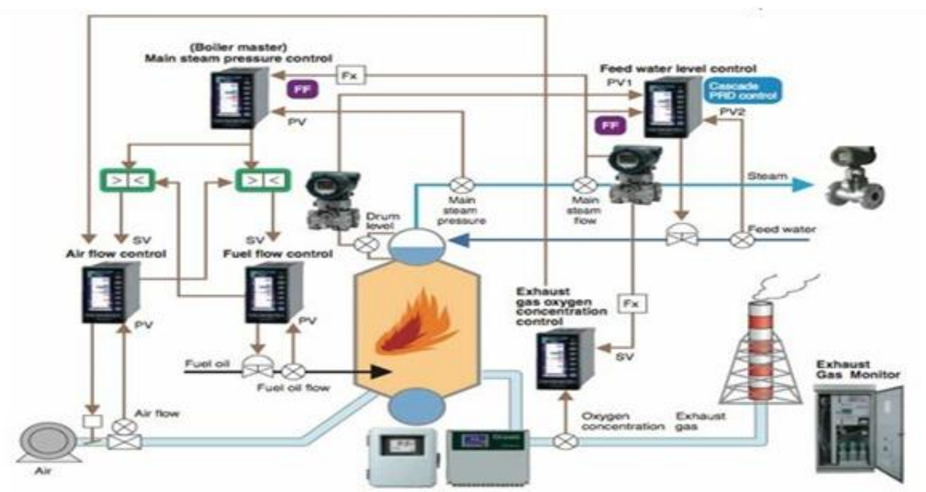
Cairo University
Faculty of Engineering
Mechanical Power Department

Boiler Control System



Under the Supervision of

Dr. Prof. Mohsen Soliman   Dr. Prof. Ashraf Sabry

Project Team

Mahmoud Elgohary Youssef	74149
Kirollos Nabil El-badry	74100
Ahmed Seifeddein Sayed Taha	74017
Karim Tarek Niazy	74098

7/19/2022

Acknowledgment:

In the beginning, praise be to God. This moment has come, and this work has been accomplished. Thank you to Faculty of engineering in Cairo University for preparing us to be successful engineers and for providing all the necessary support and assistance to implement this project in the full picture.

We extend our sincere gratitude to Dr. Mohsen Soliman & Dr. Ashraf Sabry for all their continuous support throughout the years of study within the department.

We would like to thank our parents, who are our motivation, visionary and great supporter. They always push us and push us to success. Not forgetting all who helped us, prayed for us, wished us well, or pushed us forward and bearded so much to help this work of life.

Dedication:

First of all, We Would like to dedicate this work to everyone in our family, our friends and our doctors who, throughout the long past ages, have contributed to the joys of life through their efforts. We also like to dedicate this work to Mechanical power engineering department of Cairo University. This book is also dedicated to every engineer who want to learn about boiler control system.

Abstract:

The main objective of this project is to study, investigate and do a comprehensive analysis for various types of practical automatic control systems used in an industrial water tube boiler. These systems are very essential for both accurate and safe operation of the different parts of the boiler in addition to increasing the overall boiler efficiency and stability.

In the 1st part of our study, we used practical, on-line, interactive and non-educational virtual lab software which simulates the detailed operation processes of a 120 ton/hr. water tube boiler. This virtual lab is used for management and operation of the boiler. It showed Synoptic diagram for flow directions of many types of input and output fluids moving inside various parts of the boiler in addition to showing different elements of many control boards, sensors, gauges, critical control signals and boiler alarms. The virtual lab was used to change boiler operation parameters and to perform diagnostics and troubleshooting runs. The lab included data recording, file saving and keeping operator reports. The results for each boiler successful run show charts of heat balance on different boiler sections and boiler overall thermal efficiency. Using this virtual lab we practiced engineering simulation for many critical control alarms, input/output signals, operation and instrumentation setups and plotting tools. We investigated also thermal balance calculations for various types of mass, heat and energy transfer processes involved in operation and automatic control of the boiler.

In the 2nd part of this project, the main objective was to do comprehensive research for the real-practical sensors, transmitters and control systems which were used in the virtual lab simulation. The 2nd part included investigations of the following:

1- Adjusting the optimum air-to-fuel ratio for maximum combustion efficiency at different boiler loads.
2- Firing rate demand for industrial boiler.
3- Handling, storage and treatment of liquid fuels.
4- Adjusting a safe and constant water level in the boiler superior drum for different boiler loads or operation conditions.
5- Control the maximum allowable steam pressure in the water tube boiler.

6- Control the superheated steam temperature at the super heater outlet point.
7- Control the flow rate and temperature of the feed water supply into the economizer section.
8- Control the number of dissolved gasses in the feed water through the de-aerator tank.
9- Control the blow-down process of the boiler both manually and automatically.
10- Furnace pressure control.
11- Boiler following and Turbine following mode.

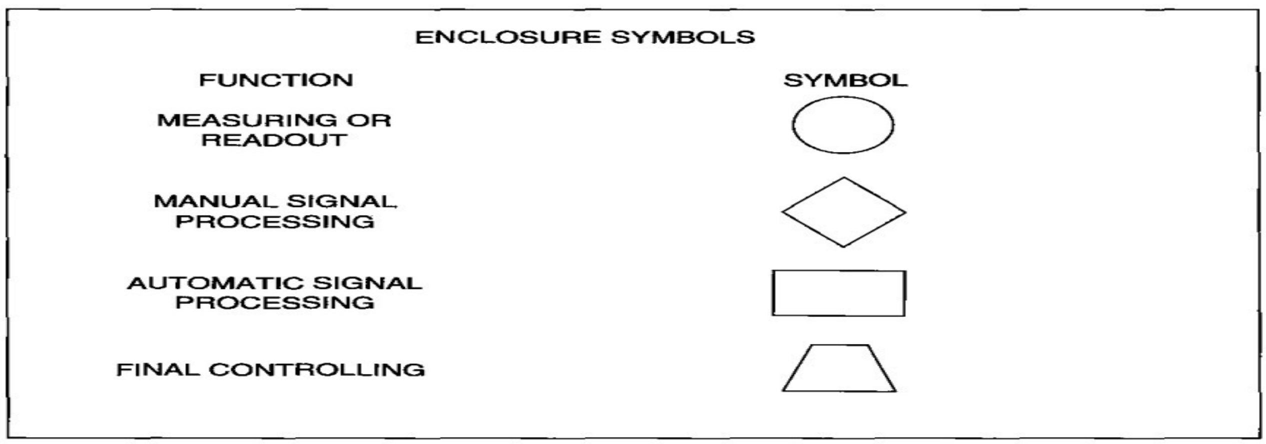
Table of Contents

Table of figures

List of tables:

List of Symbols:

SAMA Symbols (Scientific Apparatus Makers Association)

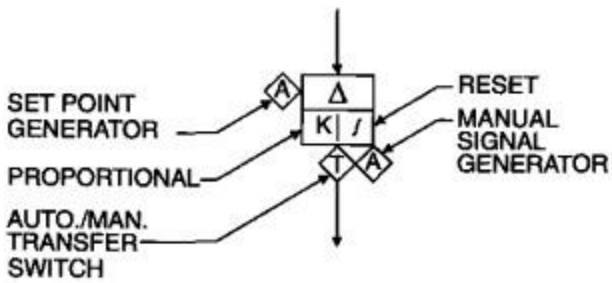


SAMA Symbols

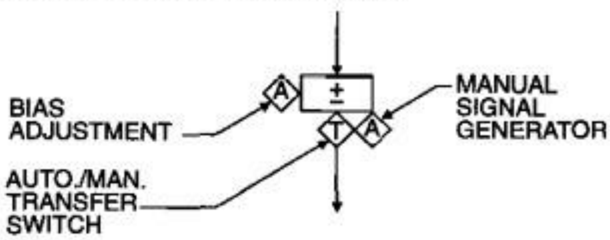
FUNCTION	SIGNAL PROCESSING SYMBOL	FUNCTION	SIGNAL PROCESSING SYMBOL
SUMMING	Σ or +	INTEGRATE OR TOTALIZE	Q
AVERAGING	Σ/n	HIGH SELECTING	>
DIFFERENCE	Δ or -	LOW SELECTING	<
PROPORTIONAL	K or P	HIGH LIMITING	$\not>$
INTEGRAL	$\int$ or I	LOW LIMITING	$\not<$
DERIVATIVE	d/dt or D	REVERSE PROPORTIONAL	-K or -P
MULTIPLYING	X	VELOCITY LIMITING	V $\not>$
DIVIDING	+	BIAS	$\pm$
ROOT EXTRACTION	$\sqrt{}$	TIME FUNCTION	f(t)
EXPONENTIAL	X^n	VARIABLE SIGNAL GENERATION	A
NON-LINEAR FUNCTION	f(x)	TRANSFER	T
TRI-STATE SIGNAL (RAISE, HOLD, LOWER)	$\updownarrow$	SIGNAL MONITOR	H/, H/L, /L

Note: *SAMA and ISA Symbols are the same.*

1. CONTROLLER



2. AUTO MANUAL + BIAS STATION



○	MEASURING OR READOUT
▭	AUTOMATIC SIGNAL PROCESSING
◇	MANUAL SIGNAL PROCESSING
⏢	FINAL CONTROLLING
[I]	SIGNAL REPEATER
Σ	SUMMING Σ/h AVERAGING d/dt DERIVATIVE
Δ	DIFFERENCE ∫ INTEGRAL
K, −K	PROPORTIONAL, REVERSE PROPORTIONAL
X	MULTIPLYING ÷ DIVIDING √‾ ROOT EXTRACTING
f(x)	NON LINEAR OR UNSPECIFIED FUNCTION
f(t)	TIME FUNCTION
>	HIGH SELECTING < LOW SELECTING
≯	HIGH LIMITING ≮ LOW LIMITING
V ≯	VELOCITY OR RATE LIMITER
+,−,±	BIAS
T	TRANSFER
A	ANALOG SIGNAL GENERATOR

List of Abbreviations

FD: forced draft

ID: induced draft

TDS: total dissolved solids

HE: heat exchanger

RTD: Resistance temperature detector

1 Introduction:

Boilers are a key power source for electrical generation in the United States and around the world and for providing heat in process industries and buildings. [9]

1.1 What is a steam boiler?

A boiler is a closed vessel in which a liquid, typically water, has heat energy applied to create steam. Boilers of the nineteenth century were usually made with very expensive, high-quality wrought-iron. Modern boilers, on the other hand, are made of steel or steel alloys to combat higher-temperature characteristics and for better strength-to-weight ratios. [9]

1.2 How a steam boiler work?

Heat energy is provided to the boiler chamber by burners fueled by natural gas, oil, coal, or electric heaters. While boilers are widely used in many industries, some typical applications of steam boilers are:

- Steam power generators
- Hot water applications
- Food preparation
- Water sanitation purposes

When discussing boiler design, we should take care of four important parameters which are Safety, Stability, Accuracy and Efficiency. [9]

1.3 Water tube boiler parts and their functions:

There are many pressure parts and non-pressure parts in a water tube boiler we only discuss main water tube boiler parts and function. [10]

1. Steam drum
2. Mud or water drum
3. Water walls
4. Super heater
5. Economizer
6. Air heater
7. Boiler fans

Steam drum

Steam drum is a collection vessel for steam & water. Here water & steam is separated. It has steam separators. Steam goes from top side to superheater & water goes from the bottom through down comer Mud drum, then to furnace bottom ring headers (bottom of furnace water wall). [10]

Mud or Water Drum

Mud or water drum the lower drum is directly attached to upper steam drum with large no of straight tubes bundles called boiler bank tubes. Solids and mud can settle in this mud drum for removal through periodic blowdown. Sometimes desuperheater coil also installed in this drum to recover heat from superheated steam. Draining arrangement of this drum is through one or two boiler blowdown connections to control TDS or to fully drain the boiler when out of service. [10]

Water walls

Tubing arrangement around the furnace to extract heat from fuel to generate steam is called water wall circuit. These water walls can be arranged in line arrangement or stagger arrangement. Water walls get the heat from radiation and approximately absorb the 50% of the total heat produced in the furnace. [10]

Super heater

If the temperature of the steam is above its saturation temperature, then it is called superheated steam. The super heater (heat exchanger) is used to increase the temperature of the steam. These are bundles of high strength tube which can bear temperature 600C Depending upon the material of tubes Mostly SA-213 is used. In most industrial water tube boilers, the superheater is placed where flue gases make their turn from the radiant to the convection section of the boiler. There are three types of super heaters convection and radiation super heaters. [10]

Economizer

Economizer (heat exchanger) is the boiler accessory used to recover the heat of flue gas that leaving the boiler by heating feed water. The efficiency of a boiler can be increased with an economizer. 60C rise in feed water temperature with the help of economizer can save up to 1% of fuel. Typically, economizer is used before the air heater in flue gas path of the boiler to increase the boiler efficiency. [10]

Air Heater

Air supplied to a boiler for combustion is pre heated with the help of air heater by recovering the heat of waste flue gas that leaves the economizer. 20C rise in temperature of combustion air can save up to 1% of total fuel. Preheated air is also required for the operation of pulverized coal furnaces. Primary air is needed for drying coal in the pulverizer.

Air heaters are classified into two main types recuperative Air heaters and regenerative Air heaters. [10]

Boiler Fans

For combustion of fuel in the boiler furnace air is drawn from the atmosphere and pushed through the ducts with forced draught fan to furnace where air reacts with fuel and become flue gas, the flue gas is then extracted from the furnace with the help of Induced draught fan. The fan used in large water tube boilers are FD fans, ID fans, Primary air fans, Secondary air fans and Gas recirculation fans.

Other main water tube boiler parts are burning equipment burners and furnace and gas cleaning devices like ESP Cyclone Separators and bag filters. [10]

1.4 Two Main Types: Fire-Tube and Water-Tube Steam Boilers

There are two main types of Industrial Steam Boilers: Fire-Tube and Water-Tube Boilers. Fire-Tube boilers consist of a series of straight tubes housed inside a water-filled outer shell. In fire-tube boilers, hot combustion gases pass through inside the tubes to heat the water that surrounds the outside of them causing steam. This construction is more straightforward with less rigid treatment requirements for the water used in the outer shell. This design is well suited for space heating and low pressure hot-water industrial applications, but not for high power steam generation. [9]

1.4.1 Applications for Fire-Tube Boilers:

- Home heating systems
- Trains
- Small Factories

1.4.2 Applications of Water-Tube Boilers:

- Steam power generation
- Paper manufacturing
- Chemical and oil refining

1.5 Differences between Fire-tube boiler and Water-tube boiler:

The main difference between fire-tube and water-tube boilers is that fire-tube boilers send fire through tubes to heat water on the outside of the tubes see figure 1-1 and water-tube boilers send water through tubes to be heated by burning gases on the exterior of the tubes. These tubes extend between an upper header, called a steam drum, and one or multiple lower headers or drums. Water-tube boilers produce steam much more quickly and allow for the generation of lower weight-per-pound of steam. Generally, both these types of boilers can handle pressures up to 5,000 PSI with the steam generated reaching very high temperatures. Proper controls of these high pressures and temperatures are necessary to prevent catastrophic events from happening. Two drums are needed for water containment, making water-tube boilers extremely large and bulky with a typically much higher initial capital cost. [9]

Figure 1-1 fire tube boiler

2 Objective of Control on boiler:

WHY BOILER CONTROL?

a) 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.

b) Protect environment and 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.

c) 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.

d) 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.

3 Virtual lab:

- We cannot effectively control a system if we do not understand all of its parts and components (subsystems), as well as all of the different inputs and outputs signals and parameters that are present in this system. For this reason, it is important to comprehend and examine all of the different control and alarm systems that are included in the **Automatic Control Virtual Lab**.

- First, we ensure that we fully comprehend the real processes and systems that we are analyzing. Second, because using or testing real parts or actual circuit components is very expensive, time-consuming, can be limited in applications, may be harmful, needs maintenance and repairs, etc., we analyze and test real processes/systems using computer simulation rather than real hardware.

- Modern Applications for PCs and Its produced new types of Virtual Lab Programs/Software that work on all PCs & simulate to a great extent real Automatic Control Systems used in all industrial & practical applications of Mechanical Power Systems. These Virtual Labs are specially designed to give the user a broad-based understanding of the most important concepts of practical automatic control tools & real thermo-fluid processes in industrial mech. power systems such as operation and control of electric power generation Steam-plants or operation& control of refrigeration and freezing plant or solar heating system...etc. The Virtual Labs must include simple sketch (called Synoptic diagram) for real Control System of interest as shown. The interactive Synoptic diagrams in include also flow visualization of various fluids which exist & move in real/actual control system under investigation. In addition to the shown Synoptic diagrams, these Virtual Labs consist of and display many essential control-boards and instrumentation-panels, which are identical and do the same functions as many industrial automatic control systems existing in practical mechanical power systems.

3.1 Advantages of automatic control virtual lab:

For training and education, Virtual Labs are excellent tools.

3.2 Disadvantages of automatic control virtual lab:

Virtual Labs may be:

- expensive
- have fewer applications,
- contain software errors or bugs
- be overly ideal and ignore important effects

- They may also have been developed by non-experts, which could result in errors in science or engineering and, as a result, produce unreliable results that must be confirmed or tested.
- In this research, we used virtual lab for simulating how a water tube boiler (which is previously mentioned in details) is controlled and led to its automatic control mode, and this is the catalogue of the program.

4 Catalogue:

4.1 Requirements:

4.1.1 Hardware:

It is recommended a minimum configuration of a Pentium P.C., 16 Mbyte of RAM and a monitor resolution not higher than 800 x 600 with max 24-bit colors (with 32-bit error on GDI.EXE module). The program doesn't support the option large fonts (image splitting).

Note: For an optimal configuration of the computer see Microsoft® manuals inherent to the installed operating system.

4.1.2 Software:

The simulation software has been made using Visual-Basic language and it is, absolutely, a Windows application; this means that it needs Windows as operating system. Therefore, the use of quick selection keys for accessibility functions in Windows environment is provided as described in Microsoft manuals.

4.1.3 User Interface:

The simulation is realized using the mouse; this choice has been motivated because the use of mouse results immediate for users not accustomed to deal with computer.

As regards interface 'philosophy', the use of mouse makes available to the user everything the mouse identifies (icon, menu or symbol). That means you can activate menu controls (help, options, info, etc.…).

4.2 Program Management:

4.2.1 Installation:

Execute the following operations:

1. Start the computer.
2. Put the installation CD into the drive unit.

If the CD drive is set for the Autorun, to install programs click with mouse on the icon of the selected program.

If the CD drive is not set for the Autorun you have to run:

X/Autorun/Autorun.exe

where X is the CD drive.

If you have problems with the Autorun the selected program can be directly installed using the instruction:

X/Name/Setup.exe

where Name is the program directory.

FOR THE UNINSTALL:

Use the Windows utility:

from "Set up", "Control Panel", "Add/Remove Applications" select the program to uninstall and follow the indicated procedure.

4.2.2 Start:

At the end of installation, the following icon appears on the menu start Programs - Plants Simulation:

and the title click on the icon and then on the key **OK** of the logo to start the program.

4.2.3 Program Overview:

4.2.3.1 Introduction:

The Steam generators (Boilers) are those complex apparatus used for water transformation into steam exploiting the thermal energy developed into the combustion process. They are commonly called boilers see figure 4-1 and figure 4-2.

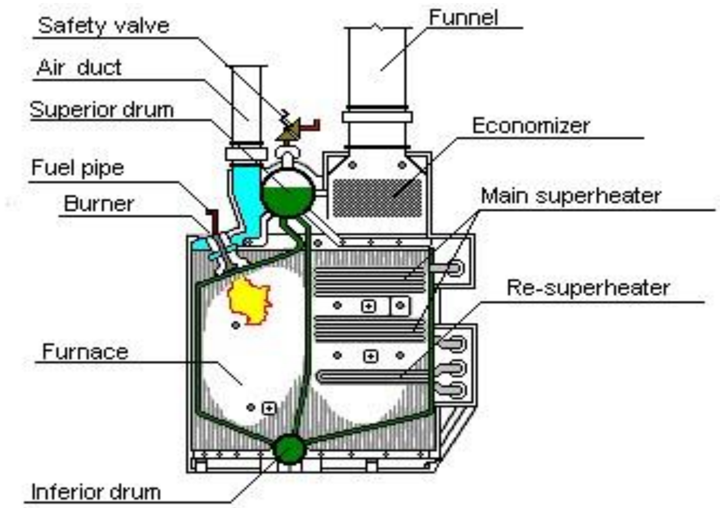


Figure 4-1

Water-tube boilers are those boilers where the water, or the steam water mixture is contained into tubes externally lapped by the combustion products (fumes) that from the combustion chamber move towards the funnel.

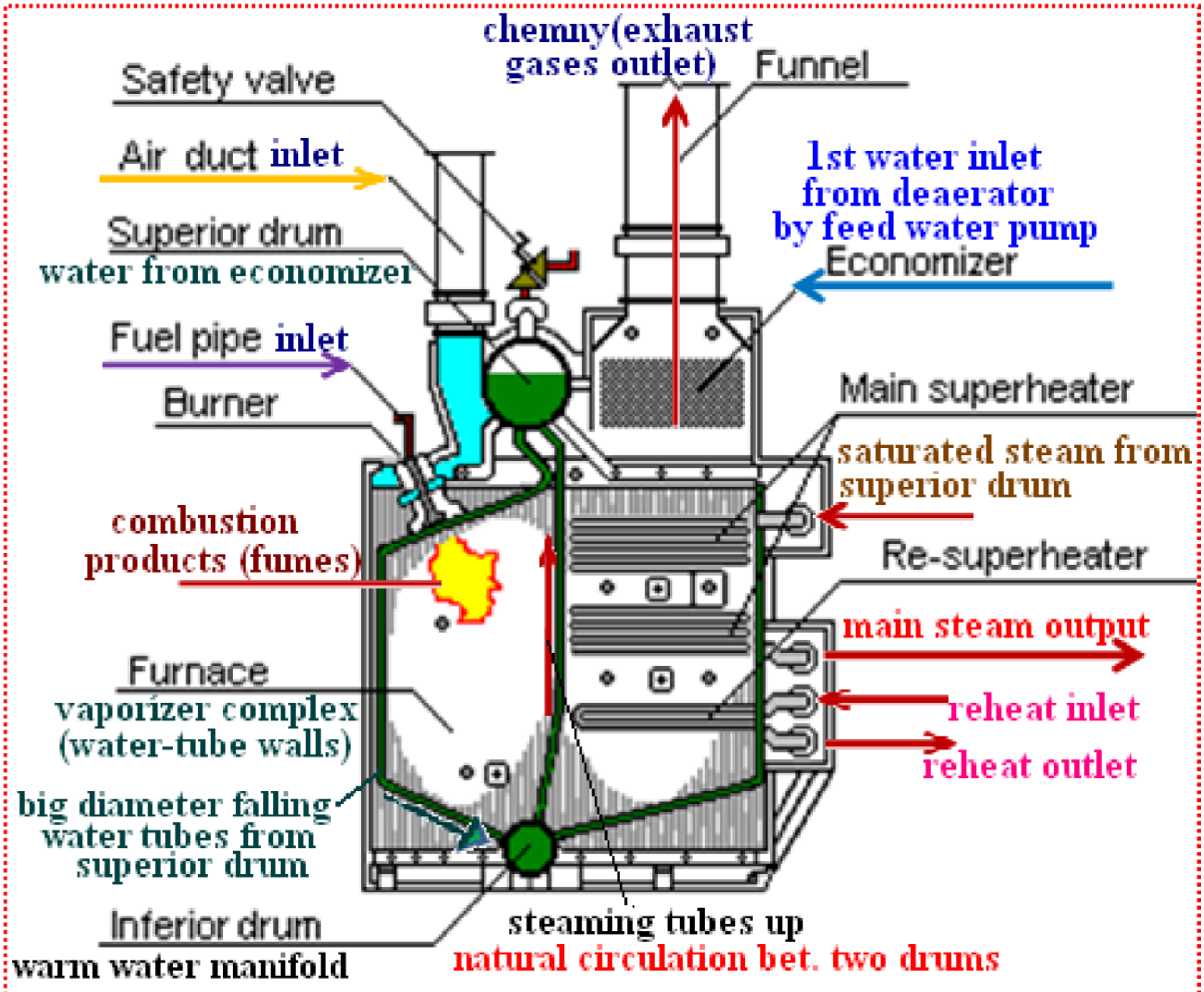


Figure 4-2

Each water-tube boiler can be considered as a vaporizer complex formed by many communicating or connected tubes where the feeding water coming from the *economizer*, pushed by the feeding pump, arrives into the *superior manifold*, called also collector of water and steam. From here because of the gravity, through the big diameter *falling tubes* situated at the boiler exterior to be subjected to the warm gases and subtract the gases heat. The higher density water comparatively cold comes to the *inferior manifold* called also water manifold. From here the *steaming tubes* start, exposed to the main flow of the combustion gases that transmit the heat quantity necessary to water steaming, contained into their interior. The mixture of lower density water and steam re-ascends again into the superior manifold. In this way, a natural circulation between the two manifolds establishes due to density difference. The steam is then drawn from the superior manifold, sent to the *main super-heater* and *re-super-heaters* and subsequently to the users. The boiler insulation is obtained by covering the combustion chamber inside walls with a framing made of big diameter tubes that have a function of absorbing the furnace radiant heat and it is called *water wall*. The water wall is realized with the system of tangent tubes, placed side by side, with all their surface exposed to the radiant heat, with refractory material placed on the back of the tubes. The water walls through *manifold heads* are connected to superior and inferior manifolds. The following figure 4-3 is called **Synoptic**.

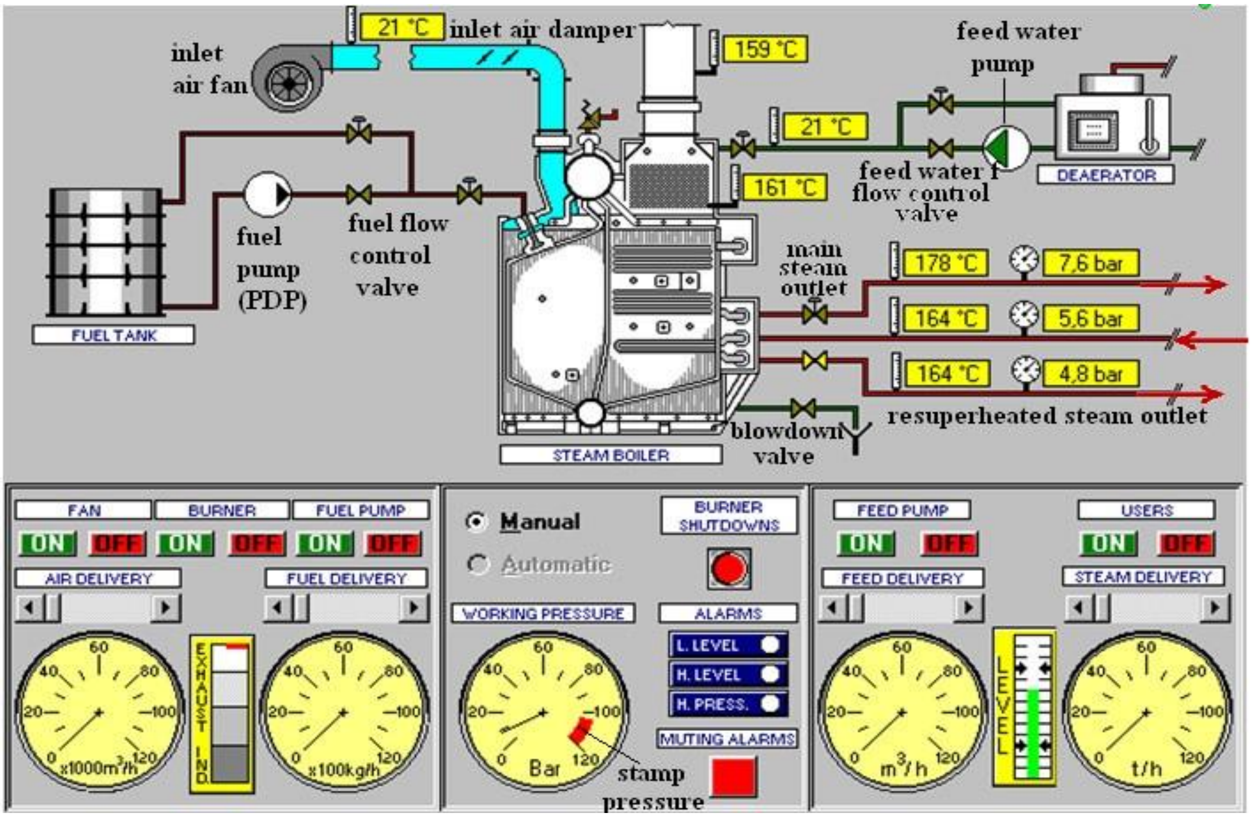


Figure 4-3

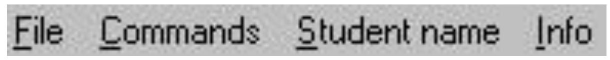
Boiler characteristic parameters are:

- The exercise or stamp pressure. It is the range of effective pressure of the steam produced in normal working conditions; it is indicated on the boiler front with proper stamp. Normally on the boiler pressure gauge the zone the pressure must not exceed is red. In shown figure the maximum working pressure is 102 bar as on the pressure gauge.

- The efficiency. Expressed in **kg / h** or **T / h** it is the steam production per hour in kilogram or tones, in the normal working conditions;
- The effective steaming index. It is the ratio between the produced steam quantity per hour and the burned fuel quantity per hour;
- The heating surfaces. It is defined as the generator surface that on one side is drawn by the combustion products and on the other one by the water; it is measured in m2 from the side of the combustion products;

- The specific efficiency. It is the quantity of produced steam per hour and per m2 of heating surface;
- The specific capacity. It is the ratio between the water volume contained into the generator and the heating surface.

4.2.3.2 Menu Bar:

The menu bar includes 4 items: 

that can originate a submenu or open some operative windows. Select with the mouse the desired item and click on it.

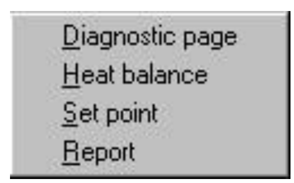
4.2.3.2.1 File:

It gives the access to a submenu that includes:

- Restart: this selection cancels all data, setting the program for the execution of a new exercitation;
- Exit: it closes the program.

4.2.3.2.2 Commands

It gives the access to a submenu that includes:



- Diagnostic page (figure4-4): this selection opens the following window (whenever you open this window you find numerical values are always changing during the boiler operation). Good run shows nonzero values for steam output along with other reasonable values:

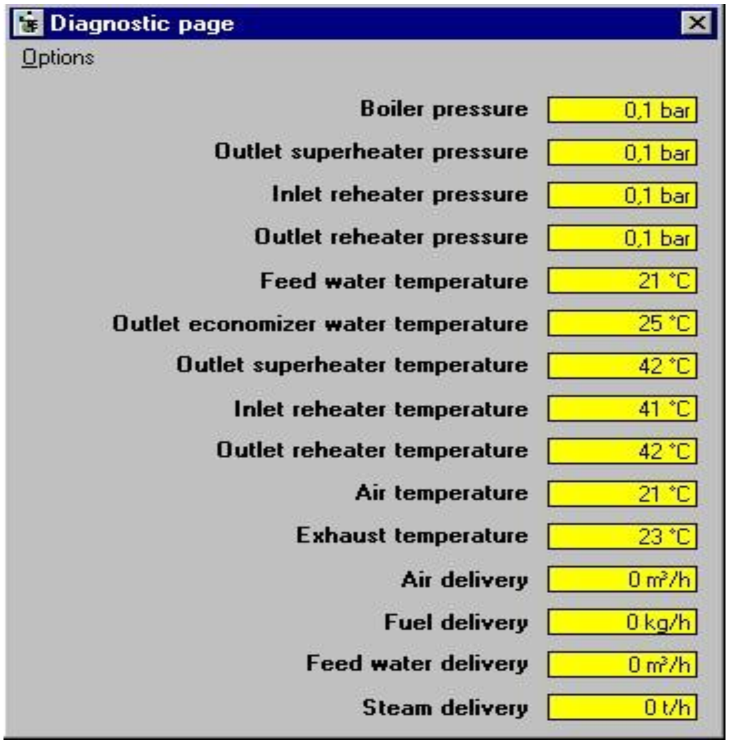


Figure 4-4

Where all the numeric quantities necessary for the heat balance calculation are indicated. From the menu bar the unique **Options** item allows:

- To come back to the main synoptic (Exit);
- To print (Print);
- To obtain the pie diagram (Heat balance).

