

Cairo University, Faculty of Engineering.
4th Year, Mechanical Power Department.

Automatic Control

Virtual Lab.

Graduating Project



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Working Group

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Introduction

Abstract

The Mechanical Engineering Technology (MET) program of Technology promotes itself as a hands-on, minds-on program that incorporates lab activities into most of its classes. The MET program has outstanding resources, but the similar programs that belong to the statewide system and mission do not have access to such outstanding resources. A good example is the sophomore-level class in fluid power.

During these sessions, students are divided into groups of three or four and asked to conduct a lab exploring a variety of fluid power topics. While one group is working, the instructor has historically struggled to find a meaningful task for the rest of the class. Also, the dynamics of the group performing the lab is not always ideal, with one member doing most of the work while others watch.

Examples of what used in Virtual lab :

Specifically, the MET program has two refrigeration/heat pump trainers, a heat exchanger trainer, a hydrostatics bench, a process control trainer, PLC trainers with peripheral benches, structural trainers, hardness testers, a tensile testing machine, heat treating and tempering ovens, an aluminum foundry for sand casting, machining and welding equipment, and a new mechatronics apparatus. While the introduction of virtual lab software has provided many benefits at a reduced cost, physical lab facilities still dominate the MET program.

Why Virtual lab is useful ?

The real question to be answered by the faculty of the MET program is not whether the virtual lab software is better or worse than working with real equipment but whether using the software improves student learning and satisfies MET program outcomes. In the absence of real hardware, does the virtual lab increase student learning, satisfy program outcomes, and meet core learning objectives of each of the classes?

Developed a refrigeration simulation program that “mimicked the physical operation of the equipment with realistic data outputs” . Found several advantages in using the simulation of the real equipment.

Typically, students finished the activity in less time than using the real equipment. were that a process that normally takes hours or days can be simulated in minutes; any number of students can be trained at any time.

Eliminating the potential danger involved when dealing with high pressure equipment, the simulation activity was safer and further eliminated the need for supervision of the students while using the real equipment.

Basically, the students did not need to be supervised to complete the activity, making it more convenient and adaptable to distance education. conclusion is that a virtual lab “provides advantages in terms of pedagogical approach, cost, and access.”

Additionally, in the current economic environment where technology changes rapidly, virtual lab software saves money by not having to invest in expensive equipment that may be outdated in only a few years.

The central question explored was if computer simulation is as effective as physical lab activities in teaching college-level electronics. Students were tested on knowledge retention, as well as their attitudes about the virtual activity. Post-activity test scores and lab completion time differences were quantified for students who were randomly assigned to either the simulation group or the physical testing group. Concept tests were given during the fifth and eighth weeks of the semester and were graded by the course instructor and a second instructor who was not familiar with the study.

The results of the study were that the simulation group performed higher on the post-activity concept tests after both the fifth and eighth weeks and that the simulation group used significantly less time to complete the labs. Surveys of the students revealed that the simulation group had a more positive attitude about the lab activity; they also found the activity less abstract, more interesting, and less time consuming. The overall conclusion of the study was that simulation programs for lab might prove more effective at higher levels of cognitive learning, and regardless of whether the students are using hardware or software, they will learn the lesson.

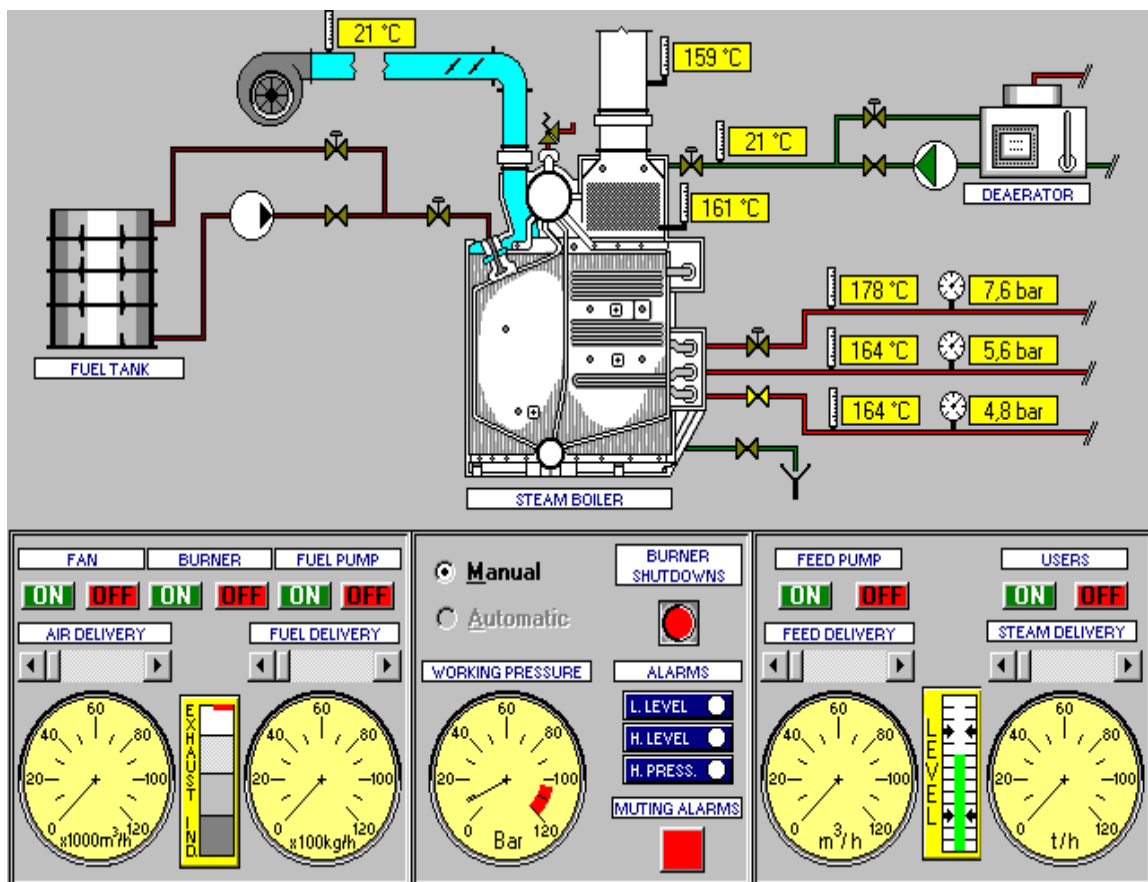
This study provided confidence that incorporating virtual lab activities into several classes in the MET program would improve learning and assist in meeting program outcomes.

Part #1

THW-1 Water tube boiler



*THW-1 Simulation of
a water-tube boiler heating unit
with thermal balance calculating
User manual*



Requirements

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.

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.

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...).

Program Management

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.

2. Start

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

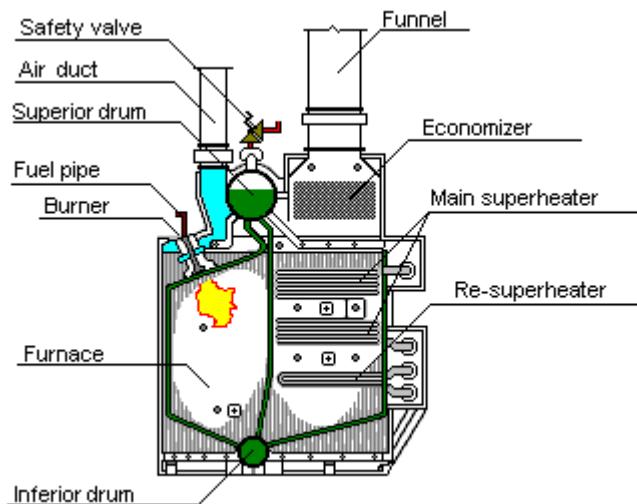


and the title click on the icon and then on the key **OK** of the logo to start the program.

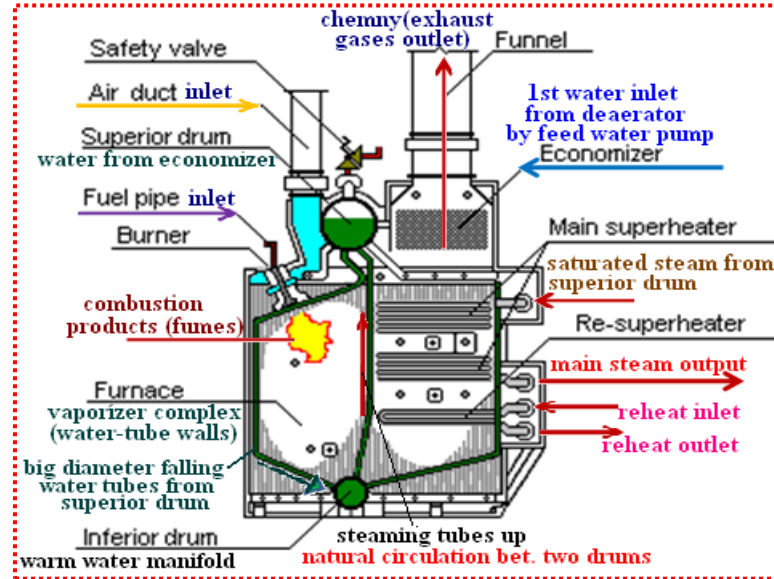
3. Program Overview

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.

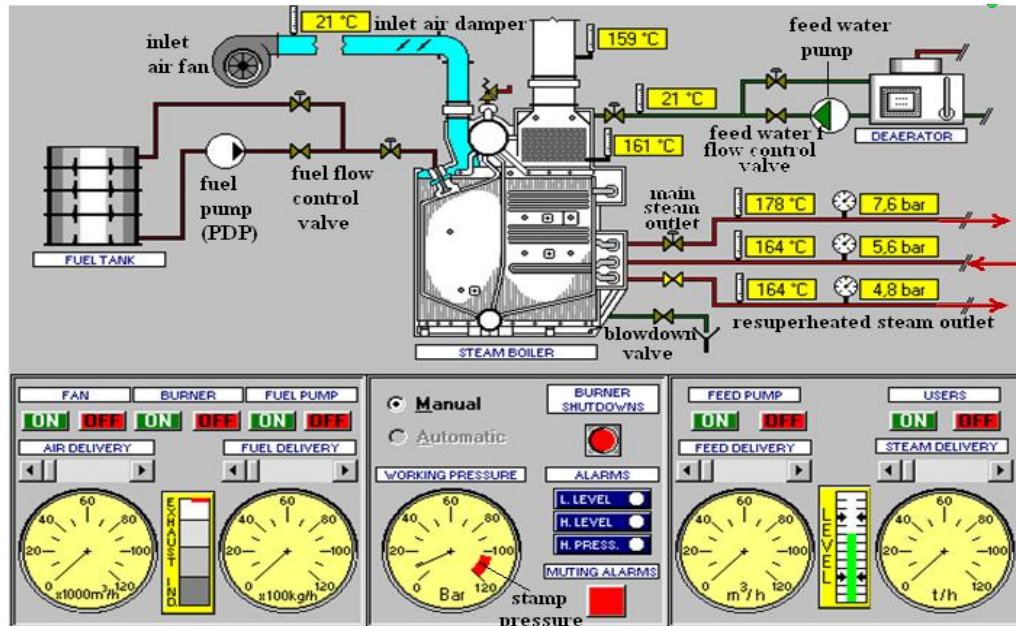


Water-tube boilers are those boilers where the water, or the steam water mixture is contained into tubes externally lapped by the combustion products (fumes) that from the combustion chamber move towards the funnel.



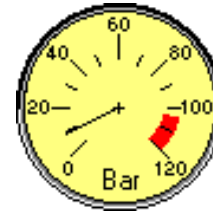
Each water-tube boiler can be considered as a vaporizer complex formed by many communicating or connected tubes where the feeding water coming from the *economizer*, pushed by the feeding pump, arrives into the *superior manifold*, called also collector of water and steam. From here because of the gravity, 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 is called *Synoptic*.



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 surface.* 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 m^2 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.

3.2. Menu Bar :The menu bar includes 4 items:

File Commands Student name Info

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

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.

Restart
Exit

Diagnostic page
Heat balance
Set point
Report

3.2.2. Commands

It gives the access to a submenu

that includes:

- *Diagnostic page*: 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:

The screenshot shows a window titled "Diagnostic page" with a menu bar containing "Options". Below the menu bar, there is a list of parameters with their corresponding values displayed in yellow boxes:

Boiler pressure	0,1 bar
Outlet superheater pressure	0,1 bar
Inlet reheater pressure	0,1 bar
Outlet reheater pressure	0,1 bar
Feed water temperature	21 °C
Outlet economizer water temperature	25 °C
Outlet superheater temperature	42 °C
Inlet reheater temperature	41 °C
Outlet reheater temperature	42 °C
Air temperature	21 °C
Exhaust temperature	23 °C
Air delivery	0 m³/h
Fuel delivery	0 kg/h
Feed water delivery	0 m³/h
Steam delivery	0 t/h

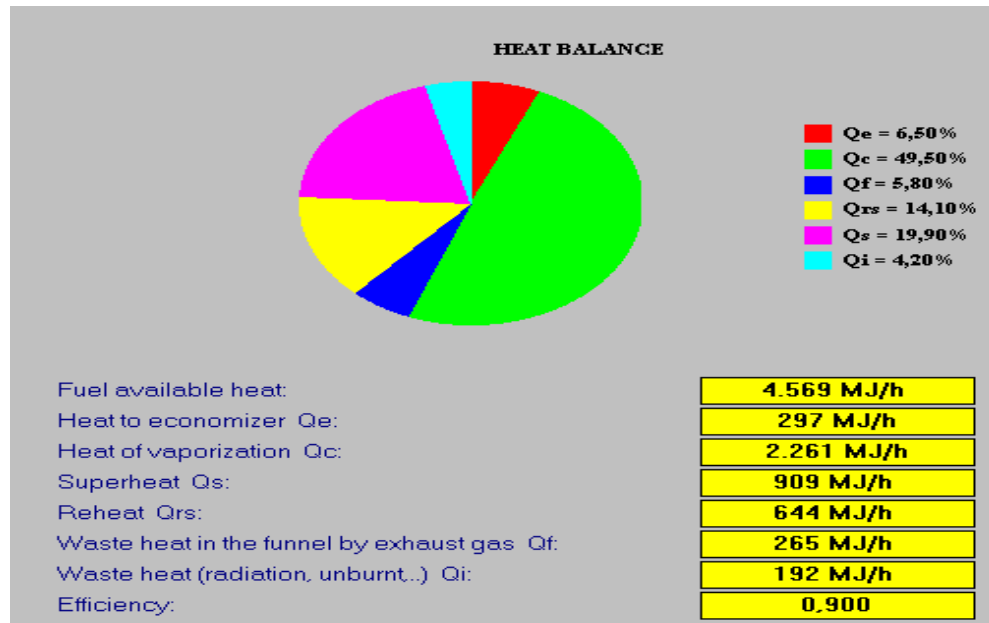
where all the numeric quantities necessary for the heat balance calculation are indicated.

