**Energy conservation in boilers**

**Introduction**

Boilers are steam generators which produces steam inside a closed vessel at a pressure above the atmospheric pressure. The steam generated in the boiler can be used to generate power in steam engines and steam turbines. This can be used in textile industries for sizing and bleaching etc.

**Boiler Specification**

Boiler are specified by its total capacity of holding water and the rate of steam generation. Modern boilers are rated as follows:

1. kW rating =

Rate of steam generation is specified by the equivalent evaporation. In practice, steam generation temperature is higher than the feed water temperature. Thus equivalent evaporation is having a slightly higher value than actual evaporation [7]

1. Equivalent Evaporation =

# Where *h* is the total heat of the generated steam (kJ/kg) and is the heat content of feedwater (kJ/kg) [7]

Also boiler is specified by the type of boiler used and the fuel used in boiler operation. Boiler specification is tabulated below

|  |  |
| --- | --- |
| **Typical Boiler Specification** |  |
| Boiler Make & Year | XYZ & 2003 |
| Maximum Continuous Rating | 10 TPH (F & A 1000C) |
| Rated Working Pressure | 10.54 kg/cm2(g) |
| Type of Boiler | 3 pass Fire tube |
| Fuel Fired | Fuel oil |
| *Source: Bureau of Energy Efficiency* | |

**Classification of boilers**

Boilers are classified as follows

1. **Horizontal, Vertical or Inclined**

On the basis of the axis of the boilers, these can be named accordingly. If boiler axis is placed vertical, then it is called vertical boiler. Similarly, if the axis is placed horizontal then it is termed as horizontal boiler. If the boiler axis is inclined, then it is called inclined boiler [2]

1. **Fire tube and water tube boiler**

In case of fire tube boiler, hot gases will flow inside the tubes, surrounded by water. Some of the fire tube boiler are Cochran, Lancashire, Locomotive boilers. Similarly in case of water tube boiler, water flows inside the tubes and hot gases are surrounded outside the tubes. Some example of water tube boilers are Babcock and Wilcox, Stirling, Yarrow boiler etc [2]

1. **Externally fired boiler and internally fired boiler**

In case of externally fired boiler, the furnace is located outside the shell. Example of such types of boilers are Babcock and Wilcox, Stirling boilers etc. But in case of internal fired boiler, the furnace is placed inside the shell as incase of Cochran, Lancashire boilers etc [2]

1. **Forced circulation and natural circulation**

In case of forced circulation, a pump is used to force the water to flow along the route in the boiler system. Examples of such boilers are Benson, La Mount, Velox boilers. Forced circulation helps to increase the steam generation rate. In natural circulation boilers, the flow is caused by means of density difference of hot and cold water. Examples are Babcock and Wilcox, Lancashire, Locomotive boilers etc [2]

1. **High pressure and low pressure boilers**

If steam is generated at a pressure of 15bar to 20 bar then the boiler is said to be low pressure boiler. Example Cochran, Cornish, Lancashire, Locomotive boilers etc.

If steam is generated at a pressure above 80 bar then the boiler is said to be high pressure boiler. Examples of such boilers are Babcock and Wilcox, Benson, La Mount, Velox boilers etc [2]

1. **Stationary boiler and Portable boiler**

Stationary boilers are used in generating power in thermal power plants, for plant process steam etc. Portable boilers are used at sites for temporary power generation. Example locomotive boilers.

**Boiler selection**

The factors that are to be considered during the selection of a boiler are

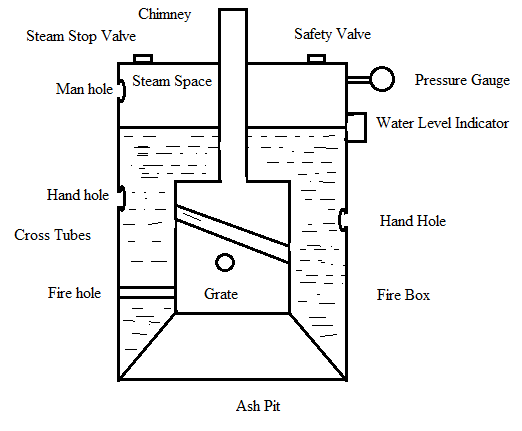
1. Steam generation rate
2. Availability of floor space
3. Accessibility for repair and maintenance
4. Comparative initial cost
5. Availability of fuel and water
6. Operating and maintenance cost
7. Erection facilities
8. Portable load factor

**2.2 Combustion in Boilers**

**(a) Fire tube boilers**

1. **Simple vertical Boiler**

It is a vertical, cylindrical shell having a fire grate just below the fire holes. Small cross tubes are connected above the grate. When coal is fired on the grate in the fire box, hot flue gases is produced which passes through the cross tubes. The outside surrounding of the fire box is filled with water which receives heat by convection and radiation. Steam thus produced pass to the steam space provided above the water level as shown in figure. Water is circulated in the boiler by density difference of hot and cold water. Safety valve is provided at the top portion of the cylindrical shell. Its function is to release the excess steam when the pressure of steam inside the boiler exceeds the rated pressure [3]



1. **Cochran boiler**

Cochran boiler consists of a cylindrical shell with a dome shaped top where the space is provided for steam. The furnace is one piece construction and is seamless. Its crown has a hemispherical shape and thus provides maximum volume of space. The fuel is burnt on the grate. The hot flue gases pass through a short flue to a combustion chamber, small horizontal smoke tubes and are then collected in the smoke box, from where they are discharged to the atmosphere through the chimney. The heat is transferred to water by radiation through the dome of the fire place an by convection from the wall of smoke tubes. On heating, the water is vaporized and converted into steam. The generated steam is collected in the steam space above the water. This steam is then taken for use through the main steam stop valve [3]

The specification of Cochran boiler is presented below in table

|  |  |
| --- | --- |
| Efficiency | 70 to 75 % |
| Diameter of the shell | 2.75 m |
| Height of the shell | 5.79 m |
| Working pressure | 6.5 bar |
| Steam capacity | 3500 kg/h |
| Heating Surface | 120 m2 |

