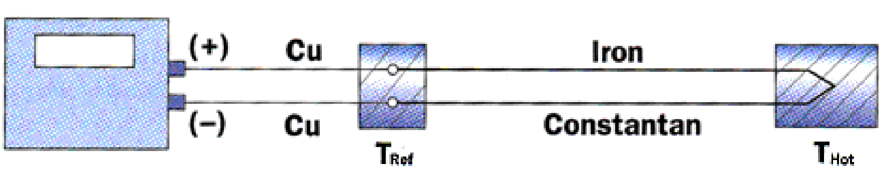



**Sensor:-**

Sensors might be thermocouples or RTD's as mentioned but we shall only mention thermocouple here as they are the sensors used in our case.

**Thermocouples:**

Thermoelectric (seebeck) effect: This is the basic principal in which a thermocouple works according to and it apposes that when two metals are connected together, a thermoelectric voltage is produced due to the different binding energies of the electrons to the metal ions. A typical J type thermocouple is as in the figure below




**We chose the series 183 thermocouple type J of Rosemount Company** because it is in the required limit which is 0 - 760˚C and has a error limit of ±1.1˚C or ±0.4% of measured temperature, whichever is greater. This suits the flow condition which is around 450˚C

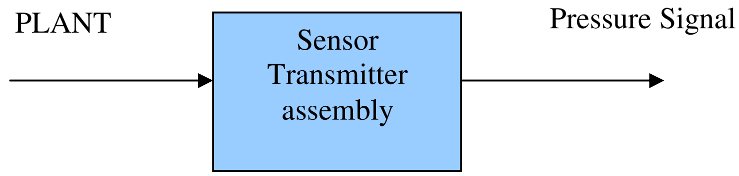
**Transmitter**

According to Rosemount Measurement Catalogue for smart temperature transmitters we chose model 3144 type J which has an input range from -180 to 760˚C and has an accuracy of ±0-02% of span.

FOR ROSEMOUNT CATALOGUE REFER TO APPENDIX C

## B) Absolute Pressure Transmitter

The pressure is measured in firing circuit ranging from 40-50 bars. A typical arrangement of the sensor and transmitter is as in the figure below:-




We choose the pressure transmitter from the catalogue of the Rosemount Company and we chose Model 1151 Alphaline absolute pressure transmitter.
The 1151 Alphaline pressure transmitter are offered in a variety of a configurations for differential, gauge, absolute, liquid-level, flow and specific gravity measurement specifications. The transmitter suitable for our case is the one below.

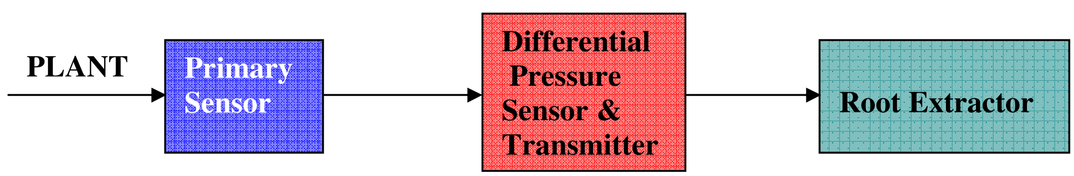
(Model 1151 AP)

| CODE | Maximum Span (bar) | Minimum Span (bar) |
|---|---|---|
| M8- (1– 5 V, Linear, Low Power/Fixed) | 69 | 34.5 |

FOR ROSEMOUNT CATALOGUE REFER TO APPENDIX D

## C) Flow Meter Measurement:

Flow meters are used in transmitting the flow rate conditions in the three basic loops for steam demand, feed water, air and fuel flow rates.
A basic flow meter arrangement is as in the figure below:-




We first calculate the correct piping size according to the flow conditions and the **ASME B31.3 TYPE & PROPERTY STANDARD**, and **ANSI B36.19 SIZING STANDARD**. These two standards offer a pipe selecting procedure.
We then calculate the primary sensor which might be an orifice, nozzle or a venturi according to the **BS 1042 ( ISO 5167-1 ) STANDARDS**, these primary sensors are responsible for making a pressure difference which sensed by a differential pressure transmitter, then the flow rate is calculated by the fact that it is directly proportional with the square root of the differential pressure.
Here are the values calculated and selected for different flow meters

- **Natural Gas Flow Meter**

Flow conditions

| Pressure (P) bar | Temperature (T) K | Density ($\rho$) kg/m$^3$ | Viscosity ($\mu$) Kg/m s | Velocity (V) m/s | Maximum Flow rate($\dot{m}$) Ton/hr |
|---|---|---|---|---|---|
| 10 | 300 | 9.13 | $71.1*10^{-7}$ | 5.61 | 6.5 |

- **Piping Dimensions and specification**

Carbon Steel Seamless Pipe

| Pipe Size (inch) | Type(ASME B31.3) | Size Schedule (ANSI B36.19) | Inner Diameter mm |
|---|---|---|---|
| 8 | API 5L | 10S* | 211.557 |

- **Orifice Plate Dimensions**.