From the menu bar the unique **Options** item allows:

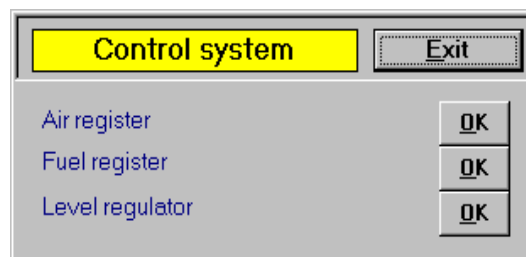
- To come back to the main synoptic (Exit);
- To print (Print);
- To obtain the pie diagram (Heat balance).

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

- **Heat balance**: 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:



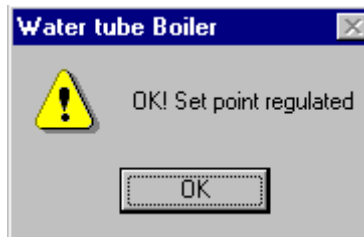
On this window it is possible to read the values that form the pie diagram. With the buttons or alternatively with the same items preset in the **Options** menu it is possible respectively:



- 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

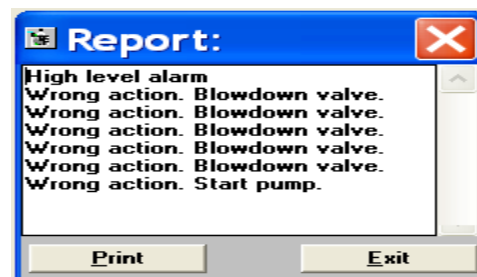


vice versa will appear a message as- - - - - →



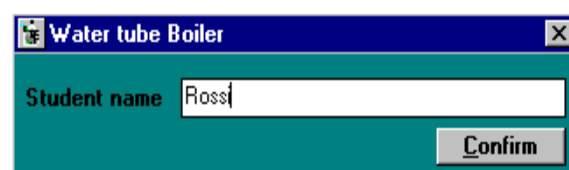
All the messages that will appear, included those of wrong maneuver will be registered and they'll can be saved on file at the program closure.

- **Report:** 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.

3.2.3. Student Name



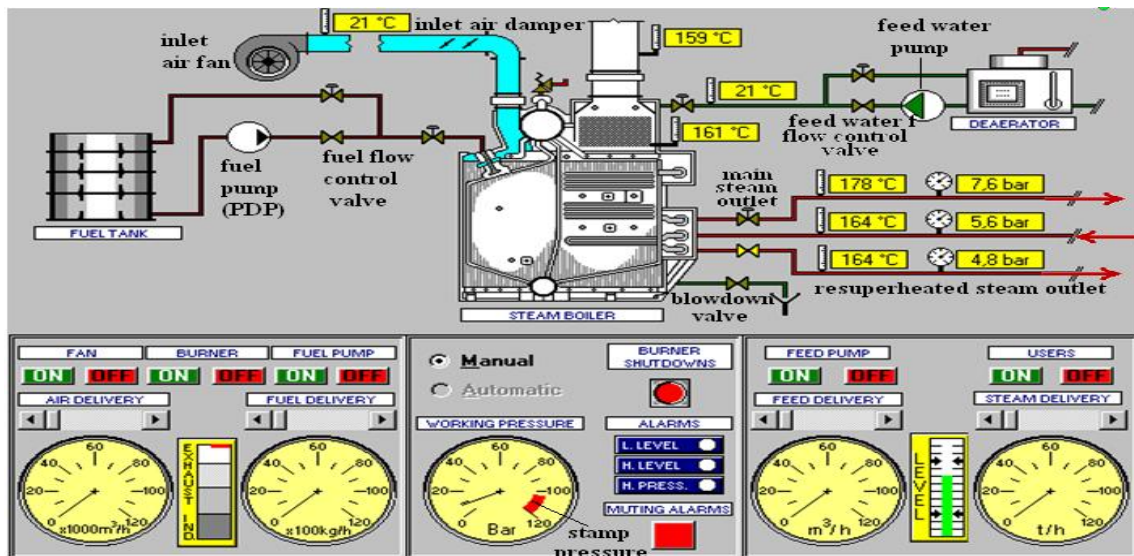
Opens the window. In this window you must insert, in the proper space, the operator name and, subsequently, confirm with the relative key. The name insertion will customize all the prints (the shall be shown on all prints).

3.2.4. Information

It gives the access to a submenu that includes:

- *Help*: this selection gives the access to an 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 loose 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.

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.

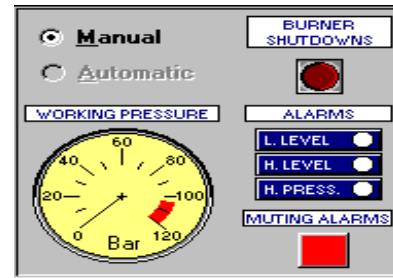
3.3.1. Lines (inlet & outlet piping)



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 brown for the fuel).

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

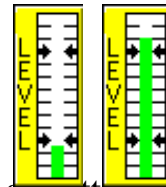
3.3.2. Alarms control board

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



1. **low level alarm:** it is activated when the level falls over the admitted limit.
When it happens, it causes the burner block (shutdown);
2. **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 are:
 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:

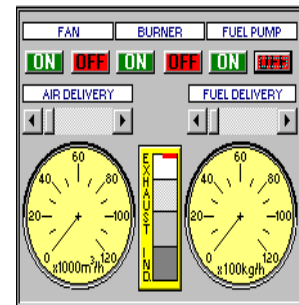


- The selection option in the boiler run: it is effectuated by clicking **indifferently** on the label or on the circle; in this shown particular case the Manual option is selected and then, the generator administration is manual and entirely up to the operator.

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.

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 coming .



For the power down click on the key , that will light coming .

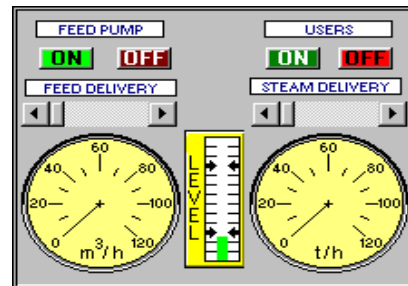
Obviously the keys are correlated (if ON lighted OFF powered down and vice versa).

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 fumes 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  .



3.3.4. Water-steam delivery control board :

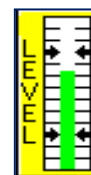
The control board allows the level administration. From here it is possible to:

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 users 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.

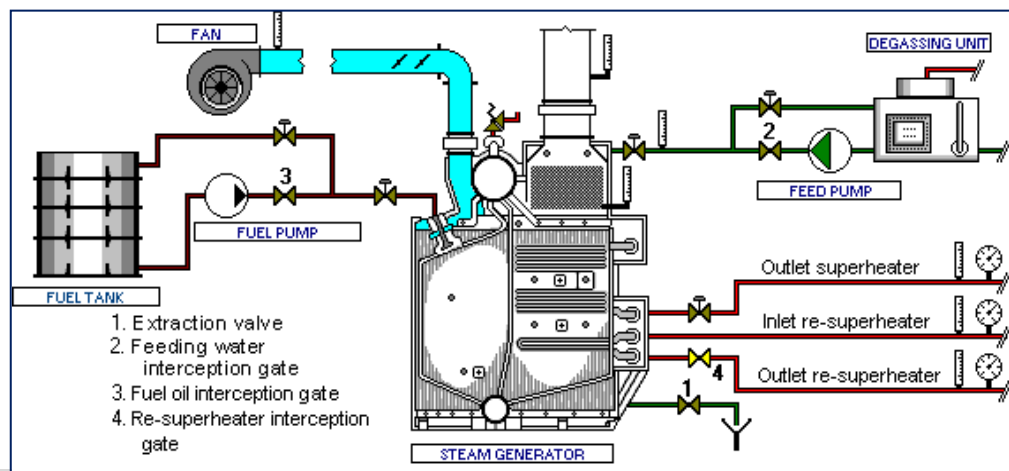
3.3.5. Valves

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 **fuel feed pump**, **feed water pump**, **re-superheat outlet**, and **boiler blow down** are all opened and closed **manually** with a “click” on them  (opened valve),  (closed valve).

Program Use

It is possible, through the gate valve of manual resuperheat 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 **the 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.



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 re-circled;
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 m³/h.

2. Conduction (Management)

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/lost 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.

Re-superheater influence on the plant

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

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.

Conclusions

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 Q_d ;
- Quantity of heat used in the economizer Q_e ;
- Quantity of heat used in the generator tubes Q_g ;
- Quantity of heat used in the superheater Q_s ;
- Quantity of heat used in the re-superheater Q_{rs} ;
- Quantity of heat lost in the funnel for fumes Q_f ;
- Quantity of heat lost for radiation and unburned Q_i .

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

$$Q_d = P_{cs} * P_g$$

where

$P_{cs} = 42.070 \text{ kJ/kg}$ fuel superior calorific power

P_g = fuel mass delivery

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

$$Q_e = P_v * (h_e - h_l)$$

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

$h_e - h_l = c_m * (T_e - T_l)$ Heat energy kept in one kg of water

$c_m = 4,270 \text{ kJ/kg } ^\circ\text{K}$ average specific heat of water

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

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

$$Q_g = P_v * (h_v - h_e)$$

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

Note: to calculate h_v 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:

$$Q_s = P_v * (h_s - h_v)$$

Where, h_s = Heat energy of the superheated steam

Note: to calculate h_s 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:

$$Q_s = P_v * (h_{ru} - h_{re})$$

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:

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

where

$$\beta = 1,225 \text{ kg/m}^3$$

Air volume mass

$$c_{mf} = 1,025 \text{ kJ/kg } ^\circ\text{K}$$

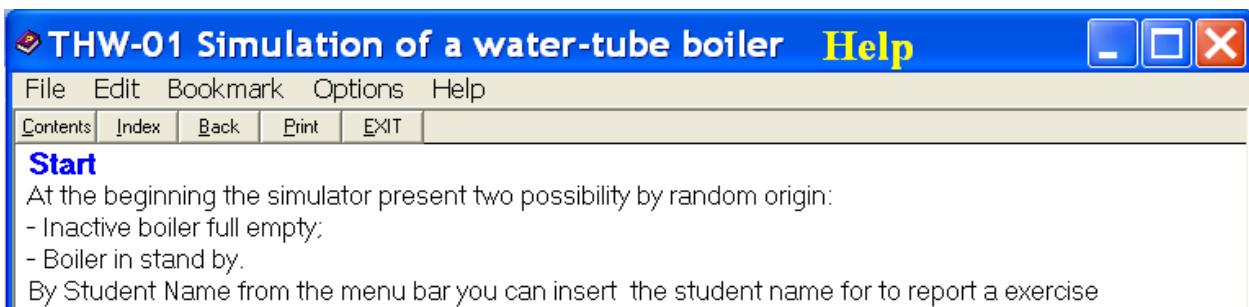
fumes average specific heat

P_a = Air volume delivery

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

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

Some parts from the Help command in the program:



Starting of the plant

- Check alarms; if the high level alarm is present, drain boiler to exact level, opening the blowdown valve.
 - Open the delivery valve of the feed pump.
 - Start the pump.
 - Start the fan.
 - Open the delivery valve of the fuel pump.
 - Start the fuel pump.
- If the alarms not present, the burner shuts down will be cut out.
- Start the burner.