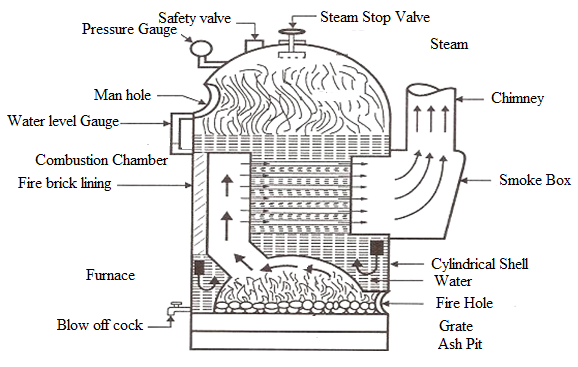


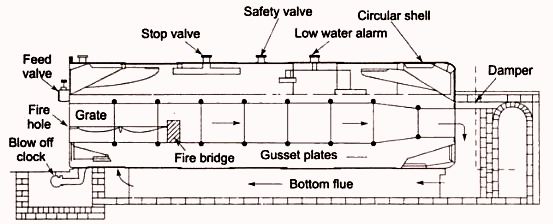
Fig. Cochran boiler

1. **Lancashire boiler**

It is a horizontal, internally fired, fire tube, natural circulation, stationary boiler. It is a widely used boiler due to its good steam generation capacity. The fuel is burnt at the grating and the hot gases travel along internal flue tubes followed by flue passage and then in downward passages. The flue gases are then collected in the chamber before they lead to the atmosphere through the chimney. The hot flue gases transfer its maximum heat contents to water during its long passages. The water is converted into steam and collected in the steam space in the shell and it is then taken out through the steam stop valve for use. This type of boiler can be used for power generation at a moderate steam pressure of 15 bar [3]

The specification of Lancashire boiler is presented below in table

|  |  |
| --- | --- |
| Efficiency | 50 to 70 % |
| Diameter of the shell | 2 to 3 m |
| Length of the shell | 7 to 9 m |
| Maximum working pressure | 15 bar |
| Steam capacity | 9000 kg/h |

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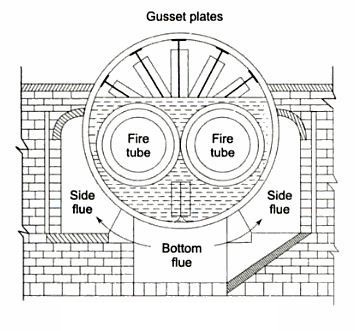
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Fig. Lancashire Boiler

1. **Cornish Boiler**

This type of boiler is similar to Lancashire boiler. It is a horizontal, fire tube, internally fired, natural circulation, stationary boiler. The flue tubes containing the furnace are located in the centre of the boiler shell. The products of combustion from the fire grate first pass forward through the central flue tube and then return by the two side flues to the front of the boiler and again pass to the back end of the boiler along the bottom flue and finally get discharged through chimney.

The specification of Cornish boiler is presented below in table:

|  |  |
| --- | --- |
| Number of flue tubes | one |
| Diameter of the shell | 1.25 to 1.75 m |
| Length of the shell | 4 to 7 m |
| Pressure of the steam | 10.5 bar |
| Steam capacity | 6500 kg/h |

Boiler mountings that are provided on this type of boiler are:

1. Steam stop valve, (b) Manhole, (c) Blow off cock, (d) Fusible plug, (e) Water gauge, (f) Pressure gauge, (g) Safety valve, (h) Low water high steam safety valve

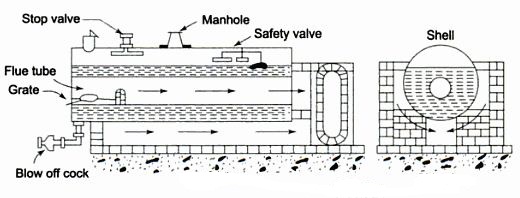
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Fig. Cornish boiler

1. **Locomotive Boiler**

It is an internally forced horizontal, multi tube mobile, fire tube boiler. The flue gases are formed due to combustion of coal in presence of air on the grate. These gases rise up ans are deflected by a rick arch for their proper distribution to pass through the smoke tubes and over superheated tubes and then finally get discharged into the atmosphere through the chimney. The steam generated is collected in the steam space provided above the water in the boiler drum. A steam regulator is located in the steam dome and is operated by a long regulator rod from the engine cabin by the driver. When this valve is opened, the wet steam passes through the superheater header and to the superheated tubes located in a smoke stube. As steam passes through superheated tubes, it picks up additional heat and becomes superheated. The superheated steam is then supplied to the steam engine.

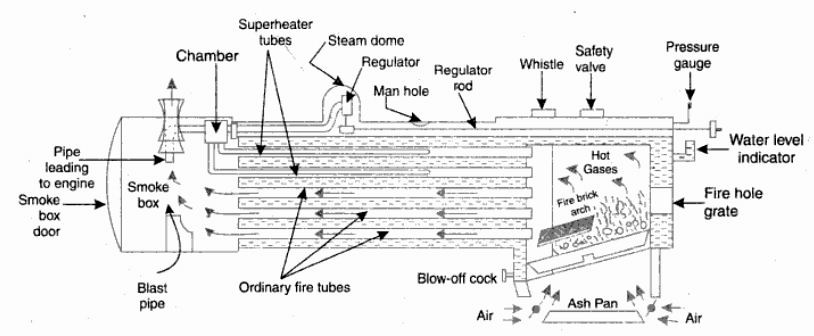
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Fig. Locomotive Boiler

1. **Scotch marine boiler**

This type of boiler consists of a cylindrical shell that houses one to four cylindrical, corrugated steel furnaces. These furnaces are internally fired and surrounded by water. A combustion chamber is located above the furnace and it is also surrounded by water. The boiler has a number of tubes passing from the front plate of combustion chamber to the front plate of the shell. These tubes are surrounded by water. The fuel burns in the furnace on the grate. The hot flue gases resulting due to burning of fuel move to the combustion chamber. Then they travel to the smoke box through the fire tubes and finally get discharged to the atmosphere through uptake and chimney. The heat is transferred to water around the furnace, combustion chamber, and fire tube and steam is generated.