Orifice Plate Flange Tapings

| Max Pressure Drop ( bar) | Diameter Ratio (β) | Discharge Coefficient (C) | Orifice Diameter mm |
|---|---|---|---|
| 0.1 | 0.4386 | 0.6015 | 92.7889 |

- **Differential Pressure Transmitter ( Rosemount Company )**

(Model 1151 DP)

| CODE | Maximum Span (bar) | Minimum Span (bar) |
|---|---|---|
| J4- (4 – 20 mA DC) Analogue square root | 0.373 | 0.06213 |

- **Steam Flow Meter**

Flow conditions

| Pressure (P) bar | Temperature (T )$^{o}$C | Density (ρ) kg/m$^3$ | Viscosity (μ) Kg/m s | Velocity (V) m/s | Maximum Flow rate ($m^{\cdot}$ ) Ton/hr |
|---|---|---|---|---|---|
| 41 | 450 | 13.15 | $2.45*10^{-5}$ | 46.6 | 100 |

- **Piping Dimensions and specification**

Carbon steel Seamless Pipe

| Pipe Size (inch) | Type(ASME B31.3) | Size Schedule (ANSI B36.19) | Inner Diameter mm |
|---|---|---|---|
| 10 | API 5L | 30 | 257.454 |

- **Nozzle Dimensions**

Nozzle ISA 1932 ISO 5167-1:1991(E)

| Max Pressure Drop ( bar) | Diameter Ratio (β) | Discharge Coefficient (C) | Orifice Diameter Mm |
|---|---|---|---|
| 1 | 0.6071 | 0.96071 | 156.3 |

- **Differential Pressure Transmitter( Rosemount company )**

(Model 1151 DP)

| CODE | Maximum Span (bar) | Minimum Span (bar) |
|---|---|---|
| J5- (4 – 20 mA DC) Analogue square root | 1.865 | 0.3108 |

- **Feed Water Flow Meter**

Flow conditions

| Pressure (P) bar | Temperature (T) $^{o}$C | Density (ρ) kg/m$^3$ | Viscosity (μ) Kg/m s | Velocity (V) m/s | Maximum Flow rate ($m^{\cdot}$ ) Ton/hr |
|---|---|---|---|---|---|
| 50 | 30 | 990 | $101.5*10^{-6}$ | 1.465 | 100 |

- **Piping Dimensions and Specification**

Carbon steel Seamless Pipe

| Pipe Size (inch) | Type (ASME B31.3) | Size Schedule (ANSI B36.19) | Inner Diameter mm |
|---|---|---|---|
| 6 | API 5L | Extra Strong | 257.454 |

- **Orifice Dimensions**

Orifice Plate with Flange Tapings
ISO 5167-1:1991(E)

| Max Pressure Drop ( bar) | Diameter Ratio ($\beta$) | Discharge Coefficient (C) | Orifice Diameter mm |
|---|---|---|---|
| 5 | 0.6806 | 0.6048 | 156.3 |

- **Differential Pressure Transmitter( Rosemount company )**

(Model 1151 DP)

| CODE | Maximum Span (bar) | Minimum Span (bar) |
|---|---|---|
| S6- (4 – 20 mA DC) Digital ,smart/variable | 13.8 | 0.92 |

- **Air Flow Meter**

Flow conditions

| Pressure (P) bar | Temperature (T ) $^oC$ | Density ($\rho$) $kg/m^3$ | Viscosity ($\mu$) Kg/m s | Velocity (V) m/s | Maximum Flow rate ($m^{\cdot}$)$m^3$/hr |
|---|---|---|---|---|---|
| 1 | 30 | 1.16 | $184.6*10^{-7}$ | 34.03 | 30.31 |

- **Piping Dimensions and Specification**

Carbon Steel Seamless Pipe

| Pipe Size (inch) | TYPE(ASME B31.3) | Size Schedule (ANSI B36.19) | Inner Diameter mm |
|---|---|---|---|
| 42 | API 5L | 55* | 1047.75 |