Operating by on/off valve placed on the line, it is possible to exclude/include the reheater

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 combustion 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,  , 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

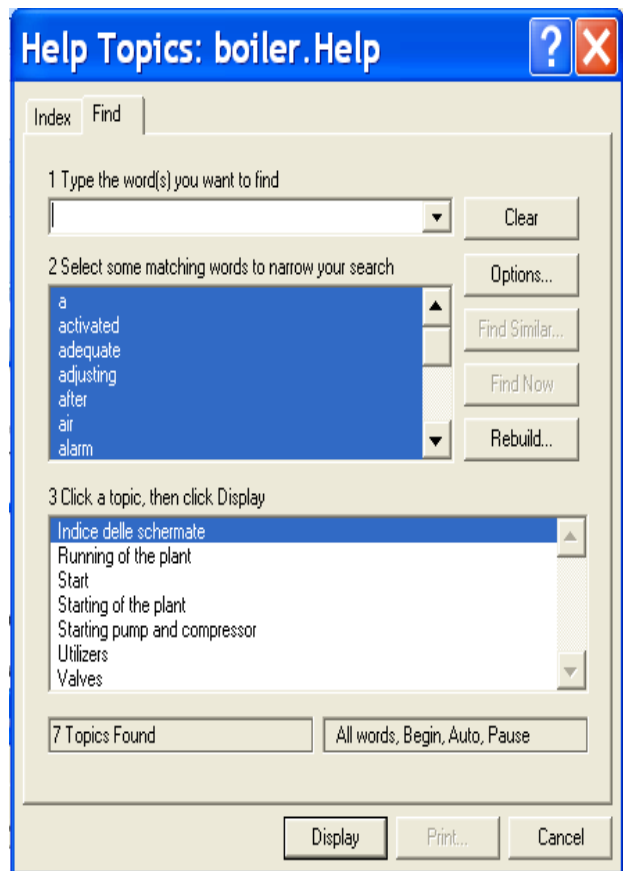
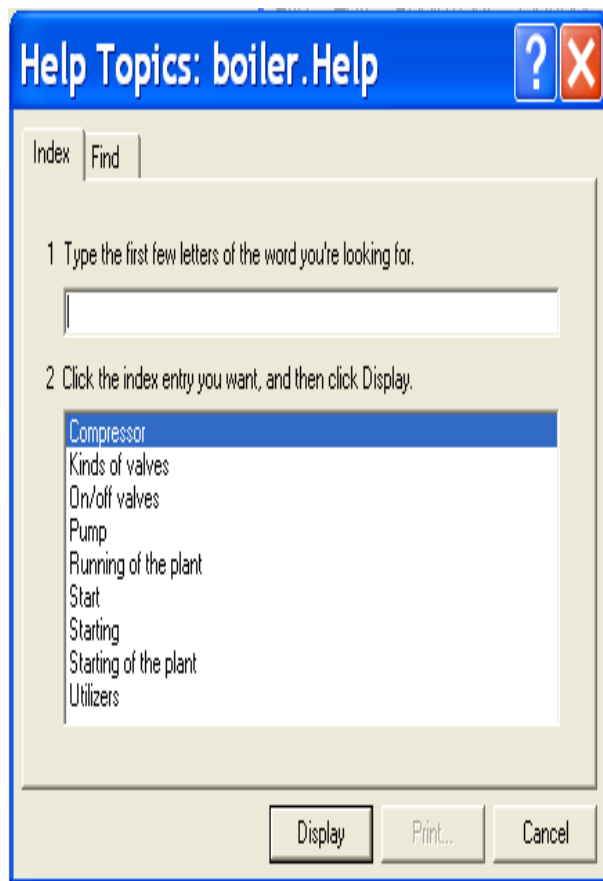
There are 2 kinds of valves:

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.

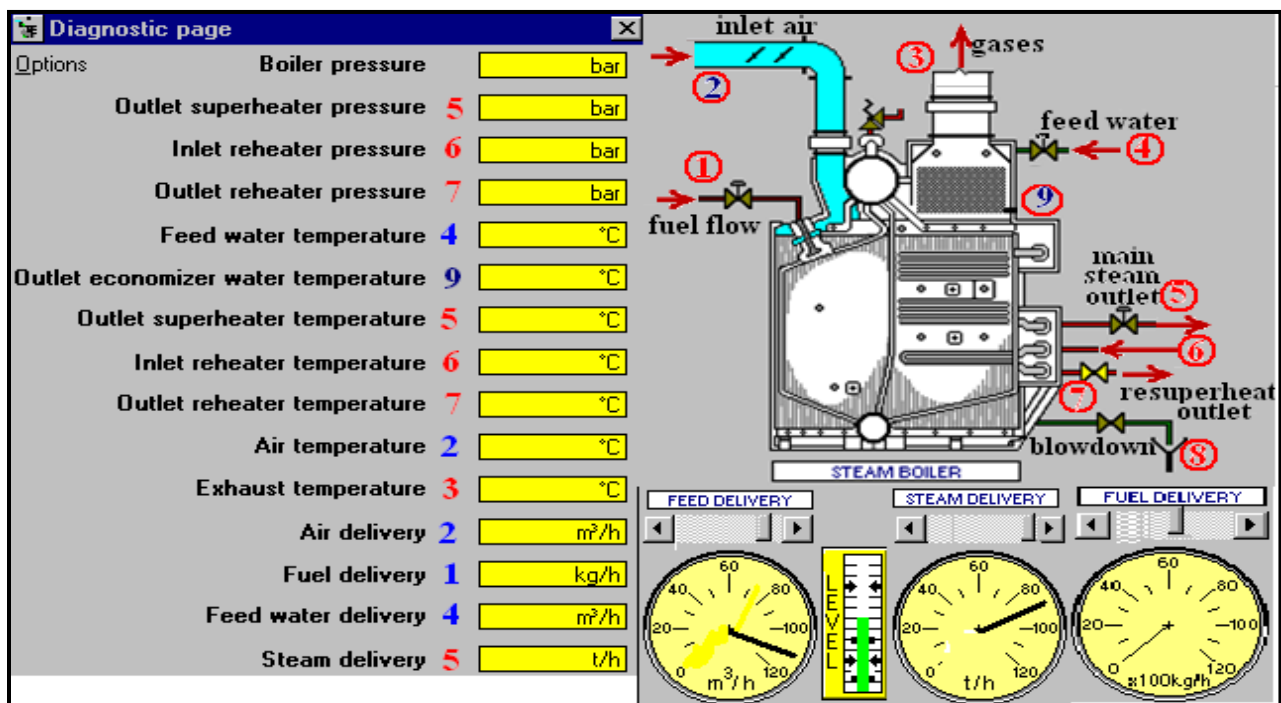


Report Requirements

Exercise # 1:

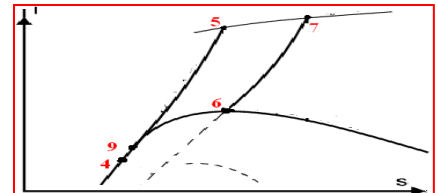
The Re-superheater is activated (the re-superheater outlet valve is opened):

- 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. Use values on that page to fill-in the following sheet:

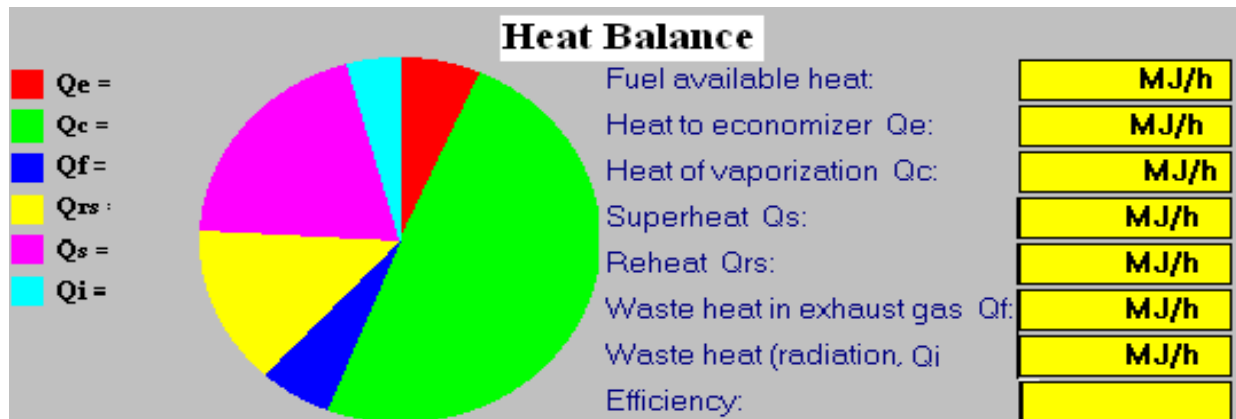


3- Calculate all the following magnitudes/values which are necessary for doing the heat balance calculations (make a comparison table between your calculations and the program calculations):

- Quantity of available heat in the fuel Q_d ;
- Quantity of heat used in the economizer Q_e ;
- Quantity of heat used in the generator tubes Q_g ;
- Quantity of heat used in the superheater Q_s ;
- Quantity of heat used in the re-superheater Q_{rs} ;
- Quantity of heat lost in the funnel for fumes Q_f ;
- Quantity of heat lost for radiation and unburned Q_i .



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

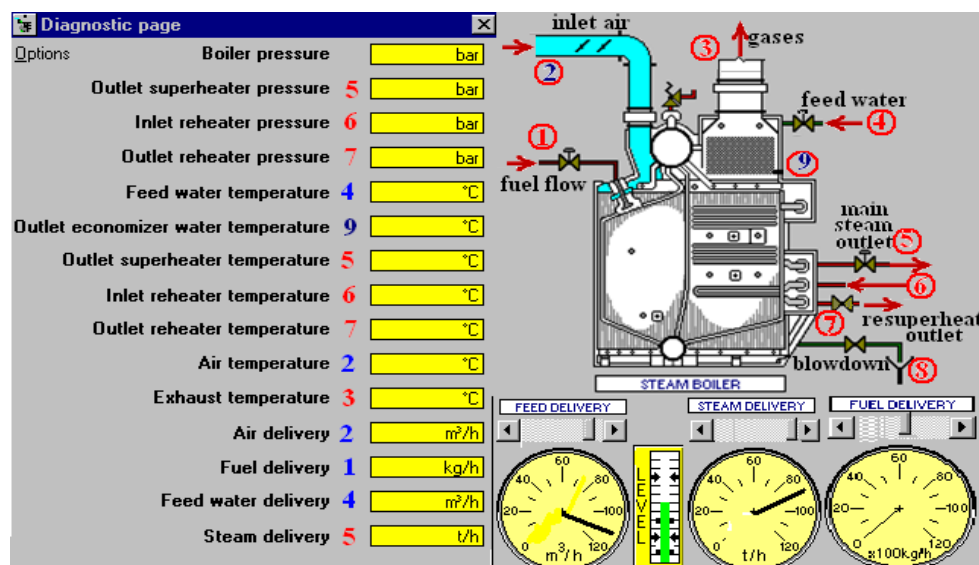


Exercise # 2:

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

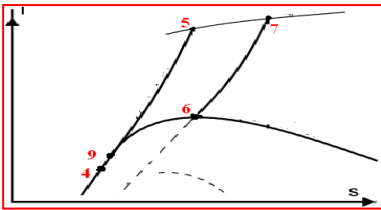
1-Run the Boiler **for 4-5 minutes** in the **automatic** mode (at a pressure of about 95 bar) and maximum main steam outlet (steam delivery control is at maximum position).

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



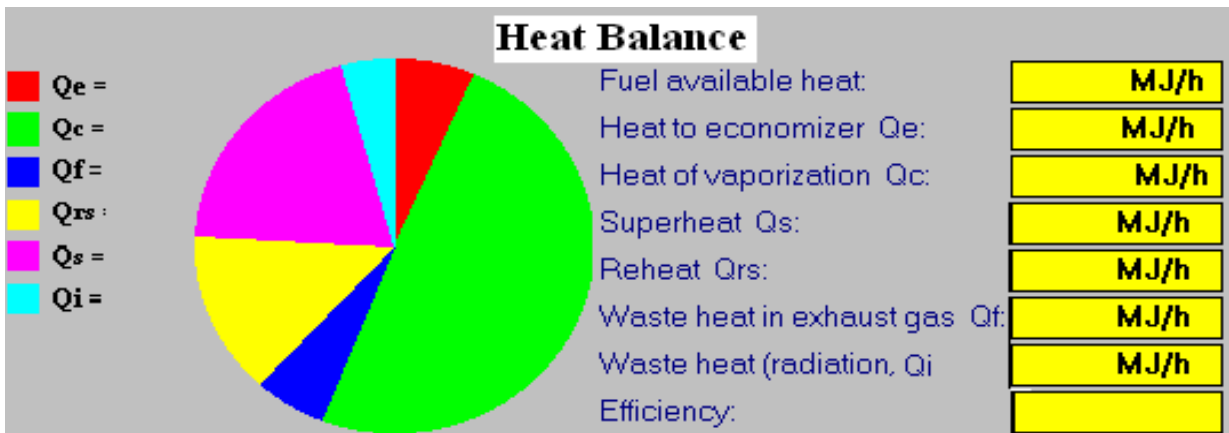
3- Calculate all the following magnitudes/values which are necessary for doing the heat balance calculations (make a comparison table between your calculations and the program calculations):

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- Quantity of heat used in the economizer Q_e ;
- Quantity of heat used in the generator tubes Q_g ;
- Quantity of heat used in the superheater Q_s ;
- Quantity of heat used in the re-superheater Q_{rs} ;
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4- Sketch the boiler heating processes on the i-s (Mollier chart for steam).