**(b) Water Tube Boiler**

**(i) Babcock and Wilcox Boiler**

The water is pumped by the feed pump and it enters the drum through the feed check valve up to the per specified level so that the headers and tubes are flooded always. When the combustion takes place above the grate, the products of hot gases come out and rush through each component of the combustion chamber. Hence, the front portion of the tubes has highest temperature and the rear portion has the lowest. When water is heated inside the tubes, it becomes lighter and rises up in the tube. Due to continuous heat supply, some of the water get vapourized into steam inside the tubes and the mixture of water and steam enters the boiler drum through the uptake header. The cold water from the boiler drum comes down through the downtake header and enters the lower end of the water tubes for getting heated further. The steam generated gets collected un the steam space above water space in the boiler drum. In order to remove all water particles from the steam. It is finally passed through the superheater tubes for its superheating. The superheated steam is then available for use.

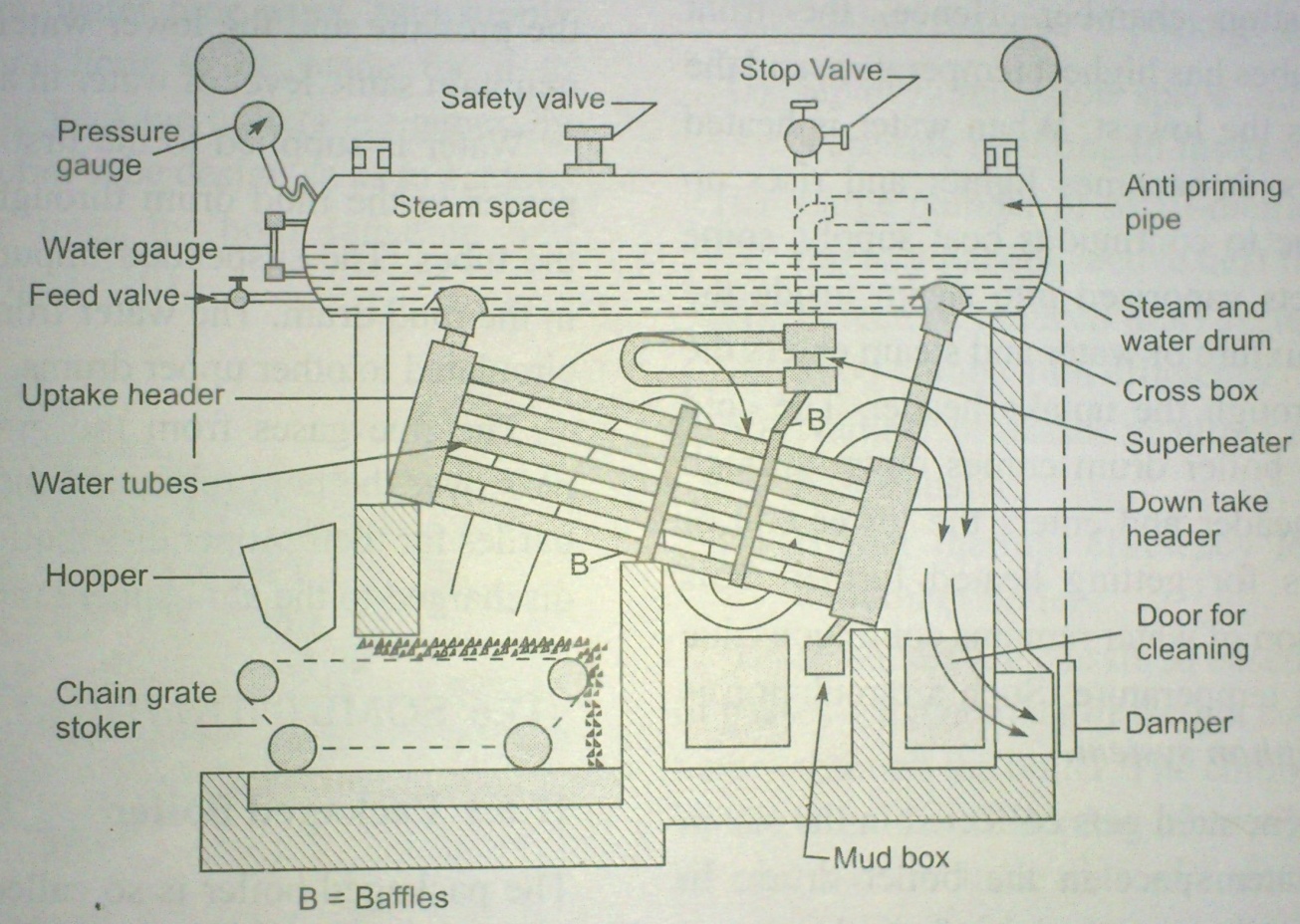


Fig: Locomotive Boiler

1. **Stirling Boiler**

It has two water steam drums at the top and a mud drum at the bottom. These drums are connected by a number of small bent tubes through which water flows. The steam drum containing water and steam are connected in series by the tubes above and below the water level. The upper tubes are steam- circulating tubes and are used to equalize the pressure and the lower water circulating tubes maintain same level of water in all drums. Water is supplied to the first drum, which the passes to the mud drum through the rear bank of the tubes. The suspended impurities are collected in the mud drum. The water from the mud drum is circulated to other upper drums. The flue gases drum the grate rises above and pass over the bent tubes and then are deflected by baffles for their proper distribution. Finally flue gases are discharge to the atmosphere through the chimney.

