جامعة فهد بن سلطان
FAHAD BIN SULTAN UNIVERSITY

MECH 452 Power Plants

CHAPTER 5

Steam Power Plants - 4

Boiler or Steam Generator,

Course lectures Slides prepared by

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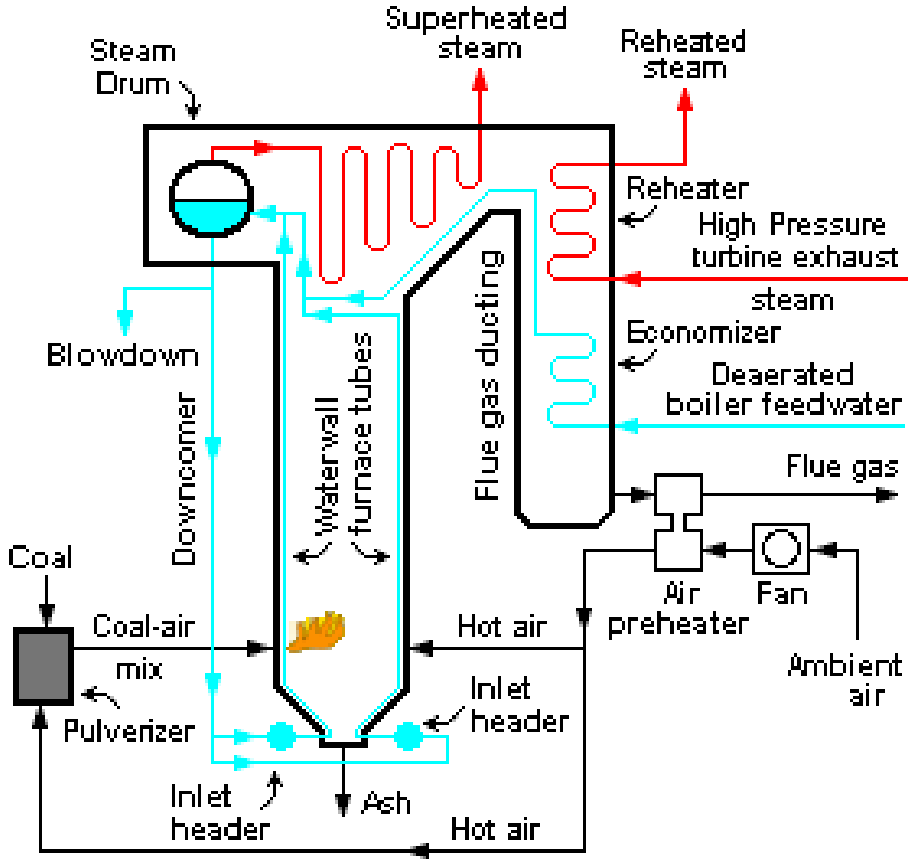
A boiler or steam generator is a device used to create steam by applying heat energy to water. Although the definitions are somewhat flexible, it can be said that older steam generators were commonly termed *boilers* and worked at low to medium pressure(0.069-20.684)bar

•but at pressures above this, it is more usual to speak of a *steam generator*



Basics

Volume of one unit mass of steam is thousand times that of water, When water is converted to steam in a closed vessel the pressure will increase. Boiler uses this principle to produce high pressure steam.

- Conversion of Water to Steam evolves in three stages.
- Heating the water from cold condition to boiling point or saturation temperature –sensible heat addition.
- Water boils at saturation temperature to produce steam -Latent heat addition.
- Heating steam from saturation temperature to higher temperature called Superheating to increase the power plant output and efficiency.

Terminology

A boiler is a closed vessel in which water is heated, a steam is generated, or steam is superheated (or any combination of these) under pressure or vacuum by the application of heat from combustible fuels, electricity, or nuclear energy. Boilers are generally subdivided into four classic types, residential, commercial, industrial, and utility:

1 –Residential boilers produce low-pressure steam or hot water primarily for heating application in private heating.

2 –Commercial boilers produce steam or hot water primarily for heating application in commercial use, with incidental use in process operation.

3 –industrial boilers steam or hot water primarily for process application with incidental use as heating.

4 –utility boilers produce steam primarily for the production of electricity.

Boiler components

To understand the operation of a boiler, it is necessary to observe what happens from input to output of the unit. Several cycles are involved in the complete operation of the unit:

1. The heat cycle
2. The water and steam cycle
3. The boiler water circulation cycle.

These cycles all interacts to produce the output of the boiler. Fuel and water are brought to the unit; water is heated to its final *pre-designated condition* (water and/or steam) and transported to the point of it's end use.