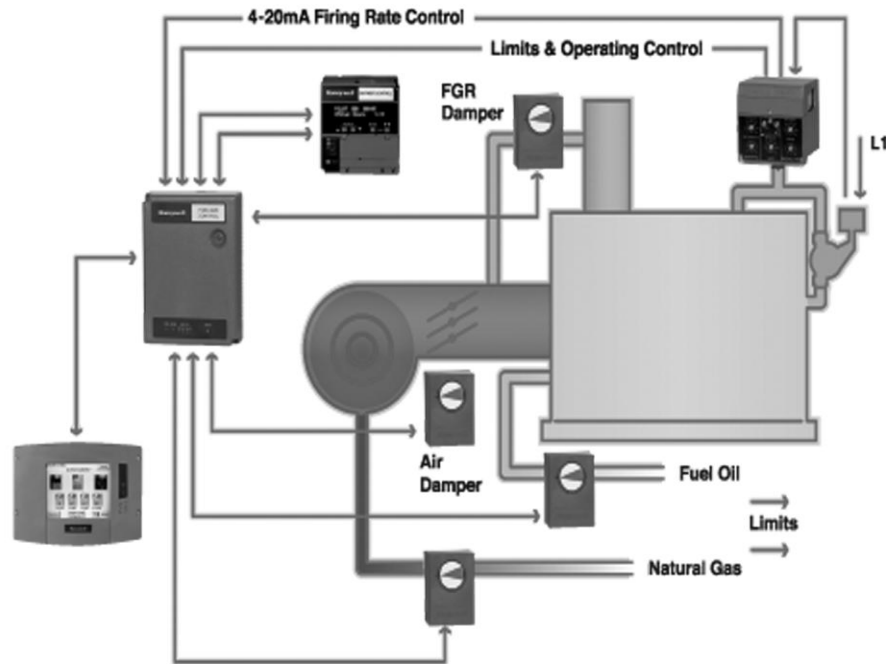
5- Calculate the Heat Balance Bi-diagram and compare your calculations and program calculations



Controlling Technology

Fuel-Air Ratio Control

Boiler Application — ControlLinks Fuel Air Ratio Control System



Air-fuel ratio (AFR)

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

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

As show in the figure (E-1)

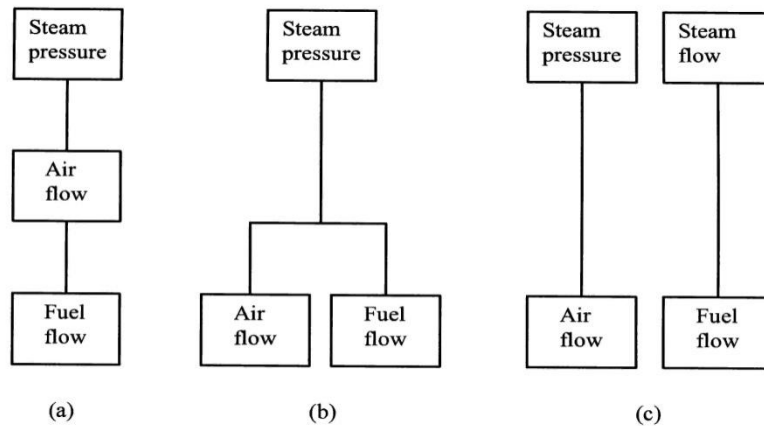


Figure (E-1)

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

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

- c) The ***Cross Limiting System*** is used when large or frequent load changes are expected. This is a dynamic system which helps compensate for the different speed of response of the fuel valve and air damper. It prevents a “fuel-rich” condition and minimizes smoking and air pollution from the stack. The system is also known as a *lead-lag* system. When demand increases, a low selector blocks then increase forcing the air flow signal to become the set point to the fuel flow controller. A high selector passes the increase to the air flow controller’s set point. This means fuel flow cannot increase until air flow has begun to increase, i.e. **air increase leads fuel increase**. When demand decreases, the low selector passes the signal to the fuel flow controller set point, while the high selector passes the fuel flow signal to the air flow controller set point. This means flow cannot decrease until the fuel flow begins to drop hence **air decrease lags fuel decrease**. This means a fuel rich condition is avoided, regardless of the direction of load change.
- The Fuel Air Ratio Control System shall utilize signal inputs from the firing rate control, stack or water temperature sensor and the burner management control to control the relationship between fuel, air flow and flue gas recirculation (if used) on a full modulation power burner. Up to four (4) independently controlled positioning actuators shall be commanded by the control. Actuators control damper positioning for air and flue gas and valve positioning for the primary and secondary fuels

COMBUSTION STRATEGIES

1) Fixed Position Parallel Control

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

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

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

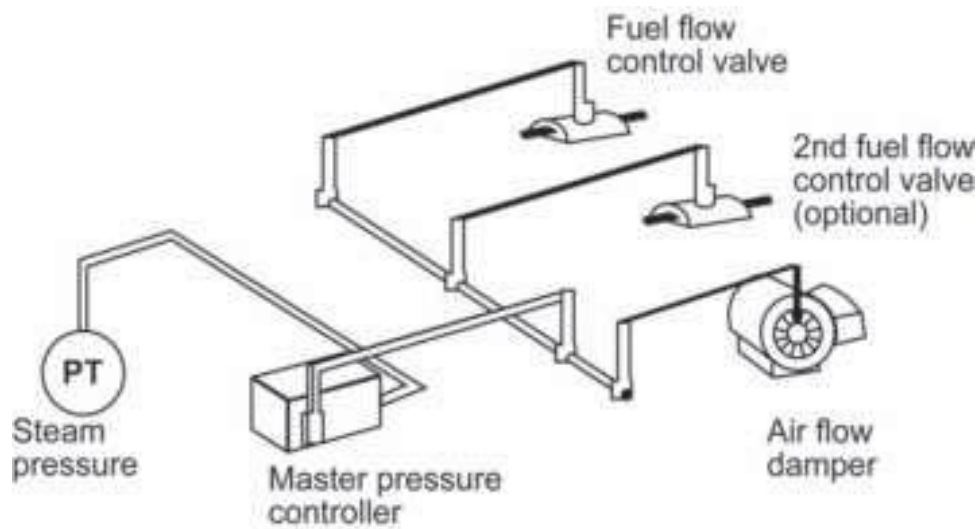


Figure (E-2)

2) Parallel Positioning Control Systems

Parallel positioning control (PPC) systems function very much like a Fixed Position Parallel system except that the fuel and air end devices are separated and driven by their individual positioners. Modern electronic PPC systems incorporate an end-device-positioning signal, which ensures the fuel and air positioners have moved to their pre-specified positions for a specific firing rate. This signal, while not actually proving final end device position and true fuel-air ratio flow, is a market improvement over FPC systems. The new systems are gaining wide acceptance with many users who have traditionally used FPC systems and are seeking an economic means to improve overall combustion efficiency. The modern PPC system is suitable for boilers ranging from 100 through 900 boiler horsepower operating with relatively stable loads. Larger systems are also becoming more prevalent. Modern electronic positioning PPC systems can hold excess oxygen levels to within 3-4 percent on many applications. It should be noted however, that when holding excess oxygen levels to these minimums the PPC control

strategy should be used with caution in applications with extremely fast load swings. Controllers and positioners, which might be set too tight may not properly respond and still maintain a safe fuel-air ratio on large and very fast upsets. This is due in part to the lack of process variable feedback in the fuel-air system. And like the FPC system, it is impossible for the PPC system to compensate for any changes in fuel or combustion air characteristics. Thus, issues such as fluctuations in fuel pressure, air temperature or humidity will have adverse effects on combustion processing using this system. Show figure (E-3)

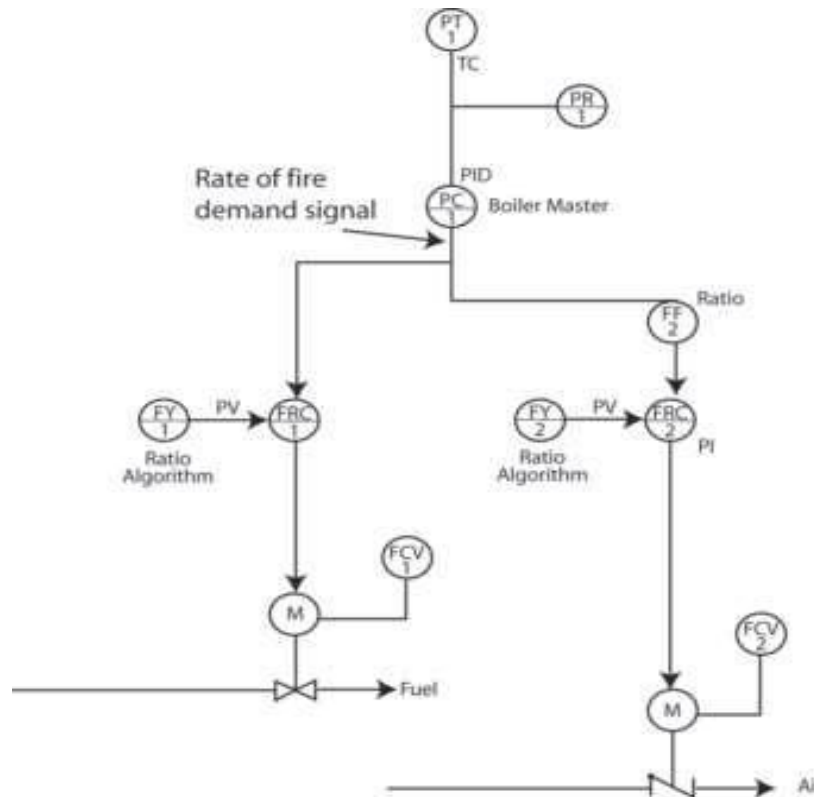


Figure (E-3)

3) Series Metered Control System

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

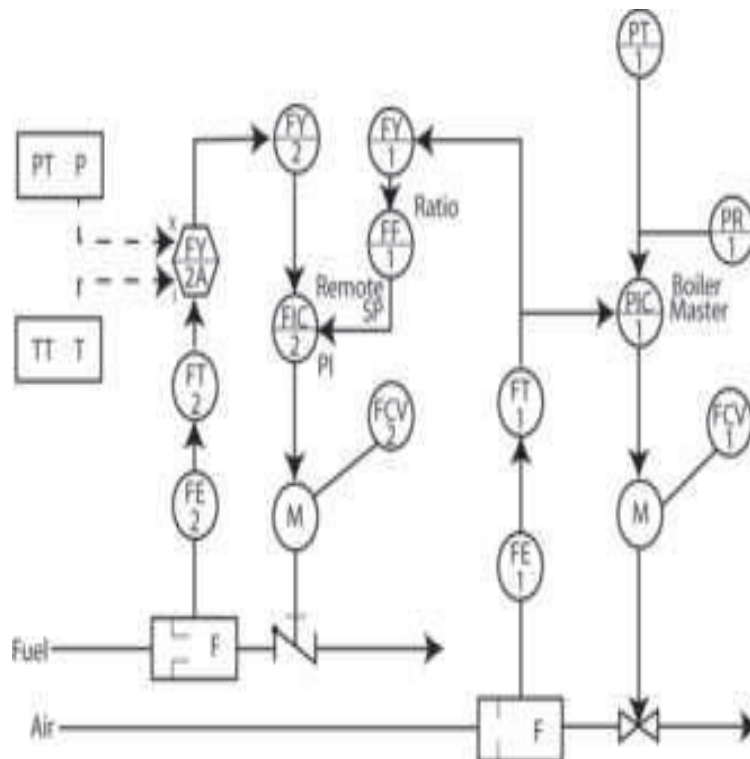


Figure (E-4)

4) Metered Parallel Positioning Control

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

system relies on near identical response from both the air and fuel control loops to prevent fuel rich or air rich mixtures in the furnace. The difficulty in maintaining this near identical response limits the application of the MPPC system to applications with modest demand swings.

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

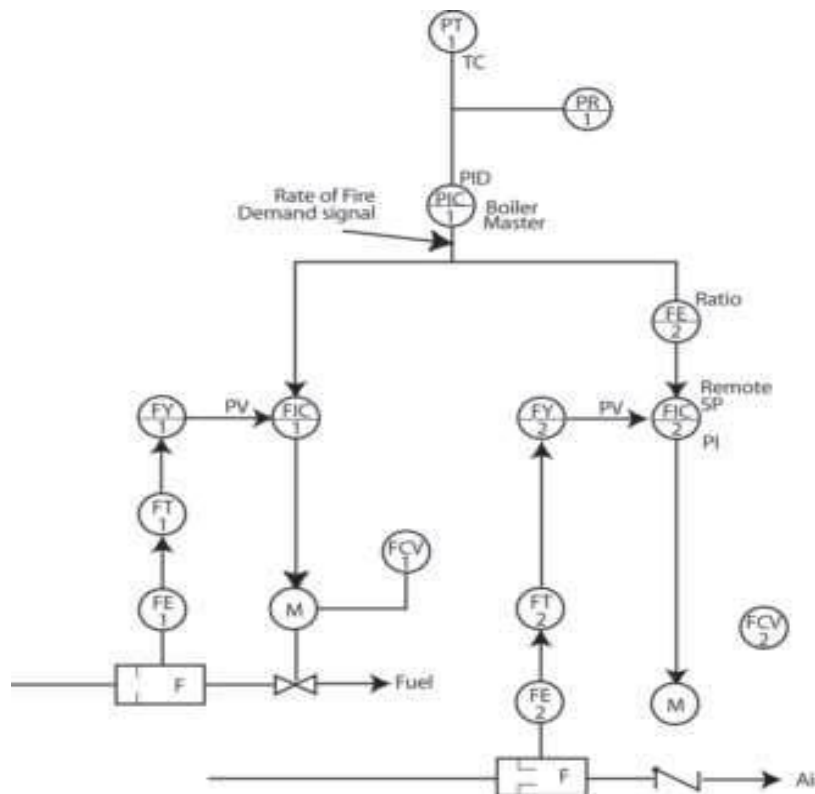


Figure (E-5)

5) Cross-Limited Metered Control

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

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

Show figure (E-6)

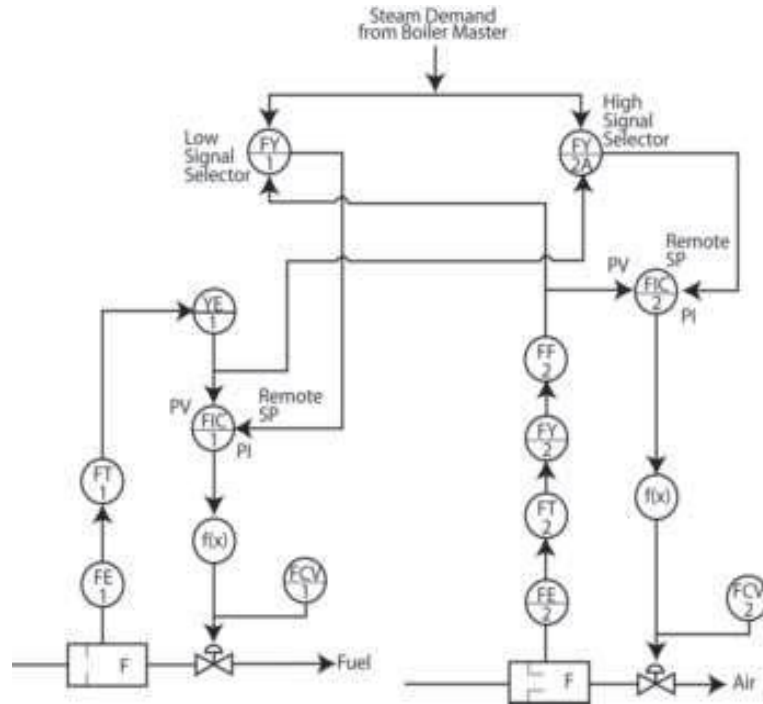


Figure (E-6)

Component Model Description

R7999A, B (ControLinks™ Fuel Air Ratio Controller)



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

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

R7999B: Meets international approvals. 200-240Vac.