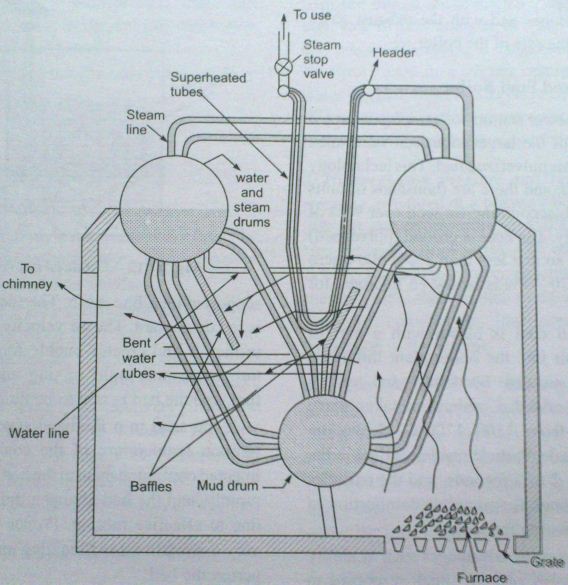


Fig: Stirling boiler

**(c) High Pressure Boilers**

1. **La Mont Boiler**

It is a water tube and high pressure boiler. Centrifugal pump is used to circulate the water. The feed water is circulated through the water walls and drums continuously and prevents the tubes from being overheated. The feed water passes through the economizer. Most of the sensible heat is supplied to the feed water in the economizer. Then water enters the boiler drum. A water circulation pump draws water from the drum and delivers to the tubes of the evaporating section, where water is heated in a large number of small diameter tubes and a mixture of steam and water is formed. The mixture is stored in the drum. The convective superheater draws the wet steam from the drum and heats the steam for its superheating. The superheated steam is supplied to the prime mover.

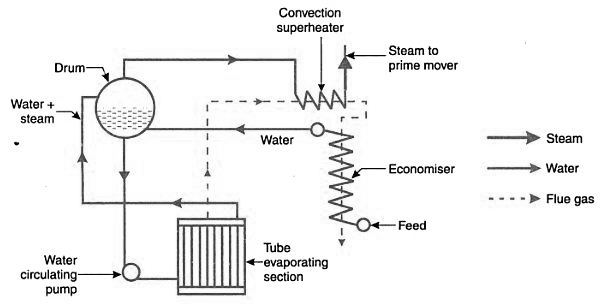


Fig. LaMont Boiler

1. **Loeffler Boiler**

In Loeffler boiler, water is forced to flow inside the tube. Figure shows the different parts of the boiler. Feed water pump helps in forcing the water to pass through the economizer where water after being heated is passed to the evaporator drum. About one third of the superheated steam coming from the convective superheater is passed through the evaporator. This superheated steam helps in evaporating the heated water inside the evaporator drum and the remaining two third of the superheated steam is used to run the prime mover. Saturated steam produced inside the evaporator drum is forced by the steam circulation pump to pass through the radiant superheater and convective superheater. The hot flue gases generated will glide to the atmosphere through the chimney.

Deposition of salt and sedimentation can be seen inside the boiler shell of Loeffler Boiler. This results in decreasing the heat generation capacity due to reducing heat transfer rate. Overheating of tubes is mainly due to salt deposition.

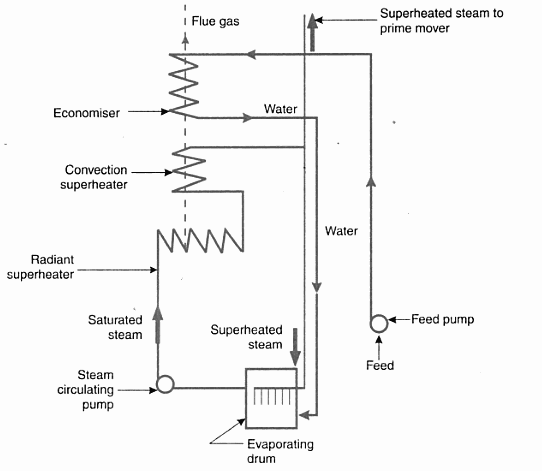
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Fig. Loeffler Boiler

1. **Benson Boiler**

It is also a water tube boiler. It is having a feed pump, economiser, radiant parallel tube section, transit section, convective superheater. Water is being fed into the economizer section of the boiler with the help of feed pump where water is heated and passed to the radiant parallel tube section. In this section, the heated water is is partly evaporated. The mixture of water and steam is then passed through the transit section where it is completely converted into saturated steam. This saturated steam then directed towards the convective superheater where temperature will increase to produce superheated steam, finally which can be used in the prime mover.

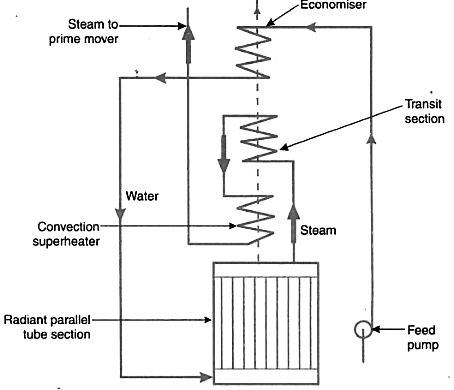


Fig: Benson boiler

**Supercritical Biolers**

The operating pressure of this type of boilers are 221 bar. It consists of and economizer and superheater. These types of boilers are used in industrial purpose.

**Comaprative advantages and disadvantages of water tube and fire tube boiler [6]**

|  |  |  |  |
| --- | --- | --- | --- |
| **Sl. No** | **Parameters** | **Fire tube boiler** | **Water tube Boiler** |
| 1 | Rate of steam generation | Less rapid | More rapid |
| 2 | Suitability for power plants | Unsuitable | Suitable. All major power plants are based on these |
| 3 | Operating steam pressure | Limited to 25 kgf/cm2 | can exceed 25 kgf/cm2 |
| 4 | Chance of explosion | Less | More |
| 5 | Risk of damage due to explosion | Much more | Much less |
| 6 | Water treatment | Not very necessary | Required |
| 7 | Floor space requirement | Much | Less |
| 8 | Skill required for efficient operation | Less | More |
| *Source: Boiler operation Engineering* | |  |  |

**2.3 Performances evaluation of Boilers**

Boiler performance can be evaluated on the basis of evaporating capacity, efficiency and heat balance sheet. Poor combustion, heat transfer surface fouling and poor operation leads to the decrease in performance of boiler. Poor performance can also be seen in new boilers. This may be due to water quality, fuel quality etc. Boiler efficiency test can be performed for testing the performance evaluation of boilers.