Note: The heat balance item is written in negative when is inactive.

<u>Heat balance</u>: this selection can be done/effectuated when the values/transcription from negative comes positive; to obtain this, the burner must work and the steam must be taken (nonzero steam output). When possible, the following window is opened: (see figure 4-5)

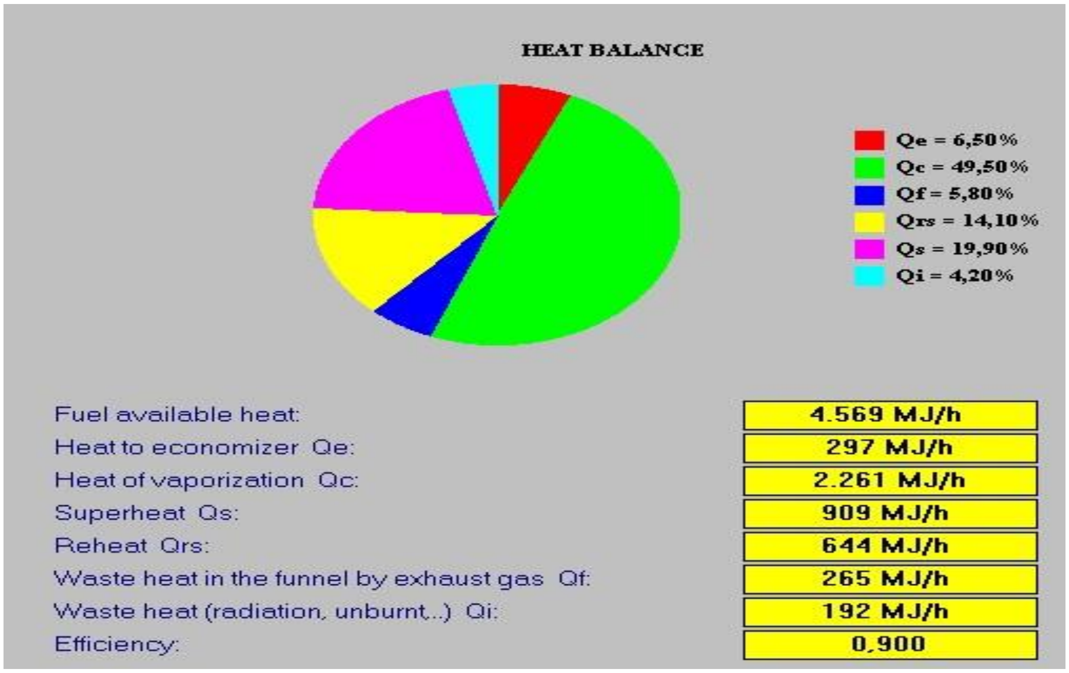


Figure 4-5

On this window it is possible to read the values that form the pie diagram. With the buttons or alternatively with the same items preset in the **Options** menu it is possible respectively:

- To print;
- To come back to the diagnostic page; • To come back to the main synoptic.

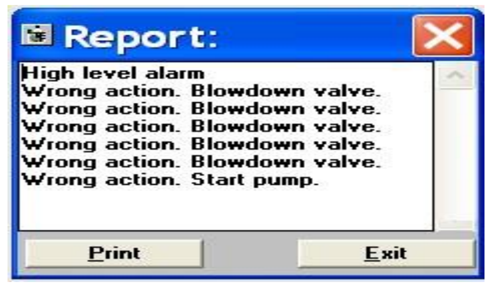
Set point (for automatic run): The program with casual source (not intended) can insert some anomalies (non-standard or unusual values) into the register of air, of fuel and into the level stat setting. The anomalies are activated during the automatic conduction/ run. As the steam generator, even if with a worsening of its efficiency equally works, the operator could ignore the anomaly; for this reason, when printing the exercitation recording/report (see following paragraph), the anomaly if present is transcribed. Vice versa, if the operator locates the anomaly, with this selection enters following window shown here:

from this window through the OK keys, you can exclude the anomaly. If the anomaly has been individuated correctly will appear the message

vice versa will appear a message as- - - - - →

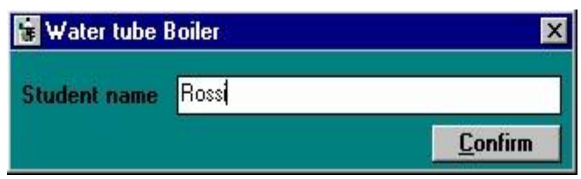
All the messages that will appear, included those of wrong maneuver will be registered and they'll can be saved on file at the program closure.

<u>Report:</u> opens the window as shown - - - - -



in this window it is presented the recording of the done exercitation/run, in our case by Rossi. It can be printed by clicking on the proper button. To close the window, click on Exit button.

4.2.3.2.3 Student Name



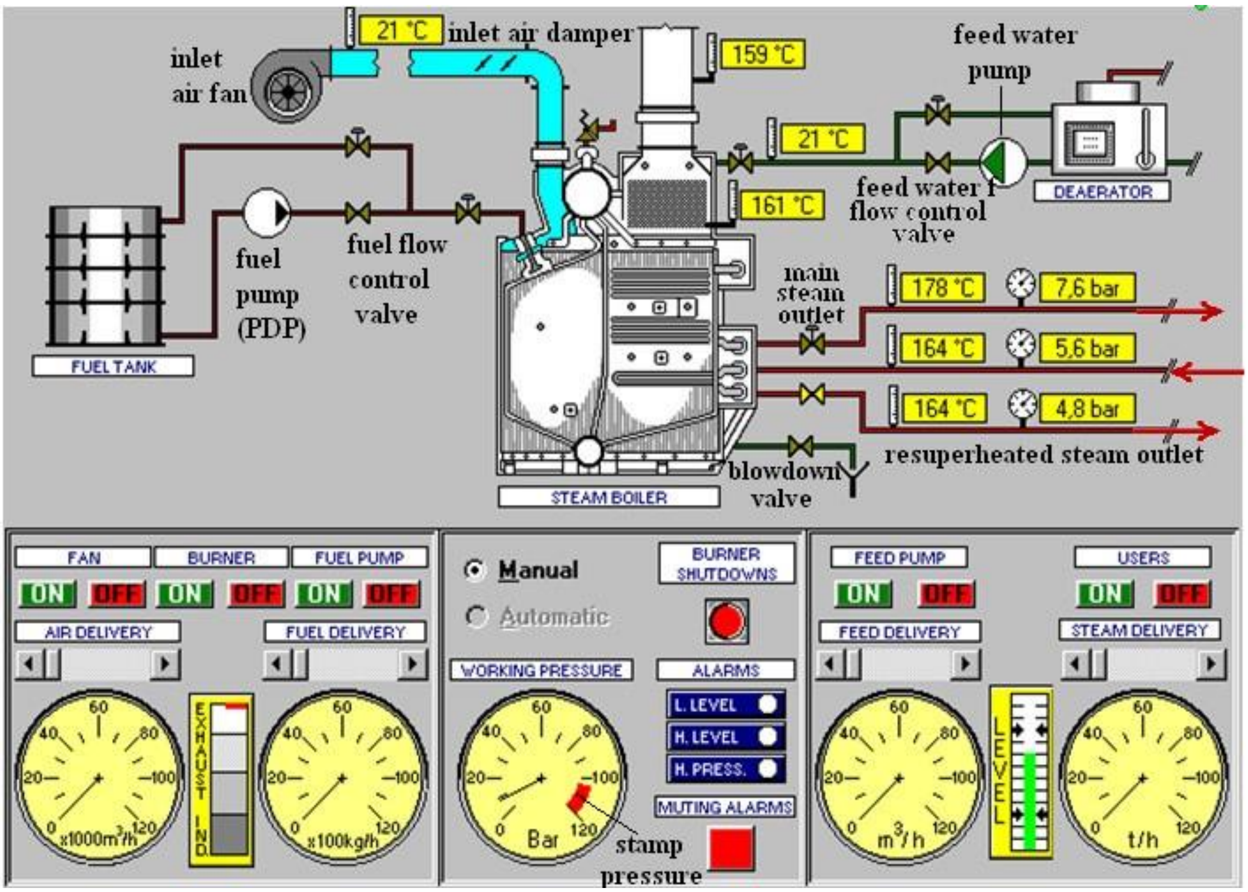
Opens the window. In this window you must insert, in the proper space, the operator's name and, subsequently, confirm with the relative key. The name insertion will customize all the prints (they shall be shown on all prints).

4.2.3.2.4 Information

It gives the access to a submenu that includes:

- *Help*: this selection gives the access to a hypertext containing some instructions for the program use. It is better to proceed to hypertext reading at the beginning or at the end of the exercise to not lose the control of it. (Some selected points of the help instructions are given by the end of this manual).
- *Logo*: it shows the program identification logo.

4.2.3.3 Synoptic



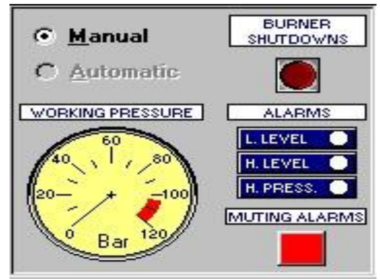
The synoptic includes: the control instrumentation; the simplified distribution of the plant lines with steam generator, complete of valves; the control board of the burner and of the feeding centrifugal pump with relative users and steam intake.

4.2.3.3.1 Lines (inlet & outlet piping)

The lines are shown in the color foreseen/recommended by the regulations/standards in force (dark green for the feeding water, red for the steam, dark brawn for the fuel).

The ones interested by the flow will visualize it, with particular attention to the motion direction.

4.2.3.3.2 Alarms control board



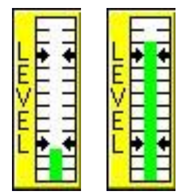
On the board following items are shown:

The pressure gauge for the boiler pressure measure (max value of working pressure 102 bar); in red the values of the scale that must not be reached because they originate the high-pressure alarm;

high pressure alarm: it is activated when the value of the working pressure on the pressure gauge enters the red zone. It causes the burner block.

The alarms  means it is excluded,  means it is active:

Water Level alarm



low level alarm: it is activated when the level falls over the admitted limit.

When it happens, it causes the burner block (shutdown);

high level alarm: it is activated when the level rises over the admitted limit;

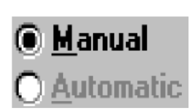
When it happens, it causes the closure of the feeding water automatic valve; **Burner shutdown alarm:**

The lamp of the burner block/shutdown  (switched off if not flashing): when the burner block/shutdown is active, **the lamp flashes continuously**. The causes that send in block or shutdown the burner is:

1. alarm for high pressure (more than stamp pressure of 102 bar);
2. alarm for low level (low water level in the upper drum);
3. fuel pump switched off;
4. fuel delivery null (fuel regulator valve closed);
5. Air-blower switched off;
6. air delivery null (air shutter closed);
7. combustion ratio insufficient (less than theoretical A/F ratio).

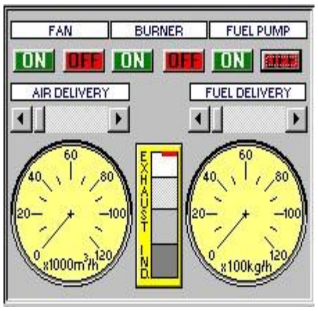
The Silence button  Alarms: “clicking” on it, excludes/switches off the siren;

Boiler Automatic operation vs Manual operation:



The selection option in the boiler run: it is effectuated by clicking **indifferently** on the label or on the circle; in this shown particular case the Manual option is selected and then, the generator administration is manual and entirely up to the operator.

The Automatic option isn't activated until or if the pressure does not reach 90 bar. The program assumes as working pressure the pressure value that the generator had in the commutation moment and leaves to the operator only the steam taking administration/control.



4.2.3.3.3 Burner control board

The burner control board allows the combustion Administration and control. From here, it is possible to:

1. Proceed to start and stop of the blower, fuel pump and burner:

For the starting click on the key  , that will light and changes to 

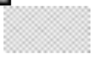
For the power down click on the key  , that will light and changes to 

Obviously, the keys are correlated (if ON lighted OFF powered down and vice versa).

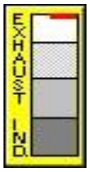
The delivery adjustment, whose value is showed on the flowmeters, is effectuated by

. It is possible effectuate it in three ways:

dragging with the mouse  (towards right it increases, towards left it decreases) at its release the flowmeter will indicate the set delivery. It is an approximated adjustment that will need a big sensibility of the operator;

-"clicking" on  fine adjustment;
-"clicking" on  normal adjustment.

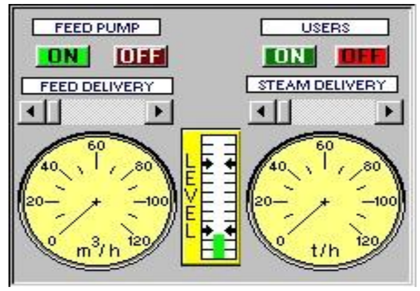
2. Control the combustion through the fume's indicator: the red bar position indicates the combustion ratio. The maximum efficiency is on the light gray



box (the second starting from the top high)

The burner block, as already said, stops the burner shutting it down, as you can verify from the box  .

4.2.3.3.4 Water-steam delivery control board



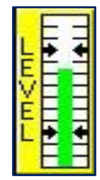
The control board allows the level administration. From here it is possible to:

1. Proceed to the starting and shutting down of the feeding water pump, and users' insertion:

The procedures are similar to the ones already described in the previous paragraph.

The user's insertion simulates a variable steam taking due to the eventual variation of needed power or to the starting or power down of auxiliary machines. *The insertion is possible only with the burner started on and with steam taking already in course.*

2. Control/shows the level variation through the indicator



It has to be kept into the zone between the arrows, appropriately adjusting the deliveries of steam and feeding water. It is right note that the scales of the two flowmeters are equivalent to facilitate the delivery adjustment.

4.2.3.3.5 Valves

The control boards control the adjusting gate valves **automatically** and the valves work as single or as a pair (opened  closed ). **The Automatic mode/option isn't activated until or if the pressure does not reach 90 bar.**

The interception valves for each of the **<u>fuel feed pump</u>**, **<u>feed water pump</u>**, **<u>re-superheat outlet</u>**, and **<u>boiler blow down</u>** are all opened and closed **<u>manually</u>** with a "click" on them  (opened valve),  (closed valve).

4.3 Program Use

It is possible, through the gate valve of manual re-superheat situated on the steam line, to realize/run a plant that can include or not the re-superheater. In the case of its exclusion (reheat valve is off) you suppose having foreseen/reviewed also the adjustment of the relative registers of the control gates (set point as on page 6). Remember, that t**he Automatic mode/option isn't activated until or if the pressure does not reach 90 bar.** The apparent incongruence or the non-possibility of having an exit fume temperature, lower than the feeding water temperature at the economizer entrance, is explained remembering the presence of the air pre-heater see figure 4-6.

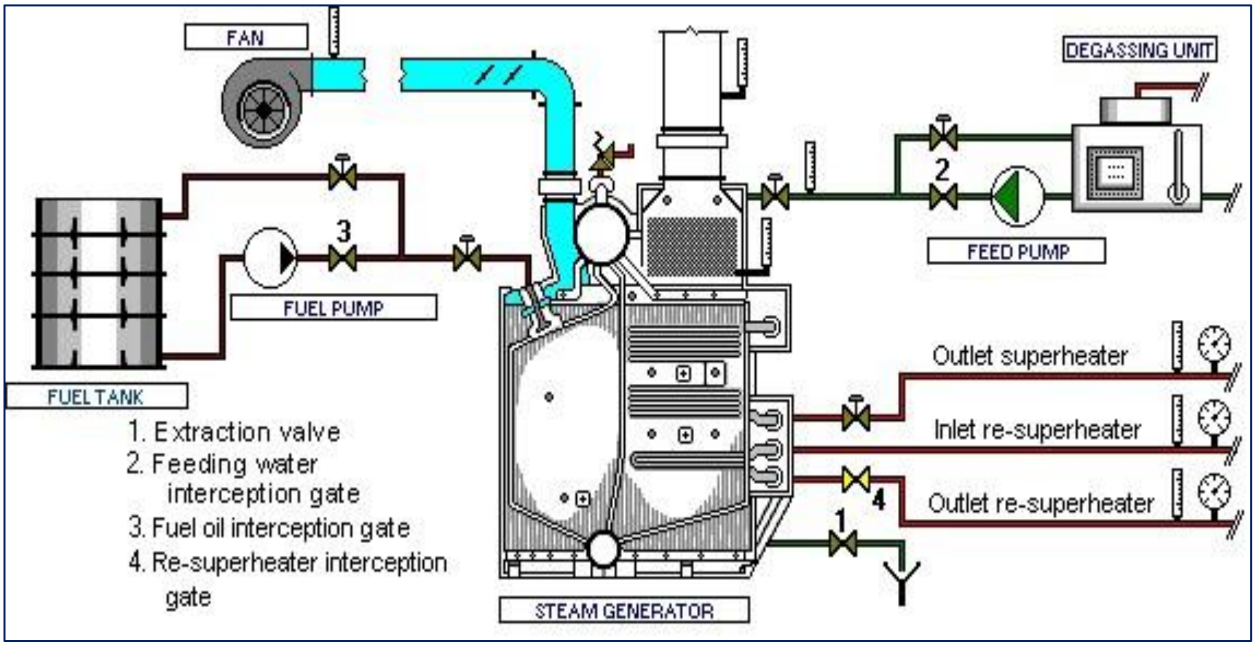
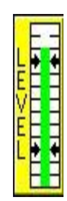


Figure 4-6

4.3.1 Starting the Boiler:

At the generator/boiler starting we can be in one of the two selected conditions with casual origin of the program.

The first one foresees/indicates the generator starting after a stop period (from previous run). In this case the generator presents itself completely filled, as you can see from the level indicator and from the high-level alarm active. 



The burner block lamp flashes.

The preliminary operation to accomplish is taking again the level into the indicator preset range opening the extraction/blow down valve 1 situated on the generator bottom and discharge the water excess.

The second one, instead, foresees/indicates the generator restart (from program bar menu, File selection). In this case the generator presents itself lightly/low values in pressure, all the alarms are excluded/switched off, the burner block lamp flashes.

The procedure for the starting from this point is the same in the two cases:

1. open the gate **2** situated on the feeding pump delivery;
2. start the feeding pump from the proper board. The water delivery will be completely recircled;
3. start the blower;
4. open the gate **3** on the fuel pump delivery;
5. start the fuel pump. The fuel delivery will be completely re-circled. The burner block lamp turns off;
6. start the burner.

The starting procedure is then completed.

Let's underline that:

The operations **1** and **2** can be inverted because the centrifugal pump can be started with the delivery closed;

Inverting the operations 4 and 5 you have a maneuver error because the fuel pump is a volumetric pump;

At the blower start the adjustment air gate is not completely closed to allow the combustion chamber ventilation;

At the burner starting the fuel-adjusting valve automatically leaves the passage of the delivery necessary to the flame maintaining.

Trouble Shouting:

If the starting procedure has been followed as indicated above but the burner doesn't start, the block lamp continues flashing:

Control/check that all the alarms are turned off;

Control/check that the air delivery is at least 1400 m^3/h.

4.3.2 Management (Conduction)

As already said the generator conduction or management can be done in manual and in automatic, **but since the automatic can be inserted only after the pressure has reached or exceeded 90 bar,** it is mandatory or a must to manage the generator in manual until the creation of conditions for its passage in automatic.

Let's remember that the modern generators/boilers, if erroneously managed, lose quickly the correct water level in *1 minute* more or less; from here the necessity of a great attention in their adjustment is needed.

A series of useful suggestions are listed here:

Always increase the air delivery before increasing the fuel delivery after maintaining fixed A/F ratio and always keep fuel delivery lower than the air one. If you drop A/F ratio below the value of the theoretic combustion ratio, the burner powers down and, if unluckily/unfortunately, you are taking a high steam delivery during burner shutdown, you lose the water level before you can begin a reaction. Also, and equally if you open too much the air gate, this causes the intervention/loss of the control on the register to avoid "exaggerated" air excesses. In the case the burner goes in block, always restart with the registers at minimum.

It is better working with reduced deliveries because when the pressure increases also the pressure increment speed increases;

Even if you do not take steam when bringing the generator to rating the level decreases, then you have to control it and if necessary open at minimum the regulator valve on the feeding water.

When you decide to take steam, if you are not in automatic, adopt the following devices:

⇒ Control the water level and, even if you are over the half work interval, before opening the steam and after compensate with the water, vice versa in the opposite conditions;

⇒ Pay attention to the value of the pressure, if pressure tends to decrease quickly it means that you are trying to take more steam than the generator produces. A further confirmation comes from the fact that even increasing the valve opening the flowmeter needle does not move. It is convenient to reduce pressure before the steam delivery and after increase the quantity of fuel to burn, this because it is easier to administer one parameter than two parameters (when you act control on the fuel you must act control also on the comburent air);

⇒ If you recall the diagnostic page or the heat balance, establish before the generator, because you are in the impossibility of controlling it.

4.4 Re-superheater influence on the plant

Analyze singularly as the re-superheater influences the plant working.

4.4.1 Unplugging the re-superheater

Unplugging the re-superheater implies a different path of the combustion products into the steam generator and, then, different values of pressure and temperature both at the superheater exit and at the economizer entrance (the feeding water in the passage through the degassing unit is preheated with the taped steam). Consequently, the quantities exchanged in the different sectors of the generator change, originating a different heat balance.

4.5 Conclusions

4.5.1 Applications

To establish the actual-real and accurate heat balance of a boiler it is necessary to effectuate particular steaming tests (i.e., perform effective runs) during which you have to detect all the magnitudes related to the calculation of the heat balance itself. Every magnitude is determined in its average value of a series of measures effectuated with maximum exactitude time at equal intervals, during the test time, that vary from 5 to 8 hours. The tests are to be effectuated at the different load rating of the boiler.

From a didactic or an educational point of view it is enough to effectuate only one detection of the interested magnitudes.

As an example, the following procedure is proposed for the heat balance calculation:

After having executed the beginning or starting selections of the generator and after switching or to commute in automatic mode according to the instructions given previously (see page 9). Print both the diagnostic page and the heat balance page.

The magnitudes or the values necessary for the heat balance calculation are:

- Quantity of available heat in the fuel Qd;
- Quantity of heat used in the economizer Qe;
- Quantity of heat used in the generator tubes Qg;
- Quantity of heat used in the superheater Qs;
- Quantity of heat used in the re-superheater Qrs;
- Quantity of heat lost in the funnel for fumes
- Qf; Quantity of heat lost for radiation and unburned Qi.

As previously exposed when we have defined the calorific power the quantity of heat per hour available will be:

$$Qd = Pcs * Pg$$

where Pcs = 42.070 kJ/kg fuel superior calorific power

Pg = fuel mass delivery

The heat quantity per hour transferred into the economizer to the water will be:

$$Qe = Pv * (he - hl)$$

where remembering the definition of specific heat and the heat energy concept you will have:

he - hl = cm * (Te - Tl) Heat energy kept in one kg of water

Cm = 4,270 kJ/kg °K average specific heat of water

Pv = Mass delivery of water or of steam (at stabilized plant are equal)

The heat quantity per hour transferred in the generator tubes will be:

$$Qg = Pv * (hv - he)$$

Where, h_v = Heat energy kept in one kg of saturated steam at the exercise pressure

Note: to calculate hv at the absolute pressure of (relative pressure +1) bar read the value of the enthalpy on the superior limit curve into the Mollier diagram of the steam The heat quantity per hour transferred into the superheater will be:

$$Qs = P\ v * (hs - hv)$$

Where h_s = Heat energy of the superheated steam

Note: to calculate hs read the value of the enthalpy at the intersection of the overheating isobaric with the overheating isotherm into the steam Mollier diagram.

The heat quantity per hour transferred into the re-superheater will be:

$$Qs = Pv * (hru - hre)$$

Where h_{re} = heat energy of the re-superheated steam at the entrance.

h_{ru} = heat energy of the re-superheated steam at the exit.

The quantity of heat lost in the funnel for fumes is obtained, remembering always the definition of specific heat:

$$Qf = (Pa * \beta + Pg) * C_{mf} * (Tf - Ta)$$

Where,

β = 1,225 kg/m3 — Air volume mass

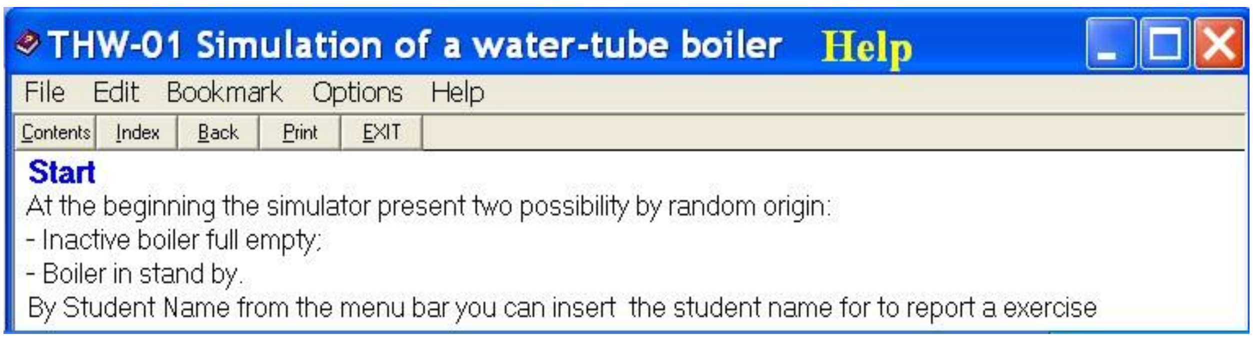
Cmf = 1,025 kJ/kg °K — fumes average specific heat

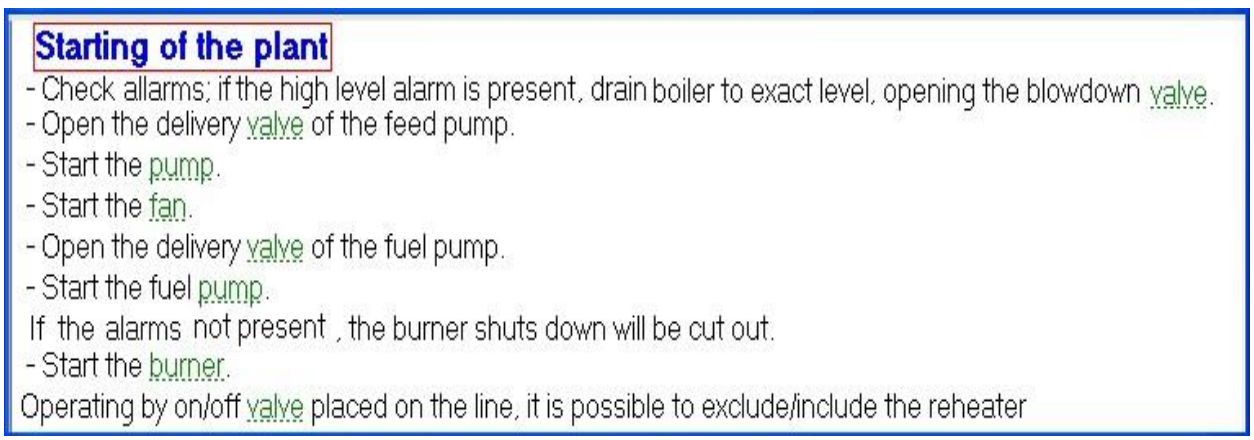
Pa = Air volume delivery

The heat quantity lost for radiation and unburned is obtained for difference:

$$Qi = Qd - Qe - Qg - Qs - Qrs – Qf$$

Some parts from the Help command in the program:





Running of the plant

Once the plant has been started, it must be kept under control remembering that:
before opening the steam supply valve from the control board, it will be necessary to reach an adequate pressure value, it is better if the pressure is the same as the working pressure value;
the water level must stay within the indicator limits, otherwise the high water level or the low water level alarms will be activated. The control can be made by adjusting the steam delivery and the feed water delivery opportunely;
the air and fuel deliveries depend on the air/fuel cumbustion ratio:
if the air/fuel ratio is correct, the fume indicator will be pointing to the light grey zone.
The fume indicator must never be pointing to the black zone;
the boiler pressure must never reach the red zone (block for high pressure).
The control can be made by adjusting the fuel delivery and relative air delivery as well as by adjusting the steam delivery.
- When the boiler pressure attains 90 Bar, it will be possible to switch the plant from manual to automatic mode (Manual / Automatic), the air/fuel rates will set themselves to the minimum value required to maintain the temperature and the pressure into the boiler.
It is possible from the menu bar you can select the diagnostic page and the heat balance.

Utilizers

The utilizers, if used, ON OFF, simulates a variable extraction of steam caused by a possible variation of required power or by starting or stopping of ancillary equipments.
It is opportune to use it only after the plant has been stabilized.

Valves

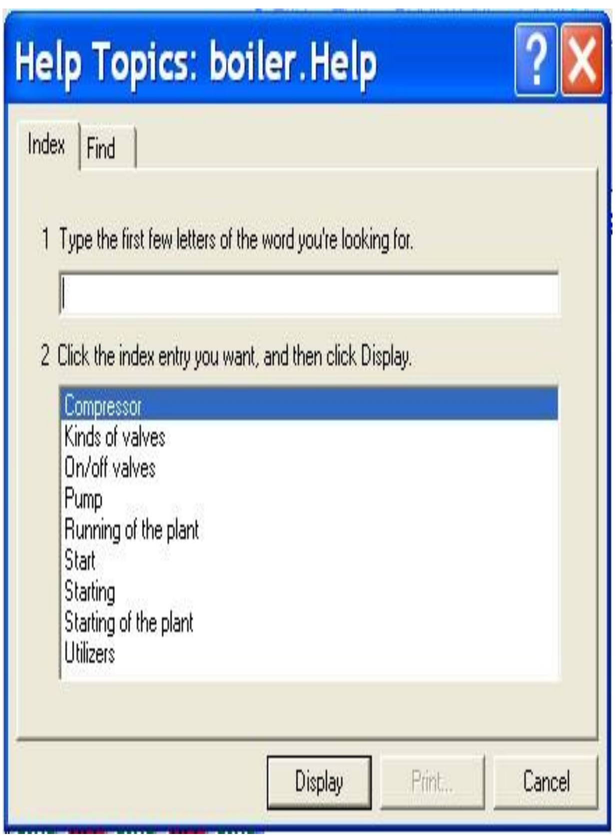
There are 2 kinds of valves:

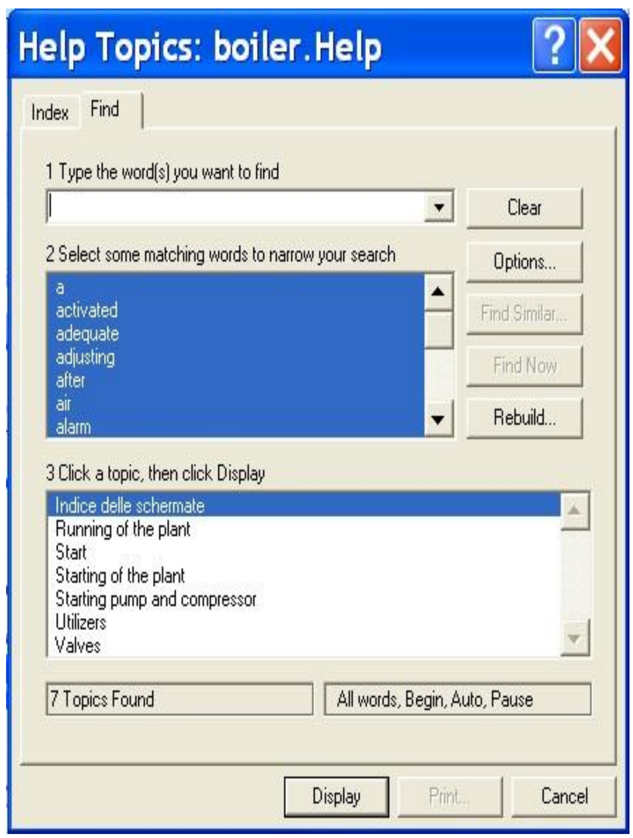
on/off valves:

This kind goes on/off by clicking on it by mouse: when valves are off they are dark otherwise light.