- **Venturi Dimensions**

ISO 5167-1:1991(E)

| Max Pressure Drop ( bar) | Diameter Ratio ($\beta$) | Discharge Coefficient (C) | Orifice Diameter mm |
|---|---|---|---|
| 0.018 | 0.7400 | 0.9352 | 777 |

- **Differential Pressure Transmitter( Rosemount company )**

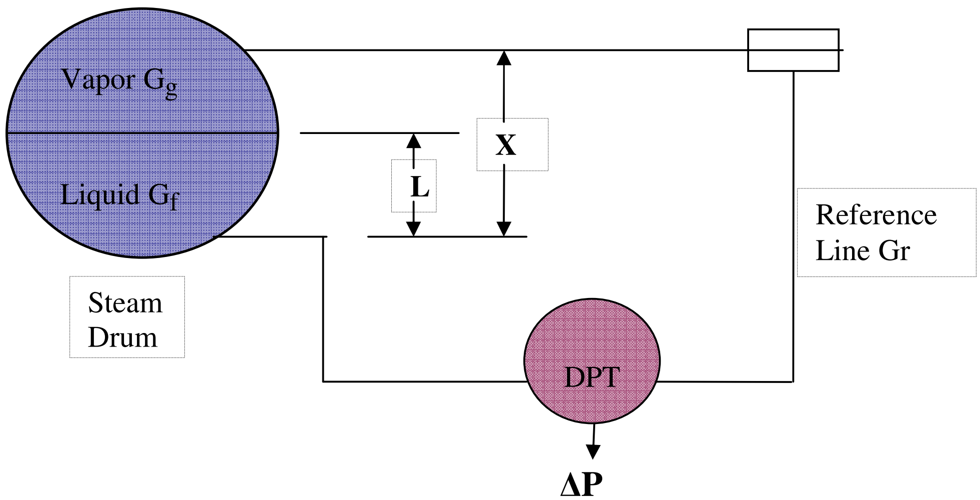
(Model 1151 DP)

| CODE | Maximum Span (bar) | Minimum Span (bar) |
|---|---|---|
| J3- (4 – 20 mA DC) Square Root Analog/variable | 0.075 | 0.0125 |

FOR PIPING CODES REFER TO APPENDIX E
FOR PRIMARY SENSOR CODES REFER TO APPENDIX F
FOR PRESSURE TRANMITTERS OF ROSEMOUNT APPENDIX D

## D) Level Measurements:

The level measurement is a hydrostatic measurement based on the differential pressure developed between top & bottom pressure tap in the drum. The differential pressure developed is function of both the water level & the densities of the water & steam in the drum. Over a wide range of pressure & temperature, the change in density has a significant effect on the differential pressure compensation corrects the differential pressure measurement to represent the actual liquid in spite of changes in density.




The equation below relates level to differential pressure

$$L = (\Delta P - Gg\ X + Gr\ X) / (G_f - Gg)$$

**Where:-**

**Gg : specific gravity of vapour = 0.0201**
**Gf : specific gravity of liquid =0.798**
**Gr : specific gravity of filled reference leg=0.9**

A chosen D.P. transmitter is as follows:

**(Model 1151 DP) of the Rosemount Company**

| CODE | Maximum Span (bar) | Minimum Span (bar) |
|---|---|---|
| S3- (4 – 20 mA DC) Digital ,smart/variable | 0.15 | 0.005 |

FOR PRESSURE TRANMITTERS OF ROSEMOUNT APPENDIX D

## E) Conductivity Measurement

For measuring the boiler water salinity for blow down we use a conductivity analyzer, a brief description of this analyzer and it's principle of operation is as follows:-

Conductivity (or puristically electrolytic conductivity) is defined as the ability of a substance to conduct. It is the reciprocal of the Resistivity. Most industrial interest is in measuring the conductivity of liquids, which generally consist of ionic compounds dissolved in water. Conductivity offers a simple test which can tell much about the quality of water, or the makeup of a solution.

## Common Processes

Table presents the conductivity of a number of specific aqueous solutions, Data is presented in most cases at 25°C; there is a temperature dependence which is described later.