ML7999A (Universal Parallel Positioning Actuator (UPPA))



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

Q7999A (Wiring Subbase)



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

Burner Controls

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

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

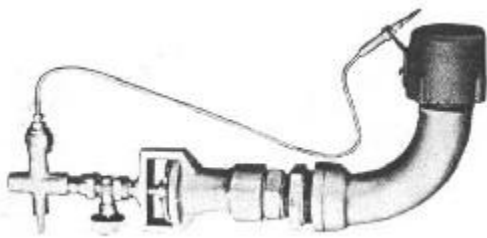
Both Fir eye and Siemens controllers offer fully integrated control in a single module, saving valuable floor space over non-integrated systems. Each system is designed to meet or exceed the reliability and safety requirements of the industrial heating industry.

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

ATMOSPHERIC (VENTURI) BURNERS

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

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



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

Low rates can be achieved by using a preheat pilot.

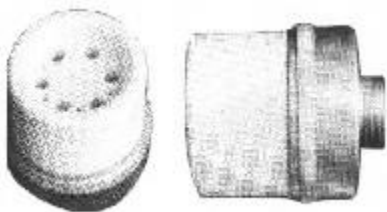
This method of firing is the cheapest in terms of equipment costs but is also the least economical. Attention should be paid to obtaining as neutral (correct mixture of atmospheric air and gas) a flame as possible as either oxidising (more air than gas) or reducing (less air) flames or atmospheres are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

It is difficult to achieve sufficient temperature in higher temperature furnaces with these burners. The greatest limitation, due to the low mixture

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

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

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



PRE-MIX OPEN AND SEALED BURNERS

These are burners using a machined mixing set and forced air from a blower or compressor.

Open burners use a suitable cast iron or steel flame retention tip and the sealed type utilise a R.I. castable tunnel or MP multiport tip (illustrated) mounted into the furnace wall. Natural gas or L. P. Gas may be used at low pressure as the forced air induces the gas and produces a blast-type flame. These burners are more efficient than

atmospheric burners as greater control is available over the air and gas mix, a hotter flame is produced and the sealed burner requires no wasteful secondary air. The open burner will need secondary air for cooling purposes to prolong the tip's life and to complete combustion. Some operators have traded tip life for lower noise and lower capacity by sealing the tip in the furnace port with fibre.

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

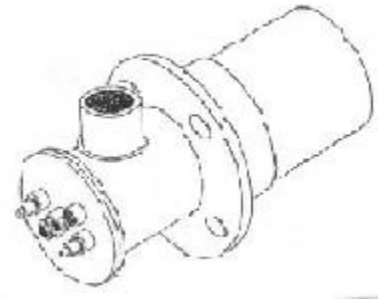
Premix burners generally have a shorter flame length than comparable nozzle mix burners, the air/gas ratio is easier to control and the burner overall generally easier to set up. Special flow regulators can be fitted to simplify adjustment enabling alteration of air flow only to raise or lower the temperature.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

State gas regulations concerning forced draft (premix, nozzle mix) burners tend to differ, with some States demanding full sequence electronic flame

failure while others may allow glory hole burners without safety if the burner is constantly supervised. All enclosed kilns, pot or tank furnaces should have quick lock out safety as these burners can produce large amounts of unignited mixture in a short period of time.

NOZZLE-MIX BURNERS

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

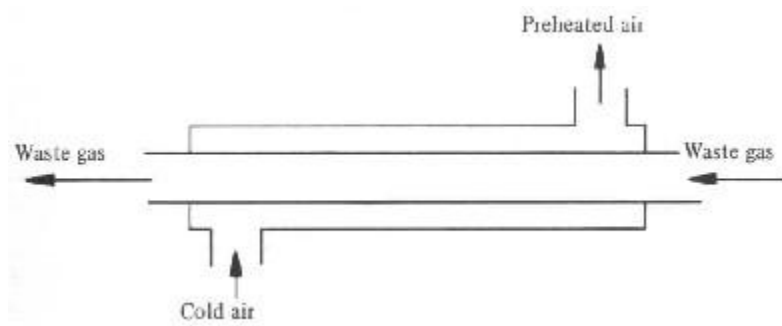


Basic cast nozzle-mix burners can handle low preheat temperatures providing some fuel savings but deterioration may result if these burners are exposed to high temperatures for a period of time. Nozzle mix burners that will provide high preheat temperatures and maximum fuel savings are constructed from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

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

RECUPERATION

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



A simple and effective recuperator uses a stainless steel tube on the flue outlet with a larger tube sited around it. The area

between the inner and outer tubes must be adequate to allow for free circulation of the cold combustion air but sufficiently restricted to enable the heat conducted through the inner tube to heat the air to the desired preheat temperature by the time the air exits the recuperator and flows to the burner head. The passage of the hot combustion products flowing through the inner tube must similarly be restricted to allow sufficient heat penetration. Baffles may be added to the inner tube or the single inner tube exchanged for multiple tubes to increase the available surface area. It is important not to exceed the working temperature of the steel and a refractory base or longer section may need to be used to take the initial heat. Experience has shown that over a period of time a coating of products produced by the glass

making process tend to accumulate on the inner tube surface. Provision must be made for periodic cleaning of the inside tube and it is a good idea to have a small reservoir underneath the flue outlet to gather these products rather than allow them to block the furnace outlet. Refractory recuperators can be made to increase the preheated air temperature to the burner and prolong life.

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

FIRING LOW TEMPERATURE OVENS

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



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

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

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

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

HIGHER TEMPERATURE FURNACES

These furnaces fire to higher temperatures (more than 700°C) but can employ similar burners. Downdraft designs are effective for general work but it is also possible to fire high pressure smaller burners across the product. This method relies not only on convection heat input but also, to a degree, on radiation from the flame. It is important if using this method that sufficient draw is available from the fluing system particularly in the early

stages of a firing. It may be necessary to preheat the flue but in any case pressure drops across the flue pipe and exit port must be minimised. Sealed burner tips are better.

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

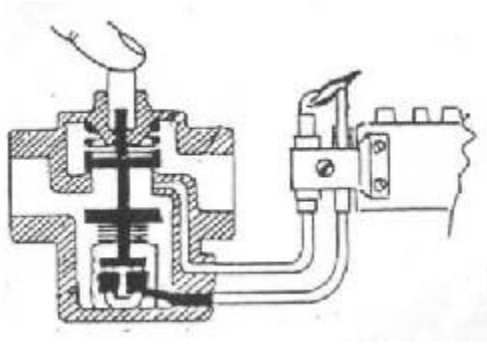
Automatic temperature programmers are important and can be effectively connected with any gas burner system. Multiple tips commonly utilise a ladder type pilot arrangement on either side, modulating the main burners to relight from the pilot for accurate temperature control. Flame safety is simply fitted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

SAFETY CONTROLS

Safety controls for gas appliances vary from over-temperature controls to sophisticated automatic start-up and flame failure controllers. Flame safety controls are recommended for all types of burners where there is the risk of a build-up of unignited gas should the flame be extinguished. Flame rectification or UV units are required on all forced air burners and gas will not be connected unless they are fitted. The regulations cover natural gas and L.P. Gas. In some instances the authorities may also insist on over temperature protection or explosion relief. Explosion relief is simply a panel fitted to the furnace of the correct dimensions of a material with less resistance to an explosion than the furnace itself. Non-return check valves may also be required in the gas main to prevent air flowing back to the

meter. A regulator is always required on either natural gas or L.P. gas installations to monitor the gas flow and provide the correct pressure outlet. All valves and fittings must be approved and pipe fittings particularly must be suitable for gas. Safety valves should be listed in the gas association bulletin and the burners and controls installed by a licensed person.

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



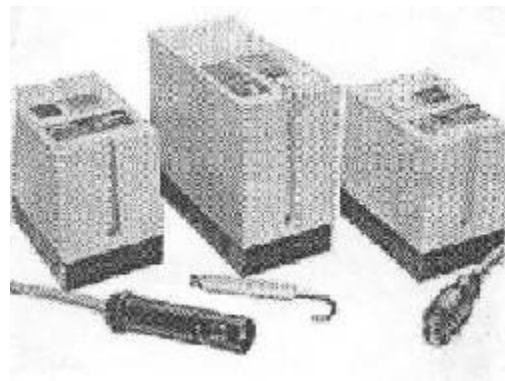
THERMOELECTRIC SAFETY

This is the simplest form of flame safety and is permitted on atmospheric burners with a capacity under 500 MJ/hour.

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

ELECTRONIC QUICK-LOCKOUT

These units require power and are usually fitted to forced air burners or safer atmospheric burners. They shut down on a flame failure in approx. one second by closing a solenoid valve fitted



into the gas line. Two main types are available; the flame rectification type and the ultra-violet type. Flame rectification relies on the ability of ionised

gases in the flame to rectify on AC current from the control unit. A flame sensing rod made from special high temperature material is used and must be situated near the edge of the main flame. A micro-amp meter may be used in series with the rod to check the best position and minimise nuisance shutdowns. The wire must be sturdy enough to resist drooping or deterioration at high temperatures and the porcelain insulators must be kept clean or replaced if cracks develop. For reliable operation the earthing point on the burner must have at least four times the area of the rod in the flame.

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

NOTES ON FIRING HIGH TEMPERATURE FURNACES

Nozzle mixing and premix furnace burners can be oversized to reduce the ambient noise level providing control is not compromised. Ideally furnaces should be commissioned using combustion analysers, however in the absence of these tools, a slightly reducing gas/air mix with the air rate kept at a minimum will achieve the temperature required. The open type premix burners can have the primary air reduced further as a percentage is entrained as secondary air. The ideal open flame has slight yellow tips; sealed burners should be blue without hard, defined cones. Furnace pressures should be

slightly positive to ensure the flue is not drawing excessively and there is no possibility of wasteful ingress of secondary air. This can be tested in a basic fashion by using a hollow tube fitted through a gap in the door. Seal the rest of the door opening completely with ceramic fibre and fit a balloon on the other end of the tube. A slight inflation of the balloon indicates slight positive pressure.

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

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

control is preferred, this screw may be set for maximum gas only and the manual air and gas valves adjusted to alter the flow.

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

Drum water level control

Why do I need boiler water controls and alarms?

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

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

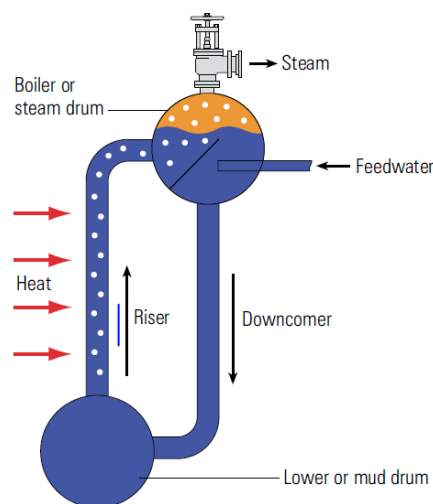


Fig. 3.3.2
Natural water circulation in a water-tube boiler

Drum Level and Feed water Control

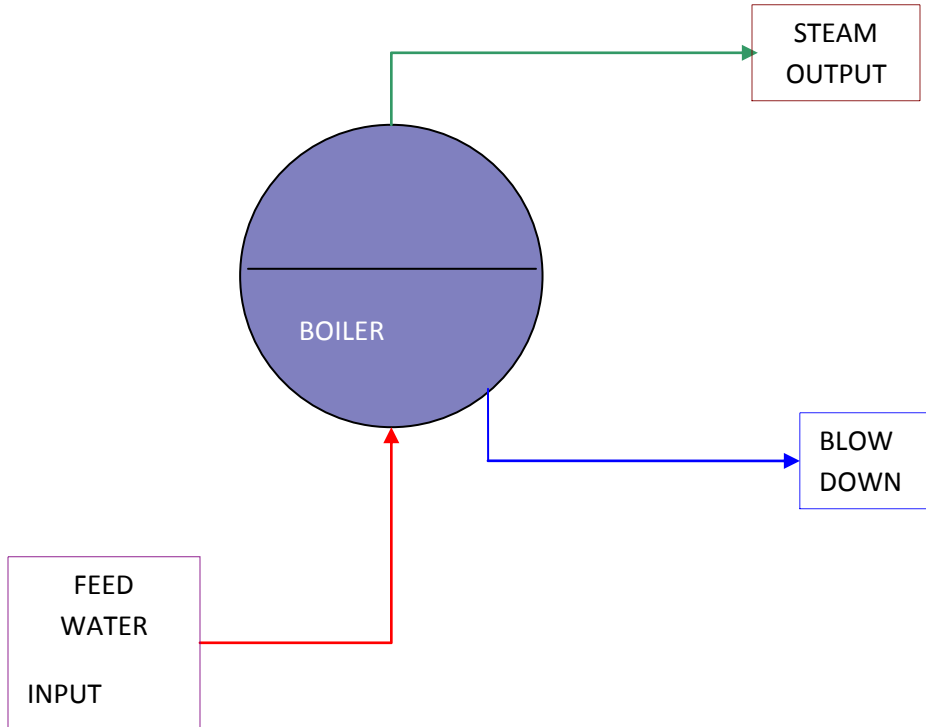
A very common control problem, and one used in many examples elsewhere, is that of controlling the level in a boiler drum. Many industrial plants have boilers for generating process steam, and of course boilers are central to thermal power generation. can run dry resulting in mechanical damage of the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

feed water is controlled to keep the drum level .