Automatic and safety valves:

This kind goes on/off by the program depending on the data values.





<u>The following is the answer for the attached Exercise in the Catalog</u>

4.6 Exercise # 1:

The Re-superheater is activated (the re-superheater outlet valve is opened):

1- Run the Boiler for 4-5 minutes in the automatic mode (at a pressure of about 95 bar) and maximum main steam outlet (steam delivery control is at maximum position).

2- Print the diagnostic page for above run see figure 4-7. Use values on that page to fill-in the following sheet:

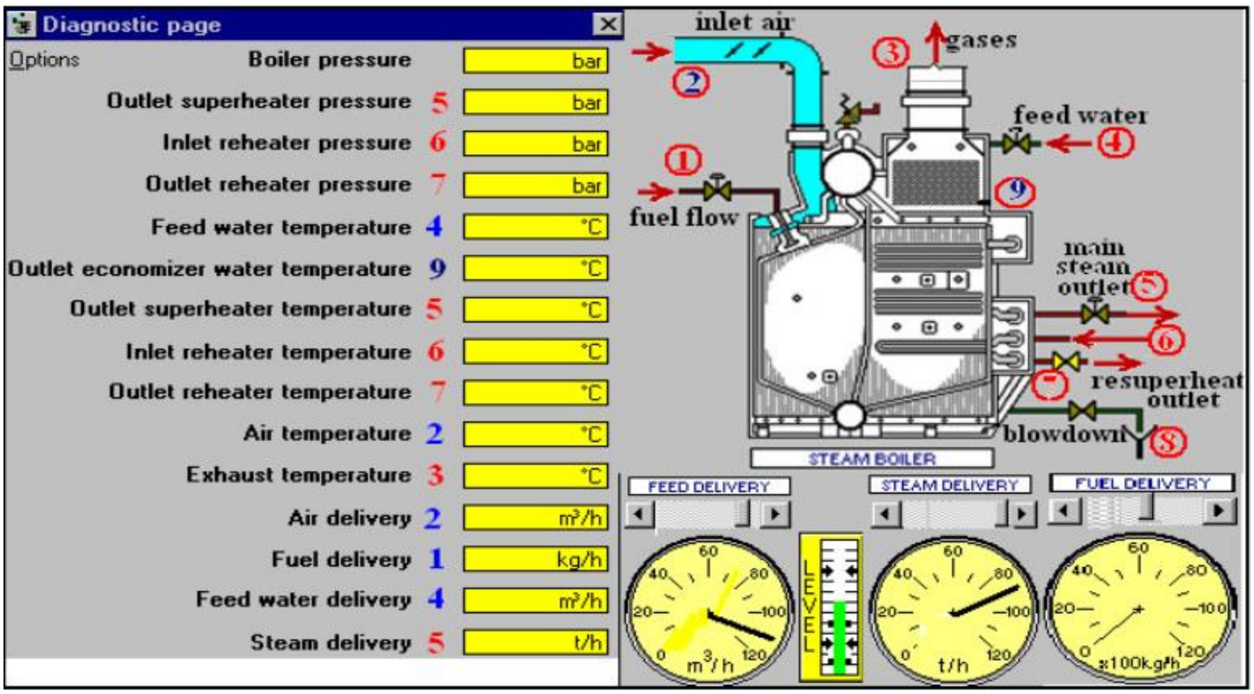


Figure 4-7 Diagnostic page

3- Calculate all the following magnitudes/values, which are necessary for doing the heat balance calculations (make a comparison table between your calculations and the program calculations):
Quantity of available heat in the fuel Qd.
Quantity of heat used in the economizer Qe.
Quantity of heat used in the generator tubes Qg.
Quantity of heat used in the superheater Qs.
Quantity of heat used in the re-superheater Qrs.
Quantity of heat lost in the funnel for fumes Qf.
Quantity of heat lost for radiation and unburned Qi.

4- Sketch the boiler heating processes on the h-s (Mollier chart for steam).
5- Calculate the Heat Balance Bi-diagram and compare your calculations and program calculations.

Results from program for the re-superheater is activated:

Boiler pressure	96.3 bar
Outlet superheater pressure	94.5 bar
Inlet reheater pressure	16.1 bar
Outlet reheater pressure	14.3 bar
Feed water temperature	201 oC
Outlet economizer water temperature	255 oC
Outlet superheater temperature	526 oC
Inlet reheater temperature	302 oC
Outlet reheater temperature	525 oC
Air temperature	10 oC
Exhaust temperature	160 oC
Air delivery	87251.9466 m3/h
Fuel delivery	7373.6449 kg/h
Feed water delivery	96 m3/h
Steam delivery	92 t/h
Fuel available heat Qd	316.540 MJ/h
Heat to economizer Qe	20.792MJ/h
Heat of vaporization Qc	153.088 MJ/h
Superheat Qs	65.320 MJ/h
Reheat Qrs	45.540 MJ/h
Waste heat in the funnel Qf	18.479 MJ/h
Waste heat by radiation or others Qi	13.321 MJ/h
Efficiency η	0.900

Calibration:

Quantity of available heat in the fuel= calorific value* fuel mass flow rate.

$Q_d = P_{cs} * P_g$ = 42.07*7373.6449=310.2092409 MJ/h.

Quantity of transferred heat into the economizer = water mass delivery * average specific heat of water * (outlet economizer water temperature – feed water temperature).

Qe = Pw * Cm * (Te – Ti) = (96*1/0.0013)*0.00427*(255-201).

Qe =17.02745 MJ/h.

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

Qc = Pv * [hv – (Cm * Te)] =92000*[2.7347- (.00427 * 255)].

Qc =151.4182 MJ/h.

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

Qs = Pv * (hs – hv) =92000*(3.445-2.7347).

Qs =65.3476 MJ/h.

Quantity of transferred heat into the re-superheater = steam delivery * (heat energy of the re-superheated steam at the entrance – heat energy of the re-saturated steam at the exit).

Qrs = Pv * (hru – hre) =92000*(3.520-3.0362).

Qrs= 44.5096 MJ/h.

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

Qf = [(Pa * β) + Pg] * Cmf * (Tf – Ta)

Qf = [(87251.9466 * 1.225) + 7373.6449] * .001025 * (160 – 10)

Qf = 17.5671 MJ/h

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

Qi = Qd - Qe – Qc - Qs - Qrs - Qf

= 310.2092409-17.02745-151.4182-65.3476- 44.5096 - 17.5671

= 14.3393 MJ/h

Efficiency = heat gained ÷ heat paid

η = (Qe + Qc + Qs + Qrs) ÷ Qd

= (278.30285) ÷ 310.2092409

= .897146

This is a comparison between the calculation got from the program and the calibrated calculation.

Value Calculated	Program calculations	Calibrated calculations
Fuel available heat Qd	316.540 MJ/h	310.2092409MJ/h
Heat to economizer Qe	20.792MJ/h	17.02745 MJ/h
Heat of vaporization Qc	153.088 MJ/h	151.4182 MJ/h
Superheat Qs	65.320 MJ/h	65.3476 MJ/h
Reheat Qrs	45.540 MJ/h	44.5096 MJ/h
Waste heat in the funnel Qf	18.479 MJ/h	17.5671 MJ/h
Waste heat by radiation or others Qi	13.321 MJ/h	14.3393 MJ/h
Efficiency	0.900	0.89715

4.7 Exercise # 2:

The Re-superheater is not activated (the re-superheater outlet valve is closed):

1-Run the Boiler **for 4-5 minutes** in the **automatic** mode (at a pressure of about 95 bar) and maximum main steam outlet (steam delivery control is at maximum position).

2- Print the diagnostic page for above run see figure 4-8. Use values on that page to fill-in the following sheet:

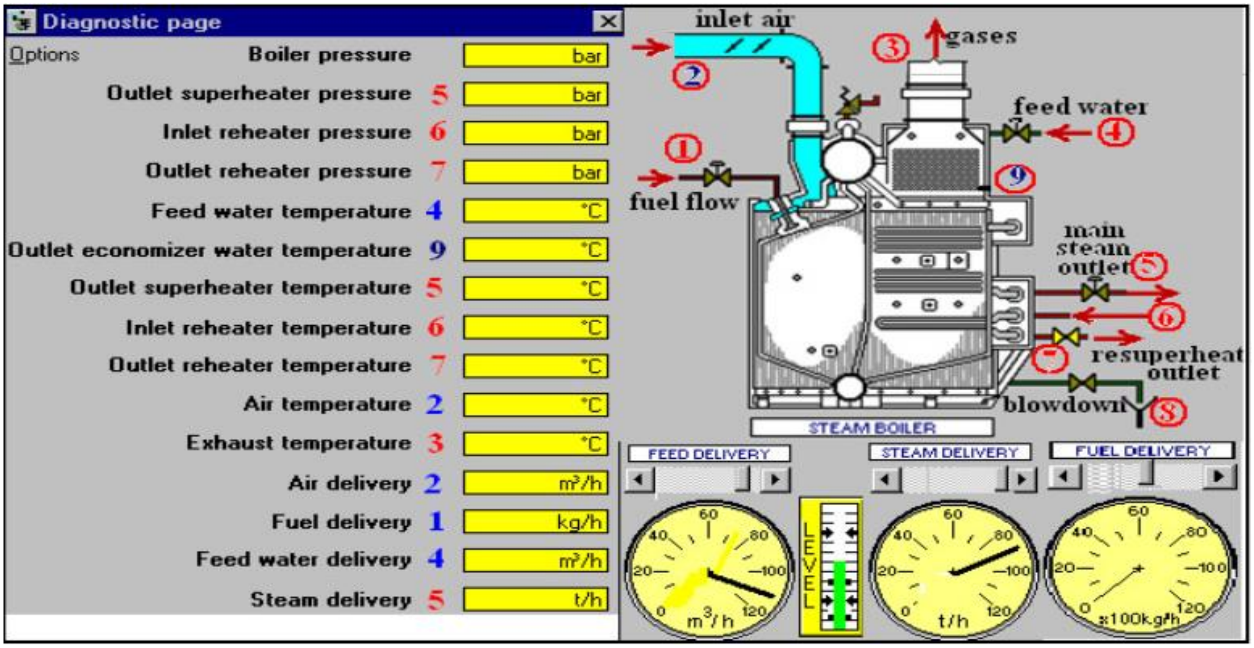


Figure 4-8 Diagnostic page

3- Calculate all the following magnitudes/values, which are necessary for doing the heat balance calculations (make a comparison table between your calculations and the program calculations):
Quantity of available heat in the fuel Qd.
Quantity of heat used in the economizer Qe.
Quantity of heat used in the generator tubes Qg.
Quantity of heat used in the superheater Qs.
Quantity of heat used in the re-superheater Qrs.
Quantity of heat lost in the funnel for fumes Qf.
Quantity of heat lost for radiation and unburned Qi.
4- Sketch the boiler heating processes on the h-s (Mollier chart for steam).
5- Calculate the Heat Balance Bi-diagram and compare your calculations and program calculations

Results from program for the re-superheater isn't activated:

Boiler pressure		96.5 bar
Outlet superheater pressure		94.7 bar
Inlet reheater pressure		5.8 bar
Outlet reheater pressure		5.8 bar
Feed water temperature		165 ^{o}C
Outlet economizer water temperature		237 ^{o}C
Outlet superheater temperature		527 ^{o}C
Inlet reheater temperature		164 ^{o}C
Outlet reheater temperature		165 ^{o}C
Air temperature		10 ^{o}C
Exhaust temperature		160 ^{o}C
Air delivery		77607.4194 m^3/h
Fuel delivery		6558.5878 kg/h
Feed water delivery		87 m^3/h
Steam delivery		92 t/h
Fuel available heat	Q_d	281.551 MJ/h
Heat to economizer	Q_e	27.784 MJ/h
Heat of vaporization	Q_c	160.080 MJ/h
Superheat	Q_s	65.320 MJ/h
Reheat	Q_{rs}	0 MJ/h
Waste heat in the funnel	Q_f	16.437 MJ/h
Waste heat by radiation or others	Q_i	11.930 MJ/h
Efficiency	η	0.899

Calibration

Quantity of available heat in the fuel= calorific value* fuel mass flow rate.

$Q_d = P_{cs} * P_g$ = 42.07*6558.5878=275.9198 MJ/h.

Quantity of transferred heat into the economizer = water mass delivery * average specific heat of water * (outlet economizer water temperature – feed water temperature).

$Q_e = P_w * C_m * (T_e – T_i)$ = (87*1/0.0013)*0.00427*(237-165).

Q_e =20.574831 MJ/h.

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

$Q_c = P_v * [h_v – (C_m * T_e)]$ = 92000*[2.7347- (.00427 * 237)].

Q_c =158.489 MJ/h.

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

$Q_s = P_v * (h_s – h_v)$ =92000*(3.445-2.7347).

Q_s =65.3476 MJ/h.

Quantity of transferred heat into the re-superheater = steam delivery * (heat energy of the re-superheated steam at the entrance – heat energy of the re-saturated steam at the exit).

$Q_{rs} = P_v * (h_{ru} – h_{re})$ =92000*(2.768-2.768).

Q_{rs} =0 MJ/h.

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

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

Q_f = [(77607.4194 * 1.225) + 6558.5878] * .001025 * (160 – 10)

Q_f = 15.6252553MJ/h.

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

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

= 275.9198 -20.574831 -158.489 -65.3476 - 0 - 15.6252553

= 12.8829 MJ/h

Efficiency = heat gained ÷ heat paid

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

= (244.42) ÷ 275.918 = 0.886

This is a comparison between the calculation got from the program and the calibrated calculation.

Value calculated	Program calculations	calibrated calculations
Fuel available heat Qd	281.551 MJ/h	275.9198 MJ/h
Heat to economizer Qe	27.784 MJ/h	20.574831 MJ/h
Heat of vaporization Qc	160.080 MJ/h	158.489 MJ/h
Superheat Qs	65.320 MJ/h	65.3476 MJ/h
Reheat Qrs	0 MJ/h	0 MJ/h
Waste heat in the funnel Qf	16.437 MJ/h	15.6252553 MJ/h
Waste heat by radiation or other Qi	11.930 MJ/h	12.8829 MJ/h
Efficiency	0.899	0.886

5 Introduction for sub control systems in boiler

The boiler control system is the vehicle through which the boiler energy and mass balances are managed.

Control systems are divided into furnace, drum level feedwater, fuel air, and temperature control (see Figure 5-1).

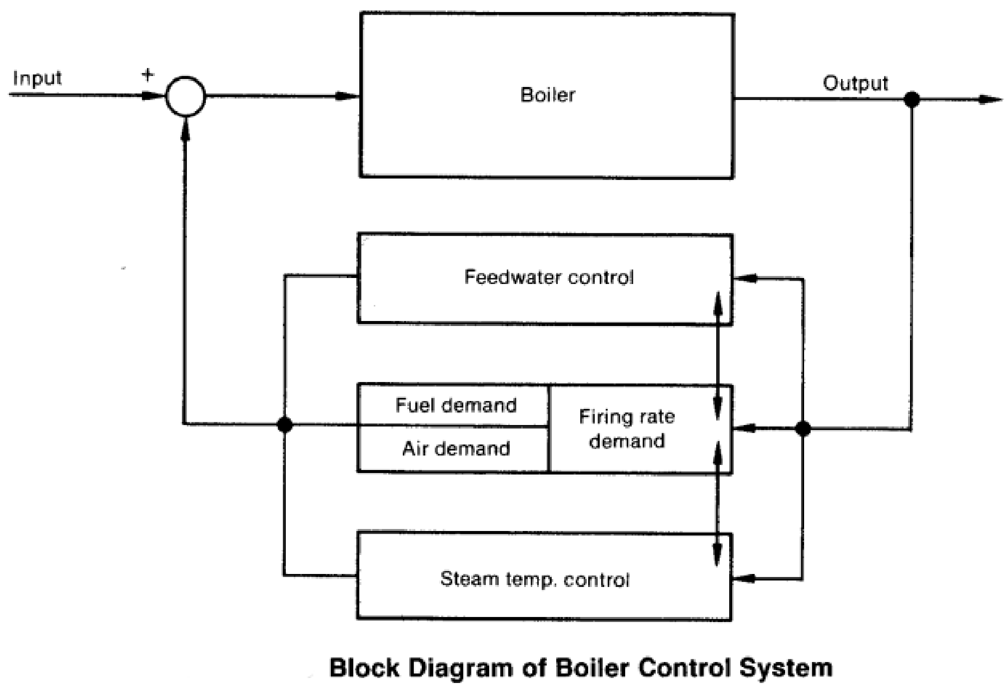


Figure 5-1 Block Diagram of Boiler Control System

For the energy input requirement, a firing rate demand signal must be developed. This firing rate demand creates the separate demands 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 water in the boiler. The final steam temperature condition must also be regulated (for boilers generating superheated steam and having such control capability), and this is accomplished by the steam temperature control system. The effects of the input control actions interact, since firing rate also affects steam temperature and feedwater flow affects the steam pressure, which is the final arbiter of firing rate demand. The overall system must therefore be applied and coordinated in a manner to minimize the effect of these interactions. The interactions can be greatly affected by the control system design.

5.1 Basic of control:

5.1.1 Element of automatic control

Any control system should consist of sensor, actuator, controller, controlled device

(See figure 5-2)

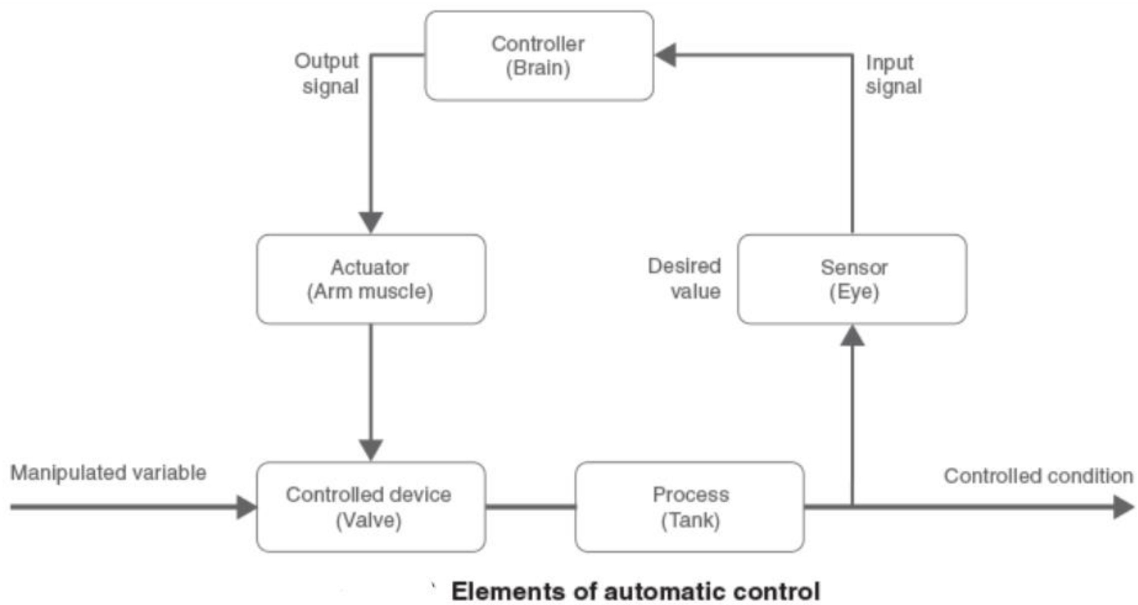


Figure 5-2

5.1.2 Modes of control

There are three modes of control:

- On/off control
- High/Low/off control
- Modulating control

On-Off control is the simplest form of feedback control. An on-off controller simply drives the manipulated variable from fully closed to fully open depending on the position of the controlled variable relative to the setpoint.

High/Low/off control is a slightly more sophisticated version than on/off where the process operates at high or low or off according the situation.

Modulating controls are devices that are used to regulate control loops in a process.

6 Handling, storage and treatment of different liquid fuel

The most common liquid fuel is fuel oil, a product of the oil refining process. While crude oil as produced from the well is sometimes used, the most common fuel oils used for boiler fuel are the lightweight No. 2 fuel oil and the No. 6 grade of heavy residual fuel oil. The normal ranges of analyses of these two fuel oils are shown in table 6-1.

Other liquid fuels that are used as auxiliary fuels are process by-products such as tar, pitch, or acid sludge, and, in some cases, liquid sewage. In some of these cases, the heat content alone may not pay for burning the fuel and the economics may be based on a comparison with the costs of other methods of waste disposal. [1]

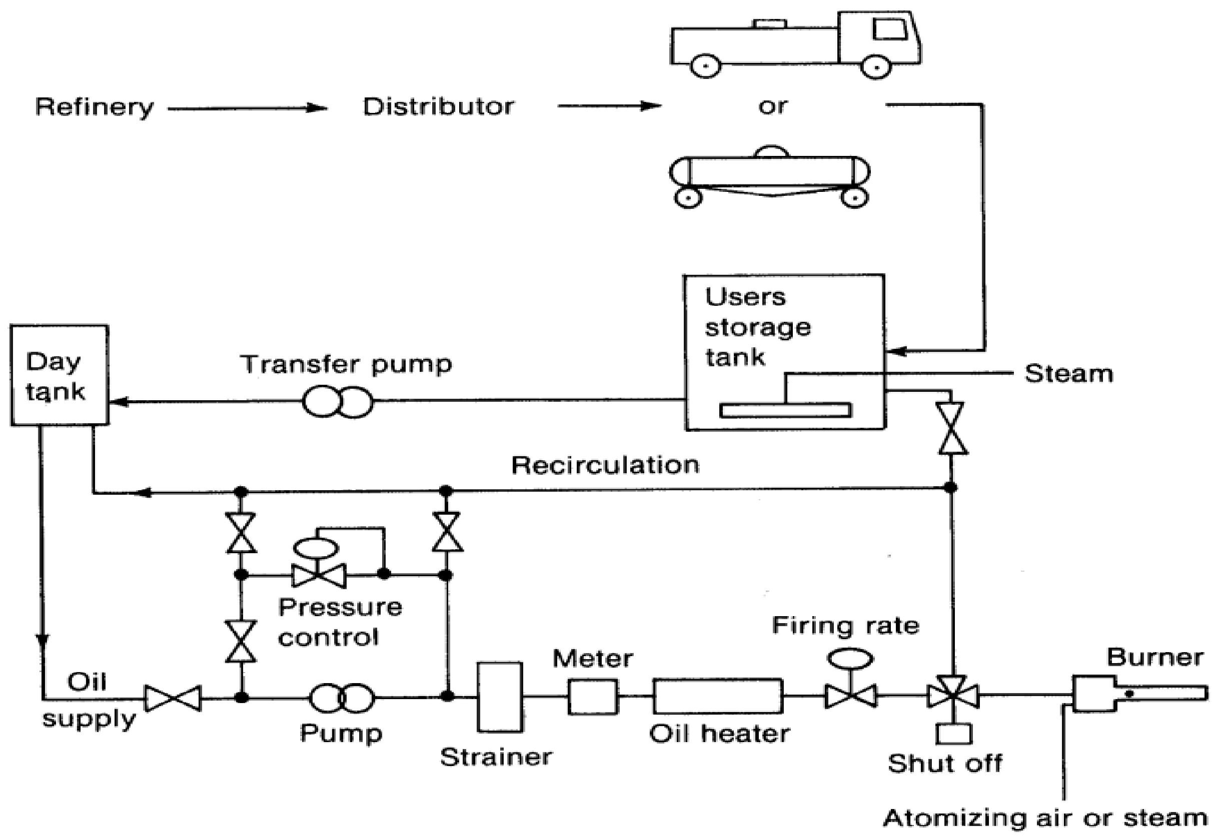
Table 6-1 *fuel oil analysis*

	No.2	No.6
Carbon	86.1 to 88.2	86.5 to 90.2
Hydrogen	11.8 to 13.9	9.5 to 12.0
Sulphur	0.05 to 1.0	0.7 to 3.5
Nitrogen	Nil to 0.1	-------
Ash	0	0.01 to 0.5
Heating value: (Btu/lb.)	19,170 to 19,750	17,410 to 18,990
Water and sediment	0 to 0.01	0.05 to 2.0
Spec. gravity	0.887 to 0.825	1.022 to 0.922
Lb. per gal	7.39 to 6.87	8.51 to 7.68

If the user is not an oil refinery, the fuel oil is purchased in lots and delivered to the plant by truck, railroad tank car, or oil tanker. The fuel oil is pumped from these delivery vehicles into a user's fuel oil storage tanks and stored there until used. A generic arrangement including the fuel oil preparation is shown in figure 6-1.

In this arrangement the fuel oil is delivered to the storage tanks. From the storage tanks the fuel may be taken directly to the fuel preparation equipment, or it may be transferred to a smaller tank, sometimes called a day tank. From the day tank, fuel oil pumps provide the pressure necessary for the fuel control and atomizing system.

If the fuel is No. 2 fuel oil, heating of the fuel is normally unnecessary. If the fuel is a heavy oil such as No. 6, it is usually necessary to heat the oil in the tanks so that it can be easily pumped through the system. If heavy fuel oil in a tank is unused for a period of time, the tank heating may cause the evaporation of some of the lighter constituents, ultimately making the oil too thick to remove from the tank by any normal means.



Typical Fuel Oil Pumping and Heating Arrangement

Figure 6-1 Typical Fuel Oil Pumping and Heating Arrangement

In some installations water may be present in the oil system. This may be water that has condensed from the atmosphere over a period of time or water originating from cleaning the tanks with water. The mixture of oil and water can be burned with good results if the water is emulsified with the oil before atomizing at the burner. Emulsification forms tiny droplets of the water that are surrounded by a film of oil. As the water droplets enter the furnace, the furnace heat causes the water droplets to suddenly flash to steam - causing fine atomization of the oil film.

As a result of this type of action, water may be intentionally added to oil and emulsified to improve atomization. [1]

7 Firing rate demand:

The demand or a change in demand on the boiler system is generated by the steam users' requirements for energy flow. As they open valves to get more of the energy locked into the steam energy carrier, the pressure drops in the total storage system, triggering the release of some of the heat energy from storage. The steam header pressure is the energy balance point between the energy demands of the steam users and the supply of fuel and air to the boilers to supply the energy to the header system. At a constant steam flow or energy requirement, a constant pressure in the steam header indicates that energy supply and demand are in balance.

Generally, the boiler controls can be classified in two main groups: on/off and modulating. On/off controls are subdivided into basic on/off (full on and off) and high/low/off, which has a high and low fire "on" condition plus the "off' condition. [1]

7.1 ON/OFF and High/Low/OFF Control:

The simplest, most basic, and least costly control and the one used to control firing rate on only the smaller fire-tube and water-tube boilers is on/off. The control is initiated by a steam pressure or hot water temperature switch. As the pressure or temperature drops to the switch setting, the gas valve is opened (or the fuel pump started) along with the combustion air fan motor. The fire is ignited usually with a continuous pilot flame. The fuel and air continue operating at full firing rate capacity, and the pressure or temperature rises until the switch contact is opened.

7.1 Modulating control

Modulating control is a basic improvement in controlling combustion. A continuous control signal is generated by a controller connected to the steam piping system. Reductions in steam pressure increase the output signal, which calls for a proportionate increase in firing rate.

This is a different control system performance comparison show in table 7-1

Table 7-1 Control System Performance Comparison

	Efficiency at % load			
Type of Control	25%	50%	75%	100%
On/off	70.28	74.28	75.61	76.28
On/off with flue damper	73.28	75.28	75.95	76.28
Hi/low/off	76.88	76.48	76.35	76.28
Modulating	76.88	77.68	77.15	76.28

7.1.1 Steam pressure or steam flow feedback control

It is possible to arrange the system as shown in figure (7-1) so that the control for boiler can be switched between steam pressure and steam flow control. The switching procedure would require the boiler operator to switch the control to manual, adjust the set point to the desired value of the variable being switched to, operate the transfer switch, and then transfer the control back to automatic operation. In either steam pressure or steam flow, a change in these variables is equated to a system demand for energy. [1]

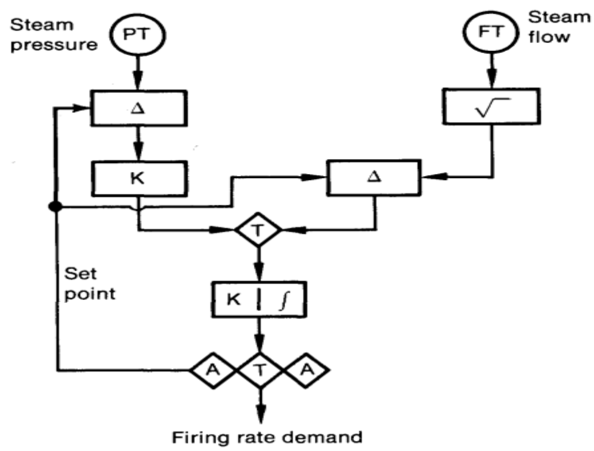


Figure 7-1 steam pressure or steam flow feedback control

7.1.2 Feedforward-plus-Feedback - Steam Flow plus Steam Pressure:

A feedforward-plus-feedback arrangement is often used. One of the two most frequently used variations is shown in figure (7-2). In this arrangement the steam flow (a) is the feedforward demand. The proportional multiplier function (b) is adjusted at the input of summer (c) so that a change in steam flow will produce the correct steady-state change in firing rate demand. The steam pressure controller (d) provides the correct adjustment of the firing rate demand for the necessary overfiring or under-firing to adjust energy storage. With any such feedforward system, the fuel flow signal change is directly linked to the steam flow change. This results in immediate and faster action on the fuel flow change since the full fuel change occurs before appreciable change in the steam pressure. This results in less energy withdrawal from storage. Since energy withdrawal from storage is directly related to drop in steam pressure, less withdrawal means that there has been a smaller steam pressure deviation from set point. [1]

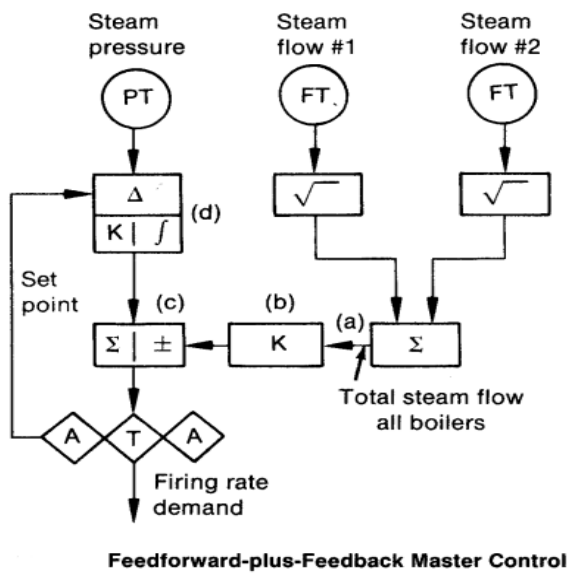
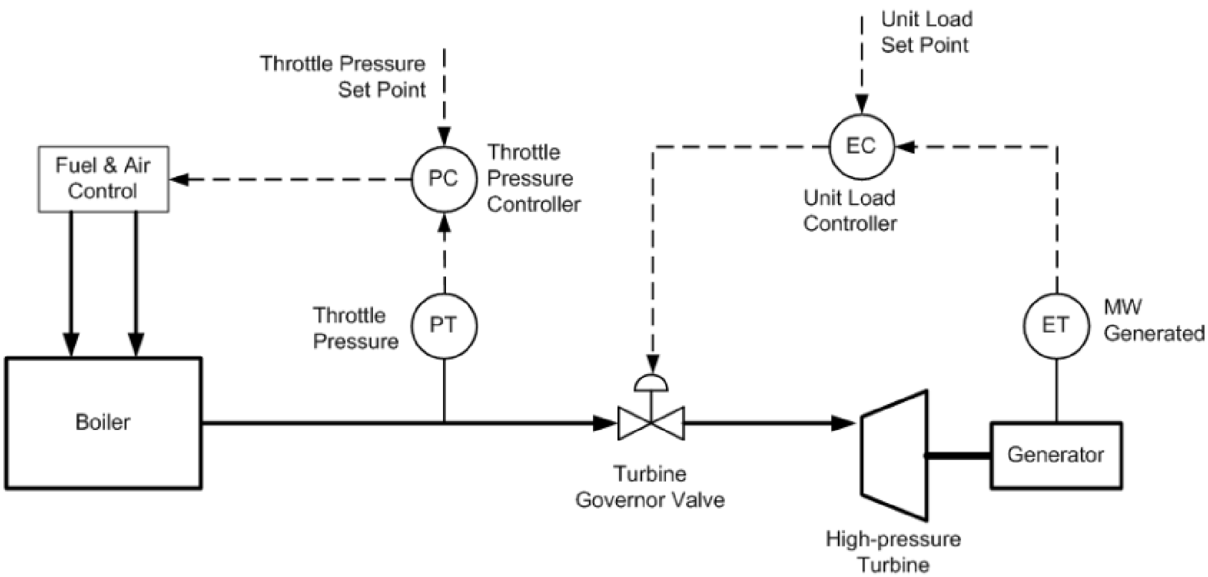


Figure 7-2 Feedforward-plus-feedback master control

8 Boiler Following - Firing Rate Demand and Development:

In boiler following control, the control systems for the boiler and turbine are separate and uncoupled. Starting with steady-state loading, any control system demand for more electric power is applied only to the turbogenerator. Figure (8-1) shows a block diagram of the control arrangement for boiler following control. Either from additional load on the electrical system or from a remote demand signal, the turbine governor valves open. The result is that the turbine asks for additional energy input in the form of superheated steam

Since the boiler was previously producing an amount of steam with a lower total energy level, the pressure will begin to drop. As the pressure drops, some steam will be produced due to the release of energy from boiler energy storage. The drop in throttle pressure and the change in steam flow requirement activate the combustion control system to increase the firing rate of the boiler and bring the steam pressure back to its set point.