**Boiler efficiency:**

Thermal efficiency of boiler is defined as the percentage of heat input that is effectively utilised to generate steam. Boiler efficiency is computed as per the Indian Standards (IS 8753). There are two methods of assessing boiler efficiency.

***Direct method:*** Where the energy gain of the working fluid (water and steam) is compared with the energy content of the boiler fuel. This is also known as 'input-output method' due to the fact that it needs only the useful output (steam) and the heat input (i.e.fuel) for evaluating the efficiency. This efficiency can be evaluated using the formula [1]

Boiler Efficiency = × 100 %

Boiler efficiency is calculated on the basis of the parameters monitored during the test run. The parameters for calculating boiler efficiency by direct method are as follows.

1. Quantity of steam generated per hour (Q) in Kg/hr.

2. Quantity of fuel used per hour (q) in Kg/hr.

3. The working pressure (in Kg / cm2) and superheat temperature if any

4. The temperature of feed water (°C)

5. Type of fuel and gross calorific value of the fuel (GCV in Kcal/kg of fuel)

Boiler efficiency (η) =

*where*, hg  is the enthalpy of saturated steam in kcal/kg of steam, hf  is the enthalpy of feed water in kcal/kg of water and GCV is the gross calorific value of fuel used.

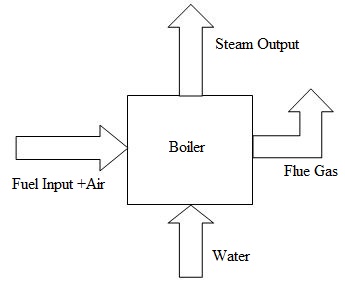


Fig: Direct Method Testing

**Advantages of direct method:**

1. Plant people can evaluate quickly the efficiency of boilers
2. Requires few parameters for computation
3. Needs few instruments for monitoring

**Disadvantages of direct method:**

1. Does not give clues to the operator as to why efficiency of system is lower
2. Does not calculate various losses accountable for various efficiency levels

***Solved Problem (Direct Method)***

*Question 1.*Find out the efficiency of the boiler by direct method with the data given below: –

Type of boiler : Coal fired

**Heat Output data**

Quantity of steam (dry) generated : 8 TPH

Steam pressure (gauge) / temp : 10 kg/cm2 (g)/ 180°C

Feed water temperature : 85°C

Enthalpy of steam at 10 kg/cm2 pressure : 665 kCal/kg (saturated)

Enthalpy of feed water : 85 kCal/kg

**Heat Input data**

Quantity of coal consumed : 1.8 TPH

GCV of coal : 3200 kCal/kg

Boiler Efficiency (η) =

= =80 %

Evaporation ratio = = = 4.44

**Indirect method for testing of boiler efficiency:**

Due to some limitation in calculating the efficiency of boiler by direct method, it is now a days common to determine the boiler efficiency by indirect method or heat loss method, since this is an easy measuring process of calculating the losses occurring in the boilers. In case of indirect method, testing of boiler efficiency is done with some standards such as British Standards, BS 845: 1987 and USA Standard is ASME PTC-4-1 Power Test Code Steam Generating Units. This method is also useful in determining boiler efficiency since a slight error in measuring the heat loss does not make a huge difference in boiler efficiency.

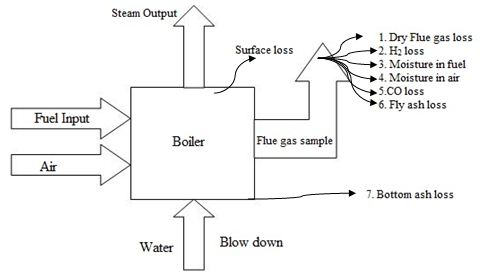


Fig. Indirect method of testing

Some of the losses that persists in indirect method of calculation of boiler efficiency of solid, liquid and gas fired boilers are listed below:

L1 – Losses due to dry flue gas

L2 – Losses due to hydrogen in fuel

L3 – Losses due to moisture in fuel

L4 – Losses due to moisture in air

L5 – Losses due to carbon monoxide

L6 – Losses due to surface radiation, convection and other unaccounted losses

In addition to the above, some losses that occur in solid fired boilers are

L7 – Losses due to unburnt fly ash

L8 – Losses due to unburnt bottom ash

Thus boiler efficiency is given by = 100 – (L1 + L2+ L3+ L4+L5+L6+L7+L8)

Table: 1 Boiler performance test can be measured by the following instrument

|  |  |  |
| --- | --- | --- |
| **Instrument** | **Type** | **Measurements** |
| Flue gas analyzer | Portable or fixed | Percentage CO2, CO and O2 |
| Temperature indicator | Thermocouple, liquid in glass | Flue temperature, flue gas temperature, combustion air temperature, boiler surface temperature, steam temperature |
| Draft gauge | Manometer, differential pressure | Amount of draft used or available |
| Total dissolved solids (TDS) meter | Conductivity | Boiler water TDS, feed water TDS, make up water TDS |
| Flow meter | As applicable | Steam flow, water flow, fuel flow, air flow |
| *Source: Bureau of Energy Efficiency* | |  |

**Calculation procedure for finding out the boiler efficiency by indirect method**

**Problem:** The following are the data collected for a typical oil fired boiler.

|  |  |
| --- | --- |
| Type of boiler | Oil fired |
| Ultimate analysis of Oil | C : 84 %, H2: 12%, S: 3%, O2: 1 % |
| Gross calorific value of Oil | 10200 kCal/kg |
| Pressure of the generated steam | 7 kg/cm2 (g) -saturated |
| Enthalpy of steam | 600 kCal/kg |
| Feed Water temperature | 600C |
| Oxygen in flue gas | 7 % |
| CO2 in flue gas | 11 % |
| Flue gas temperature | 2200C |
| Ambient temperature | 270C |
| Humidity of air | 0.018 kg/kg of dry air |

Find out the efficiency of the boiler by indirect method and Boiler Evaporation ratio.