Conductivity of Various Aqueous Solutions at 25°C

| | Conductivity | Resistivity |
|---|---|---|
| Absolute Water (pure $H_2O$) | 0.055 µS/cm | 18.3 MΩ-cm |
| Distilled Water | 0.5 µS/cm | 2.0 MΩ-cm |
| Power Plant Boiler Waters | 1.0 µS/cm | 1 MΩ-cm |
| Pure Mountain Stream | 10 µS/cm | 100 kΩ-cm |
| Good City Water | 50 µS/cm | rarely used |
| 0.01N KCl Soln (Standard) | 1 409 µS/cm | ↓ |
| Maximum for Potable Water | 1 500 µS/cm | ↓ |
| Ocean Water (Mid-North Atlantic) | 53 mS/cm | ↓ |
| 10% NaOH | 355 mS/cm | ↓ |
| 10% $H_2SO_4$ | 432 mS/cm | ↓ |
| 31.0% $HNO_3$ (Maximum known) | 865 mS/cm | ↓ |

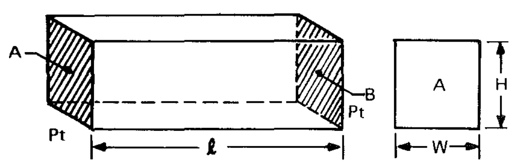
Conductivity is used extensively in the measurement of water supplies for city, hospital, and industrial use. Other applications include salinity measurements in connection with hydrology and oceanography, and waste stream measurements where a relatively high concentration of dissolved material is involved.

- **Advantages & Disadvantages**

In general, conductivity offers a fast, reliable, in-line, non destructive, inexpensive, and durable means of measuring the ionic content of a sample stream. Accuracy, reliability. and repeatability are excellent. Typically, repeatability is about 1 % of the upper range value. Conductivity is a non specific measurement it cannot distinguish between different types of ions, giving instead a reading proportional to the combined effect of all ions present

- **Theory & Concept of Cell Constant (Cell Factor)**

A very simple conductivity sensor could be constructed as a cell as follows:




The cell is constructed of an insulating material, with platinum or other metallic pieces at the ends. If the cell is filled with a solution of conductivity L, the conductance as measured between ends A and B is:

$$G = L\,\frac{A}{\ell}$$

where: $G$ = Conductance in siemens
$L$ = Conductivity in siemens/cm
$A$ = Area normal to current flow in $cm^2$ (= w x h)
$\ell$ = Length between electrodes in cm

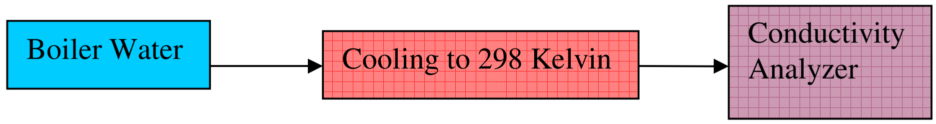
$$R = \rho\,\frac{\ell}{A}$$

The electrode less probe also has a definite cell constant determined by the geometry of the conducting loop of solution.

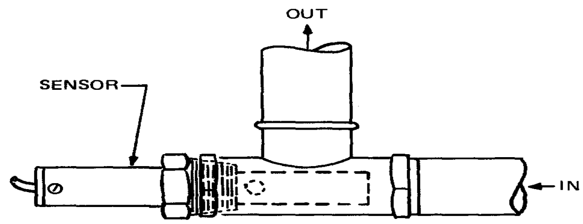
- **Temperature Effect**

The conductivity invariably increases with increasing temperature, opposite to metals but similar to graphite. It is affected by the nature of the ions, and by the viscosity of the water. The conductivity has a substantial dependence on temperature. This dependence is usually expressed as a relative change per degree Celsius at a particular temperature. Temperature makes a large difference in conductivity, and the effect is very troublesome when a high degree of accuracy is required.

The conductivity sampling system is as below




While the sensor is mounted as in the figure below:




**Recommended Mounting of Conductivity Sensor in Process Line**

REFER TO APPENDIX G

## F) <u>Flame Detector</u>

The flame detector is an important element in burner management systems, they have many specifications according to N.F.P.A., the most important is that it must be self checking. A suitable one is the ultraviolet flame detector as our application is gas firing burners that produce flames emitting ultraviolet radiations.

- **<u>Principles of Operation</u>**

The 451JV5 scanners use a UV-eye detector. This detector is a sealed, gas filled, ultraviolet-sensitive tube containing two electrodes connected to a source of AC voltage. When ultraviolet (UV) radiation of sufficient energy falls upon the electrodes, electrons are released and the inter-electrode gas becomes conductive, resulting in an electric current flow from one electrode to the other. The current flow starts and ends abruptly and is known as an “avalanche.”