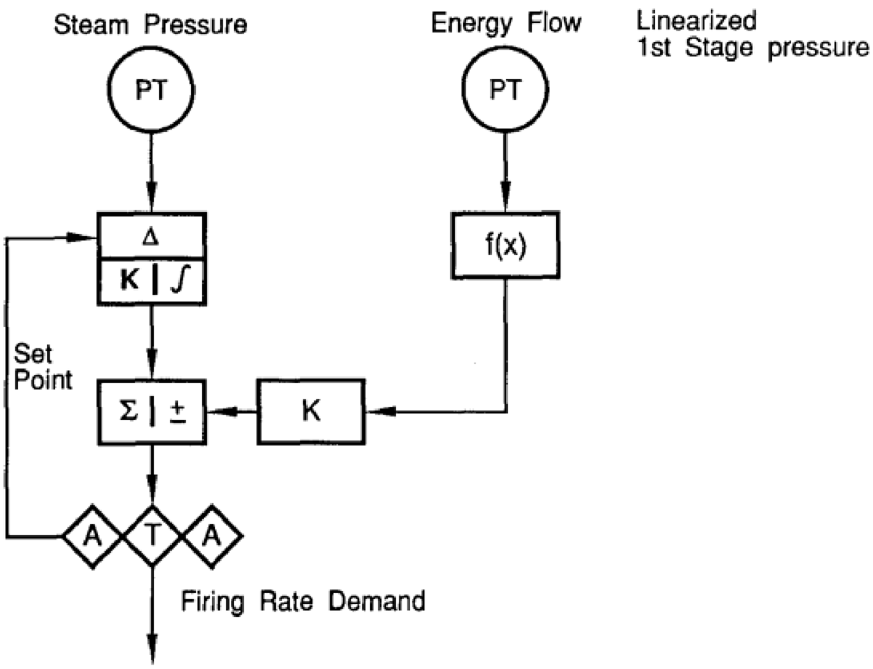


Boiler-following mode.

Figure 8-1 Boiler-following mode

8.1 Improvement with feedforward:

Due to the slow response of the pressure feedback control loop and the known, measurable disturbance acting on it (steam flow), pressure deviations can be reduced by using a feedforward from steam flow rate or first stage turbine pressure. This becomes the main driver for boiler fuel flow set point, while the throttle pressure controller simply trims the fuel flow to make up for deviations from its set point. In addition to the pure feedforward, the derivative of first-stage pressure or steam flow rate can be added to the firing rate to obtain overfire and under-fire during load ramps (see figure 8-2) [1]



Boiler Following Control Logic Using First-Stage Pressure Feedforward

Figure 8-2 Boiler Following Control Logic Using First-Stage Pressure Feedforward

9 Turbine following mode

The alternative to boiler-following mode is turbine-following mode in which the boiler firing rate is manipulated to control generator load, and the governor valves are manipulated to control boiler pressure (see figure 9-1). This results in very stable throttle pressure control, but imprecise and slow-responding generator load control [4]

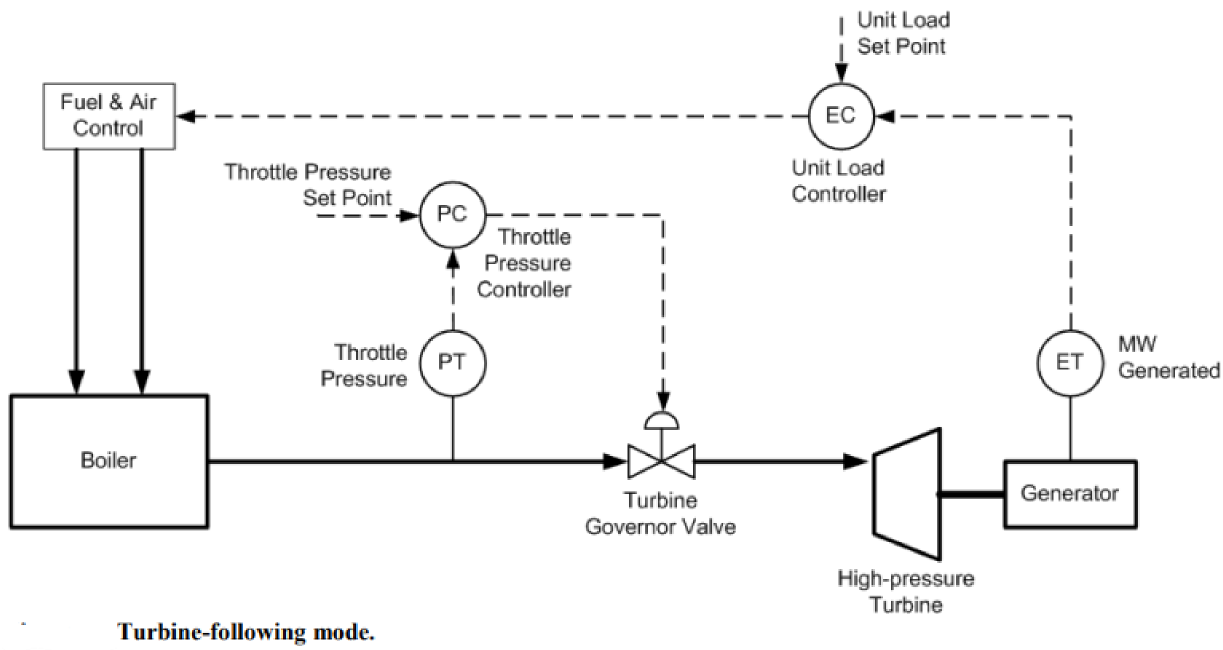


Figure 9-1 Turbine-following mode

10 Furnace pressure control:

Most large power plant boilers have two or more forced draft (FD) fans and two or more induced draft (ID) fans [7]. These will normally be run in pairs consisting of one FD fan and one ID fan. The FD fans force air into the furnace while the ID fans extract the post-combustion gasses from the furnace. Air flow rate through the fans can be manipulated with vanes, dampers, or by changing fan speed. Air flow through the FD fan is controlled based a set point derived from the fuel flow rate and the air/fuel ratio. The flow through the ID fan is manipulated to control the furnace pressure. Furnace pressure is maintained at a slightly negative gage pressure (slightly below atmospheric pressure) so that fuel, ash, and flue gas won't escape through furnace inspection doors and other crevices. Under normal operating conditions the furnace pressure acts like an integrating process. If there is a mismatch between draft in and out, the furnace pressure will change and continue to change until the high- or low-pressure trip point is reached. Consequently, the flow rates in and out of the furnace must be dynamically balanced so that the furnace remains close to its set point. A large deviation from set point will result in a boiler trip to keep the plant safe. The furnace pressure controller changes the induced draft flow rate to keep the furnace pressure at its set point. If airflow rate is measured at the ID fans, a cascaded flow controller can be implemented for improved control figure (10-1). If airflow rate is not measured, the furnace pressure controller will manipulate the control element directly.

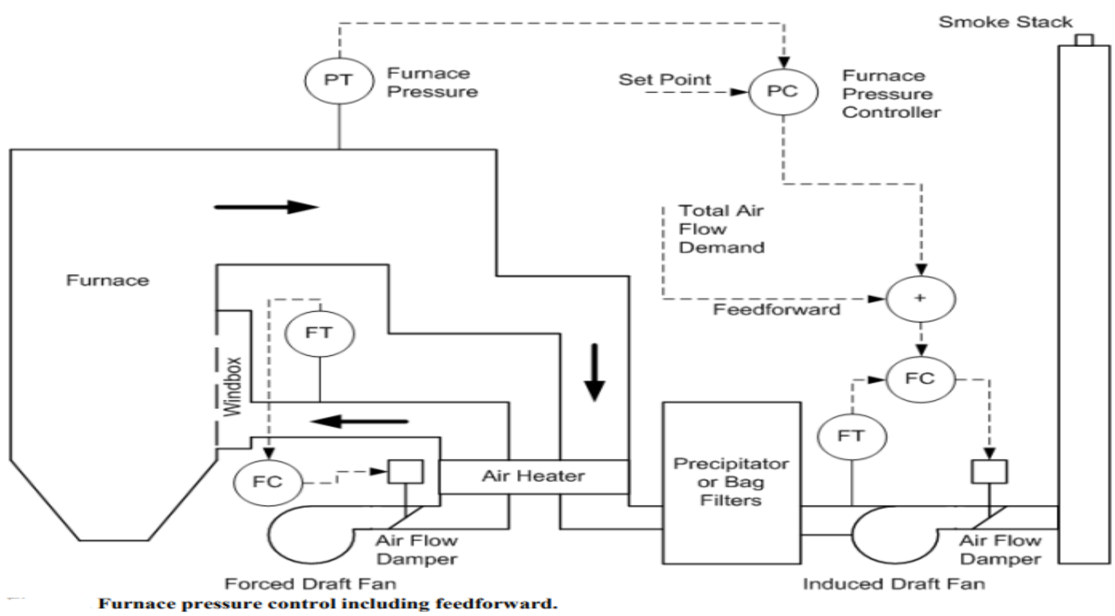


Figure 10-1 Furnace pressure control including feedforward

11 Combustion control methods:

The theoretically perfect combustion of a fuel requires the provision of exactly the right amount of air needed for complete combustion of the fuel. It means that the fuel and air being delivered to the burner are controlled to get complete combustion. Unfortunately, when the realities of practical plant are involved, the situation once again becomes far more complex than this simple analysis would suggest.

So, in this chapter we talk about how control for adjusting the optimum air-to-fuel ratio for maximum combustion efficiency. Techniques for controlling the ratio of air flow to fuel flow vary with the size of equipment controlled. There are two ways to control as following:

- On–Off and High–Low Controls
- Modulating control

11.1 On–Off and High–Low Controls:

The simplest technique is on-off operation, where the burner operates at a specific setting, and shuts off when the demand, as defined by temperature or pressure, is met.

A slightly more sophisticated version is a high-low system in which the burner operates at a specific high firing rate until temperature or pressure demand is satisfied, then drops back to a specific low fire condition until high fire is again required. Both these systems are limited to processes such as space heating applications that can tolerate the cycling in temperature or pressure.

11.2 Modulating control:

11.2.1 Mechanical Jackshaft Controls

Processes that need more careful control require burners that adjust firing rate over their operating range. The simplest type of modulating burner control uses a jackshaft arrangement in which a single actuator motor adjusts its jackshaft arm according to a master load (demand) signal. As shown in figure (11-1), the air and fuel control devices are connected to the jackshaft by a series of mechanical linkages and cams. As the actuator motor moves the jackshaft arm, the arms connected to the fuel valve and fan damper move with it. The relative movement can be varied by means of the cam adjustments, thereby determining the air/fuel ratio. For multiple-fuel burners, a second cam adjusts the standby fuel valve.

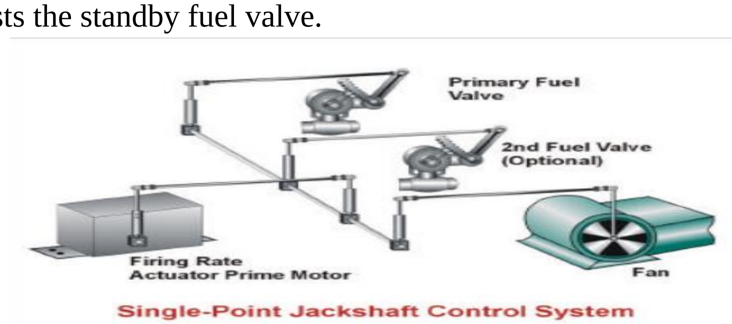


Figure 11-1 Single-Point Jackshaft Control System

Usually, the cams have a number of setscrews that can be adjusted to control fuel valve position relative to the jackshaft arm position. Calibrating the system involves combustion tests in which the actuator is positioned to various settings, usually at least ten, and at each setting the setscrews are adjusted to achieve the desired level of oxygen in the flue gas. It is important that, once the adjustments are complete, all the jackshaft arms are pinned and that all the setscrews are locked in their final position [3].

Oxygen trim control is possible by using a signal from an oxygen analyzer to adjust the linkage between the jackshaft and the fan damper arm. However, the range of oxygen trim is usually very limited and the control response must be very slow to ensure that the burner reaches steady state before the oxygen trim control acts

A mechanical jackshaft system does not include measurement of air flow or fuel flow, nor does it sense changing air temperature or fuel condition. It does not detect any play in the jackshaft and linkages. As a result, it must be set up with sufficient air for safe operation under all conditions, which is usually more than the optimum for efficiency. Common applications are small burners where the cost of more complex controls cannot be justified.

11.2.2 Parallel control:

Parallel control systems provide separate controllers and drives to adjust fuel and air flow, each controller taking its signal from a master control, as shown in figure (11-2). Its main advantage over jackshaft control is that the operator can adjust the air and fuel individually, and can override the automatic control settings, if desired.

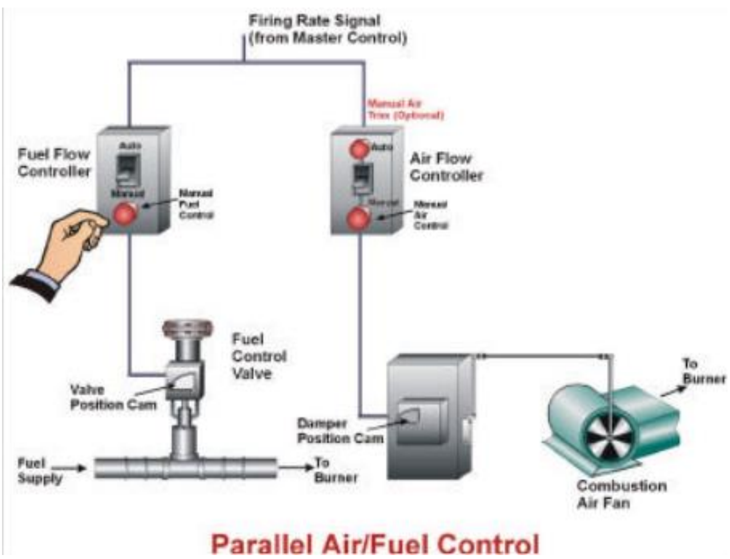


Figure 11-2 Parallel Air/Fuel Control

Parallel control has traditionally been applied to older, medium-sized boilers equipped with pneumatic controls. It can also be applied to newer, electronic controllers, but with little additional cost these can be designed as more advanced, cross-limiting controllers, discussed later. Like jackshaft control, parallel control does not measure fuel or air flow, does not sense changing air temperature or fuel conditions, and must take into account any hysteresis or play in the control drives and linkages. Therefore, to provide a margin of safety, the system must be set up with more than the optimum excess air [3].

The system can be enhanced with respect to safety by mounting position transmitters on the actuators, so that an alarm sounds if the actuator position does not match the control signal.

This advises the operator if an actuator has failed or if calibration has been lost, for example, if a shaft or linkage has slipped. To provide some improvement in efficiency by reducing excess air, oxygen trim can be provided via an additional controller which modifies the signal to the fan damper positioner. But, as with jackshaft controls, range of oxygen trim is limited and response must be slow.

Calibration of a parallel control system is carried out similarly as for a jackshaft control system. Combustion tests are done in which the primary fuel valve is set to ten positions, spanning the full operating range, and at each position, the air dampers are adjusted to provide an appropriate level of excess air, providing a safety margin as already discussed. The resulting data are then used to set up the controllers. With pneumatic control systems the cams in the fuel valve and fan damper actuators are cut to provide the correct air and fuel flows for the same output signal from the air and fuel controllers. With programmable controllers it is a simple matter of entering the appropriate data. When the controls have been calibrated for the primary fuel, the procedure is repeated to create a second data curve or cam for the standby fuel.

Finally, to ensure safe operation, oxygen in the flue gas should be measured at various firing rates, approached from both higher and lower firing rates. It is also important to check for any spikes in oxygen or carbon monoxide during rapid load changes. If the fuel valve actuator and the fan damper actuator react at significantly different speeds, the air/fuel ratio may become dangerously low during load swings. Where oxygen trim control is employed, care must be taken to ensure that it does not respond quicker than the primary controls see figure (11-3). If the furnace is a balanced draft furnace, the connection to the furnace draft control loop is shown at (d). This connection is not necessary if the furnace draft is controlled with a simple feedback control loop

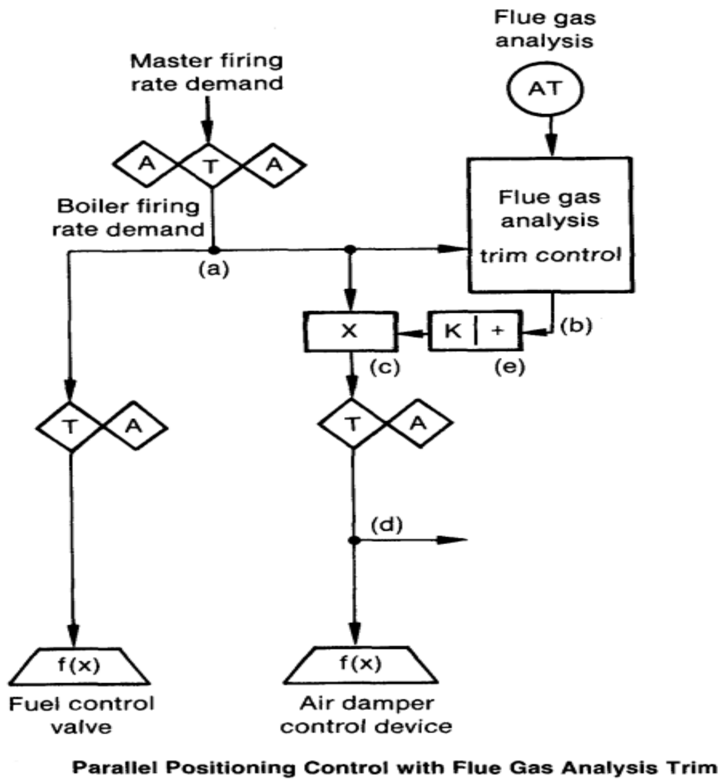


Figure 11-3 Parallel Positioning Control with Flue Gas Analysis trim

11.2.3 Cross-Limiting Control:

Cross-limiting control is a more sophisticated system that addresses some of the shortcomings of the parallel system. It provides separate fuel and air control devices, measurement of air and fuel flow, and more powerful controllers, all of which make it more expensive. But for larger boilers, at least, it can provide operating savings because it can sense and compensate for some of the factors that affect optimum air/fuel ratio [3].

Cross-limiting control is shown schematically in figure (11-4). It takes its name from the important safety feature that does not allow either air flow to be reduced below what is required for the existing fuel flow, or fuel flow to be increased above what is required for the existing air flow. It also monitors air and fuel flow, and adjusts air flow to maintain the optimum value as determined during the calibration tests. Further improvement is possible by continuously measuring oxygen and carbon monoxide in the flue gas, and using this information as a further factor in air control.

Calibration tests are carried out in much the same manner as with other control systems. The primary fuel valve is set for various fuel flows, perhaps ten, at each setting the air flow is adjusted to the minimum acceptable level of oxygen in the flue gas, and a curve of the air/fuel relationship is generated. With pneumatic control systems, the cam in the fuel valve and in the fan damper actuators are cut so that the air and fuel flow meter readings (usually in percent) have a constant relationship over the burner operating range. With programmable controllers, the curve points can be easily programmed into controllers, with the flow measurements in the actual flow units (kg/h, SCFM, etc.)

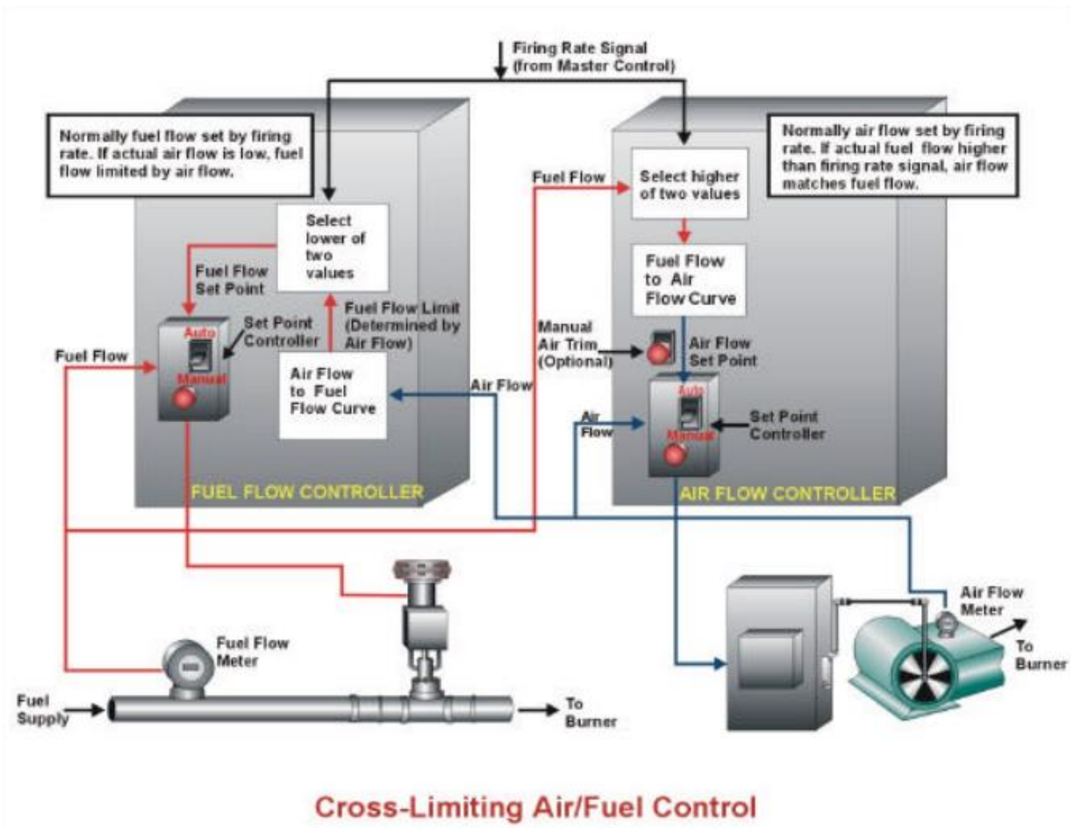


Figure 11-4 Cross-Limiting Air/Fuel Control

For multiple-fuel burners with pneumatic controls, settings for the standby fuel are determined for the same air settings that were obtained when calibrating for the primary fuel. With programmable controls an independent fuel/air curve is developed for the standby fuel; the controller selects the applicable curve based on the fuel selected.

Oxygen trim is possible, but again has a limited range of adjustment, and must respond slowly enough to allow the primary controls to reach equilibrium this is illustrate in Figure 11-5. Since cross-limiting control systems can – and should – be set up to operate with minimum excess air, it is doubly important to run the burner up and down its operating range to check for spikes in oxygen and carbon monoxide. If any are found, due to the fuel and air actuators reacting at different speeds, the controllers can be tuned to make their responses match.

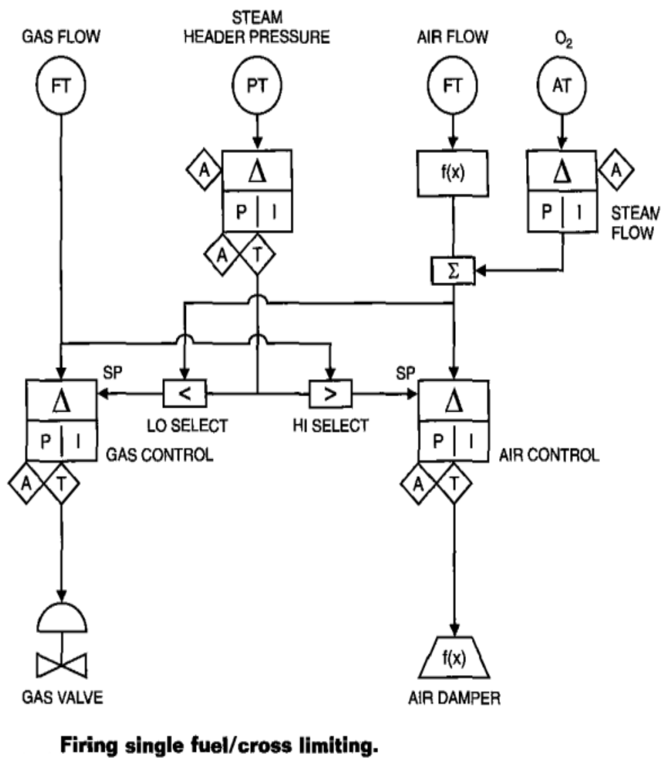


Figure 11-5 Firing single fuel/cross limiting

Because the air and fuel flows are measured, cross-limiting systems correct for some variations. For example, they will respond to changes in fuel flow caused by changes in supply pressure. However, attention must be paid to how the flows are measured. Most techniques for measuring air and natural gas flow: Pitot tube, orifice plate, vortex shedding, etc., actually measure volumetric flow as opposed to mass flow. These volumetric flow measurements, of themselves, do not compensate for temperature and pressure variations. While fuel/air control is better with cross limiting based on volumetric flows (as opposed to no flow measurement), the most precise control can only be achieved with mass flow measurement, usually by temperature and pressure compensation on the volumetric flow measurement. Many flow meters have optional pressure and temperature compensation directly within the transmitter. Fortunately, liquid flowmeters are not affected by minor changes in temperature, but when large temperature variations may occur, as when No. 2 oil is stored outside without any temperature control, the effect on the flow measurement should be checked.

The safety feature of cross-limiting control can be provided without the cost of air and fuel flowmeters by using position transmitters on the fuel valve and fan dampers. However, this arrangement does not compensate for flow variations and cannot provide tight control of fuel/air ratio.

Valves are used

Air damper and fuel valve to control the flow rate as

- Linear types include globe valves and slide valves.
- Rotary types include ball valves, butterfly valves, plug valves and their variants

Sensor to measure fuel flow rate and air flow rate as

- Orifice plate flowmeters.
- Turbine flowmeters (including shunt or bypass types).
- Variable area flowmeters.
- Spring loaded variable area flowmeters.
- Direct in-line variable area (TVA) flowmeters.
- Ultrasonic flowmeters

12 Control the maximum allowable steam pressure:

There are some valves to control maximum allowable steam pressure

The construction of plant means that each item has a maximum allowable working pressure if this is lower than the maximum possible steam supply pressure, the pressure must be reduced so that the safe working pressure of the downstream system is not exceeded

12.1 Pressure relief valve:

First **Safety valves** should be installed wherever the maximum allowable working pressure (MAWP) of a system or pressure-containing vessel is likely to be exceeded. In steam systems, safety valves are typically used for boiler overpressure protection and other applications such as downstream of pressure reducing controls [6].

The terms ‘safety valve’ and ‘safety relief valve’ are generic terms to describe many varieties of pressure relief devices that are designed to prevent excessive internal fluid pressure build-up.

Pressure relief valve - A spring-loaded pressure relief valve which is designed to open to relieve excess pressure and to reclose and prevent the further flow of fluid after normal conditions have been restored. It is characterized by a rapid-opening ‘pop’ action or by opening in a manner generally proportional to the increase in pressure over the opening pressure. It may be used for either compressible or incompressible fluids, depending on design, adjustment, or application.

This is a general term, which includes safety valves, relief valves and safety relief valves.

Safety valve - A pressure relief valve actuated by inlet static pressure and characterized by rapid opening or pop action.

Safety valves are primarily used with compressible gases and in particular for steam and air services. However, they can also be used for process type applications where they may be needed to protect the plant or to prevent spoilage of the product being processed.

Relief valve - A pressure relief device actuated by inlet static pressure having a gradual lift generally proportional to the increase in pressure over opening pressure.

Relief valves are commonly used in liquid systems, especially for lower capacities and thermal expansion duty. They can also be used on pumped systems as pressure overspill devices.

Safety relief valve - A pressure relief valve characterized by rapid opening or pop action, or by opening in proportion to the increase in pressure over the opening pressure, depending on the application, and which may be used either for liquid or compressible fluid.

In general, the safety relief valve will perform as a safety valve when used in a compressible gas system, but it will open in proportion to the overpressure when used in liquid systems, as would a relief valve [6].

12.2 Pressure reducing valve

A pressure-reducing valve is a self-operating valve that is used to reduce any excess pressure in a system

Self-acting principle means that no external power is required.

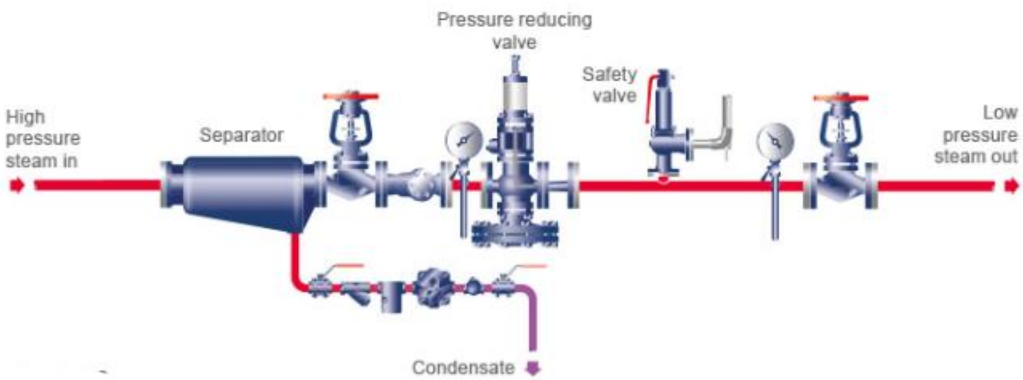
A pressure-reducing valve in a steam system works by balancing the steam pressure with a spring. Most of the modern pressure-reducing valves are manufactured using this basic concept. Based on the mechanism of controlling the valve opening, pressure reducing valves are classified into two types:

Direct acting pressure reducing valve and

Pilot-operated pressure reducing valve

See the arrangement of direct operating self-acting pressure reducing valve in Figure 122-1

12.3 Pressure reduction – pneumatic



General arrangement of a pilot operated, self-acting pressure reducing station

Figure 12-1 General arrangement of a pilot operated, self-acting pressure reducing station

Description

These control systems may include: P + I + D functions to improve accuracy under varying load conditions. Set point(s), which may be remotely adjusted. See the Figure 122-2 the arrangement of pneumatic pressure reducing station

Advantages:

- Very accurate and flexible.

- No limit on valve size within the limits of the valve range.
- Acceptable 50:1 flow rangeability (typically for a globe control valve).
- Suitable for hazardous environments.
- No electrical supply required.
- Fast operation means they respond well to rapid changes in demand.
- Very powerful actuation being able to cope with high differential pressures across the valve.