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

Level Circuit (Water Side Circuit):-

$$\text{Feed water input flow} = \text{steam flow} + \text{blow down} + f(\text{level})$$

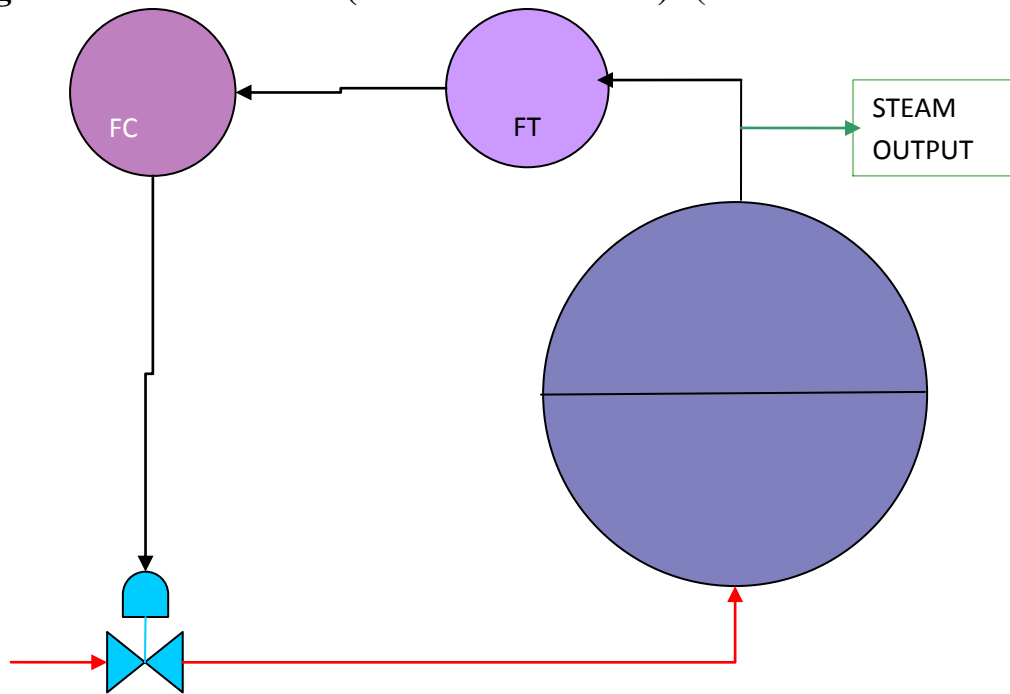


Level control circuit

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

$$\text{Feed water input flow} = \text{steam flow} + \text{blow down} + f(\text{level})$$

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



Single-element Control

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

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

Disadvantages of Single-element Control:

(SHRINK and SWELLING)

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

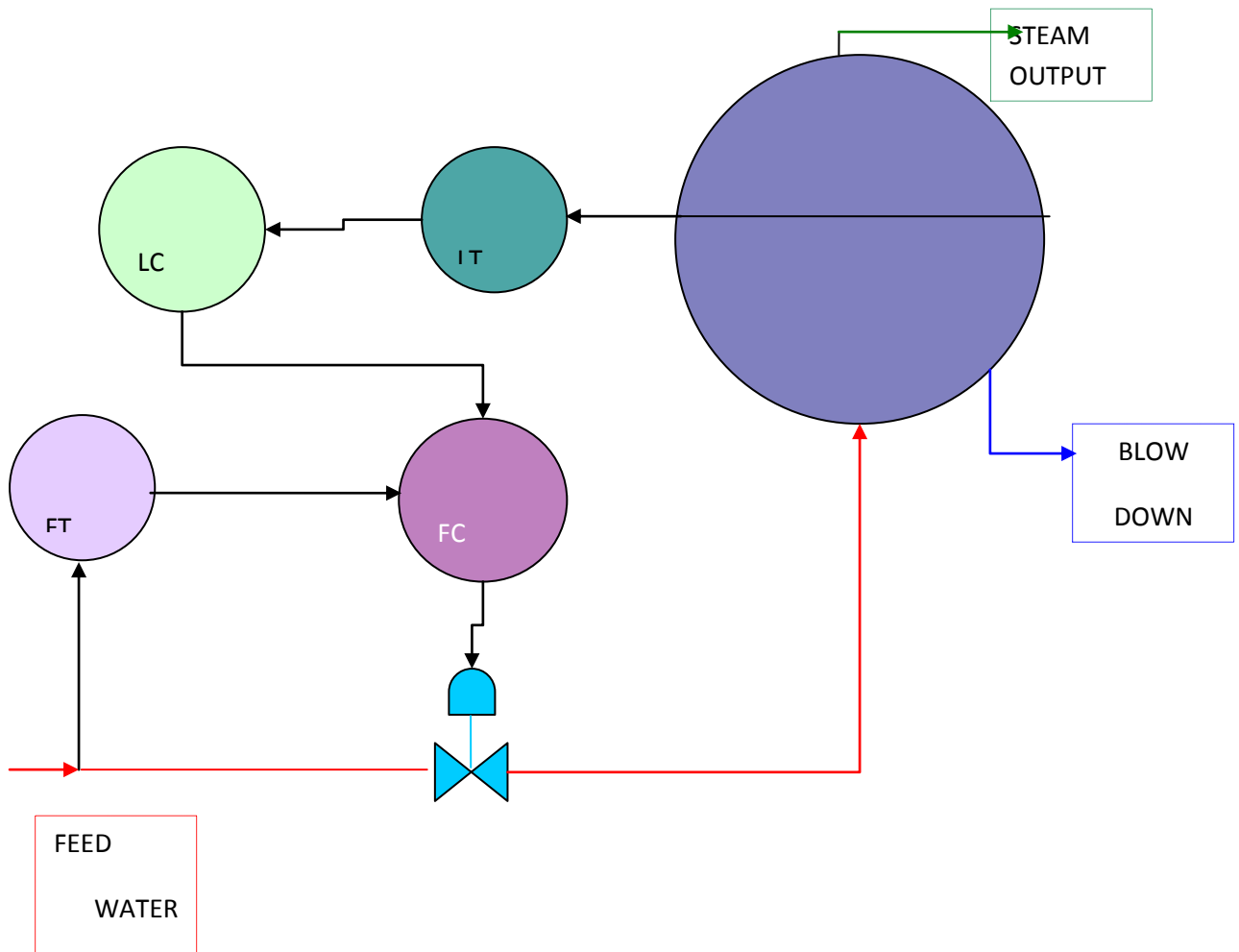
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This will in effect reduce the water inventory and after the swell effect the water drum level will drop significantly. This is a disadvantage of one element control system, therefore we use only this system structure at (20 to 25 % load), and we have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

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Two-element Control (Cascade Control)

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



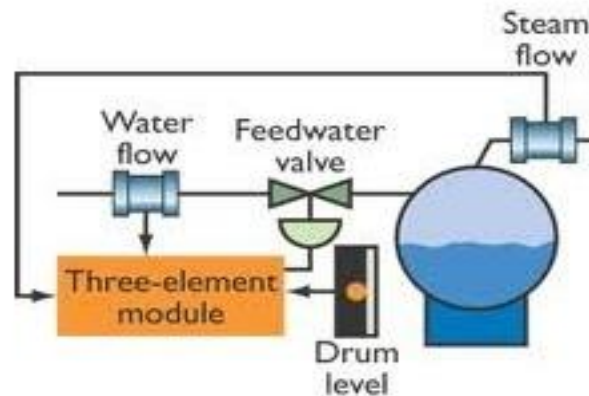
Two-Element Drum Level Control

Three-element Control (Cascade + Feed forward Control)

Drum level

Feed water flow

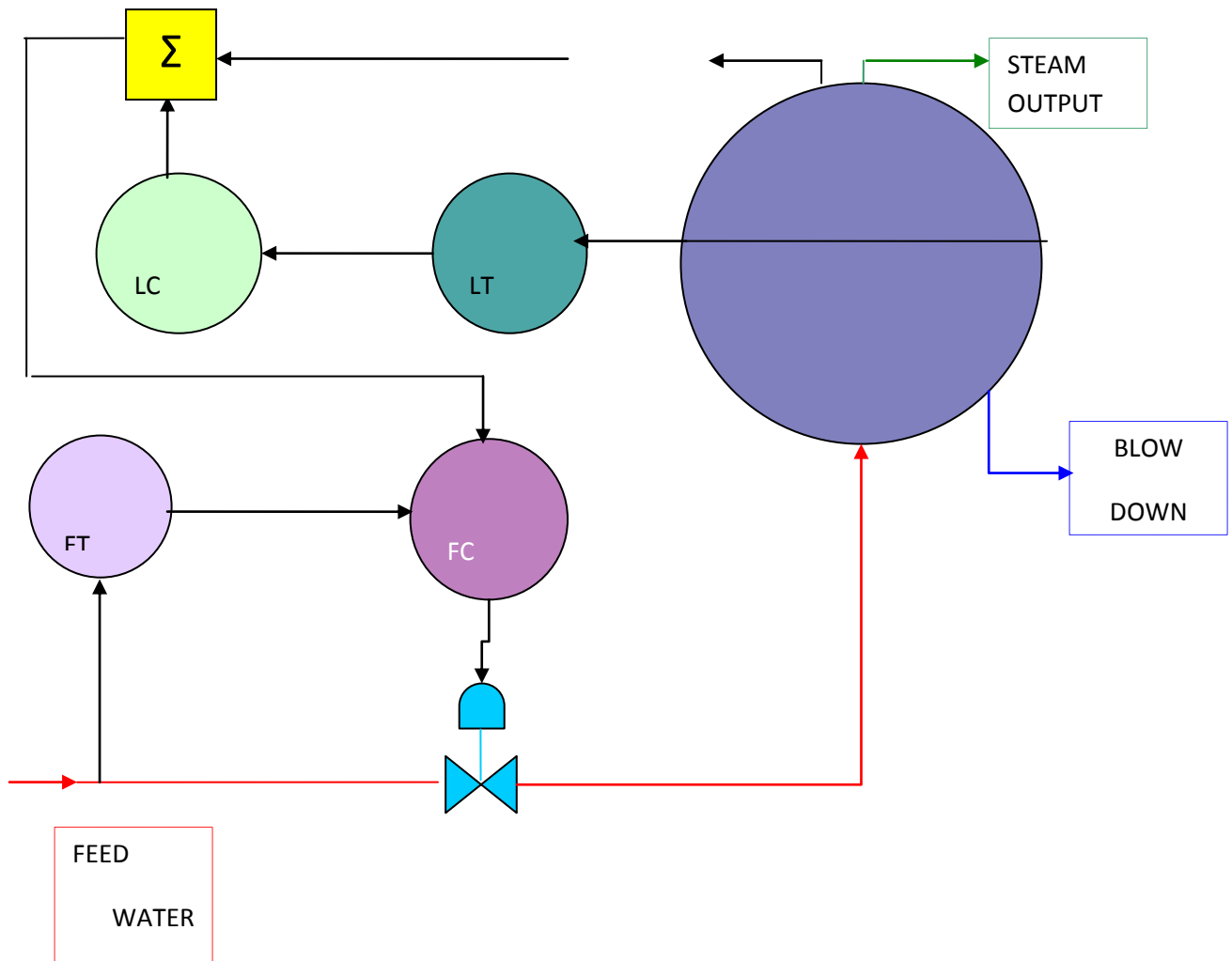
Main steam flow



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

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

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



Three-Element Drum Level Control

Advantages of control of water level in drum :

constant water level can be maintained

Excess water level can be avoided by high alarm signal

Low water level can be avoided by low alarm signal

Continuous steam & water flow is possible

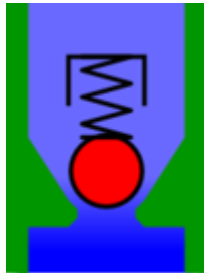
Smooth & efficient working of the boiler

Variation in steam pressure, temp & flow is minimized.