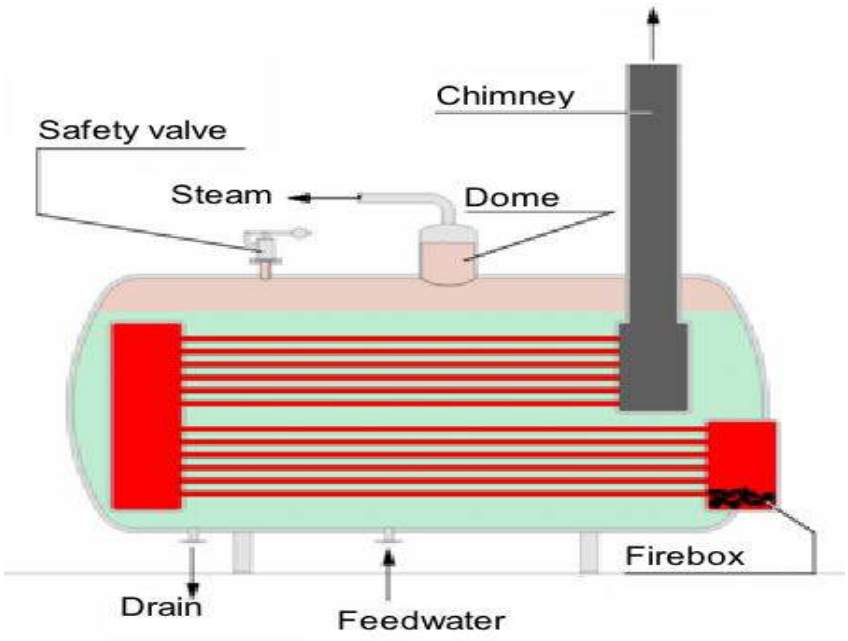
When the heat has been taken out of the water, the remaining steam and water mixture (or condensate), if usable is returned to the unit and recycled.

The major components generally incorporated in an industrial or utility boilers are :

1. Furnace
2. Boiler section
3. Super-heater
4. Air pre-heater
5. economizer

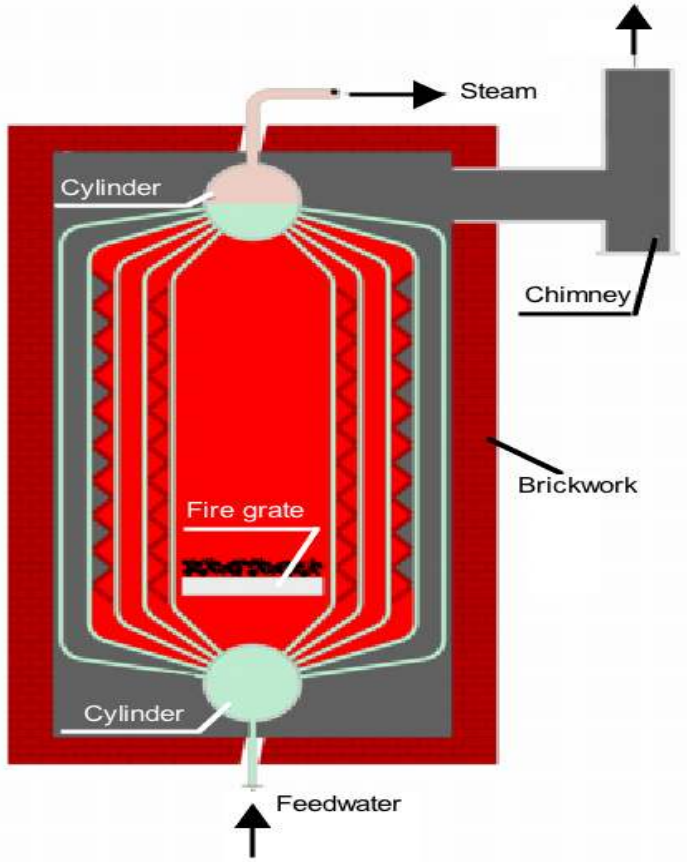
1 a -Fire tube boilers

- *Fire tube boilers have almost become extinct; however this can be classified as :*
- Locomotive boilers, which ruled rail transportation before diesel and electric engine came.
- Industrial boilers, mainly used for green projects where initial steam is required
- Domestic use boilers