Disadvantages:

- More expensive than self-acting controls.
- More complex than self-acting controls.
- Not directly programmable

Application: A system which requires accurate and consistent pressure control, and installations which have variable and high flowrates and/or variable or high upstream pressure, including autoclaves, highly rated plant such as large heat exchangers and calorifiers, and main plant pressure reducing stations.

Points to note:

- A clean, dry air supply is required.
- A skilled workforce is required to install the equipment, and instrument personnel are required for calibration and commissioning.
- The control is 'stand-alone', and cannot communicate with PLCs (Programmable Logic Controllers).
- The failure mode can be important. For example, a spring-to-close on-air failure is normal on steam systems.

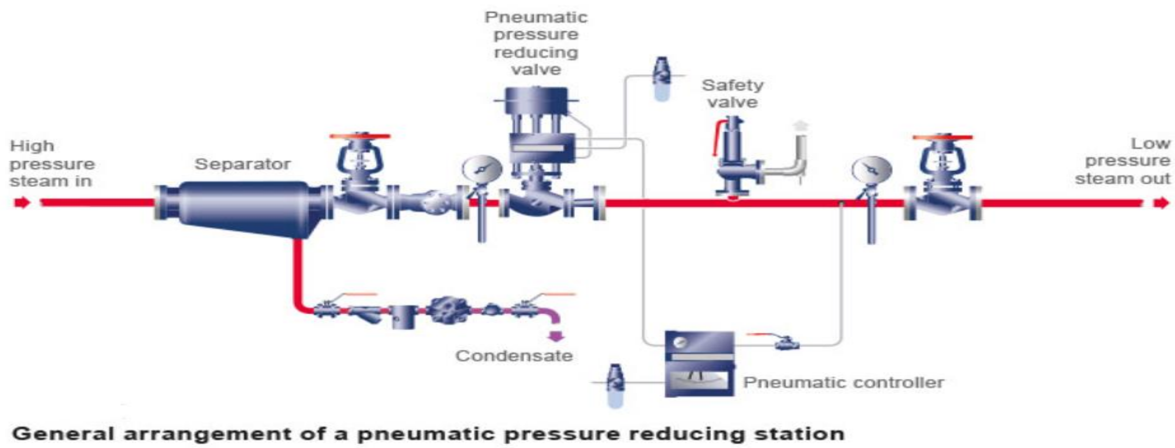


Figure 12-2 General arrangement of a pneumatic pressure reducing station.

12.4 Pressure reduction – electropneumatic:

Description

These control systems may include: P + I + D functions to improve accuracy under varying load conditions. Set point(s) which may be remotely adjusted, with the possibility of ramps between set points. (See Figure 122-3)

Advantages:

- Very accurate and flexible.
- Remote adjustment and read-out.
- No limit on valve size within the limits of the valve range.
- Acceptable 50:1 flow rangeability (typically for a globe control valve).
- Fast operation – rapid response to changes in demand.
- Very powerful actuation being able to cope with high differential pressures across the valve.

Disadvantages:

- More expensive than self-acting or pneumatic controls.
- More complex than self-acting or pneumatic controls.
- Electrical control signal required. Costly for hazardous areas.

Application: A system which requires accurate and consistent pressure control, and installations which have variable and high flowrates and/or variable or high upstream pressure, including autoclaves, highly rated plant such as large heat exchangers and calorifiers, and main plant pressure reducing stations [7].

Points to note:

- A clean, dry air supply is required.
- A skilled workforce is required to install the equipment, and instrument personnel are required for calibration and commissioning.
- Can be part of a sophisticated control system involving PLCs, chart recorders and SCADA systems.
- Always consider the failure mode, for example, spring-to-close on-air failure is normal on steam systems

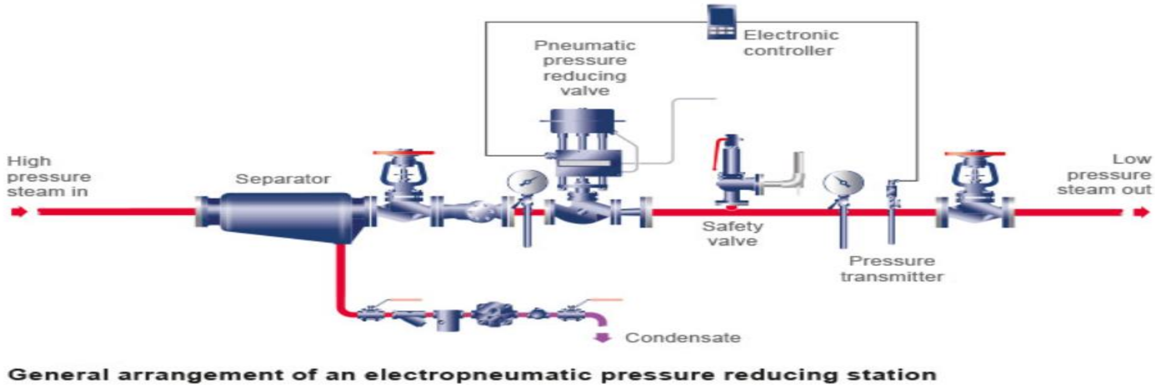


Figure 12-3 General arrangement of an electropneumatic pressure reducing station

12.5 Pressure reduction – electric:

Description

These control systems may include: P + I + D functions to improve accuracy under varying load conditions. Set point(s), which may be remotely adjusted. (See Figure 122-4)

Advantages:

- Both controller and valve actuator can communicate with a PLC.
- No compressed air supply is required.

Disadvantages:

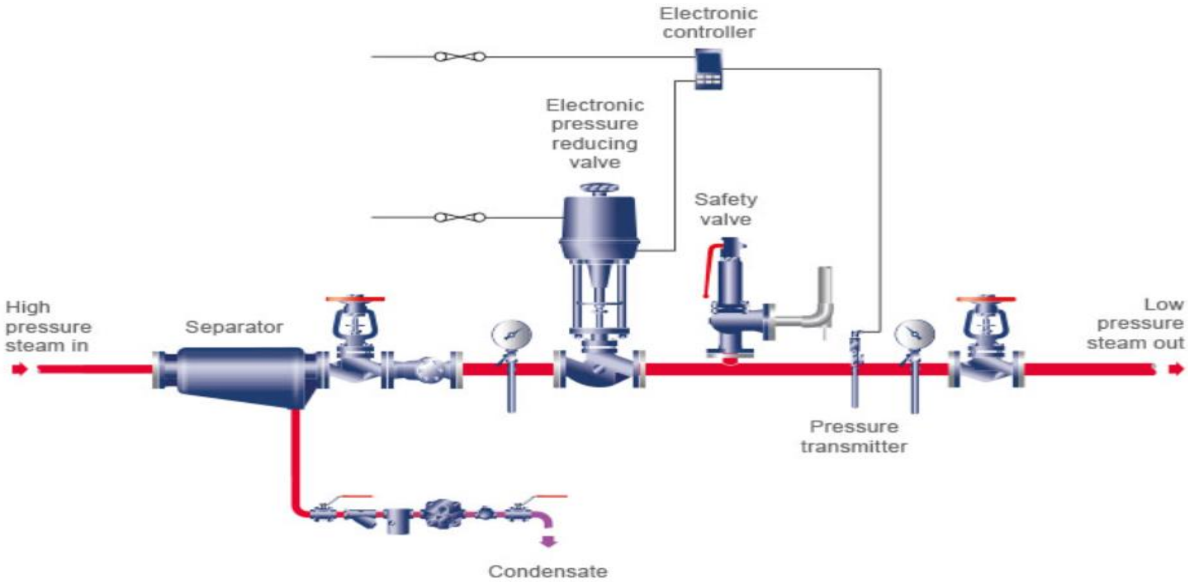
- If a spring return actuator is required, the available shut-off pressure may be limited.
- Relatively slow actuator speed, so only suitable for applications where the load changes slowly.

Application:

- Slow opening/warm-up systems with a ramp and dwell controller.
- Pressure control of large autoclaves.
- Pressure reduction supplying large steam distribution systems.

Points to note:

- Safety: If electrical power is lost the valve position cannot change unless a spring return actuator is used.
- Spring return actuators are expensive and bulky, with limited shut-off capability.



General arrangement of an electric pressure reducing station

Figure 12-4 General arrangement of an electric pressure reducing station

13 Control the super-heated steam temperature at the super heater outlet point:

Why is superheated steam temperature controlled?

The superheated steam temperature of the boiler is required to maintain within the limit. The main steam temperature must be equal to the set point or the design temperature.

To drive the steam turbine, the superheated steam temperature must be equal to the rated design value. And to minimize thermal stress, the temperature must be maintained within its limits.

When steam demand drops, the steam temperature increases, and flow in the superheater reduces.

When steam demand rises, the flow in the superheater increases, and steam temperature decreases.

13.1 Methods to control the temperature of superheated steam:

1. Separately – fired superheater method
2. Excess air control method
3. Gas Bypass Method
4. Tilting or Adjustable Burner Control
5. Turning the burners
6. Coil Immersion in Boiler Drum
7. De-superheating or Attemperation Method:

13.1.1 Separately – Fired Superheater Method:

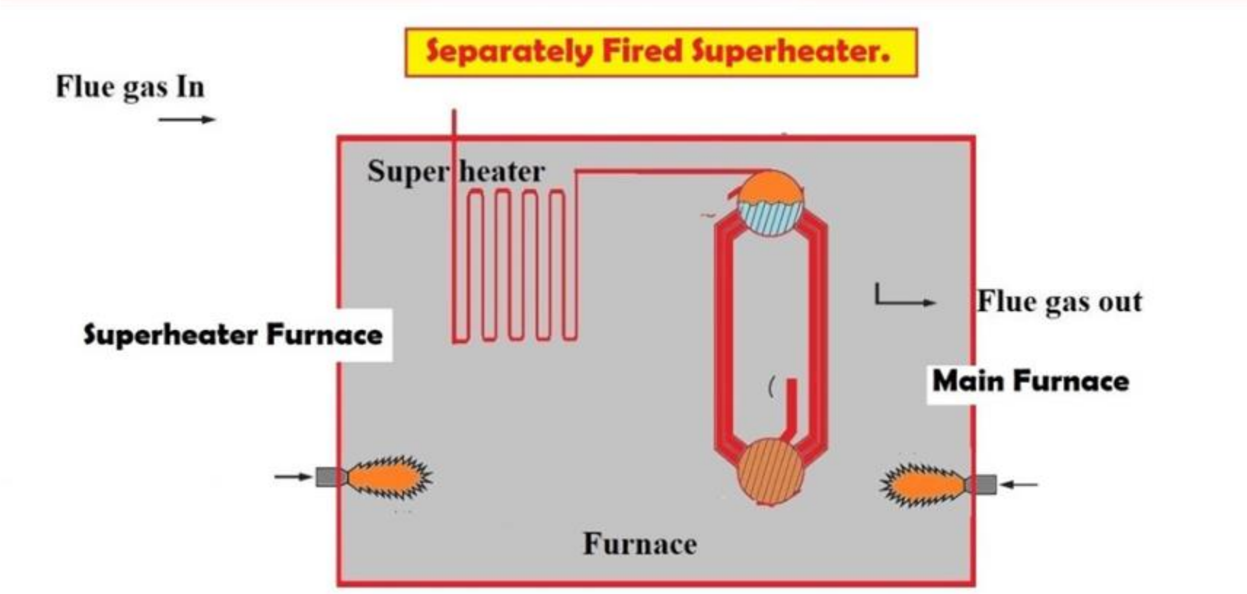


Figure 13-1 Separately – Fired Superheater

In this method (illustrated in figure 13-1), there are two superheaters and two furnaces. The radiant superheater is placed in another furnace and the convective superheater is placed in between the common flue gas path of both furnaces, i.e., in between the main boiler furnace and superheater furnace, the rise in superheated steam temperature depends upon the firing rate in the furnace [8].

13.1.2 Excess Air Control Method:

This is done by controlling the mechanical draught systems. The air supply to the furnace can be varied accordingly to control the temperature of the superheated steam. To increase the superheated steam temperature the air supply must be increased.

The radiant heat transfer is proportional to the difference in the fourth power of the temperatures of furnace and the water wall (i.e., T4g – T4w). The lower radiant heat absorption by water walls will reduce the water wall temperature but will increase the steam temperature. However, the increased mass flow rates of gases due to excess air will cause high heat rejection into chimney. Therefore, it will lower the boiler efficiency.

The flue gas temperature is raised by supplying excess air through mechanical draught systems and the heat absorption rate of the furnace water wall is reduced. If excess air is supplied more heat transfer takes place at the superheater tube and the steam temperature increases.

If the combustion air is reduced the steam temperature decreases and heat absorption at the water wall increases. Heat contents in the flue gas decrease and the heat transfer to the superheater decreases as well. This type of control is mostly used where a convective superheater is used [8].

13.1.3Gas Bypass Method:

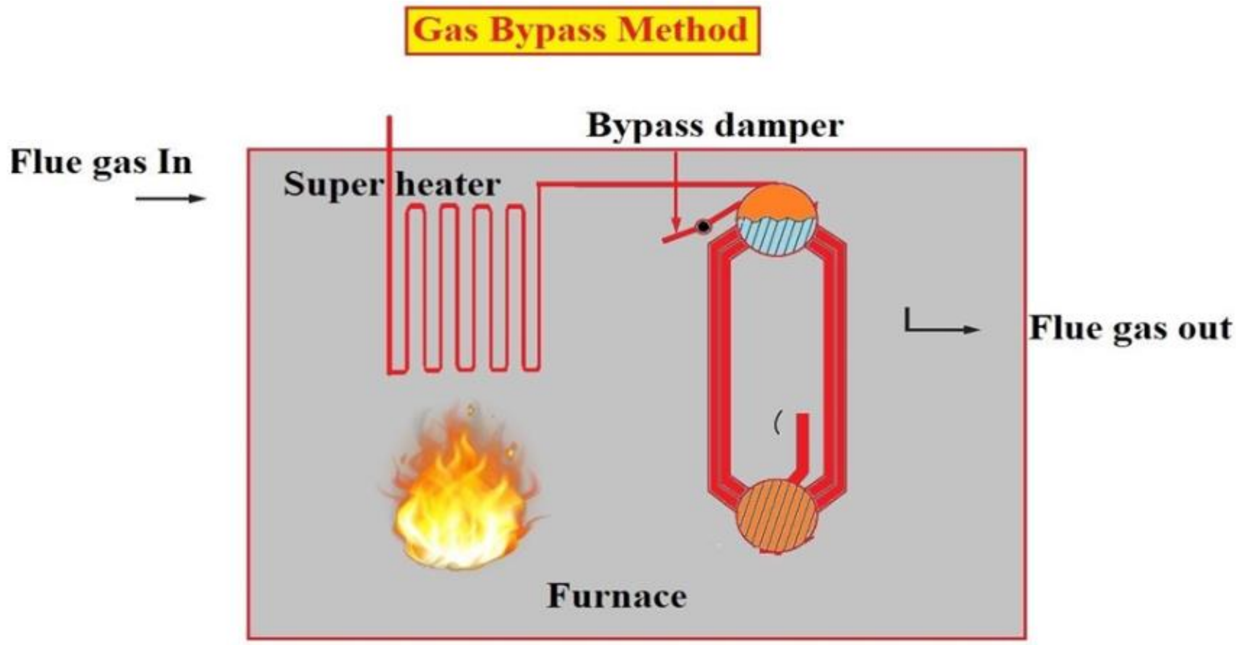


Figure 13-2 Gas Bypass method

In this method (illustrated in figure 13-2), the damper is used to bypass the flue gas path so that some quantity of flue gas does not flow through the superheater. During low load when the steam flow is less in the superheater, the bypass damper is kept open. Some quantity of flue gas is bypassed. As less volume of hot flue gas flows through the superheater, the temperature of steam can be maintained constant during lower load conditions. During higher load, the damper is closed and the entire flue gas is allowed to flow through the superheater.

According to the desired temperature at a certain load, the damper is set at a certain position.

The damper has to operate at a high temperature and in an erosive environment. The draft loss in the flue gas path varies periodically.

The draft loss is more when the damper is closed so that flue gas flows through the superheater.

The draft loss is less when the damper is opened so that the flue gas path is bypassed [8].

13.1.4Tilting or Adjustable Burner Control:

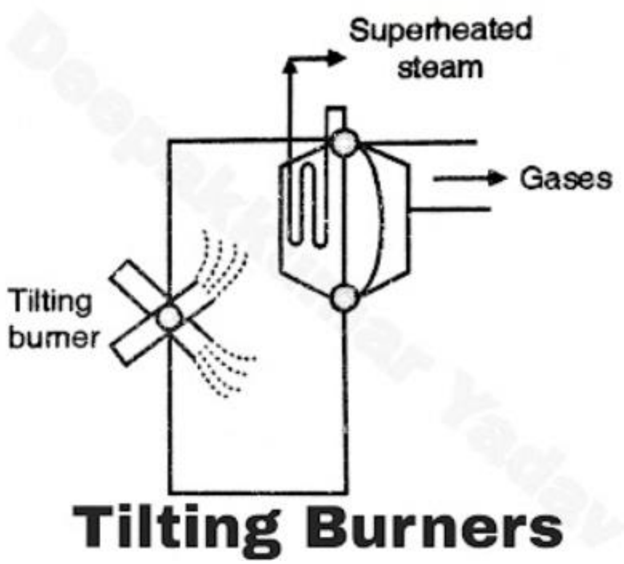


Figure 13-3 Tilting Burners

In this case (illustrated in figure 13-3), the burner is tilted or adjusted to control the superheated steam temperature. And the burners are designed in such a way that they can be tilted upward or downward.

Depending upon the requirement, the burner may be tilted upward or downward

When the burner is tilted downward, the flue gas temperature towards the superheater zone is reduced and the temperature of the water wall is raised.

When the burner is tilted upward, the flue gas temperature towards the superheater zone is raised and the temperature of the water wall is reduced.

13.1.5Turning the burners:

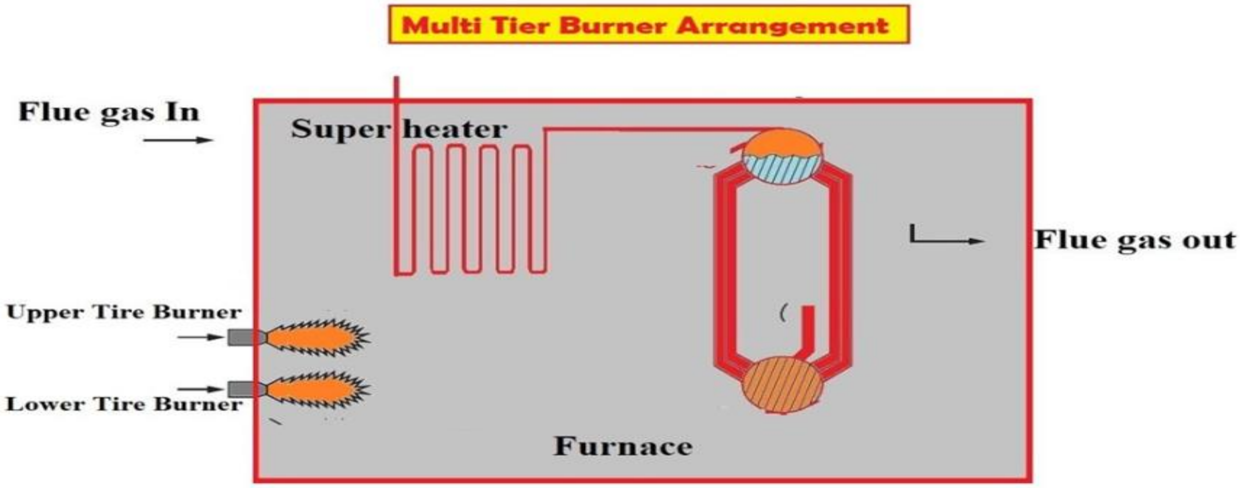


Figure 13-4 Multi-Tier Burner Arrangement

In this case (illustrated in figure 13-4), during low load, the upper tire burners are taken into service. So that the flue gas temperature at the furnace exit-side (superheater inlet), and the steam temperature increase.

During higher load, both the lower tire burners and upper tire burners are used so that the furnace exit temperature is maintained constant [8].

13.1.6Flue Gas Recirculation Method:

To control the superheated steam temperature, the flue gas exhausted from the economizer is circulated back to the boiler furnace with the help of a mechanical draught system

If more gas is recirculated, the superheated steam temperature will increase. Heat absorption at the water wall will decrease. (See figure 13-5) [8].

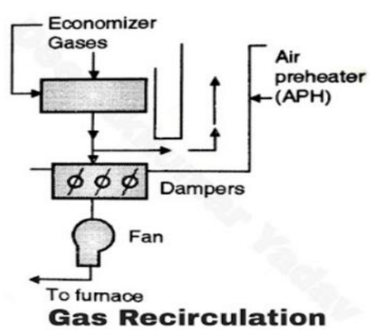


Figure 13-5 Gas Recirculation

13.1.7Coil Immersion in Boiler Drum:

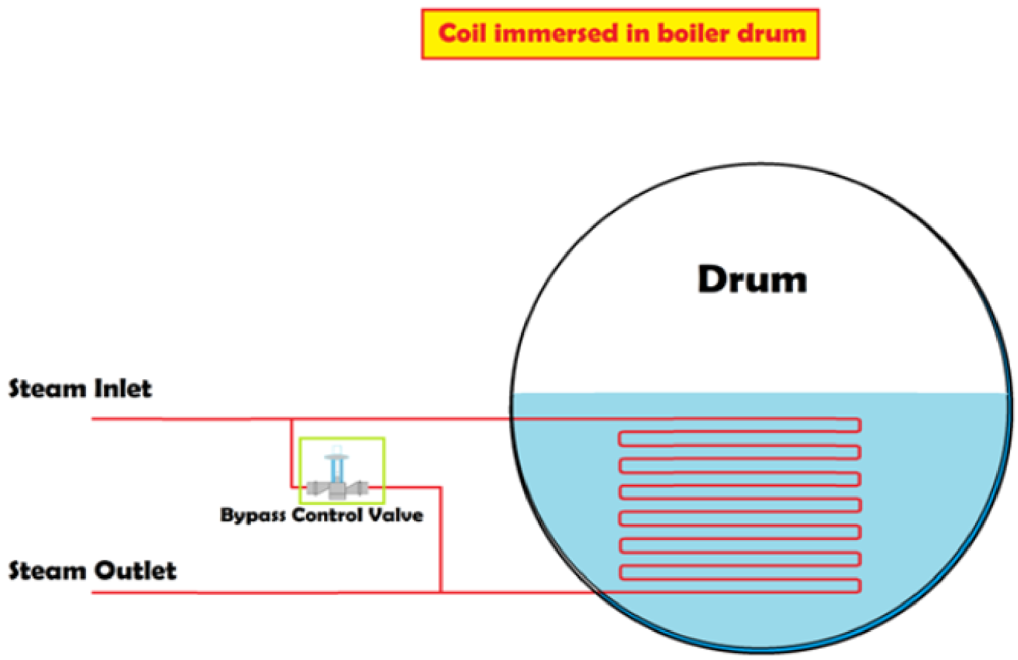


Figure 13-6 Coil immersed in boiler drum

In this method (illustrated in figure 13-6), some part of the superheated steam is passed through the boiler drum by immersing a coil in it. And the bypass valve is provided to control the flow of steam to the drum.

If the superheated steam temperature rises. The superheated steam is passed through the coil immersed in the boiler drum and the temperature of the steam is controlled. During this time the bypass valve must be closed.

When the superheated steam temperature decreases, the bypass control valve is opened. And most of the steam is passed through the bypass line and now the superheated steam temperature is increased [8].

13.1.8 DE-superheating or Attemperation Method:

This is the most common method to control the temperature of the superheated steam. In this method, the condensate (normally boiler feedwater) is sprayed directly into the superheated steam. Sometimes superheated steam is cooled in a heat exchanger where the steam flows in the coil and feedwater flows in the shell. Both these methods are very effective.

The three superheaters called a primary superheater, intermediate superheater and secondary superheater are used to control the temperature of the superheated steam, and the two attemperators are installed between these superheaters. One is between primary and intermediate and the other is between intermediate and secondary superheater.

As the superheated steam passes through the secondary superheater the moisture in the steam is easily eliminated [8].

As De-superheating is the most common method so we will focus on it in the next words.

There are two types of DE superheating methods:

13.1.8.1 Spray Type Attemperator:

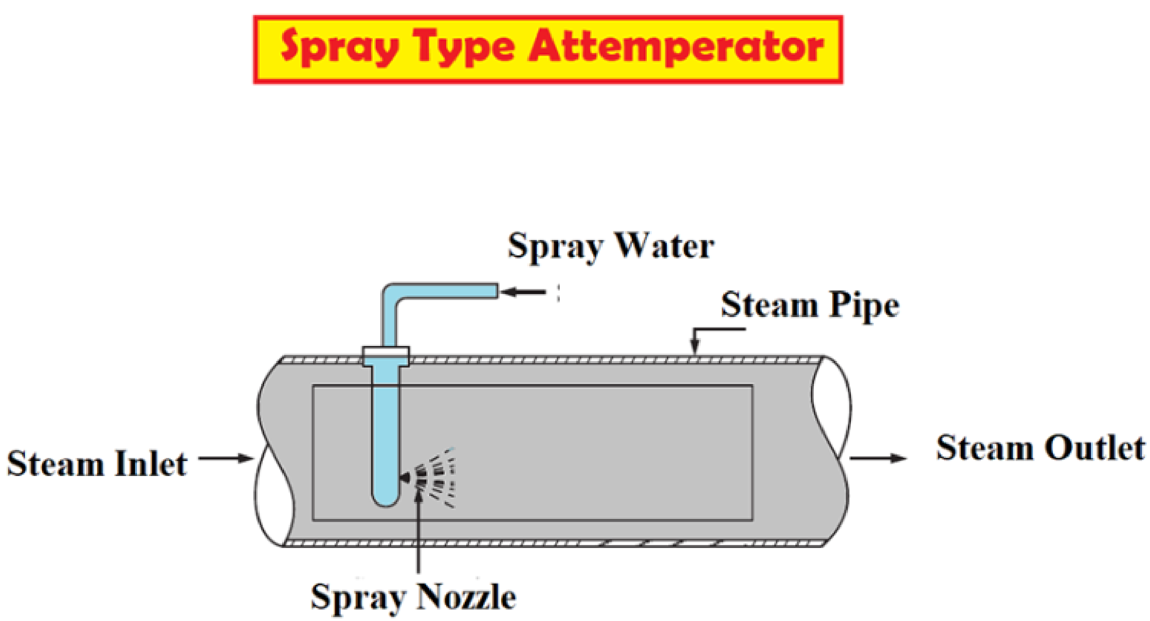


Figure 13-7 Spray Type Attemperator

In a spray-type attemperator, the spray nozzle is fixed to the steam header with a suitable pipe connection (illustrated in figure 13-7).

It is the most common type of desuperheater where the atomized spray water is sprayed directly to the superheated steam through a set of nozzles.

If the outlet temperature of the intermediate superheater is high then the control valve allows more spray water through the nozzle to reduce the temperature to the set point.

The temperature control loop is set in such a way that the spray water quantity can be adjusted automatically.

The spray water evaporates completely at the end. So that there is no chance of rust or corrosion to the steam turbine blades.

13.1.8.2 Surface Type Attemperator:

Here the feedwater doesn’t come in contact with the superheated steam. And the superheated steam temperature is controlled by varying the feedwater flow in a heat exchanger.

Feedwater flows in the calendria of the heat exchanger and the superheated steam flows inside the tube. To control the temperature of the superheated steam the excess water is allowed to flow. If not, the feed water is bypassed with the help of the control valve.

The advantage of a surface-type attemperator is the steam doesn’t come in contact with water.

13.1.8.3 How to control DE superheating method?

1. Basic feedback control
2. Cascade steam temperature control
3. Gain scheduling
4. Direct Energy Balance technique

13.1.8.3.1 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 (see figure 13-8). 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.

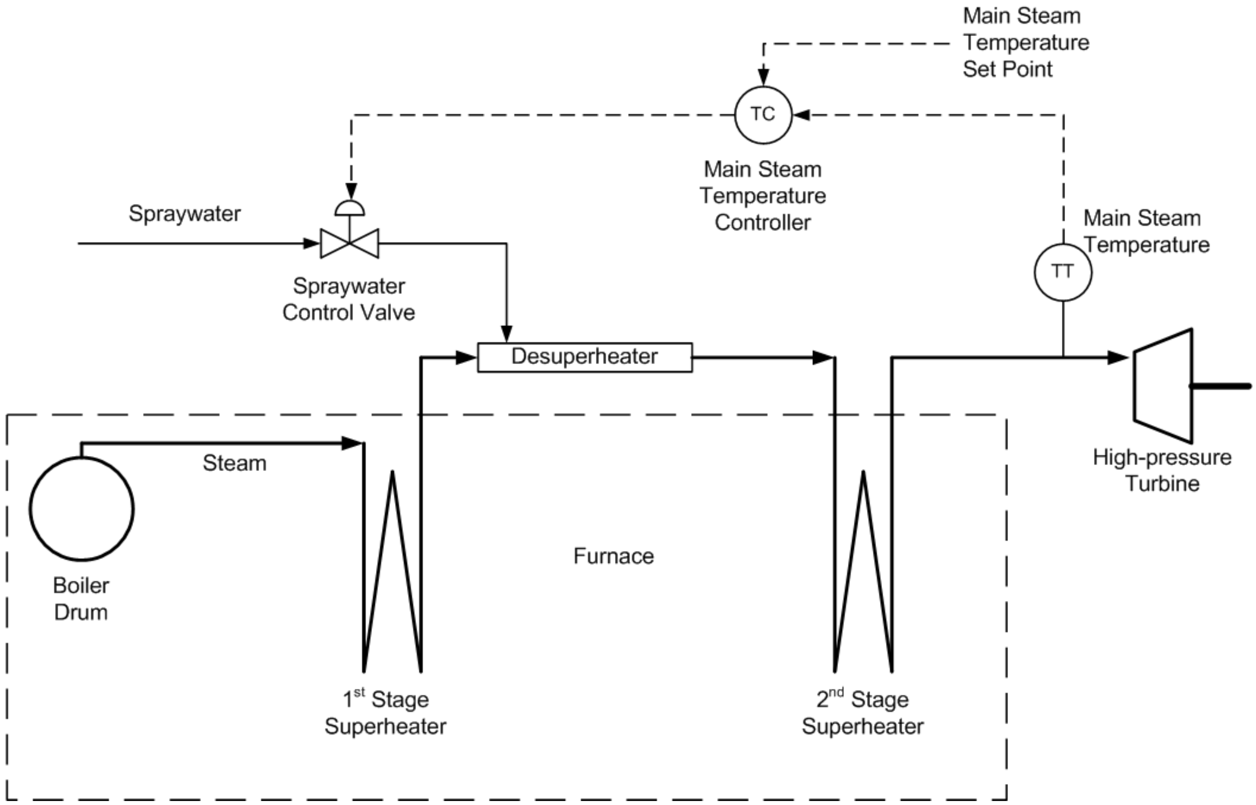


Figure 13-8 Basic feedback control

13.1.8.3.2 Cascade 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.

This arrangement is called cascade control (see figure 13-9).