A very intense source of UV radiation will produce several hundred avalanches or pulses per second. With less radiation there will be fewer pulses per second. Upon total disappearance of flame, the detector output ceases. Thus, the presence or absence of pulses is an indication of the presence or absence of flame; the frequency of the pulses is a measure of flame intensity.

**The type chosen is 45UV5 Self-Checking UV Scanner of Fire-eye Company.**

## G) <u>Flue Gas Analyzers</u>

We use an oxygen analyzer in the firing circuit to transmit the oxygen percentage from the flue gasses in the chimney; the analyzer used is the zirconium oxide oxygen (Zirconia) analyzer.

### <u>Zirconia analyzer</u>:-

These devices make use of the fact that Oxygen ions become highly mobile in Zirconia ($ZrO_2$) heated to temperatures above 300°C. Thus it is possible to use Zirconia as a solid electrolyte for an Oxygen sensor provided it is heated (typically 500°C to 800°C). The Zirconia substrate has two electrodes (Platinum, Gold or Silver typically) coated onto its surface. One is exposed to the test gas and the other to air , each electrode reaches a potential depending on the Oxygen partial pressure it sees. Gas, which reaches the sensing electrode, is either oxidized or reduced, liberating or consuming electrons from the external electrical circuit. The external circuit connects to the counter where a balancing reaction occurs. The number of electrons flowing in the circuit is then a measure of the number of molecules reacting at the sensing electrode. The cell output is the voltage of the sensing electrode relative to either the second electrode if this is in a known atmosphere, for example. The signal then becomes the current flowing between the two electrodes

**The chosen analyzer is The FGA31 1 in Situ Oxygen Flue Gas Analyzer of panametrics company. FOR CATALOGUE REFER TO APPENDIX H**

## 2.2.2 Controllers:

A controller is considered to be the element that takes the decision in a certain loop, the controller used in a conventional process control system is a P.I.D. controller, and in a later section we shall present a simulation concerning this type and other types of controllers.

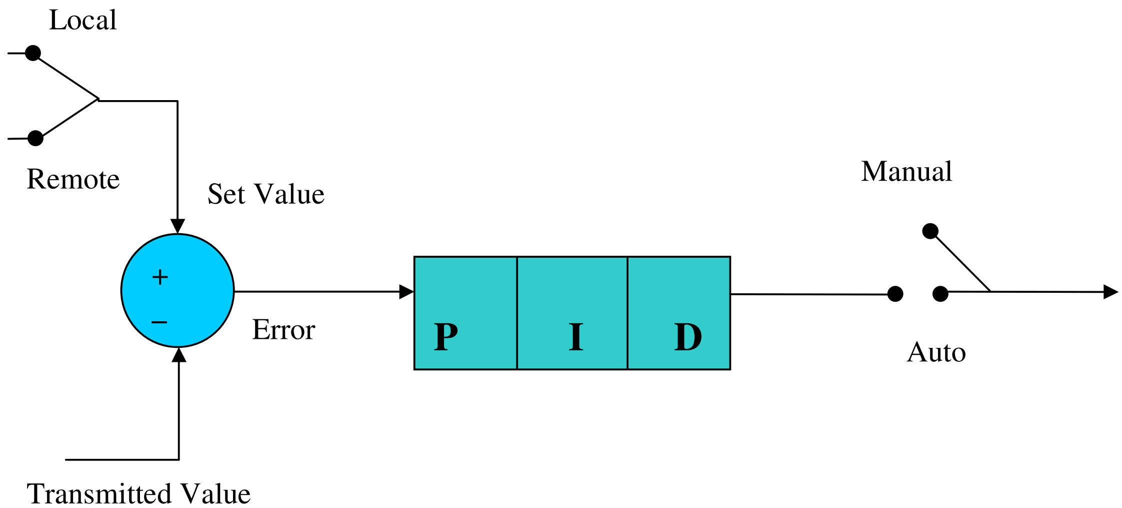
Any controller shall contain the following (as in fig):-

Error comparator

P.I.D. function with tunable weights

Remote/Local set point switch

Manual/Auto switch




**Controller Tuning:-**

The process of choosing the weights of PID controllers is called tuning this is usually done by Nichols-Ziegler methods, for explanation of this methos refer to appendix I

## 2.2.3 Signals:

Signals are considered to be the communicative elements of a control loop, they have many forms and mainly divided into two major categories namely:-

**a) Electric ( 4 – 20 ) mA Signal**

**b) Pneumatic (3 – 15) PSI Signal**

These signals are sophisticated signals for further explanation of pneumatic signals and their specifications refer to appendix J

## 2.2.4 Actuators:

The element that is manipulated to fulfill the orders of a controller is called the actuator, our actuator is usually a control valve, the following presents control valve selection criteria. We need control valves on fuel line and feed water line, also we need to control the air flow but this is controlled by draft fan guide vanes and this is not mentioned here.