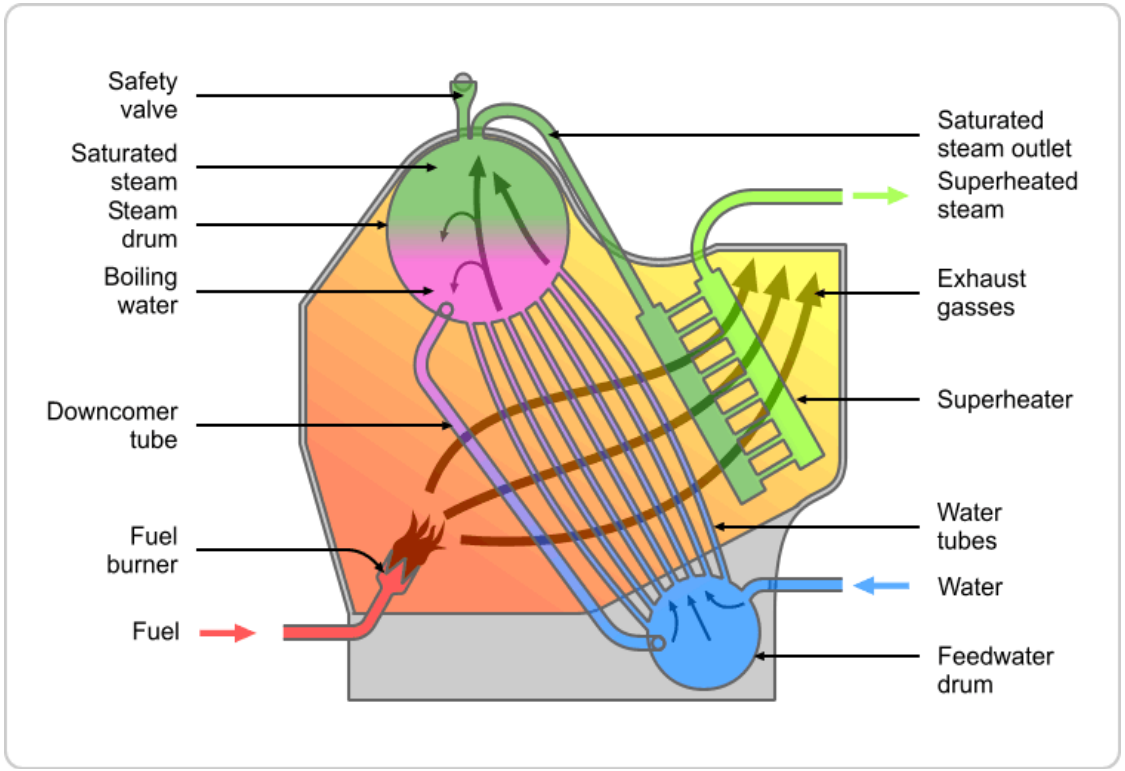
1 b -Water tube boilers

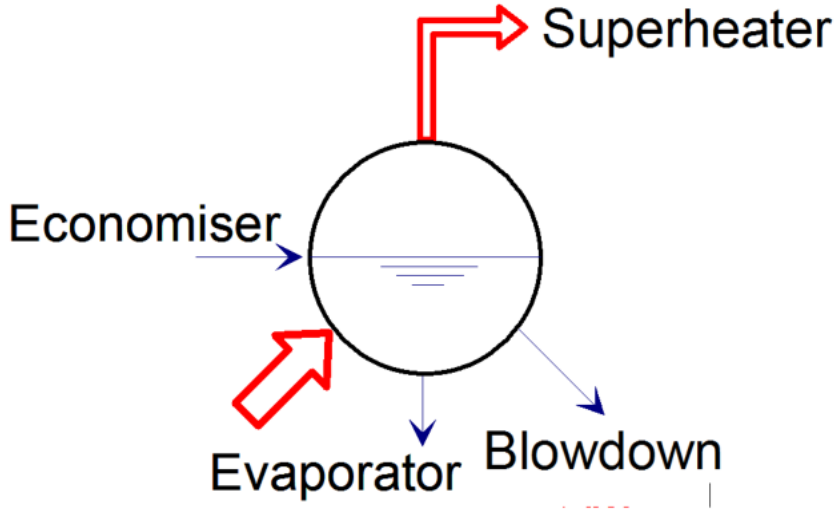
- *Water tube boilers took over when size and capacity increased. This can be classified depending on type of circulation used to generate steam as*
- Natural circulation boiler
- Forced circulation boilers
- Super critical pressure boilers or zero circulation boilers



Steam drum

• A **steam drum** is a standard feature of a water-tube boiler. It is a reservoir of water/steam at the top end of the water tubes. The drum stores the steam generated in the water tubes and acts as a phase-separator for the steam/water mixture. The difference in densities between hot and cold water helps in the accumulation of the "hotter"-water/and saturated-steam into the steam-drum.