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. <u>The desuperheater outlet temperature control loop</u> 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 <u>to provide very fast disturbance rejection</u>. However, in many cases spray water flow rate is not measured at the individual attemperators

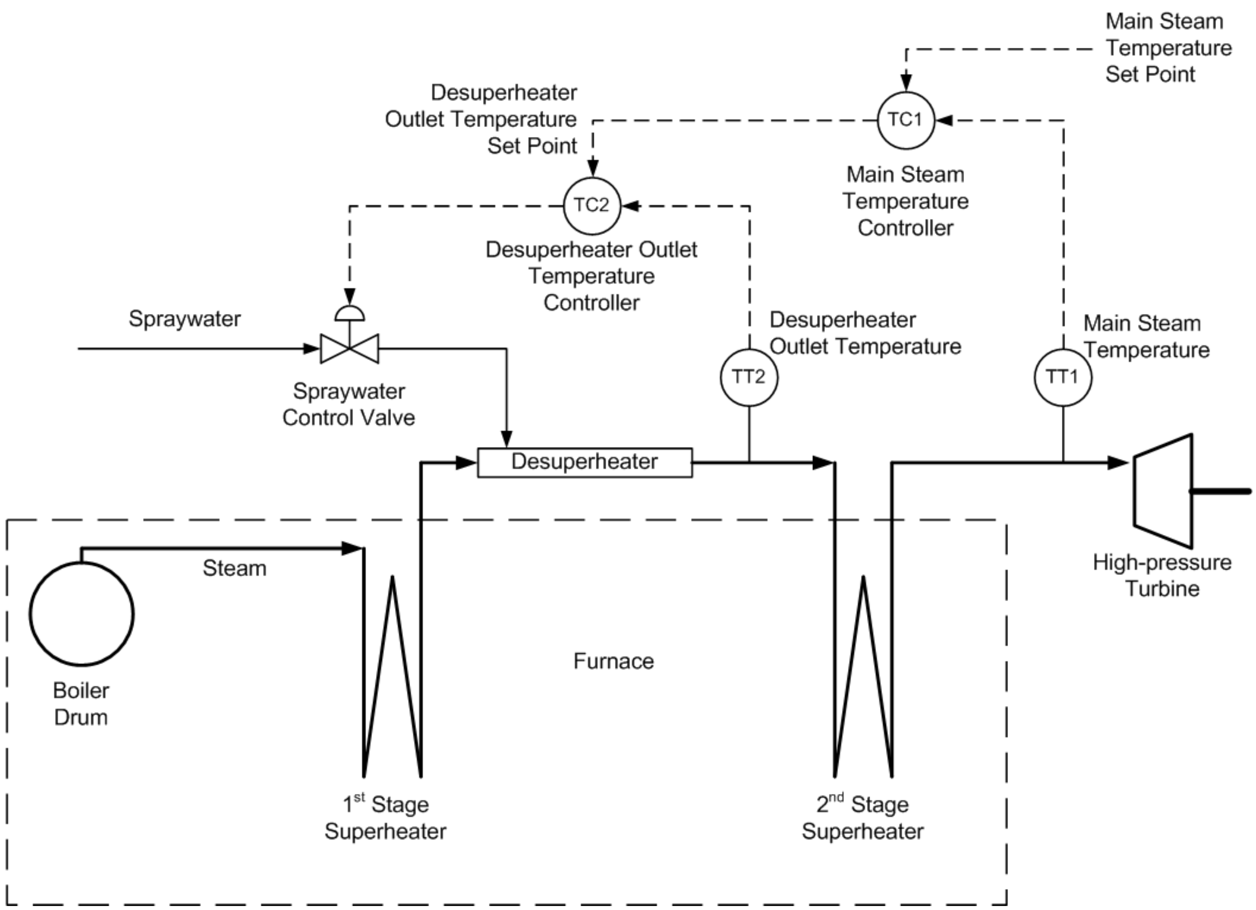


Figure 13-9 cascade steam temperature control

13.1.8.3.3 Gain scheduling

Since inherently, temperature loop is slow, the total effect of spray flow change could not be responded by thermocouples for SH outlet temperature measurement up to several minutes. In view of the above cascade PID control loop with inner slave control loop as shown is used mostly. In master controller, set point is compared with the SH outlet temperature to generate the set point for the slave controller where it is compared with DSH outlet Temperature controller to generate control demand for the spray control valve opening. During start up to low load Main stream (MS) temperature set point is kept low or may be derived from air flow which is proportional to boiler load. When steam flow is less naturally due to low flow the process dead time increases affecting adversely on the stability of the control loop. Therefore, it is necessary to schedule the controller gain at various loads (see figure 13-10).

Also, this calls for adjustment of I & D parameters of the controller. As DSH outlet temperature will be affected by steam flow rate (e.g. Less cooling for same spray flow at higher steam flow) also at higher load DP between steam and FW will be less; hence there will be less spray flow. Therefore, gain adjustment of the secondary controller is necessary. In addition to gain scheduling feed forward (illustrated in figure 13-11) is also very help tool to get better response from the loop. During any load change there will be change in steam flow, which affects the steam temperature directly. Therefore, a number of parameters such as MS flow, Fuel flow, air flow, and (depending on applicability): Burner tilt/ Drum pressure are used as feed forward signal to further enhance the response of the loop.

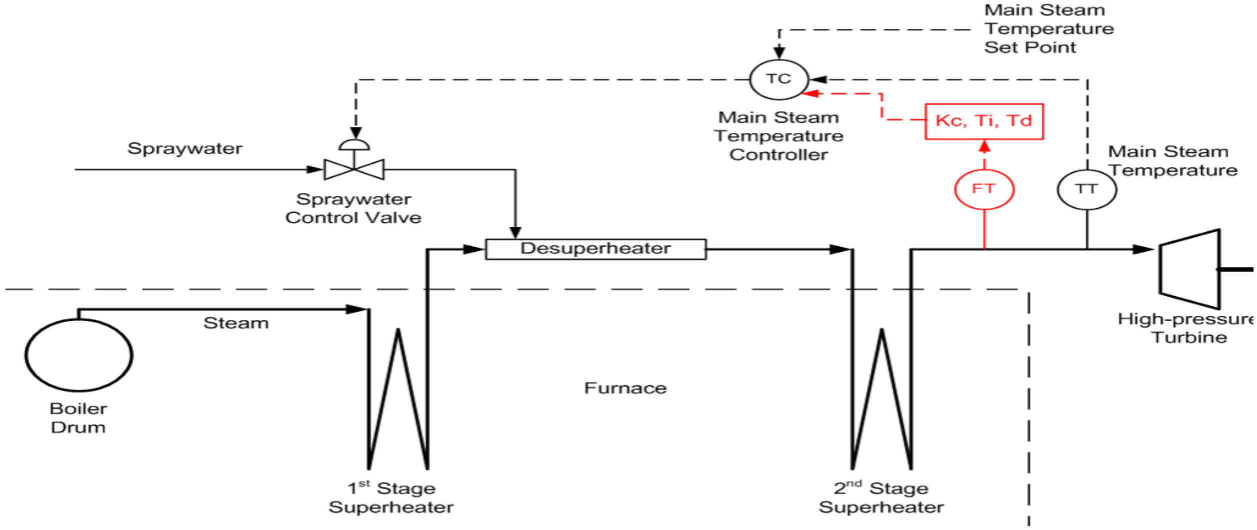


Figure 13-10 DE superheating control by gain scheduling

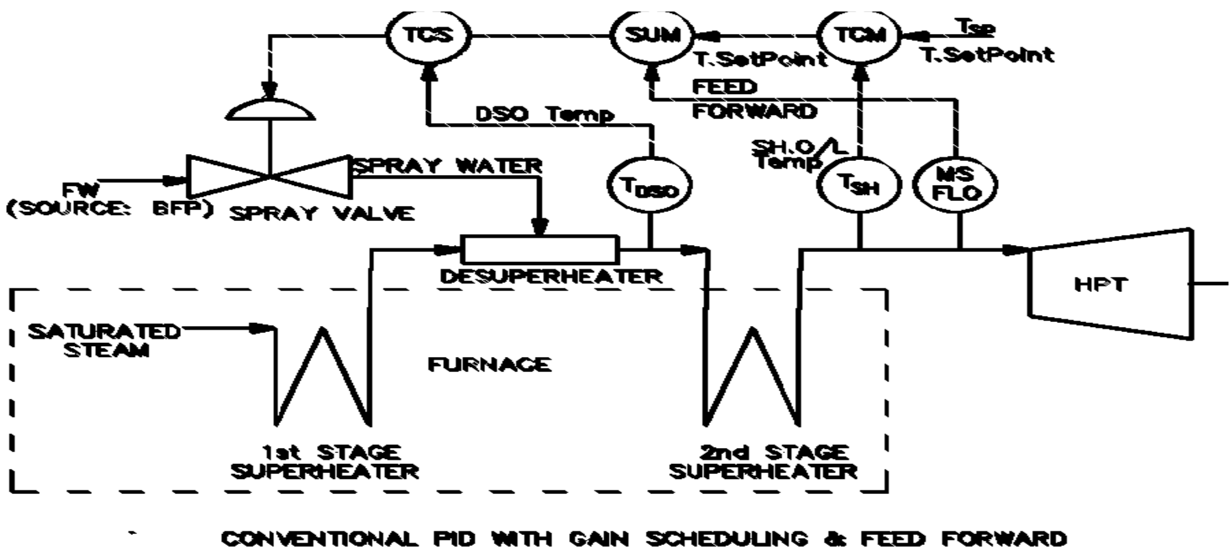


Figure 13-11 CONVENTIONAL PID WITH GAIN SCHEDULING & FEED FORWARD

Summary

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 integral and derivative times must be scheduled in addition to the controller gain.

13.1.9 Direct Energy Balance technique

This technique is used on the utility boiler for control the temperature of superheated steam which use More than one of the previous methods.

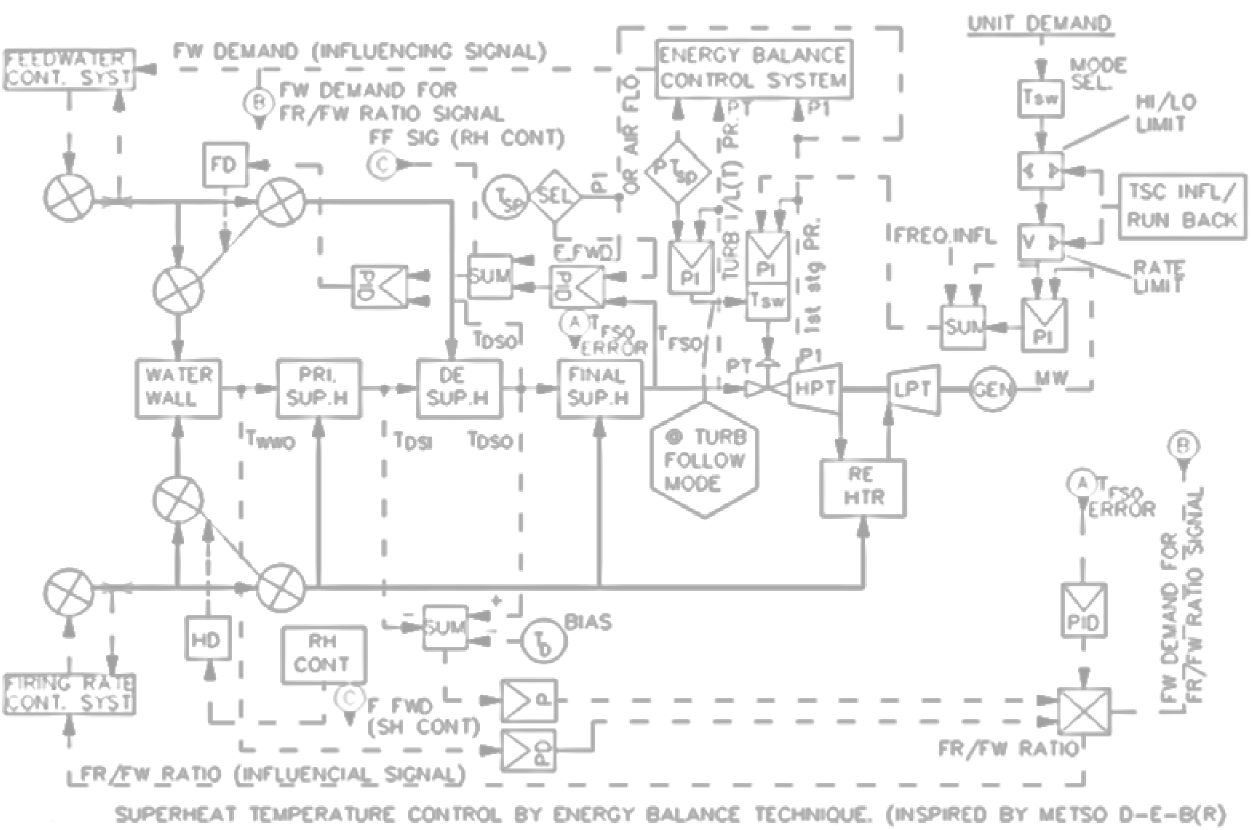


Figure 13-12 Direct Energy Balance technique

13.2 Sensors

The sensor is the part of the control system, which experiences the change in the controlled variable

In this Section the subject of temperature measurement will be covered

Types of sensors:

1. Filled system sensors
2. Resistance temperature detectors
3. Thermistors
4. Thermocouples

13.2.1 Filled system sensors

With pneumatic controllers, filled system sensors are employed figure 13-13 illustrates principles of system

When the temperature changes, the fluid expands or contracts, causing the Bourdon tube to tend to straighten out. Sometimes a bellows is used instead of a Bourdon tube.

In the past, the filling has often been mercury. When heated, it expands, causing the Bourdon tube to uncoil; cooling causes contraction and forces the Bourdon tube to coil more tightly. This coil movement is used to operate levers within the pneumatic controller enabling it to perform its task.

Note: for health and safety reasons, mercury is now used less often. Instead, an inert gas such as nitrogen is often employed [6].

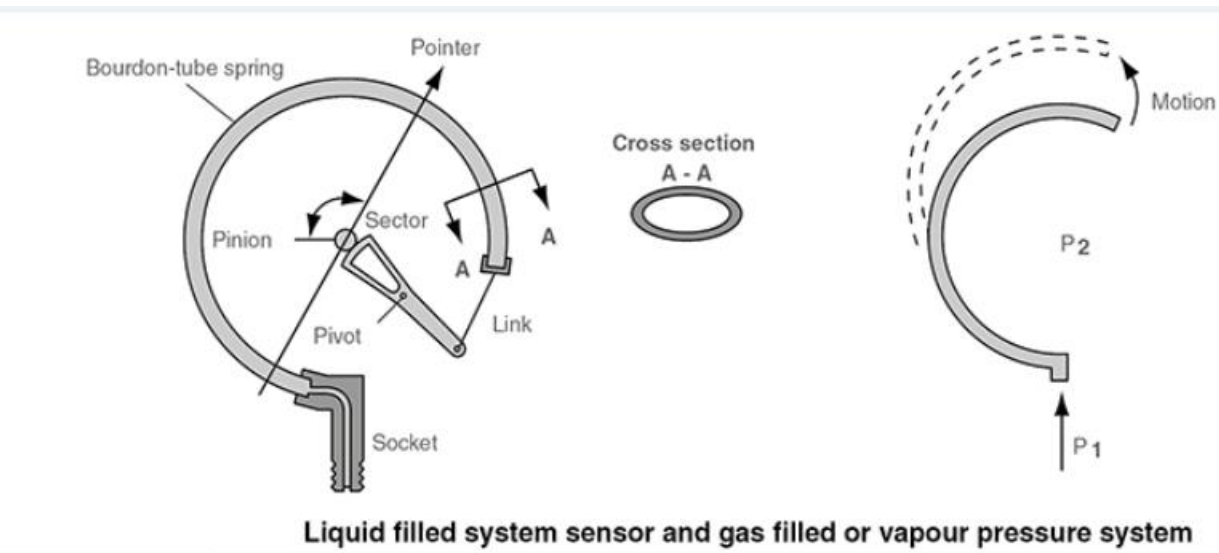


Figure 13-13 Liquid filled system sensor and gas filled or vapor pressure system

It is also used for self-acting temperature controls

There are two main forms of self-acting temperature control available on the market:

- Liquid filled systems
- Vapour tension systems

Self-acting temperature controls are self-powered, without the need for electricity or compressed air

The control system is a single-piece unit comprising a sensor, capillary tubing and an actuator.

This is then connected to the appropriate control valve (See figure 13-14)

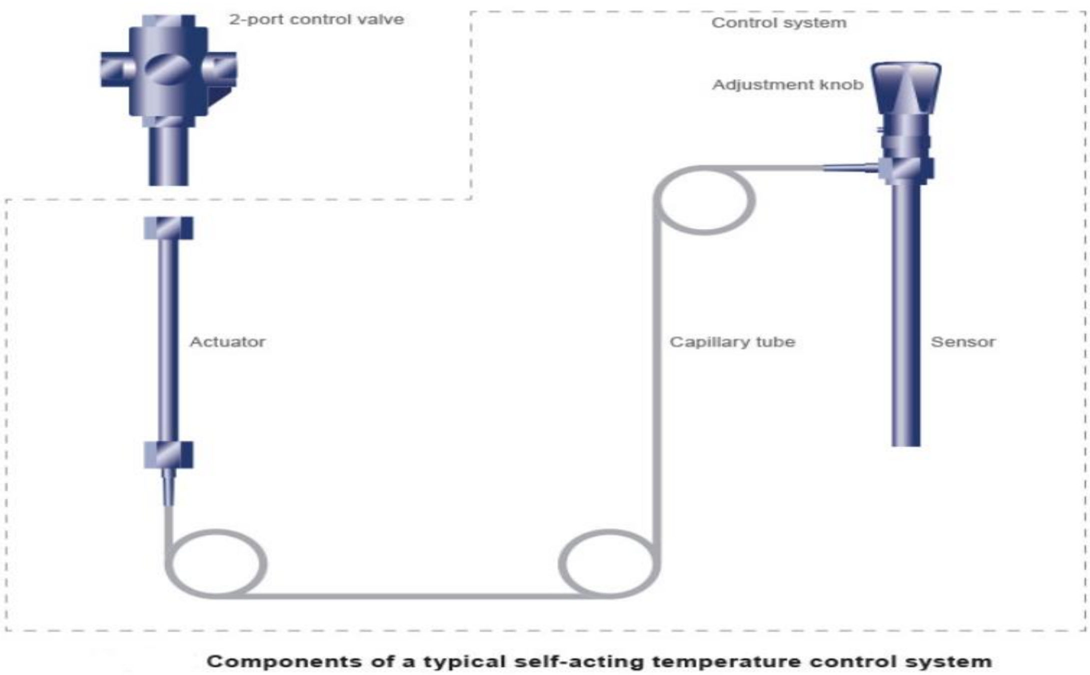


Figure 13-14 Components of a typical self-acting temperature control system

The self-acting principle:

If a temperature sensitive fluid is heated, it will expand. If it is cooled, it will contract. In the case of a self-acting temperature control, the temperature sensitive fluid that fills the sensor and capillary will expand with a rise in temperature.

The force created by this expansion (or contraction in the case of less heat being applied to the sensor) is transferred via the capillary to the actuator, thereby opening or closing the control valve, and in turn controlling the flow of fluid through the control valve [6].

13.2.2 Resistance temperature detectors (RTDs)

RTDs (figure 13-15) employ the fact that the electrical resistance of certain metals change as the temperature alters. They act as electrical transducers, converting temperature changes to changes in electrical resistance. Platinum, copper, and nickel are three metals that meet RTD requirements and Figure 13-15 shows the relationship between resistance and temperature.

A resistance temperature detector is specified in terms of its resistance at 0°C and the change in resistance from 0°C to 100°C. The most widely used RTD for the typical applications covered in these Modules are platinum RTDs. These are constructed with a resistance of 100 ohms at 0°C and are often referred to as Pt100 sensors. They can be used over a temperature range of -200°C to +800°C with high accuracy (±0.5%) between 0°C and 100°C.

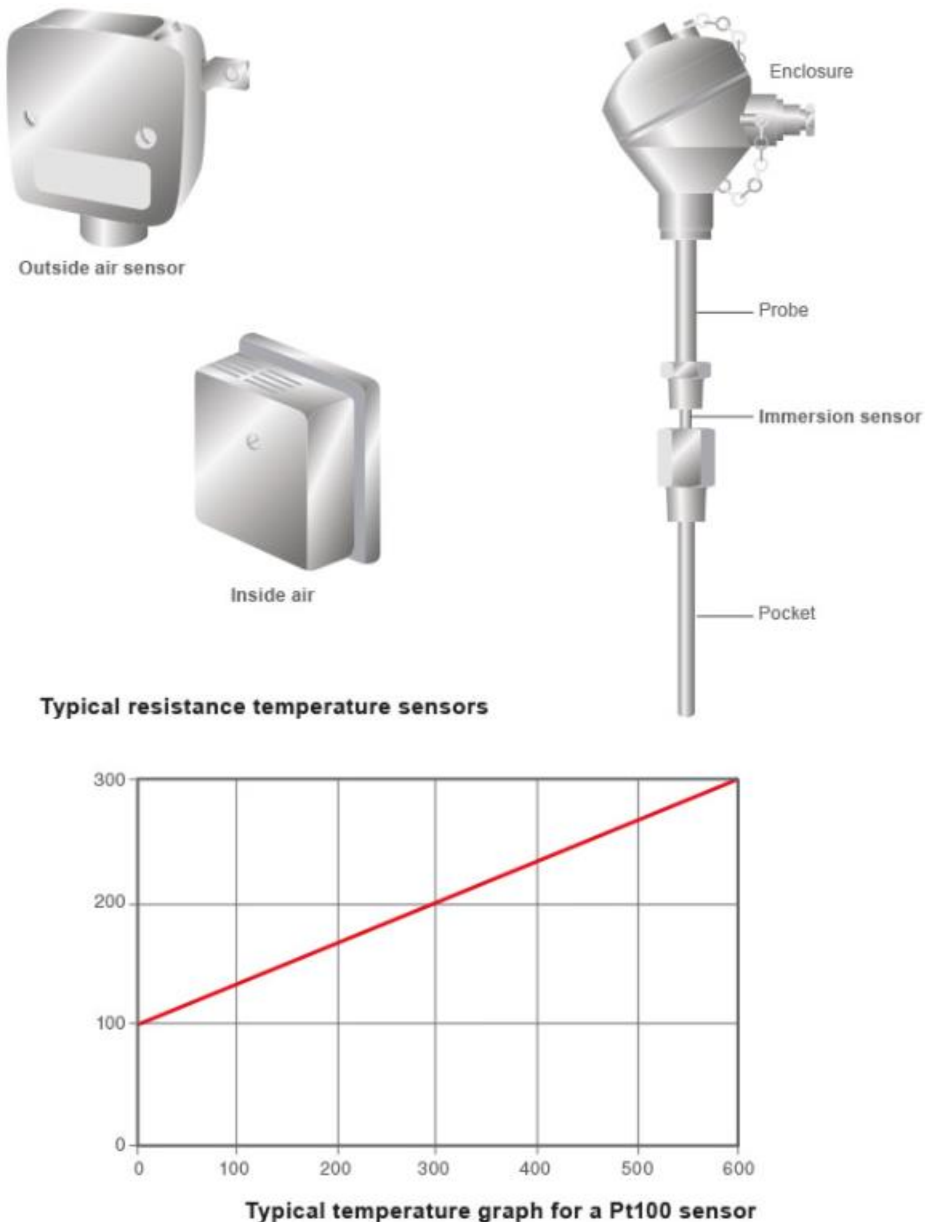


Figure 13-15 RTD

13.2.3Thermistors

Thermistors use semi-conductor materials, which have a large change in resistance with increasing temperature, but are non-linear. The resistance decreases in response to rising temperatures (negative coefficient thermistor). see figure 13-15

Thermistors are less complex and less expensive than RTDs but do not have the same high accuracy and repeatability. Their high resistance means that the resistance of the connecting cable is less important [6].

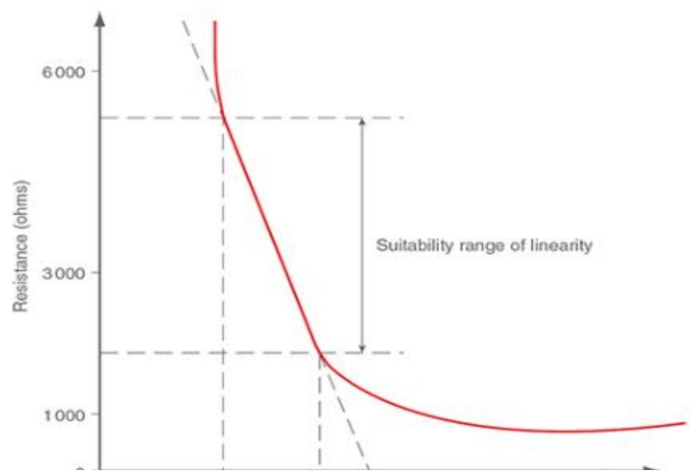


Figure 13-16 negative coefficient thermistor

13.2.4 Thermocouples

If two dissimilar metals are joined at two points and heat is applied to one junction (see Figure 13-17), an electric current will flow around the circuit. Thermocouples produce a voltage corresponding to the temperature difference between the measuring junction (hot) and the reference junction (cold).

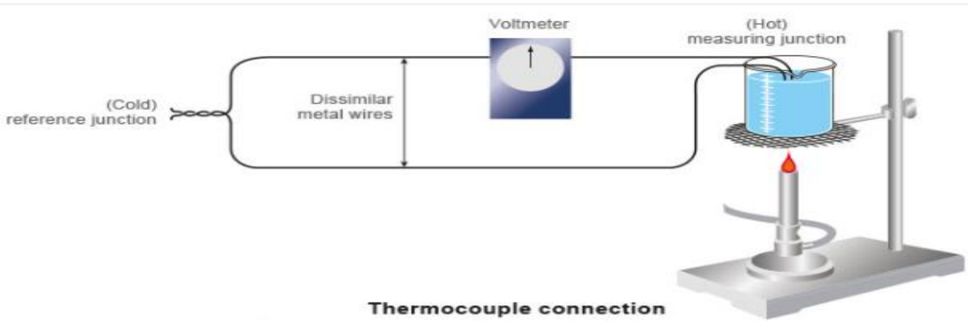


Figure 13-17 Thermocouple connection

The cold reference junction temperature must be accurately known if the thermocouple itself is to provide accurate sensing.

Traditionally, the cold junction was immersed in melting ice (0°C), but the temperature of the cold junction is now measured by a thermistor or an RTD and, from this, the indicated temperature, generally at the measuring junction, is corrected. This is known as cold junction compensation.

Any pair of dissimilar metals could be used to make a thermocouple. But over the years, a number of standard types have evolved which have a documented voltage and temperature relationship. The standard types are referred to by the use of letters, that is, Type J, K, T and others.

The most widely used general-purpose thermocouple is Type K.

The dissimilar metals used in this type are Chrome (90% nickel, 10% chromium) and Alumel (94% nickel, 3% manganese, 2% aluminum and 1% silicon) and can be used between the range 0°C to 1 260°C. Figure 6.7.10 illustrates the sensitivity of Type K thermocouples, and it can be seen that the output voltage is linear across the complete range.

Extension tail wires are used to connect the measuring junction to the reference junction in the instrument case. These extension tails may be of the same material as the wires in the thermocouple itself, or may be a compensating cable made of copper and copper-nickel alloy. Both extension tails must be of the same material.

Thermocouples are available in a wide variety of sizes and shapes. They are inexpensive and rugged and reasonably accurate, with wide temperature ranges. However, the reference junction temperature must be held at a constant value otherwise deviations must be compensated for. The low junction voltages mean that special screened cable and careful installation must be used to prevent electrical interference or 'noise' from distorting signals.

14 Adjusting a safe and constant water level in the boiler superior drum for different boiler loads or operation conditions

The maintenance of the correct water level on a steam boiler is essential to its safe and efficient operation the method of sensing the water level and subsequent control of water level is a complex

It has already been acknowledged that the water level in a steam boiler varies considerably as a result of:

- The load.
- The rate of load change.
- Water circulation within the boiler.

14.1 Water level control sensor

The method of sensing the water level

- Gauge glass
- Float level control
- Differential pressure cells
- Conductivity probes
- Capacitance probes

14.1.1 Gauge glass:

Simple gauge glass is used as the indicator on the steam/water drum or boiler shell

A gauge glass shows the current level of water in the boiler as figure 14-1 show, regardless of the boiler's operating conditions.

Gauge glasses should be installed so that their lowest reading will show the water level at 50 mm above the point where overheating will occur. They should also be fitted with a protector around them, but this should not hinder visibility of the water level

Gauge glasses are prone to damage from a number of sources, such as corrosion from the chemicals in boiler water, and erosion during blowdown, particularly at the steam end. Any sign of corrosion or erosion indicates that a new glass is required [6].

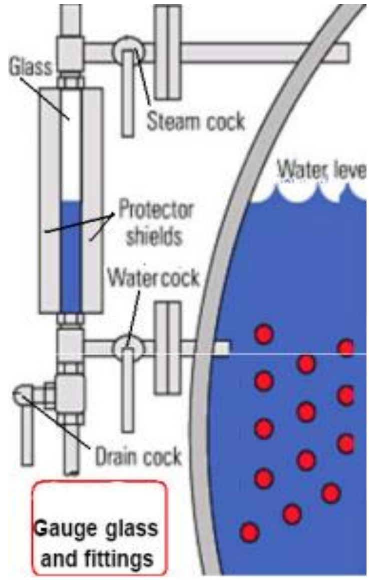


Figure 14-1 Gauge glass and fittings

14.1.2 Float level control

This is a simple form of level measurement. An everyday example of level control with a float is the cistern in a lavatory. When the lavatory is flushed, the water level drops in the cistern, the float follows the water level down and opens the inlet water valve. Eventually the cistern shuts and as fresh water runs in, the water level increases, the float rises and progressively closes the inlet water valve until the required level is reached.

The system used in steam boilers is very similar. A float is mounted in the boiler. This may be in an external chamber, or directly within the boiler shell. The figure 14-2 shows the float will move up and down as the water level changes in the boiler. The next stage is to monitor this movement and to use it to control either:

- A feed pump (an on/off level control system)

Or

- A feed water control valve (a modulating level control system)

Because of its buoyancy, the float follows the water level up and down.

At the opposite end of the float rod is a magnet, which moves inside a stainless-steel cap. Because the cap is stainless steel, it is (virtually) non-magnetic, and allows the lines of magnetism to pass through it.

In its simplest form, the magnetic force operates the magnetic switches as follows:

The bottom switch will switch the feedpump on.

The top switch will switch the feedpump off.

However, in practice a single switch will often provide on/off pump control, leaving the second switch for an alarm.

This same arrangement can be used to provide level alarms.

A more sophisticated system to provide modulating control will use a coil wrapped around a yoke inside the cap. As the magnet moves up and down, the inductance of the coil will alter, and this is used to provide an analogue signal to a controller and then to the feed water level control valve.

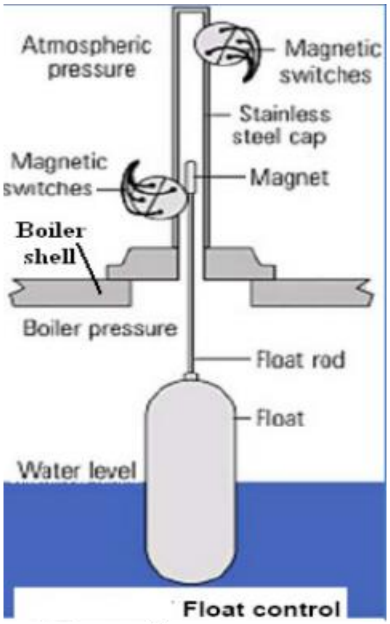


Figure 14-2 Float control

14.1.3 Differential pressure cells

The differential pressure cell is installed with a constant head of water on one side. The other side is arranged to have a head which varies with the boiler water level as figure 14-3.

Variable capacitance, strain gauge or inductive techniques are used to measure the deflection of a diaphragm, and from this measurement, an electronic level signal is produced.

Use of differential pressure cells is common in the following applications:

High-pressure water-tube boilers where high quality demineralized water is used.

Where very pure water is used, perhaps in a pharmaceutical process.

In these applications, the conductivity of the water is very low, and it can mean that conductivity and capacitance probes will not operate reliably [6].