**Solution:**

**Step I: Determination of theoretical air requirement**

= [ (11.6 C ) + { 34.8 × ( H2 - )} + (4.5 × S)] / 100 kg of air /kg of oil

= [ (11.6 × 84) + { 34.8 × (12 - )} + (4.35 × 3)] / 100 kg of air /kg of oil

= 14 kg of air/ kg of oil

**Step II: Determination of % excess air supplied**

Excess air Supplied (EA) =

= = 50 %

**Step-III: Find the Actual mass of air supplied (AAS)**

**= [ 1+**  ] × Theoretical air

= **[ 1+**  ] × 14

= 21 kg of air/ kg of oil

**Step-IV: Estimation of all losses**

1. **Dry flue gas loss**

Percentage heat loss due to dry flue gas =

where m = mass of dry flue gas in kg/kg of fuel

= mass of CO2 + mass of SO2 + mass of N2 + mass of O2

= + + + [ (21- 14)

= 21 kg /kg of oil

Percentage heat loss due to dry flue gas =

= 9.14 %

1. **Heat loss due to evaporation of water formed due to H2 in fuel**

**=**

=

=7.10 %

( c) **Heat loss due to moisture present in air**

**=**

=

= 0.322 %

1. **Heat loss due to radiation and other unaccounted losses**

For a small boiler heat loss due to radiation and other unaccounted losses is estimated to be 2%.

Boiler efficiency is estimated from the calculated value as presented below

1. Heat loss due to dry flue gas : 9.14 %
2. Heat loss due to evaporation of water formed due to H2 in fuel : 7.10 %
3. Heat loss due to moisture present in air : 0.322 %
4. Heat loss due to radiation and other unaccounted loss : 2 %

Therefore **Boiler efficiency** = 100 – ( 9.14 + 7.10 + 0.322 + 2 ) **= 81 %**

**Evaporation ratio =**

=

**= 14.11**

Equivalent Evaporation: Equivalent evaporation is defined as the amount of dry and saturated steam generated from feed water at 1000C at normal atmospheric pressure. Or in other words, it is defined as the amount of steam generated from and at 1000C

**Therefore equivalent evaporation (=**  =

Where = =

= equivalent mass of dry and saturated steam generated from and at 1000C.

*h* = enthalpy of steam.

= enthalpy of water at feed temperature.

**2.4. Feed water treatment:**

To get good quality of steam feed water should be cleaned so to remove any impurities present. The impurities may be dissolved gases, mineral and salts, mineral acids. Their presence may cause scale formation, corrosion, carry over and embrittlement.

**Methods of feed water treatment**

The various methods of feed water treatment for removing the impurities are discussed below

1. **Mechanical treatment**

(i) *Sedimentation*: Big tanks are being used for allowing water to stand at stand still so that solid particles settles at the bottom of the boiler. The accumulated solid particle at the base can be removed from the bottom either periodically or continuously.

(ii) *Coagulation:* Coagulation of minute colloidal suspensions make them settle out easily. Sedimentation or filtration process can be improved by adding coagulation like aluminum sulphate or sodium sulphate. Gelatinous material are formed by reaction between salts and alkanity which makes small particles adhere to each other, forming larger particles which settles out or filter out easily.

(*iii*) *Filtration:* It is the process of passing water through a bed of fine sand and then a layer of gravels. Filtration helps in removing the suspended matter which are unable to remove by the process of sedimentation. Sedimentation of suspended particles on the filter material by leaving clear water as it drains from the bottom. The filter material must be washed periodically in order to remove the dirt.

1. **Thermal treatment**

*(i)* *Deaeration:* The process of removing dissolved oxygen is known as deareation. Dissolved oxygen can be removed by heating water at a temperature of 1100C.

*(ii)* *Distillation by evaporation:*

1. **Chemical treatment**
2. Cold lime soda softening process,
3. Hot lime soda softening process
4. Lime phosphate softening process,

(*iv*) Ion exchange process

1. **Demineralisation**
2. **Blow down**

*(i)* Hot lime soda and hot zeolite process

*(ii)* Adding acid to control alkalinity [5]

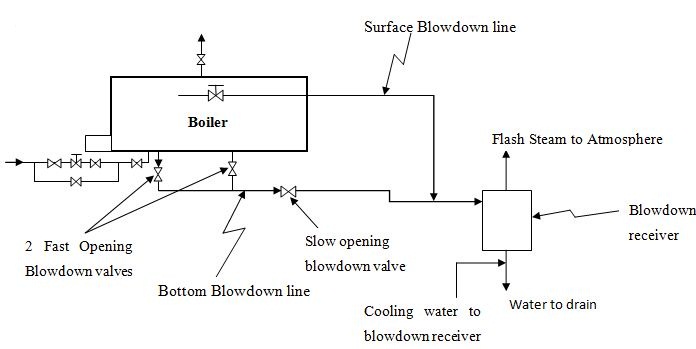
**2.5 Blow down**

The purpose of the boiler is to produce steam without any danger to human from getting overheated inside the boiler. The term blow down refers to the discharging of water from boiler in order to remove the suspended solids and bottom sludge from the boilers. In case of fire tube boiler, sludge is accumulated in the bottom, whereas for a water tube boiler, sludge is accumulated in the mud drum. Blow down is necessary at regular basis to prevent the boiler tube from choking and overheating

**Process of blow down water**

There are two processes by which water can be discharged to maintain the sludge or suspended particle concentration inside the boiler

1. *Bottom blowdown*: It refers to the removal of slug from the bottom of the boiler. This process is done at regular basis. Vessel or tube failure due to increase in heat can be stopped by removing the sludge regularly.
2. *Surface blowdown:* It refers to the removal of suspended solid from the surface of the water inside the boiler. Surface blowdown requirement mostly depends upon the amount of impurities present in the water. If excess amount of impurities are present, then greater amount of surface blowdown is required.