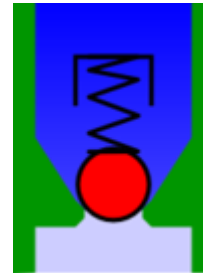
Controlling valves

Check valve

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



Open



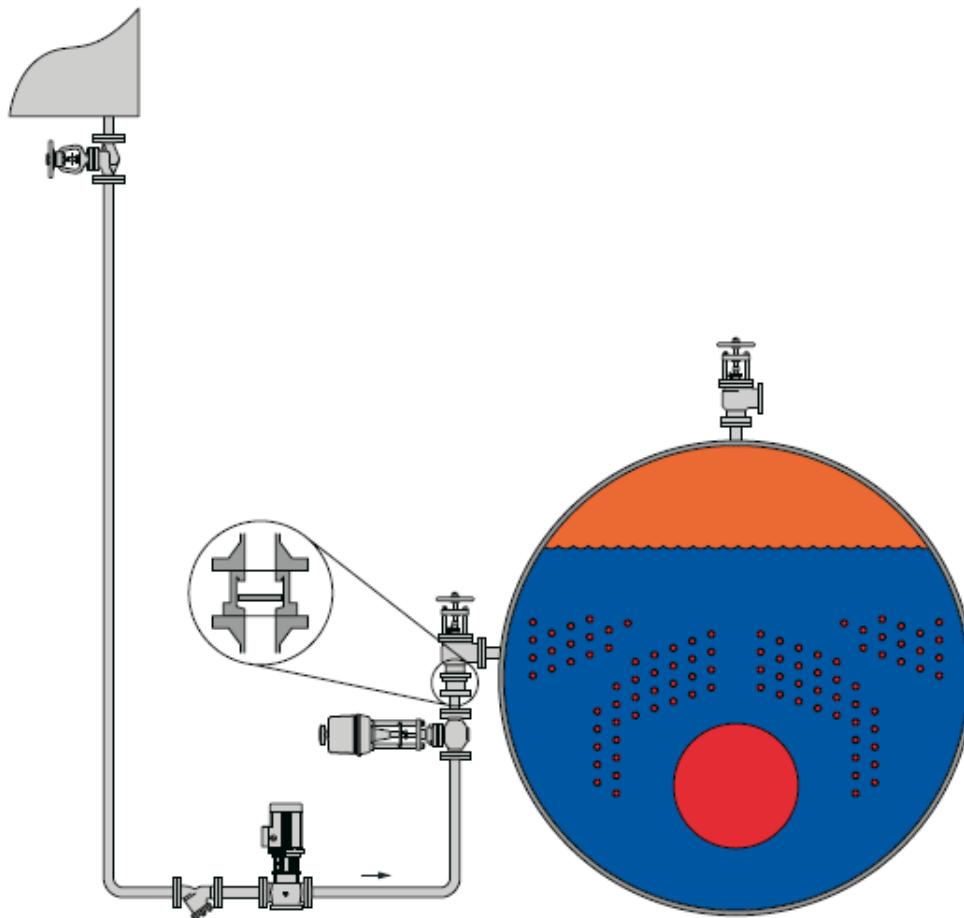
closed

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

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

Check valve in boilers:

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



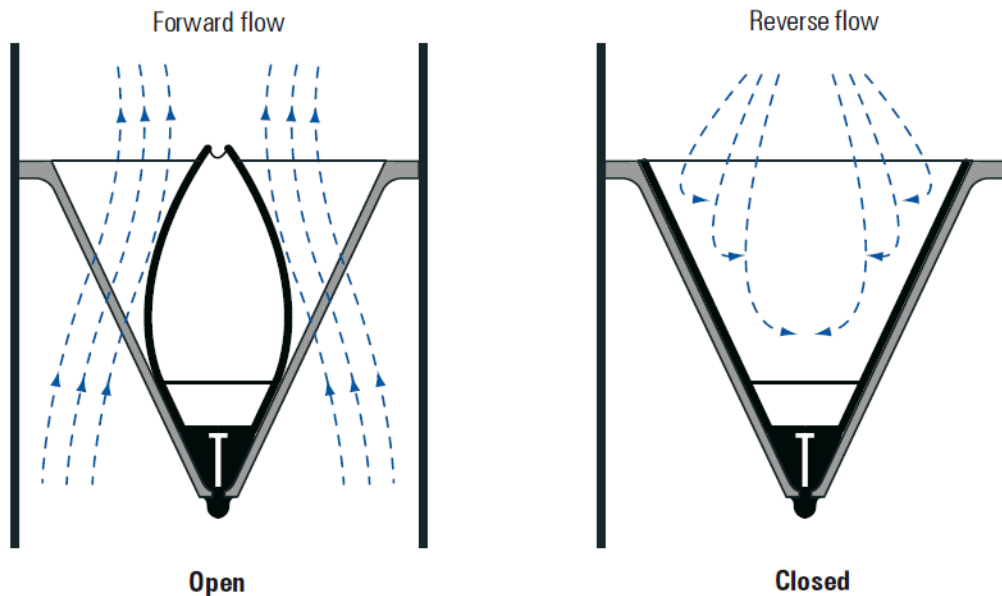
Boiler feedline applications

Types of check valves:

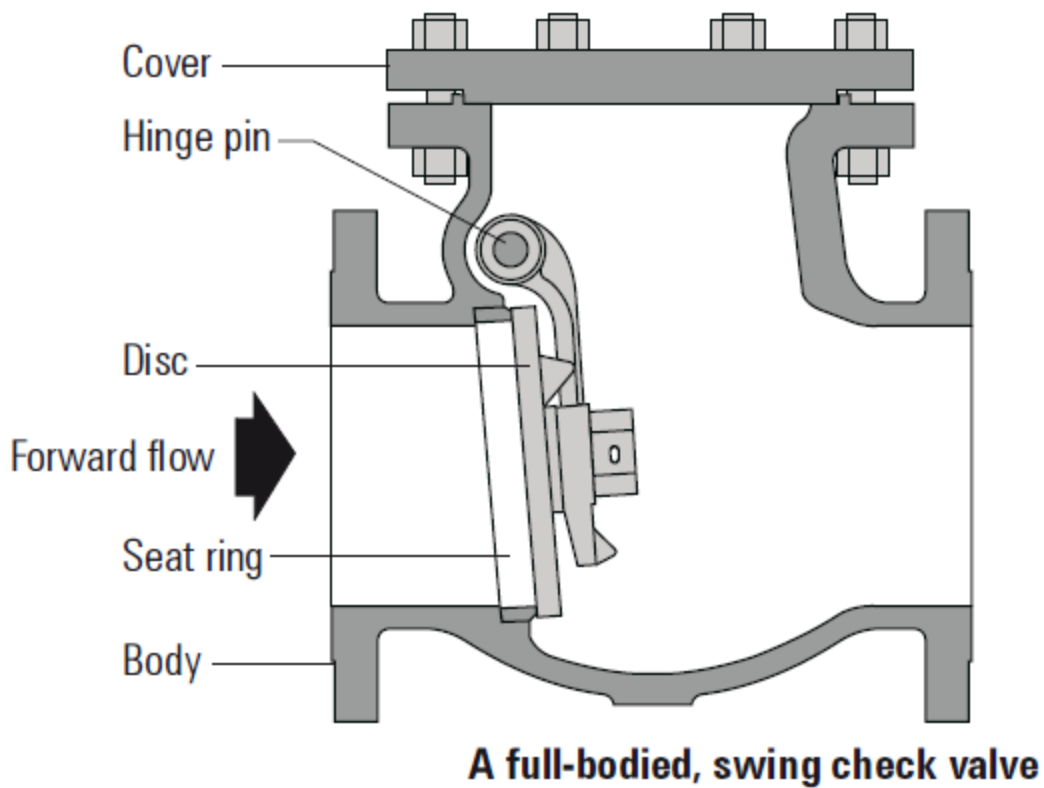
ball check valve: is a check valve in which the closing member, the movable part to block the flow, is a spherical ball. In some (but not all) ball check valves, the ball is [spring](#)-loaded to help keep it shut. For those designs without a spring, reverse flow is required to move the ball toward the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

diaphragm check valve uses a flexing rubber diaphragm positioned to create a normally-closed valve. Pressure on the upstream side must be

greater than the pressure on the downstream side by a certain amount, known as the pressure differential, for the check valve to open allowing flow. Once positive pressure stops, the diaphragm automatically flexes back to its original closed position.

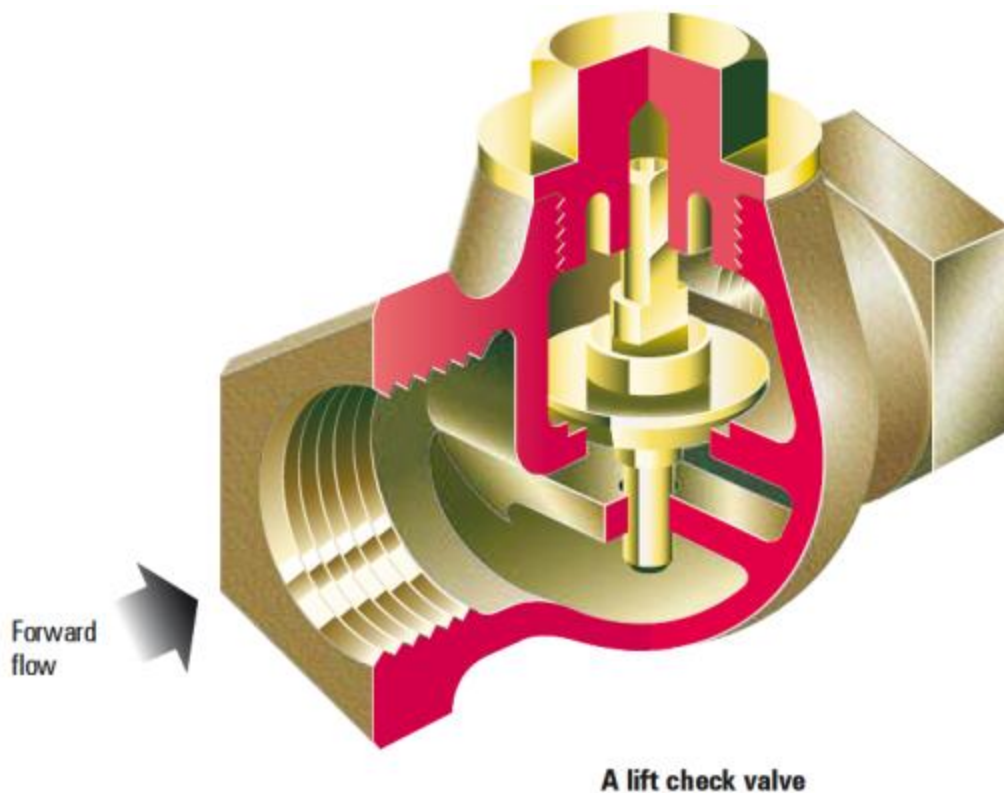


swing check valve or **tilting disc check valve** is check valve in which the disc, the movable part to block the flow, swings on a hinge or trunnion, either onto the seat to block reverse flow or off the seat to allow forward flow. The seat opening cross-section may be perpendicular to the centerline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



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

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



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

Applications:

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

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

Check valves are also often used when multiple gases are mixed into one gas stream. A check valve is installed on each of the individual gas streams to prevent mixing of the gases in the original source. For example, if a fuel and

an oxidizer are to be mixed, then check valves will normally be used on both the fuel and oxidizer sources to ensure that the original gas cylinders remain pure and therefore nonflammable.

Blowdown valve

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

How does a blowdown valve operate?

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

The blowdown valve in boiler:

It has two functions:

- Removing Suspended solids from the bottom of the boiler.
- act as a safety valve to blowdown water if the pressure of the boiler became so high.

How does it work?

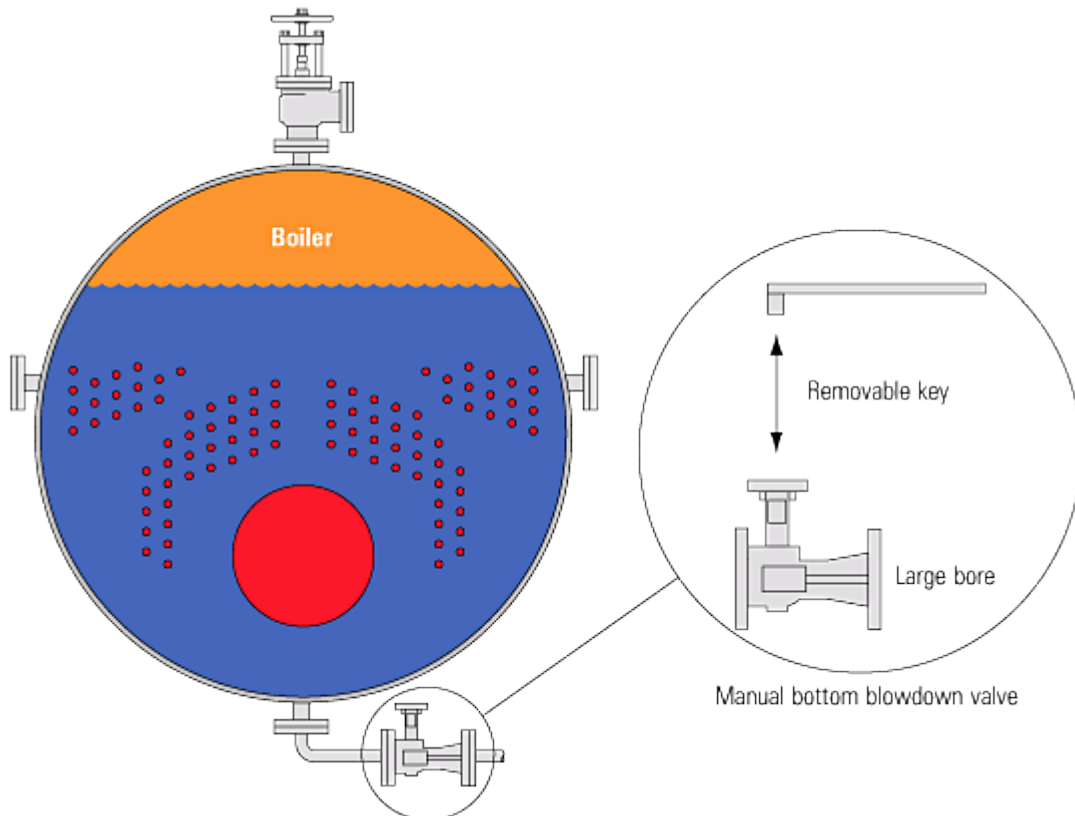
- At start-up, the valve is closed. This leads the boiler to work normally.
- when blow down is necessary the valve opening performed.