Let

m_s : kg steam /hr @ P & T

h : enthalpy of steam per kg under the generating conditions

and since

$$h = h_f + h_{fg} \quad dry\ saturated\ steam\ @P$$

$$h = h_f + x\,h_{fg} \quad wet\ steam\ with\ dryness\ fraction\ (x)@P$$

$$h = h_f + h_{fg} + C_p\left[T_{sup} - T_s\right] \quad superheated\ steam\ @P\ \&\ T_{sup}$$

If h_{f1} is the specific enthalpy of water at a given feed temperature,

Then the heat gained by steam from the boiler per unit time is :

$Q = m_s (h - h_{f1})$

Then , the equivalent evaporation (m_e) is

$$m_e = \frac{m_s\,(h - h_{f_1})}{h_{fg}} = \frac{m_s\,(h - h_{f_1})}{2257}$$

Boiler efficiency

- Boiler efficiency is *"the ratio of heat actually utilized in generation of steam to the heat supplied by the fuel in the same period"*

$$\eta_b = \frac{m_a \left(h - h_{f_1}\right)}{C}$$

m_a – mass of water actually evaporated into steam per kg of fuel at the working pressure

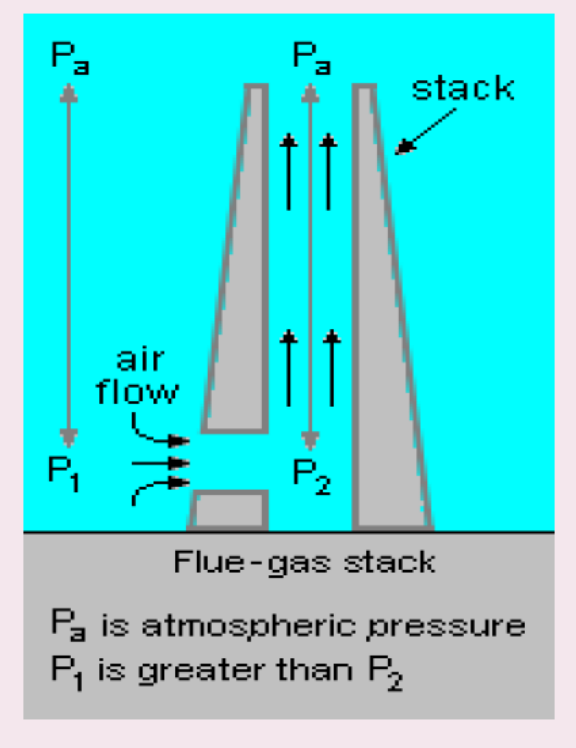
C - fuel heating value kJ/kg

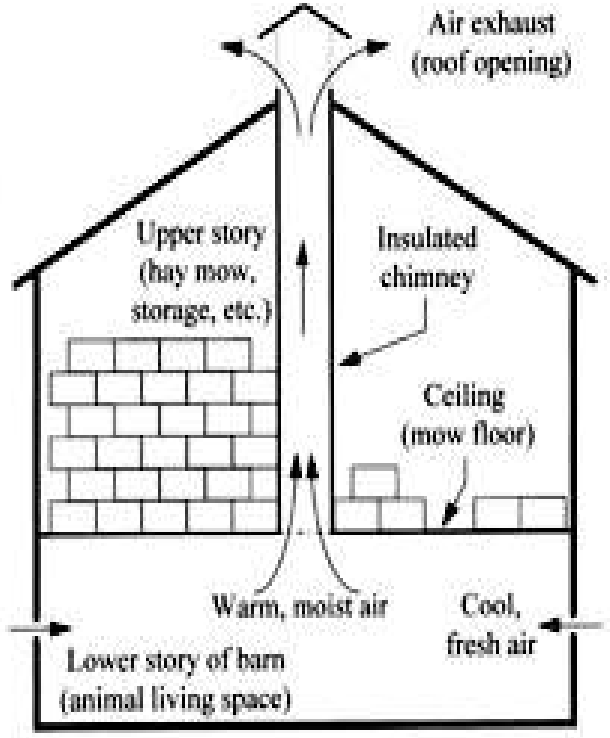
Draught fundamentals "*chimney*"

- Definition

draught is the small pressure difference which causes a flow of gas to take place.