**Selecting a control valve:-**

The selection of a control valve is divided in two parts. First, selection of a suitable valve characteristic, Secondly, the sizing of a selected valve

**Control valve flow characteristics:-**

Control valves percentage equalized valves.

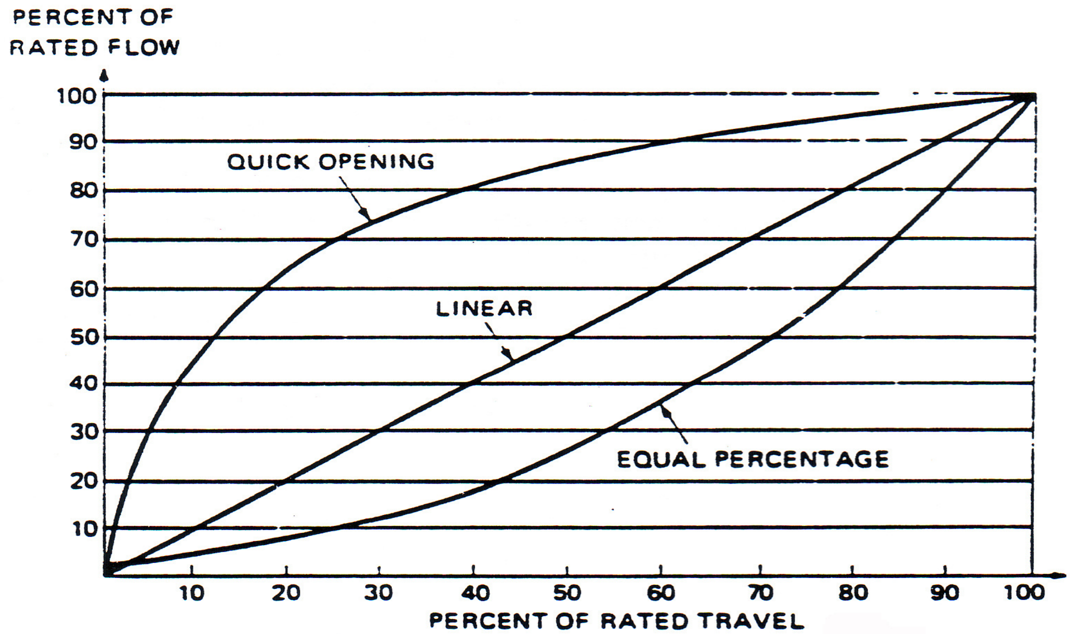
**Sizing:-**

Valve size is defined by valve constants which are as follows:-

$\mathbf{C_V}$ = quantity of water in US gallon/min passing the fully open valve at ($\Delta\rho$ = 1 p.s.i.)

$\mathbf{K_V}$ = quantity of water in $m^3$/hr passing through the fully open valve at ($\Delta\rho$ = 1 bar )

$\mathbf{C_v = 1.17\ K_v}$




Chosen valves are as follows:-

**Natural Gas Valve**

**Chosen from Neles-Jamesbury Company Catalogue**
**Series G110 globe valves (Nelsize ™ Type Code G110E)**

| Size (inch) | Valve Constant(Cv) | Relative Opening | Maximum Flow Rate (ton/hr) |
|---|---|---|---|
| 6 | 89 | 60% | 6.5 |

**Water Valve**

**Chosen from Neles-Jamesbury Company Catalogue**
**Series V510 (high pressure globe valves Nelsize ™ Type Code V510E)**

| Size (inch) | Valve Constant(Cv) | Relative Opening | Maximum Flow Rate (ton/hr) |
|---|---|---|---|
| 4 | 52 | 70% | 100 |

FOR THE NELES –JAMESBURY COMPANY CATALOGUE REFER TO APPENDIX K

**Desuperheating Valve**

DA4 Steam Desuperheater with Mechanical Water Atomization
We chose this instrument From Catalog of **EUR-CONTROL Company** Appendix L

## 2.2.5System:-

A system is the method of managing the signals from all elements and processing them, the system might be a global system as in main control loops or so, or local as to be mounted on the element itself or in the plant, the system is also responsible for all the signal calculations like root extracting and adding and biased adding etc….