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

1-manually.

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

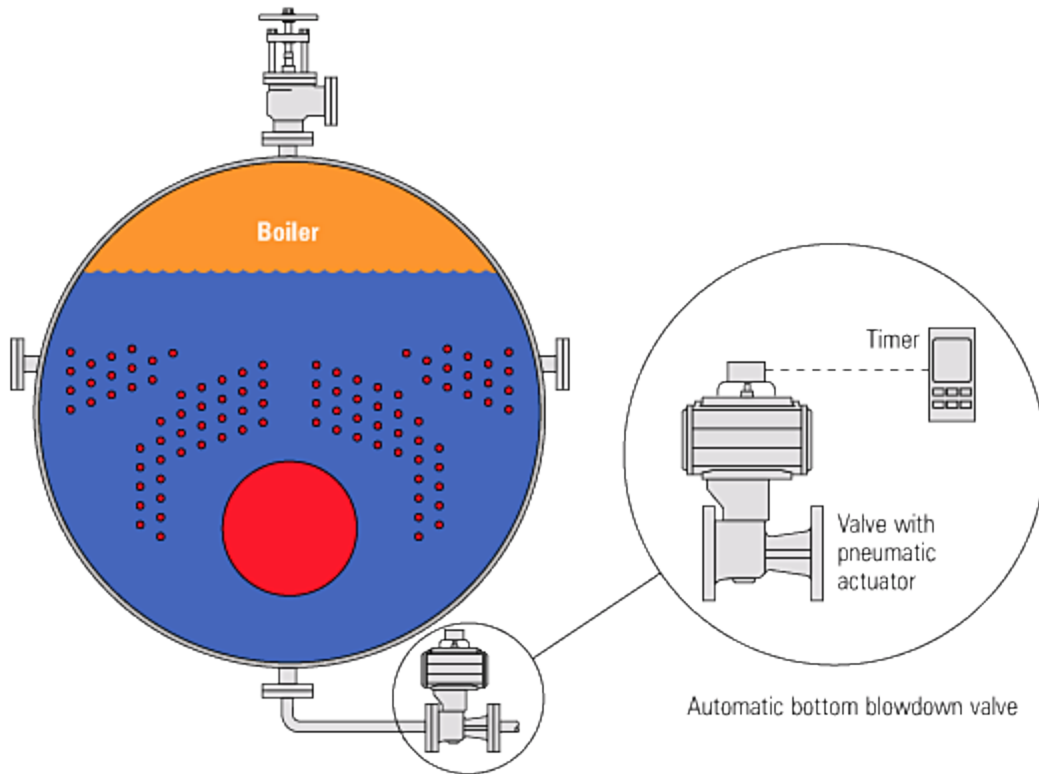
-There is no other control method except the human action.



2-Timer controlled automatic bottom blowdown:

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

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



Relief valve

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

How does a relief valve operate?

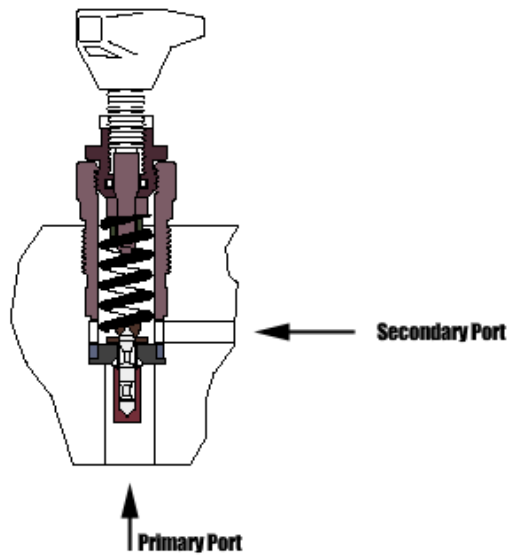
The pressure is relieved by allowing the pressurised fluid to flow from an auxiliary passage out of the system. The relief valve is designed or set to open at a predetermined set pressure to protect pressure vessels and other equipment from being subjected to pressures that exceed their design limits.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

There are two methods of actuating of relief valve:

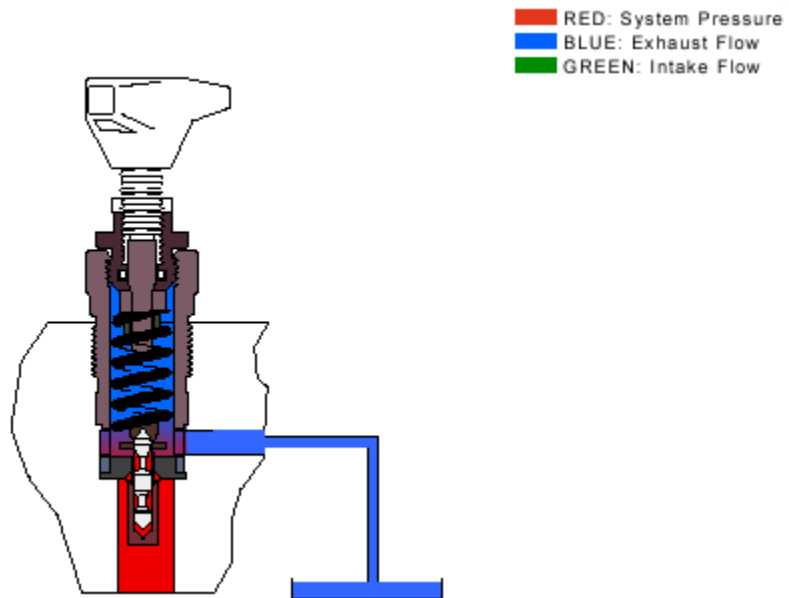
Direct acting:

It has two ports:

- first port is connected to the system pressure.
- second port is connected to the tank.



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

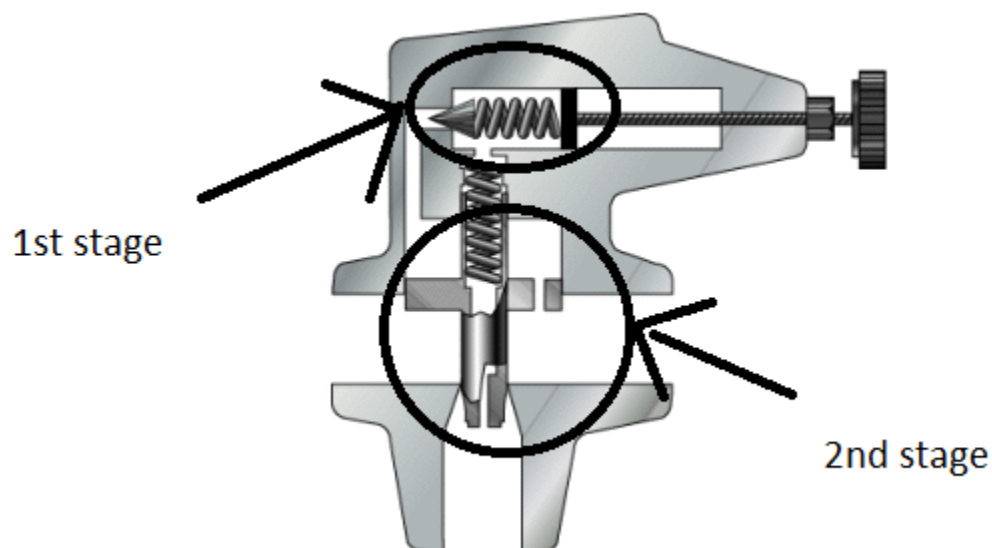


Pilot operated relief valve:

It consists of two stages:

- first stage direct acting relief valve, which adjusted to a specific pressure.
- second stage contains the main spool and subjected to the flow pipe.

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



Types of relief valves:

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

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

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

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

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

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

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

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

Calibration

Boiler (program)98i Readings:

Boiler pressure	89.1 bar	
Outlet superheater pressure	87.3 bar	
Inlet reheater pressure	14.6 bar	
Outlet reheater pressure	12.8 bar	
Feed water temperature	196 °C	
Outlet economizer water temperature	250 °C	
Outlet superheater temperature	513 °C	
Inlet reheater temperature	296 °C	
Outlet reheater temperature	513 °C	
Air temperature	24 °C	
Exhaust temperature	166 °C	
Air delivery	83726.604 m ³ /h	
Fuel delivery	7570.5244 kg/h	
Feed water delivery	94 m ³ /h	
Steam delivery	90 t/h	
Fuel available heat	Q _d	324,886 MJ/h
Heat to economizer	Q _e	20,160 MJ/h
Heat of vaporization	Q _c	152,730 MJ/h
Superheat	Q _s	60,210 MJ/h
Reheat	Q _{rs}	42,300 MJ/h
Waste heat in the funnel	Q _f	16,853 MJ/h
Waste heat by radiation or other	Q _i	32,632 MJ/h
Efficiency	η	0.848

Boiler Calculations:

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

$$Q_d = P_{cs} * P_g$$

$$= 42.07 * 7570.5244$$

$$= 318,492 \text{ MJ/h}$$

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

$$\begin{aligned} Q_e &= P_w * C_m * (T_e - T_i) \\ &= [94 * 1/.0013] * .00427 * (250 - 196) \\ &= 16,673 \text{ MJ/h} \end{aligned}$$

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)]

$$\begin{aligned} Q_c &= P_v * [h_v - (C_m * T_e)] \\ &= 90,000 * [2.746 - (.00427 * 250)] \\ &= 151,065 \text{ MJ/h} \end{aligned}$$

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

$$\begin{aligned} Q_s &= P_v * (h_s - h_v) \\ &= 90,000 * (3.4221 - 2.746) \\ &= 60,849 \text{ MJ/h} \end{aligned}$$

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

$$\begin{aligned} Q_{rs} &= P_v * (h_{ru} - h_{re}) \\ &= 90,000 * (3.5035 - 3.0311) \\ &= 42,516 \text{ MJ/h} \end{aligned}$$

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

$$\begin{aligned} Q_f &= [(P_a * \beta) + P_g] * C_{mf} * (T_f - T_a) \\ &= [(83726.604 * 1.225) + 7570.5244] * .001025 * (166 - 24) \\ &= 16,030 \text{ MJ/h} \end{aligned}$$

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

$$\begin{aligned} Q_i &= Q_d - Q_e - Q_c - Q_s - Q_{rs} - Q_f \\ &= 318,492 - 16,673 - 151,065 - 60,849 - 42,516 - 16,030 \\ &= 31,359 \text{ MJ/h} \end{aligned}$$

Efficiency = heat gained ÷ heat paid

$$\begin{aligned} \eta &= (Q_e + Q_c + Q_s + Q_{rs}) \div Q_d \\ &= (271,103) \div 318,492 \\ &= .85121 \end{aligned}$$

Conclusions:

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

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

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

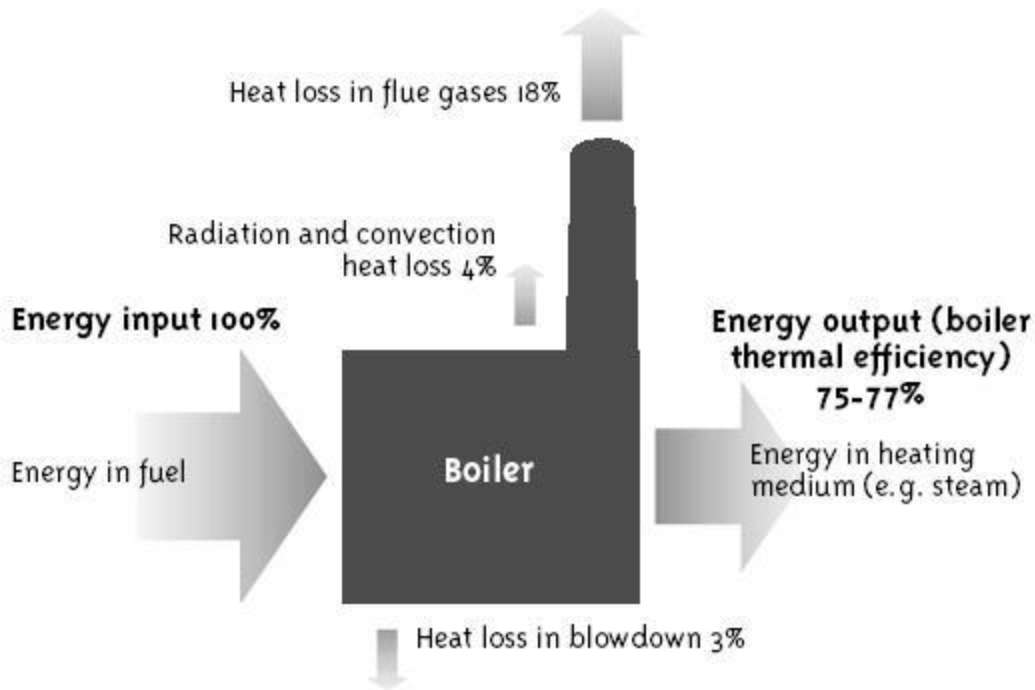
- Boiler efficiency calculations that are accurate and representative of actual boiler fuel usage require the use of proven and verified data, including:
 - Proven stack temperature
 - Accurate fuel specification
 - Actual operating excess air levels
 - Proper ambient air temperature
 - Proper radiation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

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

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

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

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



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