- Function : in case of a boiler, draught is to :
  1. Force air to the fire.
  2. Carry away the gaseous products of combustion.
- In a boiler furnace, proper combustion takes place only when sufficient quantity of air is supplied to the burning fuel.
- Tools: To obtain draught as defined above and to function as stated above, the tool required is called "chimney"





The mass of the gases flowing through any cross section is given by:

$\dot{m}_g = \rho_g . A . C$ kg/s

and since
$A = \pi/4\ D^2$
Then chimney diameter can be evaluated in terms of other variables, where (C) and (ρ_g) evaluation as derived above.
The final form of chimney diameter evaluation can be presented as

$$\rho_g = \frac{p}{RT_g} \cdot \left(\frac{m_a + 1}{m_a}\right)$$
$$= \frac{1.033 \times 10^5}{287} \cdot \frac{1}{T_g} \cdot \left(\frac{m_a + 1}{m_a}\right)$$
$$= 353 \cdot \frac{1}{T_g} \cdot \left(\frac{m_a + 1}{m_a}\right)$$

C = K [√H**1**]
Where
H1 is the height
K = 0.825 ,for brick chimney
= 1.1 ,for steel chimney

$$D = 1.128 \sqrt{\frac{\dot{m}_g}{\rho_g . C}}$$

where, $\dot{m}_g$ = Mass of gases flowing through any cross-section of the chimney,

ρ_g = Density of gases, and

C = Velocity of gases passing through the chimney.

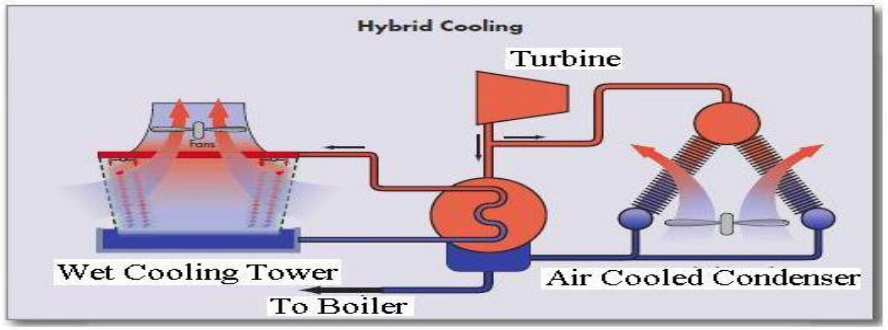
Condenser:

Hybrid Wet and Dry Cooling

- The air cooled condenser is seeing increased use for steam power plant condenser cooling because of increasing concern about the extent of power plant water usage for condenser cooling.
- Use of an air cooled condenser drastically reduces the rate of power plant water usage, but at the expense of increased capital cost, increased operating cost and a reduction in power production efficiency, especially in hot weather. Both wet and dry components (evaporative cooling and an air cooled condenser) are included in a hybrid wet and dry steam power plant condenser cooling system.

The evaporative cooling and air cooled condenser components may be used separately or they may be combined in one unit.

- The followings are examples of such hybrid cooling :



Hybrid Wet and Dry Cooling

Condenser heat balance

The heat balance of the condenser under the assumption of ideal conditions is that :

The heat gained by the cooling water is equal to heat lost from Steam

$$Q = \dot{m}_{cw}\left(T_{cw_{out}} - T_{cw_{in}}\right)$$

$$= \dot{m}_{st}\left(T_{st_{in}} - T_{st_{out}}\right)$$

Industrial water treatment

Industrial Water Treatment can be classified into the following categories:

- Boiler water treatment
- Cooling water treatment
- Waste water treatment
- Water treatment is used to optimize most water-based industrial processes, such as: heating, cooling, processing, cleaning, , so that operating costs and risks are reduced. Poor water treatment lets water interact with the surfaces of pipes and vessels which contain it.

Power plant

- Boilers feed water needs to be as pure as possible with a minimum of suspended solids and dissolved impurities which cause corrosion . Steam boilers can scale up or corrode, and these deposits will mean more fuel is needed to heat the same amount of water.
- Cooling towers can also scale up and corrode, but left untreated, the warm, dirty water they can contain will encourage bacteria to grow, and Legionnaires' Disease can be the fatal consequence