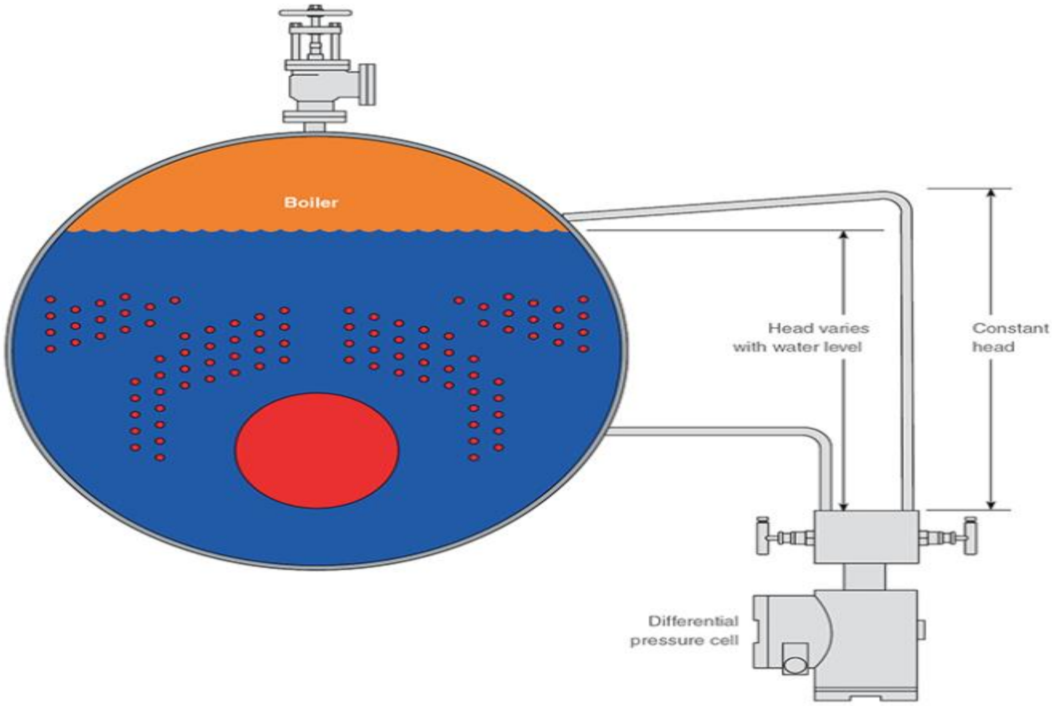


Figure 14-3 Level control using a differential pressure cell

14.1.4 Conductivity probes

Consider an open tank with some water in it. A probe (metal rod) is suspended in the tank (see Figure 14-4). If an electrical voltage is applied and the circuit includes an ammeter, the latter will show that: With the probe immersed in the water, current will flow through the circuit.

If the probe is lifted out of the water, current will not flow through the circuit.

The tip of a conductivity probe must be cut to the correct length so that it accurately represents the desired switching point

Note: An alternating current is used to avoid polarization and electrolysis (the splitting of water into hydrogen and oxygen) at the probe. A standard conductivity probe must be used to provide low water alarm in a boiler [6].

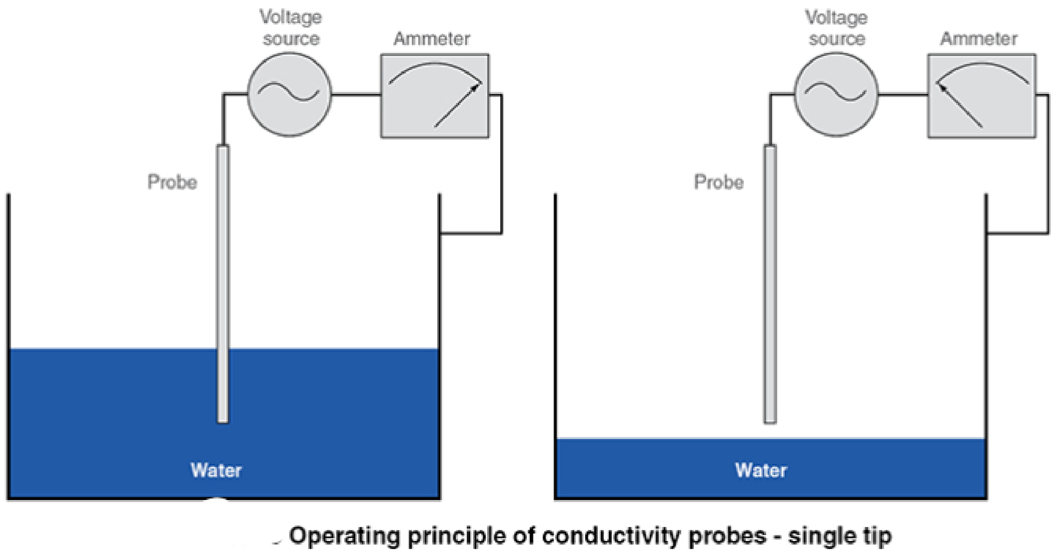


Figure 14-4 Operating principle of conductivity probes - single tip

This is the basis of the conductivity probe. The principle of conductivity is used to give a point measurement. When the water level touches the probe tip, it triggers an action through an associated controller.

This action may be to:

- Start or stop a pump.
- Open or close a valve.
- Sound an alarm.
- Open or close a relay.

But a single tip can only provide a single or point action. Thus, two tips are required with a conductivity probe in order to switch a pump on and off at predetermined levels, when the water level falls and exposes the tip at point A, the pump will begin to run. The water level rises until it touches the second tip at point B, and the pump will be switched off (see figure 14-5).

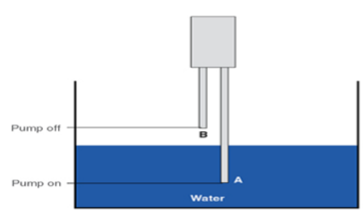


Figure 14-5 conductivity probe with high and low level

For a simple probe there is a potential problem - If dirt were to build up on the insulator, a conductive path would be created between the probe and the metal tank and current would continue to flow even if the tip of the probe were out of the water

The problem has been solved by:

- Using an insulator in the steam space.
- Using a long smooth PTFE sheath as an insulator virtually along the whole length of the metal probe.
- Adjustable sensitivity at the controller.

Actual conductivity probe as show on figure 14-6

Figure 14-6 Actual conductivity probe

14.1.5 Capacitance probes

A basic capacitor can be constructed by dipping two parallel conductive plates into a dielectric liquid. If the capacitance is measured as the plates are gradually immersed, it will be seen that the capacitance changes in proportion to the depth by which the plates are immersed into the dielectric liquid see figure 14-7.

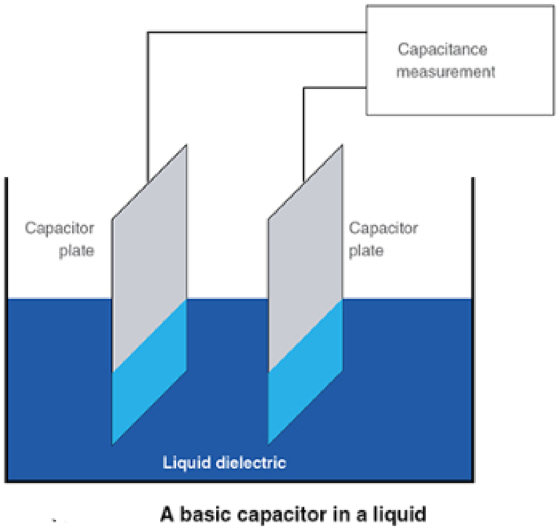


Figure 14-7 Basic capacitor in a liquid

Figure 14-8 show that the capacitance increases as more of the plate area is immersed in the liquid.

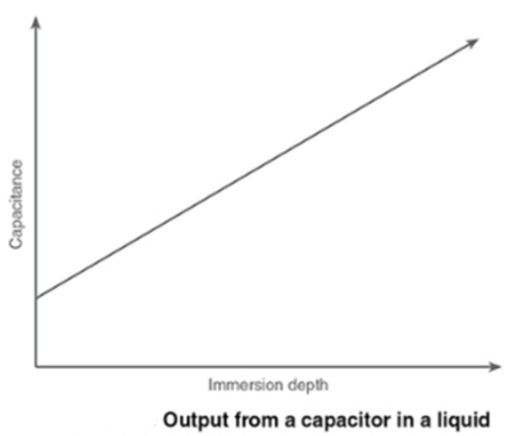


Figure 14-8 output from a capacitor in a liquid

The situation is somewhat different in the case of plates immersed in a conductive liquid, such as boiler water, as the liquid no longer acts as a dielectric, but rather an extension of the plates.

The capacitance level probe therefore consists of a conducting, cylindrical probe, which acts as the first capacitor plate. This probe is covered by a suitable dielectric material, typically PTFE.

The second capacitor plate is formed by the chamber wall (in the case of a boiler, the boiler shell) together with the water contained in the chamber. Therefore, by changing the water level, the area of the second capacitor plate changes, which affects the overall capacitance of the system.

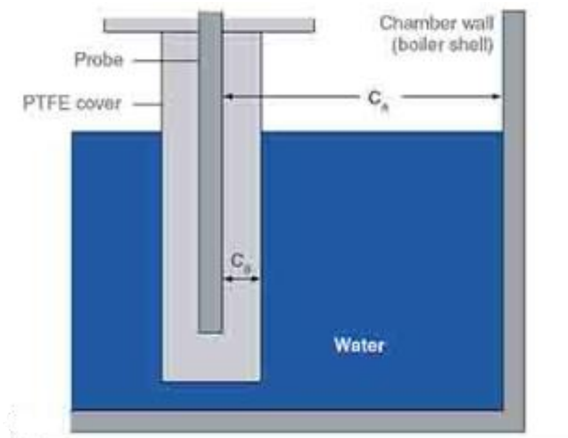


Figure 14-9 Capacitance probe

The total capacitance of the system therefore has two components (illustrated in Figure 14-9):

- CA, the capacitance above the liquid surface - The capacitance develops between the chamber wall and the probe. The dielectric consists of both the air between the probe and the chamber wall, and the PTFE cover.
- CB, the capacitance below the liquid surface - The capacitance develops between the water surface in contact with the probe and the only dielectric is the PTFE cover.

The net result is that any rise in the water level will cause an increase in capacitance that can be measured by an appropriate device

The change in capacitance is small (typically measured in Pico farads, for example, 10-12 farads) so the probe is used in conjunction with an amplifier circuit. The amplified change in capacitance is then signaled to a suitable controller.

Where the capacitance probe is used in

Liquid levels can be monitored continuously with a capacitance probe. The associated controller can be set up to modulate a control valve, and/or to provide point functions such as a high-level alarm point or a low-level alarm.

The controller can also be set up to provide on/off control. Here, the ‘on’ and ‘off’ switching points are contained within a single probe and are set via the controller, removing any need to cut the probe.

14.2 Methods of achieving actual water level:

It is required a calm area of water which is representative of the actual boiler water level.

With float and probe type level controls, this is achieved in two ways:

- **External chambers.**
- **Internal protection tubes**

14.2.1 External chambers:

Two external chambers are required

One chamber houses the level control plus the first low level alarm.

The other houses the second low level alarm plus the high-level alarm (if fitted).

This ensures that the two low alarms are in independent chambers.

The external chambers would be fitted with ‘sequencing purge valves’ and (optionally) with steam isolating valves

Traditionally float controls have been installed into external chambers, although probes work equally well, and have the advantage of no moving parts to wear out.

14.2.2 Internal protection tubes

Internal protection tubes (direct mounted level controls)

These are sometimes referred to as direct mounted level controls, and they require protection tubes to be installed inside the boiler shell as figure 14-10

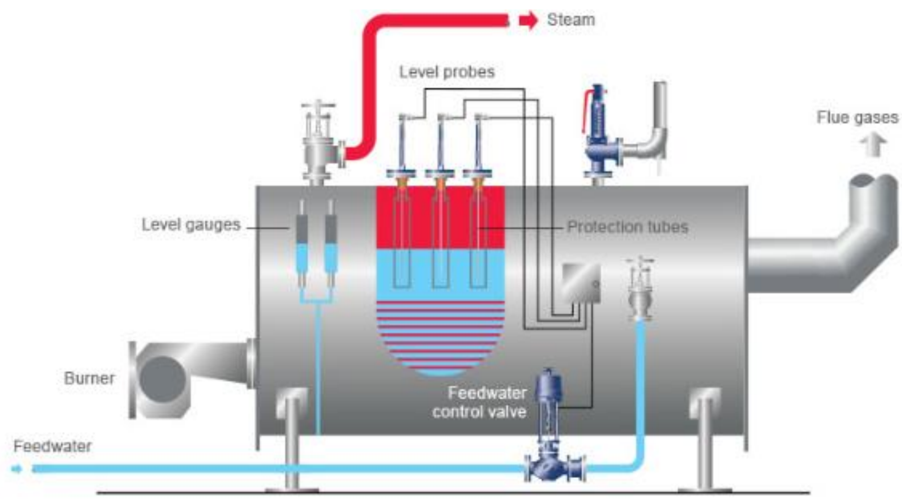


Figure 14-10 Level probe with internal protection tubes

Location

As far away as possible from the steam off-take and safety valve connection (minimum 1 m), but not too near the boiler end plates. As close to the level gauge as possible.

14.3 Methods of control:

1. **On/off control**
2. **Modulating control**

14.3.1 On/off control

All the methods of level detection described so far can be used to produce an on/off signal for level control. The most common method of level control is simply to start the feed pump at a low level and allow it to run until a higher water level is reached within the boiler.

- With a float level control, a magnetic switch with a built-in hysteresis or dead-band will be used.
- With conductivity probes, two probes are necessary, (pump on and pump off) which will give fixed switching levels.
- A capacitance probe can be used to give adjustable on/off switching levels.

This type of on/off control (as figure 14-11 shown) is not ideal for boiler control, because the relatively high flowrate of 'cold' feed water when the pump is on reduces the boiler pressure.

This causes the burner firing rate to continuously vary as the pump switches on and off.

Taking a typical example, it can be shown by calculation that even with feed water at 80°C, the burner firing rate may have to be 40% higher with the feed pump on, than with the feed pump off.

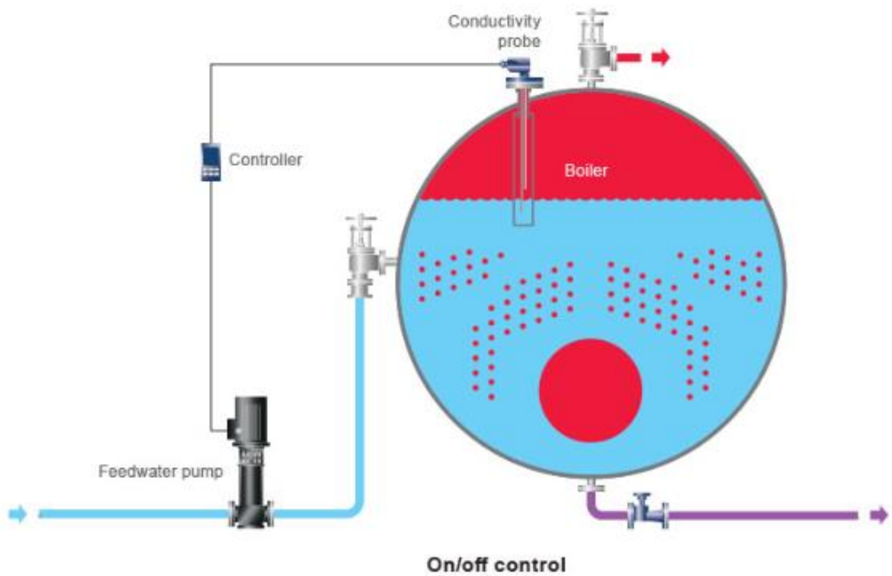


Figure 14-11 ON/OFF Control

This continuous variation causes:

- Wear on the burner controls.
- Temperature cycling of the boiler.
- Reduced efficiency.
- A 'saw-tooth' type steam flowrate as depicted by the chart recorder

Advantages:

- Simple.
- Inexpensive.
- Good for boilers on stand-by.

Disadvantages:

- Each boiler requires its own feed pump.
- More wear and tear on the feed pump and control gear.
- Variable steam pressure and flowrate.
- More boiler water carryover.
- Higher chance of daily operating problems under large load swings.

14.3.2 Modulating control

In this type of system, the feed pump runs continuously, and an automatic valve (between the feed pump and the boiler) controls the feed water flowrate to match the steam demand.

When operating correctly, modulating control can dramatically smooth the steam flowrate chart and ensure greater water level stability inside the boiler [6].

For modulating level control, the following methods can be used to sense the water level:

Floats with a continuous signal output.

Capacitance probes.

Differential pressure cells.

Recirculation is to protect the feed pump from overheating when pumping against a closed modulating valve, a recirculation or spill-back line is provided to ensure a minimum flowrate through the pump (see figure 14-12).

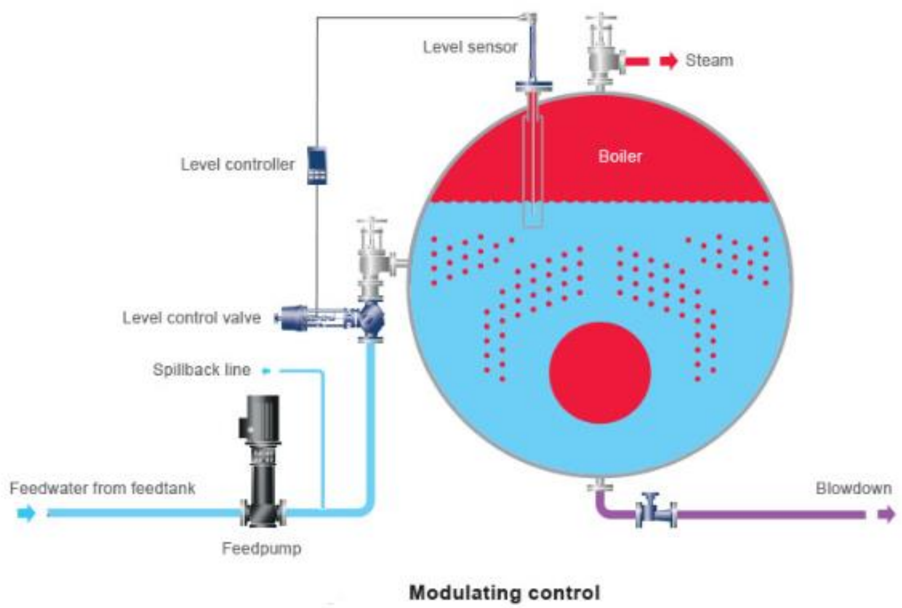


Figure 14-12 Modulating Control

This recirculation may be controlled by a valve or with an orifice plate. The amount of water to be recirculated is not great

Modulating level control by varying the speed of the boiler feed water pump

In this type of system, a modulating signal representing boiler water level (for example, from a capacitance probe) is directed to an electrical frequency controller. This controller in turn varies the frequency of the ac voltage to the boiler feed water pump motor, and hence varies its speed.

There are two ways that variable speed drive technology is generally applied:

With recirculation - When demand is satisfied and the motor speed is reduced to its minimum, and some recirculation of feed water to the feed tank is still required to avoid the pump overheating.

Without recirculation - In this case the motor controller stops the feed pump at very low boiler loads, so recirculation is not required.

But in without recirculation method the are two important factors

- The pump must not be started and stopped within a given period of time more than is recommended by the manufacturer.
- When starting, the frequency controller should be ramped up from low speed, to minimize wear on the pump.

Advantage of variable speed drives

- reduced power consumption means reduced running costs

However, the cost savings from using variable speed drives must be related to the higher cost of the control equipment. This is usually only viable for large boilers with wide variations in load or which operate in a lead/lag manner.

14.3.2.1 Single element water level control:

Boiler feed water pumps supply water to the boiler. The feed water flow rate is controlled by feed water control valves on the discharge side of the feed pumps. The water level in the drum is measured with a pressure and temperature-compensated level transmitter. The drum level controller compares the drum level measurement to the set point and modulates the position of the feed water control valves to keep the water level in the drum as close to set point as possible. Variable-speed boiler feed pumps are sometimes used to control the level instead of valves. The simple feedback control design described above is called single-element control, because it uses only a single feedback element for control – the drum level measurement (Figure 14-13) [6].

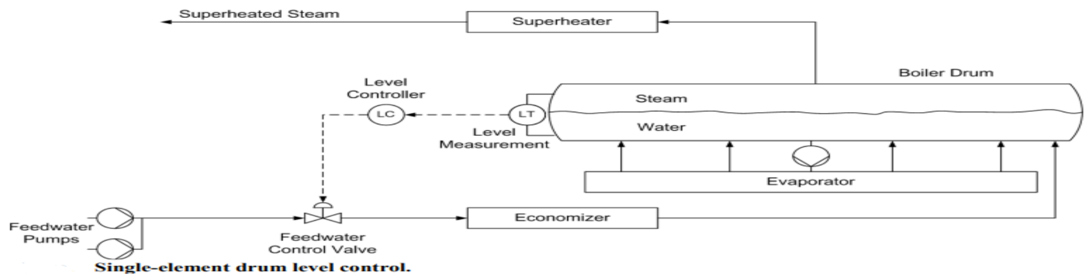


Figure 14-13 Single element water level control

However, where there are very sudden load changes, on some types of water-tube boiler, single element control has its limitations.

1. The boiler 'water' will actually contain a mixture of water and steam bubbles, which will be less dense than water alone.
2. If the demand for steam increases, the pressure in the boiler initially falls, and the control system will increase the burner firing rate. The rate of evaporation will increase to meet the increased demand
3. A decrease in the pressure in the steam header due to an increased demand for steam by the users would cause a certain quantity of water to flash into steam bubbles these steam bubbles will tend to increases the apparent level (create a 'swell')
4. The level controls will detect this apparent rise in water level, and start to close the feed water control valve, when in fact more water is required. The situation now, is that there is a high steam demand, and no water is being added to the boiler to maintain the level.
5. A point is reached where the 'swell' in the water will collapse, possibly to a level below the low-level alarms, and the boiler can suddenly 'lockout', bringing the plant off-line.

14.3.2.2 Two element water level control:

The drum level controller becomes the primary controller and its output drives the set point of the feed water flow controller, the secondary control loop. This arrangement is also called two-element control, because both drum level and feed water flow rate are measured and used for control

First element - Level signal from the water within the boiler.

Second element - Flow signal from feed water flowmeter from pump discharge (as figure 14-14).

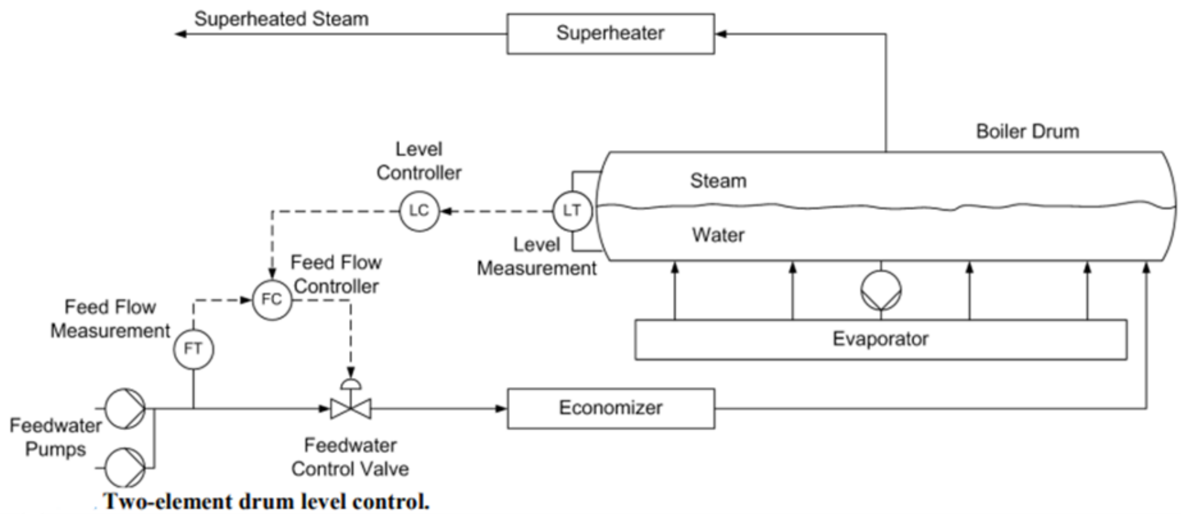


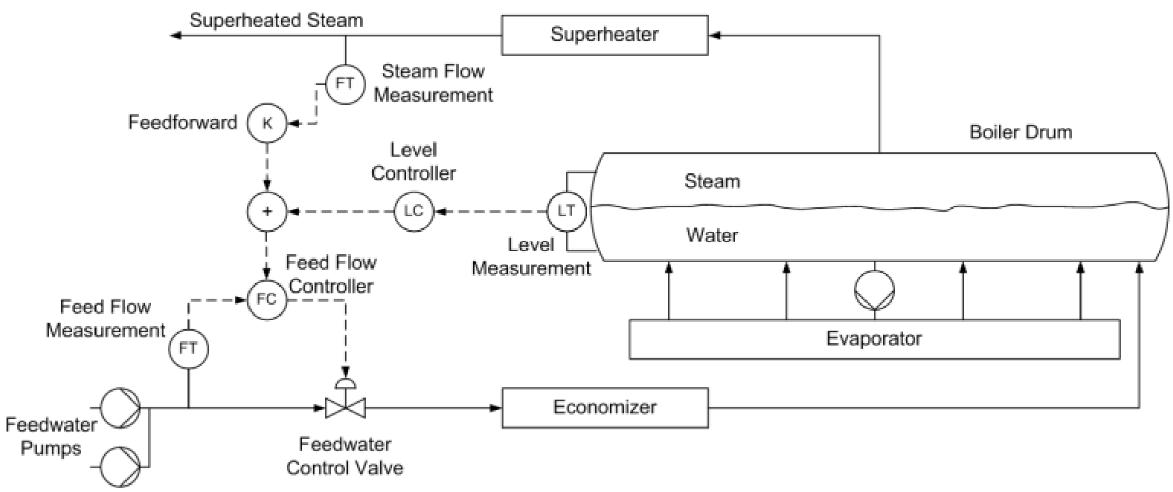
Figure 14-14 Two-element drum level control.

This strives to ensure that the quantity of water in the boiler stays constant at all loads, and that during periods of increased, sudden steam demand, the feed water control valve opens.

Level transmitter send signal to level controller (master controller) to compare with set point and send signal to flow controller (slave controller) to compare this signal with flow transmitter signal

14.3.2.3 Three element water level control

THREE-ELEMENT CONTROL (CASCADE + FEEDFORWARD CONTROL) Similar to feed flow, changes in steam flow can also cause large deviations in drum level, and could possibly trip the boiler. Steam flow rate is measurable and can be used to improve drum level control very successfully by using a feedforward control strategy. The combination of drum level measurement, steam flow measurement, and feed flow measurement to control boiler drum level is called three-element control. For the three-element control strategy, steam flow rate is measured and used as the set point of the feed water flow controller. In this way the feed water flow rate is adjusted to match the steam flow. Changes in steam flow rate will almost immediately be counteracted by similar changes in feed water flow rate. To ensure that deviations in drum level are also used for control, the output of the drum level controller is added to the feedforward from steam flow (Figure 14-15) [6].



Three-element drum level control.

Figure 14-15 Three-element drum level control.

Although three-element drum level control is superior to single- or two-element control, it is normally not used at low boiler loads. At low steam flow rates (for example during boiler start-up) steam and feed water flow measurements are not accurate enough for three-element control, so then only the drum level measurement is used for control (single-element control.) Switching between single- and three element control can be automatic or operator initiated, depending on the design of the control logic

Three element control is more often seen in boiler houses where a number of boilers are supplied with feed water from a common as figure 14-16, pressurized ring main.

Under these circumstances the pressure in the feed water ring main can vary depending on how much water is being drawn off by each of the boilers.

Because the pressure in the ring main varies, the amount of water which the feed water control valve will pass will also vary for any particular valve opening. The input from the third element modifies the signal to the feed water control valve, to take this variation in pressure into consideration.

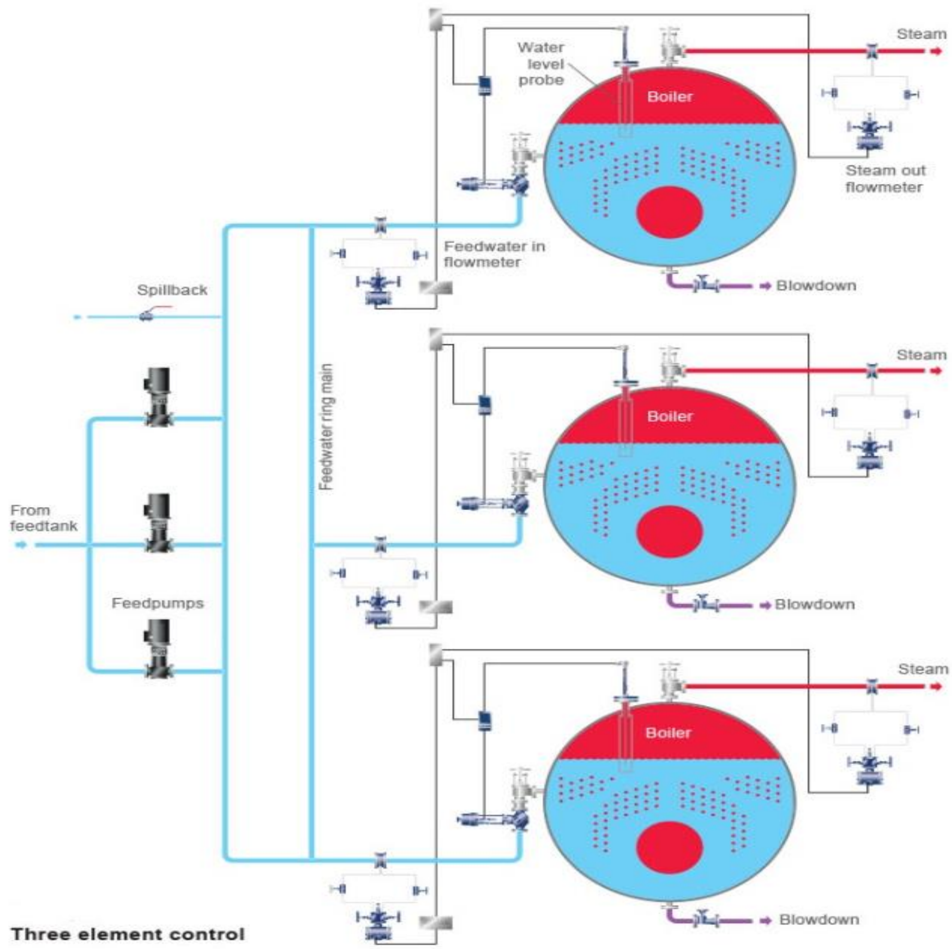


Figure 14-16 Three element control

15 Control of feed water supply:

15.1 Control on flow rate of feed water supply:

The feed water control loop should be tuned for a fast response so that it rapidly rejects disturbances in feed flow and meets the demand of the drum level controller. The change in feedwater flow rate obtained from a given change in controller output depends on the number of feedwater valves in service. To get a consistent feedwater control loop response regardless of the number of feedwater control valves in service, it is necessary to implement gain scheduling. This will change the gain of the feed water controller based on the number of feed water control valves that are in automatic control, see figure 15-1 [2].

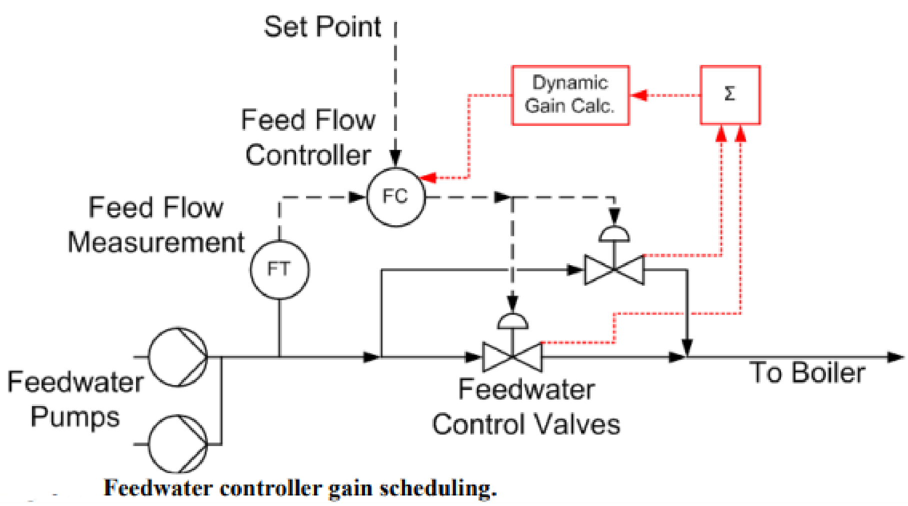


Figure 15-1 Feed water controller gain scheduling.