Conventional methods for blowing down the boiler depend on two kinds of blowdown – intermittent and continuous

**Intermittent Blowdown:** The intermittent blown down is given by manually operating a valve fitted to discharge pipe at the lowest point of boiler shell to reduce parameters (TDS or conductivity, pH, Silica and Phosphates concentration) within prescribed limits so that steam quality is not likely to be affected. In intermittent blowdown, a large diameter line is opened for a short period of time, the time being based on a thumb rule such as “once in a shift for 2 minutes”. Intermittent blowdown requires large short-term increases in the amount of feed water put into the boiler, and hence may necessitate larger feed water pumps than if continuous blow down is used. Also, TDS level will be varying, thereby causing fluctuations of the water level in the boiler due to changes in steam bubble size and distribution which accompany changes in concentration of solids. Also substantial amount of heat energy is lost with intermittent blowdown. [1]

**Continuous Blowdown:** There is a steady and constant dispatch of small stream of concentrated boiler water, and replacement by steady and constant inflow of feed water. This ensures constant total dissolved solid and steam purity at given steam load. Once blow down valve is set for a given conditions, there is no need for regular operator intervention. Even though large quantities of heat are wasted, opportunity exists for recovering this heat by blowing into a flash tank and generating flash steam. This flash steam can be used for preheating boiler feed water or for any other purpose. This type of blow down is common in high-pressure boilers [1]

Slug formation or the suspended particle concentration inside the boiler can be maintained by knowing the quantity of blowdown required from the boiler. This can be calculated as follows:

Blow down (%)

|  |  |  |
| --- | --- | --- |
| Table: Recommended TDS level for various boilers | |  |
| **Sl. No** | **Boiler type** | **Maximum TDS (ppm)** |
| 1 | Lancashire | 10000 |
| 2 | Smoke and water tube boilers (12 kg/cm2) | 5000 |
| 3 | Low pressure water tube boiler | 2000 - 3000 |
| 4 | High pressure water tube boiler with superheater etc | 3000 - 3500 |
| 5 | Package and economic boilers | 3000 |
| 6 | Coil boilers and steam generators | 2000 |
| *Source: Bureau of Energy Efficiency* | |  |

**Energy Conservation opportunities in boiler**

There are certain areas in boiler system where there is an opportunity in energy saving.The various areas are combustion, heat transfer, avoidable losses, high auxiliary power consumption, water quality and blowdown.

Examining the following factors can indicate if a boiler is being run to maximize its efficiency:

1. ***Stack temperature***

The stack temperature should be such that water vapor in the exhaust does not condenses on the stack walls. Presence of sulphur in fuel can lead to sulphur dew point corrosion if the stack temperature is very low. Waste heat can be recovered if the stack temperature is greater than 200°C.

1. ***Feed water preheating using economizer***

In modern boiler systems, the temperature of the flue gas ranges from 2000C to 3000C. Maintaining the flue gas temperature of around 2000C, corrosion due to formation of suphur oxides is absent on the heat transfer surface. As for example, economizer can be used to reduce the temperature of a older model shell boiler from 2600C to 2000C, increases the feed water temperature by 150C, which helps in increasing the overall efficiency by 3%. But for a modern 3 pass shell boiler using natural gas as a fuel, where temperature of the flue gas is reduced from 1400C to 650C by using an economizer, thermal efficiency is increased by 5%. It can be concluded from the above discussion that energy can be saved by proper installation of the type of boiler and the type of fuel being used during the process.

1. ***Combustion air preheat***

In order to improve thermal efficiency by 1%, the combustion air preheating is done where temperature must be raised by 20 °C. Most gas and oil burners used in a boiler plant are not designed for high air preheat temperatures. Modern burners can withstand much higher combustion air preheat, so it is possible to consider such units as heat exchangers in the exit flue as an alternative to an economizer, when either space or a high feed water return temperature make it viable [3].

1. ***Incomplete combustion***

Incomplete combustion results from insufficient supply of air or from surplus of fuel or poor distribution of fuel leading to smoke formation. In the case of oil and gas fired systems, CO or smoke (for oil fired systems only) with normal or high excess air indicates burner system problems [3]. Improper mixing of fuel may be one of the reasons for incomplete combustion. Improper viscosity, worn tips, carbonization on tips and deterioration of diffusers or spinner plates may be due to poor oil fires. Again incomplete combustion may be due to non uniform fuel size. Large lumps may results in poor air distribution that are unable to burn completely, while blocking of air passage may results from small pieces and fine fuel size. In sprinkler stokers, stoker grate condition, fuel distributors, wind box air regulation and over-fire systems can affect carbon loss [3].

1. ***Excess air control***

Excess air is necessary for complete combustion. Flame temperature is reduced by the excess air which means that the temperature difference between the combustion gasses and the water in a boiler is decreased. As the excess air increased, the stack temperature increases and CO increases which results in decrease in boiler efficiency. Boiler efficiency varies with furnace design, type of burner, fuel and process variables. It can be determined by conducting tests with different air fuel ratios.

Controlling excess air to an optimum level always results in reduction in flue gas losses; for every 1% reduction in excess air there is approximately 0.6% rise in efficiency.Various methods are available to control the excess air:

* Portable oxygen analysers and draft gauges can be used to make periodic readings to guide the operator to manually adjust the flow of air for optimum operation. Excess air reduction up to 20% is feasible.
* The most common method is the continuous oxygen analyzer with a local readout mounted draft gauge, by which the operator can adjust air flow. A further reduction of 10–15% can be achieved over the previous system.
* The same continuous oxygen analyzer can have a remote controlled pneumatic damper positioner, by which the readouts are available in a control room. This enables an operator to remotely control a number of firing systems simultaneously [1]

1. ***Radiation and Convection heat loss***

The flame temperature inside the boiler is very high. Heat transfer from the boiler to the surrounding is by conduction and the hot gases transfer heat by convection and radiation. Heat transfer by radiation in the boiler is governed by flame temperature, flame shape and fouling of heat transfer surface. Heat loss from the boiler mainly depends on the surface area of the boiler. Effective insulation can reduce heat loss through boiler shell. Heat loss in modern boiler design is around 1.5% of the gross calorific value at full rating. If the capacity of the boiler is increased by 25%, then there will be an increase in 6%.

1. ***Automatic blowdown control***

Using automatic blowdown control helps in minimizing the heat loss from the boiler and thus increasing the boiler efficiency, while maintaining the acceptance level of the dissolved solid boiler system. Installed that sense and respond to boiler water conductivity and pH. A 10% blow down in a 15 kkg/cm2 boiler results in 3% efficiency loss [1].