15.2 Control on temperature of feed water supply:

We can control the temperature of feed water enter to economizer by feed water heater

Let’s take a closer look at how this works. Feed water heaters use the heat of condensation of preheat water to the correct temperature for the boiler during this process shell and tube heat exchangers allow feed water to pass through the tube side and extract steam from the turbine to the shell side the primary benefit of this process is that the feed water heater decreases the fuel costs by using recovered energy rather than costly hot gas to heat the water

15.2.1 Feedback control:

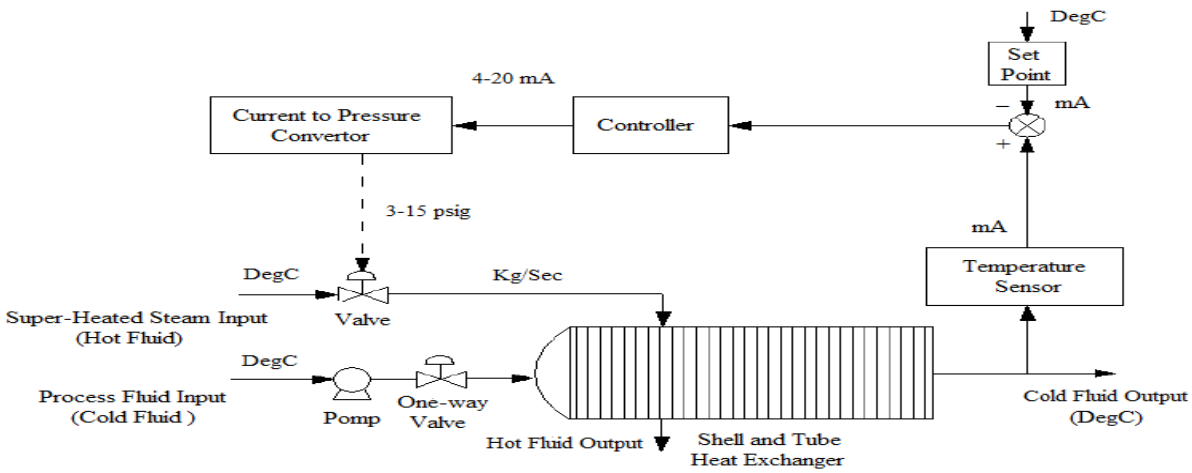


Figure 15-2 Feedback Control

As shown on figure 15-2 there is temperature sensor measure the temperature of feed water supply to economizer and send signal to controller, which compare it with the set point to control the extracted steam valve

15.2.2 Cascade control

There is temperature sensor to measure the temperature of feed water and flow transmitter to measure the amount of extracted steam to control the valve and as illustrate on Figure 15-3, there is two controllers’ temperature controller (master controller) to compare the feed water temperature with set point and send signal

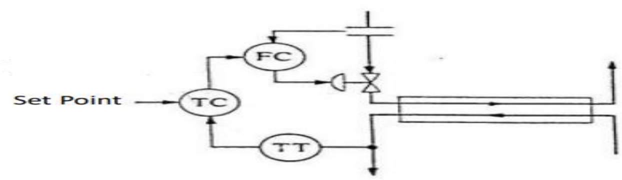


Figure 15-3 Cascade Control

16 De-aerator tank

16.1 De-aerator function

The main function of de-aerator tank is to control the number of dissolved gasses in the feed water.

Why gases need to be removed from boiler feedwater?

The two gases that we are most interested in are oxygen and carbon dioxide (co2) these gases are dissolved into the water.

The problem with having oxygen in the boiler feed water is that it can lead to corrosion, and if carbon dioxide is also present then the pH will be low, the water will tend to be acidic and this is not desired because it may lead to corrosion.

Typically, the corrosion is of the pitting type where, although the metal loss may not be great, deep penetration and perforation can occur in a short period.

The essential requirements to reduce corrosion are to maintain the feedwater at a pH of not less than 8.5 to 9, the lowest level at which carbon dioxide is absent, and to remove all traces of oxygen. The return of condensate from the plant will have a significant impact on boiler feedwater treatment - condensate is hot and already chemically treated, consequently as more condensate is returned, less feedwater treatment is required.

There are two ways to remove dissolved gases:

- Deaerators (mechanically remove dissolved gases on figure 16-1)

A typical deaerator will be designed to mechanically remove oxygen down to a level of about seven parts per billion (7ppb).

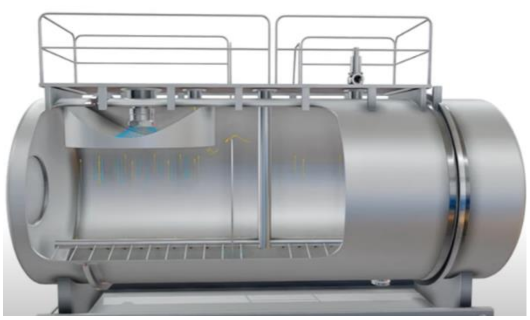


Figure 16-1 Deaerator

- Chemicals (chemically remove dissolved gases)

The addition of an oxygen-scavenging chemical (sodium sulphite, hydrazine or tannin) will remove the remaining oxygen and prevent corrosion.

For plants that need to reduce the amount of chemical treatment, it is common practice to use a pressurized deaerator.

If a liquid is at its saturation temperature, the solubility of a gas in it is zero, although the liquid must be strongly agitated or boiled to ensure it is completely deaerated

16.2 Deaerator systems

This is achieved in the head section of a deaerator by breaking the water into as many small drops as possible, and surrounding these drops with an atmosphere of steam. This gives a high surface area to mass ratio and allows rapid heat transfer from the steam to the water, which quickly attains steam saturation temperature. This releases the dissolved gases, which are then carried with the excess steam to be vented to atmosphere. (This mixture of gases and steam is at a lower than saturation temperature and the vent will operate thermostatically). The deaerated water then falls to the storage section of the vessel. See (figure 16-2)

A blanket of steam is maintained above the stored water to ensure that gases are not re-absorbed.

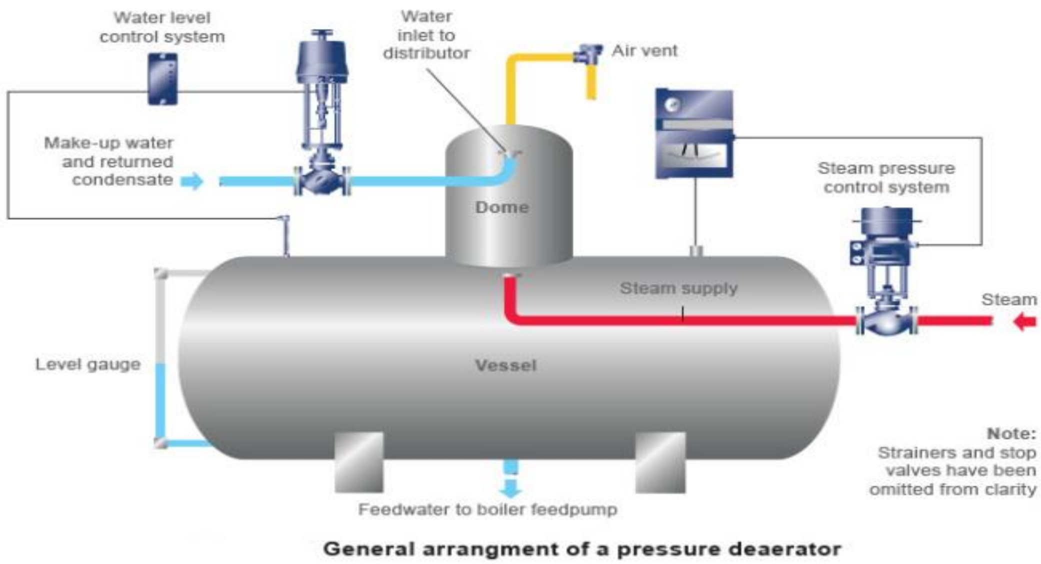


Figure 16-2 General arrangement of pressure deaerator

16.2.1 Atmospheric deaerator systems

Feed tanks fitted with a deaerator head, steam injection system and the necessary controls can be thought of as atmospheric deaerators. The deaerator head mixes high oxygen content cold make-up water with flash steam from the condensate and the blowdown heat recovery system. Oxygen and other gases are released from the cold water and can be automatically removed through a vent before the water enters the main feed tank [6].

16.2.2 Pressurized deaerator systems:

In certain boiler plants, pressurized deaerators are sometimes installed and live steam is used to bring the feedwater up to approximately 105°C to drive off the oxygen. A pressurized deaerator comprises a pressurized tank fitted with a deaerating head and various control systems. Pressurized deaerators are thermally efficient and will reduce dissolved oxygen to very low levels minimizing the need for oxygen scavenging treatment chemicals, although they do require regular insurance inspections. They can also serve as a surge collection tank for process condensate return and typically hold about 15 mins worth of treated hot water in reserve storage to meet process load changes. Normally a pressurized deaerator needs to be operated in conjunction with a feedtank that provides additional storage capacity. The head section of a deaerator breaks the water into as many small drops as possible and surrounds these with steam. The result is a large surface area of water exposed to steam to allow rapid heat transfer from the steam to the water, which quickly attains steam saturation temperature. This releases the dissolved gases, which are then carried with the excess steam to be vented to atmosphere. The deaerated water then falls to the storage section of the vessel.

16.3 Water distribution

The incoming water must be broken down into small drops to maximize the water surface area to mass ratio. This is essential to raising the water temperature, and releasing the gases during the very short residence period in the deaerator dome

Two ways to break water into droplets

There are two common methods of separating water into small drops inside the deaerator head:

• Tray type deaeration: the water flows over a cascade of perforated trays (see figure 16-3)

• Spray type deaeration: the water is forced through a spring-loaded nozzle to create a spray (see figure 16-4)

Tray type deaeration offers a very long service life of typically 40 years and achieves a very high turndown that is suited to power plant applications. Spray type deaeration is lower cost with a lifespan of around 20 years and a turndown of around 5:1, making it the more common choice for process industries

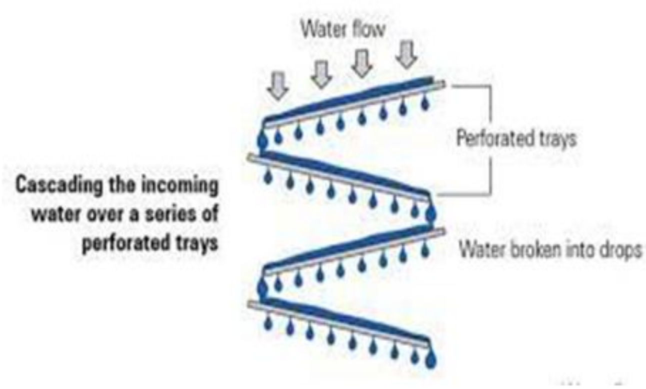


Figure 166-3

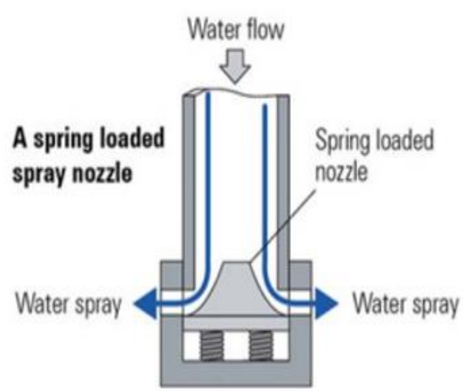


Figure 166-4

16.4 Control systems

It will be evident that two control functions are required by the deaerator: one to maintain the steam pressure at the optimum value, the other to keep the storage vessel roughly half-full of water.

It has already been explained that the steam supply may be obtained either from the boiler or from an extraction point on the turbine

16.4.1 Water control

A modulating control valve is used to maintain the water level in the storage section of the vessel. Modulating control is required to give stable operating conditions, as the sudden inrush of relatively cool water with an on/off control water control system could have a profound impact on the pressure control, also the ability of the deaerator to respond quickly to changes in demand.

This is achieved by means of a level controller whose measured value signal is obtained from a DP transmitter or from capacitive probes

The amount of water would be constant and the level in the deaerator storage vessel would remain at the correct value set during commissioning. However, losses are inevitable (e.g., due to leakages at pump glands or during soot blowing or blowdown operations), and a supply of treated water must therefore be made available. The deaerator level controller output adjusts the opening of a valve that admits this make-up water to the condenser, as shown in Figure 16-5

16.4.2 Steam control

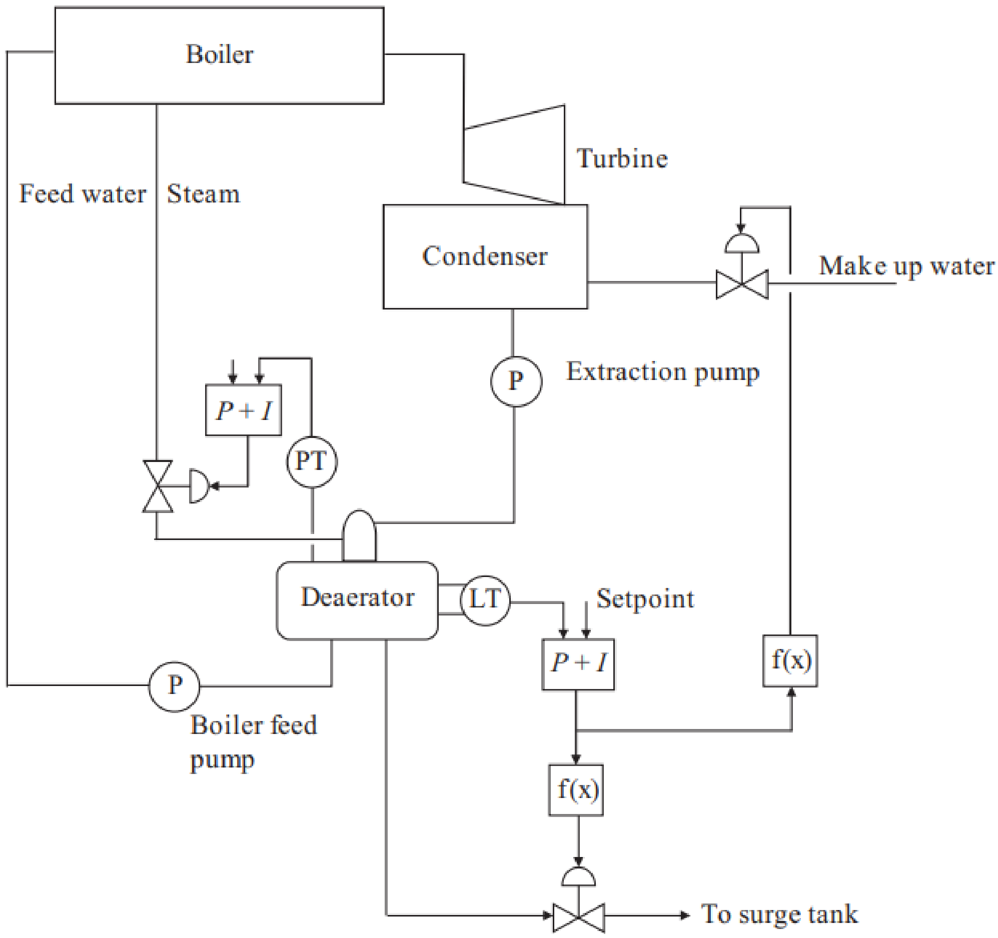
A modulating control valve regulates the steam supply. This valve is modulated via a pressure controller to maintain a pressure within the vessel. Accurate pressure control is very important since it is the basis for the temperature control in the deaerator, therefore a fast acting, pneumatically actuated control valve will be used. Note: A pilot operated pressure control valve may be used on smaller applications, and a self-acting diaphragm actuated control valve may be used when the load is guaranteed to be fairly constant.

The steam injection may occur at the base of the head, and flow in the opposite direction to the water (counter flow), or from the sides, crossing the water flow (cross flow). Whichever direction the steam comes from, the objective is to provide maximum agitation and contact between the steam and water flows to raise the water to the required temperature.

The steam is injected via a diffuser to provide good distribution of steam within the deaerator dome.

The incoming steam also provides:

- A means of transporting the gases to the air vent.
- A blanket of steam required above the stored deaerated water.



Principle of deaerator-level control system

Figure 166-5 Principle of deaerator-level control system

17 Control the blow-down process of the boiler both manually and automatically

Why need to do blow-down process?

Blowing down the boiler to maintain these TDS levels should help to ensure that reasonably clean and dry steam is delivered to the plant.

As a boiler generates steam, any impurities which are in the boiler feedwater and which do not boil off with the steam will concentrate in the boiler water.

As the dissolved solids become more and more concentrated, the steam bubbles tend to become more stable, failing to burst as they reach the water surface of the boiler. There comes a point (depending on boiler pressure, size, and steam load) where a substantial part of the steam space in the boiler becomes filled with bubbles and foam is carried over into the steam main

This is obviously undesirable not only because the steam is excessively wet as it leaves the boiler, but it contains boiler water with a high level of dissolved and perhaps suspended solids. These solids will contaminate control valves, heat exchangers and steam traps.

Whilst foaming can be caused by high levels of suspended solids, high alkalinity or contamination by oils and fats, the most common cause of carryover (provided these other factors are properly controlled) is a high Total Dissolved Solids (TDS) level. Careful control of boiler water TDS level together with attention to these other factors should ensure that the risks of foaming and carryover are minimized.

The boiler water TDS may be measured either by:

- Taking a sample, and determining the TDS external to the boiler, or by
- A sensor inside the boiler providing a signal to an external monitor

Sampling for external analysis:

When taking a sample of boiler water, it is important to ensure that it is representative. It is not recommended that the sample be taken from level gauge glasses or external control chambers; the water here is relatively pure condensate formed by the continual condensation of steam in the external glass/chamber. Similarly, samples from close to the boiler feedwater inlet connection are likely to give a false reading.

Nowadays, most boilermakers install a connection for TDS blowdown, and it is generally possible to obtain a representative sample from this location.

If water is simply drawn from the boiler, a proportion will violently flash to steam as its pressure is reduced. Not only is this potentially very dangerous to the operator, but any subsequent analysis will also be quite wrong, due to the loss of the flash steam concentrating the sample.

Since a cool sample is required for analysis, a sample cooler will also save considerable time and encourage more frequent testing.

A sample cooler is a small heat exchanger that uses cold mains water to cool the blowdown water sample (figure 17-1)

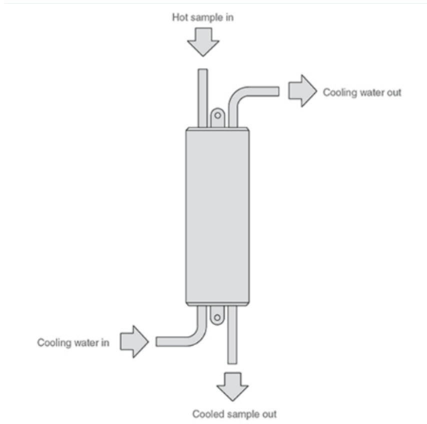


Figure 17-1 sample cooler

There are two methods for external analysis

- Relative density method
- Conductivity method

Conductivity measurement in the boiler

It is necessary to measure the conductivity of the boiler water inside the boiler or in the blowdown line. Obviously, the conditions are very different from those of the sample obtained via the sample cooler which will be cooled and subsequently neutralized (pH = 7). The main aspects are the great temperature difference and high pH.

This means that the effects of the temperature have to be allowed for in the blowdown controller, either by automatic temperature compensation, or by assuming that the boiler pressure (and hence temperature) is constant. The small variations in boiler pressure during load variations have only a relatively small effect, but if accurate TDS readings are required on boilers which are operated at widely varying pressures, then automatic temperature compensation is essential.

Controlling the blowdown rate

After measure TDS there are two ways to do blowdown

- manual operation
- automatically operation

17.1 Manual operation:

17.1.1 Orifice plate:

First, for manual operation the simplest device can be used is an orifice plate (figure 17-2)

The orifice size can be determined based on Flowrate and Pressure drop

There is a problem: an orifice is not adjustable and therefore can only be correct for one specific set of circumstances. If the steaming rate were to:

Increase - The orifice would not pass sufficient water. The boiler TDS level would increase, and priming and carryover would occur.

Reduce - The orifice would pass too much water. The blowdown rate would be too great and energy would be wasted.

Flashing-The water being drained from the boiler is at saturation temperature, and there is a drop in pressure over the orifice almost equal to the whole boiler pressure. This means that a substantial proportion of the water will flash to steam, increasing its volume by a factor of over 1 000.

It should also be remembered that the water drained from the boiler is dirty and it does not take a great deal of dirt to restrict or even block a small hole.

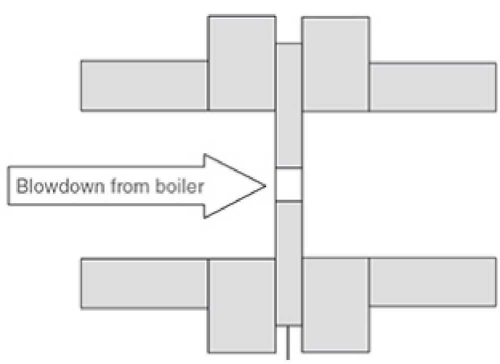


Figure 17-2 orifice

17.1.2 Needle valve:

If an increase in flowrate is required, the needle is adjusted out of the seat and the clearance between the needle and seat is increased**.** (See figure 17-3)

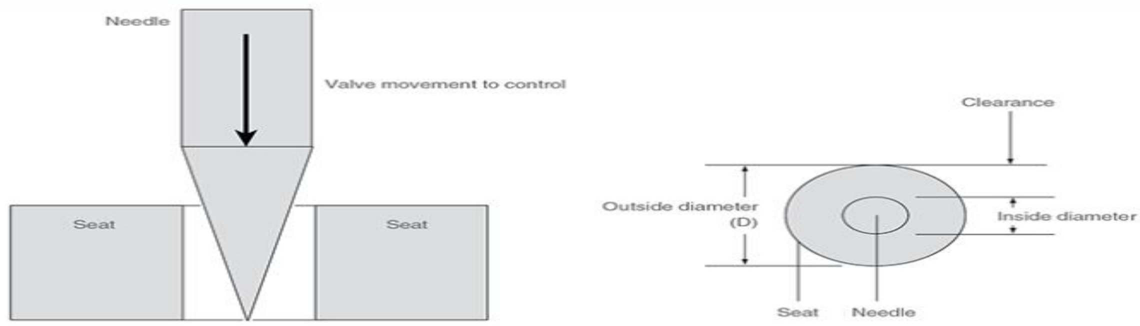


Figure 17-3 needle valve

The clearance is so small that blockage by small particles is difficult to avoid.

In addition, the problem of flashing over the valve seat still has to be addressed. The low clearances mean that a high velocity steam/water mixture is flowing close to the surfaces of the needle and the seat. Erosion (wiredrawing) is inevitable, resulting in damage and subsequent failure to shut off.

Continuous blowdown valves have been developed over many years from simple needle valves, and now incorporate a number of stages, possibly taking the form of three or four progressively larger seats in the valve, and even including helical passageways (figure 17-4). The objective is to dissipate the energy gradually in stages rather than all at once.

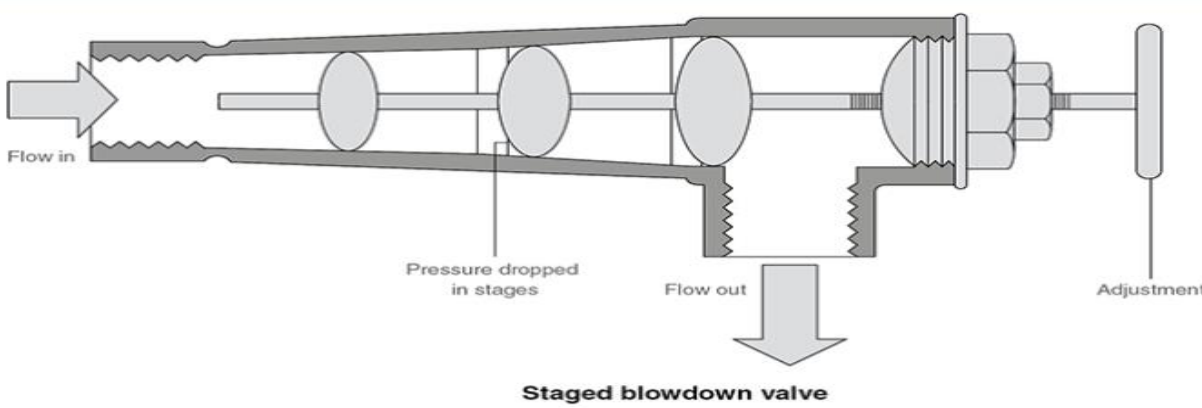


Figure 17-4 staged blowdown valve

This type of valve was originally designed for manual operation, and was fitted with a scale and pointer attached to the handle. In an operational environment, a boiler water sample was taken, the TDS determined, and an appropriate adjustment made to the valve position

17.2 Automatically operation

17.2.1 On/off boiler blowdown valves

There is an advantage to using a larger control device with larger clearances, but only opening it for some of the time. Clearly, moderation is required if the boiler TDS is to be kept between reasonable values, and DN15 and 20 valves are the most common sizes to be found (figure 17-5).

A typical arrangement would be to set the controller to open the valve at, for example, 3 000 ppm, then to close the valve at 3 000 – 10% = 2 700 ppm. This would give a good balance between a reasonable sized valve and accurate control.

The type of valve selected is also important:

For small boilers with a low blowdown rate and pressures of less than 10 bar g, an appropriately rated solenoid valve will provide a cost-effective solution.

For larger boilers with higher blowdown rates, and certainly on boilers with operating pressures over 10 bar g, a more sophisticated valve is required to take flashing away from the valve seat in order to protect it from damage.

Valves of this type may also have an adjustable stroke to allow the user the flexibility to select a blowdown rate appropriate to the boiler, and any heat recovery equipment being used.

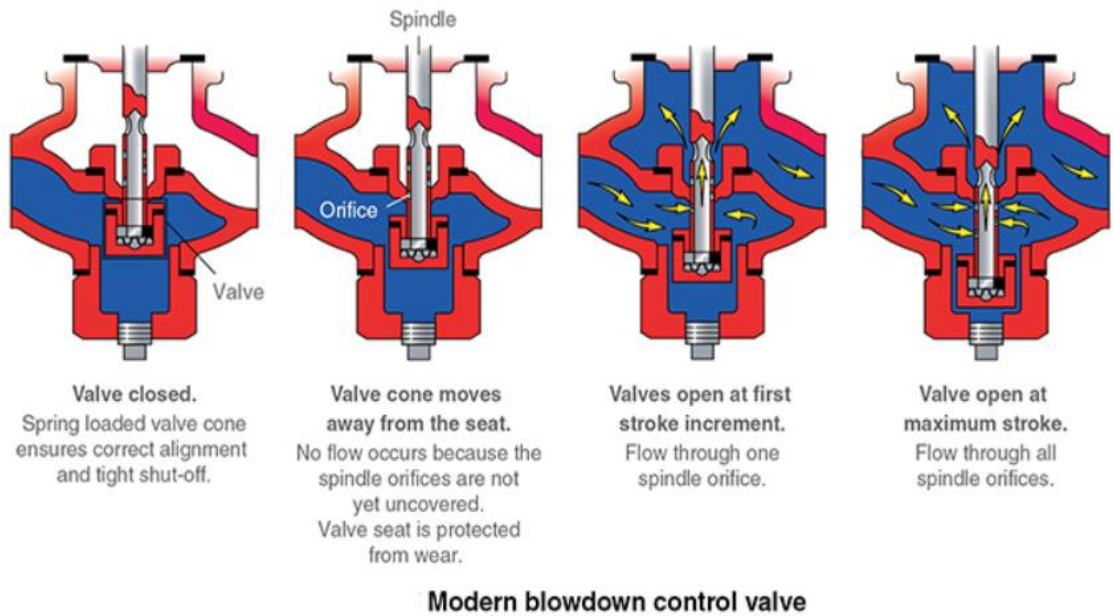


Figure 17-5 Modern blowdown control valve

17.2.2 Closed loop electronic control systems

These systems measure the boiler water conductivity, compare it with a set point, and open a blowdown control valve if the TDS level is too high.

A number of different types are on the market which will measure the conductivity either inside the boiler, or in an external sampling chamber which is purged at regular intervals to obtain a representative sample of boiler water. The actual selection will be dependent upon such factors as boiler type, boiler pressure, and the quantity of water to be blown down [6].

These systems are designed to measure the boiler water conductivity using a conductivity probe

The measured value is compared to a set point programmed into the controller by the user. If the measured value is greater than the set point, the blowdown control valve is opened until the set point is achieved see figure 17-6. Typically, the user can also adjust the 'dead-band'.

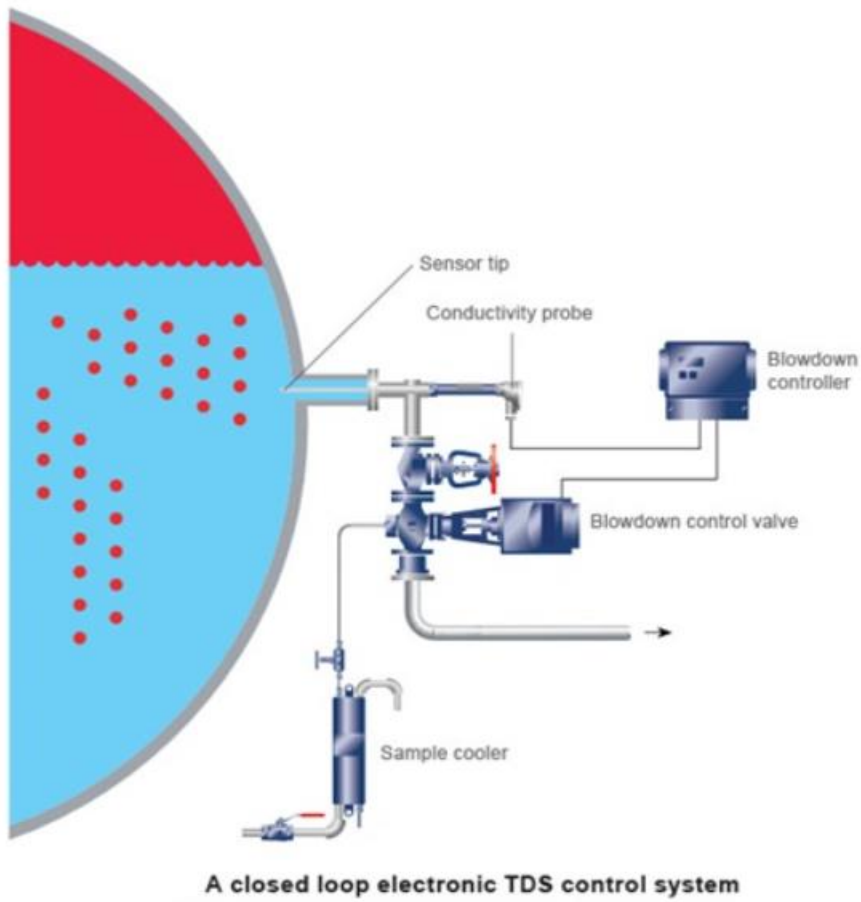


Figure 17-6 Closed loop electronic TDS control system

As mentioned earlier, an increase in water temperature results in an increase in electrical conductivity. Clearly if a boiler is operating over a wide temperature/pressure range, such as when boilers are on night set-back, or even a boiler with a wide burner control band, then compensation is required, since conductivity is the controlling factor.

The benefits of automatic TDS control

- The labour-saving advantages of automation.
- Closer control of boiler TDS levels.
- Potential savings from a blowdown heat recovery system (where installed).

18 Conclusion:

It is very complex to control the boiler and all systems must work together to achieve safety, stability, accuracy and efficiency. In large capacity boiler there are more controllers to achieve a proper operation

19 References:

1. **Dukelow S.G., The Control of Boilers – 2nd Edition, ISA, 1991**
2. **Jerry (Gilman) G, Boiler Control Systems Engineering**
3. **Thermal Power Plant Control and Instrumentation The control of boilers and HRSGs 2nd**
4. **Leopold, T., Boiler-Tuning Basics Part II, Power, May 2009**
5. **Leopold, T., Boiler-Tuning Basics Part I, Power, March 2009**
6. **https://www.spiraxsarco.com**
7. **http://acc-vlab.cu.edu.eg**
8. **https://automationforum.co**
9. **https://www.ccsdualsnap.com/temperature-and-pressure-switches-in-steam-boiler-applications/**
10. **https://boilersinfo.com/water-tube-boiler-parts-functions/**