1. ***Reduction of Scaling and Soot Losses***

Scaling and soot formation in the boiler tube reduces the heat transfer which is indicated by the stack temperature. Excessive soot build up and scale formation increases the stack temperature. By cleaning the tubes at regular basis, heat transfer can be increases. With every 220C increase in stack temperature, there is an efficiency loss by 1%. Thus a dial type thermometer at the base of the stack should be installed for monitoring the exhaust flue gas temperature [1].

1. ***Reduction of Boiler Steam Pressure***

Steam is generated at pressures normally dictated by the highest pressure / temperature requirements for a particular process. In some cases, the process does not operate all the time, and there are periods when the boiler pressure could be reduced. The energy manager should consider pressure reduction carefully, before recommending it. Adverse effects, such as an increase in water carryover from the boiler owing to pressure reduction, may negate any potential saving. Pressure should be reduced in stages, and no more than a 20 percent reduction should be considered [1]

1. ***Variable Speed Control for Fans, Blowers and Pumps***

Variable speed control is an important means of achieving energy savings. Generally, combustion air control is effected by throttling dampers fitted at forced and induced draft fans. Though dampers are simple means of control, they lack accuracy, giving poor control characteristics at the top and bottom of the operating range. In general, if the load characteristic of the boiler is variable, the possibility of replacing the dampers by a Variable speed drive should be evaluated [1]

1. ***Effect of Boiler Loading on Efficiency***

Boiler efficiency is maximum when it is operated at two-third of the full load. Deceasing the boiler load decreases the boiler efficiency. Factors affecting the boiler efficiency are:

* As the load falls, so does the value of the mass flow rate of the flue gases through the tubes. This reduction in flow rate for the same heat transfer area, reduced the exit flue gas temperatures by a small extent, reducing the sensible heat loss.
* Below half load, most combustion appliances need more excess air to burn the fuel completely. This increases the sensible heat loss

1. *Boiler replacement*

The potential savings from replacing a boiler depend on the anticipated change in overall efficiency. A change in a boiler can be financially attractive if the existing boiler is :

* old and inefficient
* not capable of firing cheaper substitution fuel
* over or under-sized for present requirements
* not designed for ideal loading conditions [1]

**Problems**

*Question: Calculate the efficiency of a boiler.*

1. *Boiler*

*Mass of the feed water = 2060 kg/h*

*Mass of coal burned = 227 kg/h*

*Calorific value of coal =30000 kJ/kg*

*Enthalpy of steam produced = 2750 kJ/kg*

*Exit temperature of feed water = 1050C*

*Solution:*

**Heat produced by complete burning of fuel**

= × CV

= 227 × 30000 = 681 × 104 kJ/h

**Heat utilized in generation of steam**

= ×

= 2060 × (2750 – 4.187 ×105 )

= 475.93 × 104 kJ/h

Therefore Boiler efficiency (η) =

= = 0.6988 = **69.88%** **Ans.**

**Exercise Problem**

1. *In a boiler trial of one hour duration, the following observations were made:*

*Steam generated = 5250 kg*

*Fuel burnt = 695 kg*

*Calorific value of fuel = 30200 kJ/kg*

*Steam condition (x) = 0.94*

*Boiler (steam) pressure = 11 bar*

*Calculate the (a) equivalent evaporation per kg of coal and (b) thermal efficiency of boiler*

*Given the properties of steam*

*At 12bar T sat = 1880C*

*h f = 798.64 kJ/kg*

*h fg = 1986.19 kJ/kg*

*At 47 bar h f 1 = 196.8 kJ/kg*

***Ans:*** *8.26 kg/kg of fuel****, 61.75%***

**Questions**

1. *How boilers are classified on the basis of tube content*
2. *What is the main difference between horizontal boiler and vertical boiler*
3. *State the energy saving opportunities in pumps and fans*
4. *Define boiler efficiency, equivalent evaporation of a boiler, evaporative capacity.*
5. *Discuss the various types of heat losses in a boiler?*
6. *How do you measure boiler efficiency using direct method?*
7. *What are the factors that affecting the selection of a boiler*
8. *Give some example of high pressure boiler*
9. *Classify different types of boiler*
10. *Explain the energy balance in a boiler. How can its performance be improved*
11. *Explain the working of a Cochran boiler with the help of a neat sketch*
12. *Explain the working of a simple vertical boiler with the help of a neat sketch*
13. *List out the merits and demerits of direct method of boiler efficiency*
14. *State two causes for rise in exit flue gas temperature in a boiler*
15. *List out any four loss components in a heat balance of a boiler.*

***Objective questions:***

1. *Boiler efficiency is defined as*

*(c )*

1. *Enthalpy of evaporation at 1000C is*
2. 2528 kJ/kg (b) 2275 kJ/kg (c) 2572 kJ/kg (d) 2257 kJ/kg
3. *Equivalent evaporation is defined as*
4. Steam generated at 1000C
5. Dry and saturated steam generated at 1000C
6. Steam generated at 1 bar and at 1000C
7. None of the above
8. *A closed vessel is termed as boiler if*
9. Its pressure exceeds 10 bar (b) its volume exceeds 22.75 litre

(c ) it consists of mountings (d) it consists of accessories

1. *In a fire tube boiler*
2. Water flows through the tubes (b) flue gas flows through the tubes

( c) Fire is produced in the tubes (d) flue gas surrounds the tube

1. *In a water tube boiler*
2. Water flows through the tubes (b) flue gas flows through the tubes

( c) Fire is produced in the tubes (d) flue gas surrounds the tube

1. *A Cornish boiler is*
2. Multi –tubular boiler (b) water tube boiler

(c) a fire tube boiler (d) flue gas surrounds the tube

1. *A boiler is said to be high pressure boiler when*

(a ) Pressure of the steam is less than 80 bar (b) Pressure of the steam is more than 80 bar

1. Which one of the following is a water tube boiler
2. Babcock and Wilcox boiler (b) Stirling boiler

(c ) La Mont Boiler (d) All of the above

1. *The rate of steam generation in water tube boilers as compared to fire tube boilers is*
2. Less (b) Same (c) more (d) none of the above

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