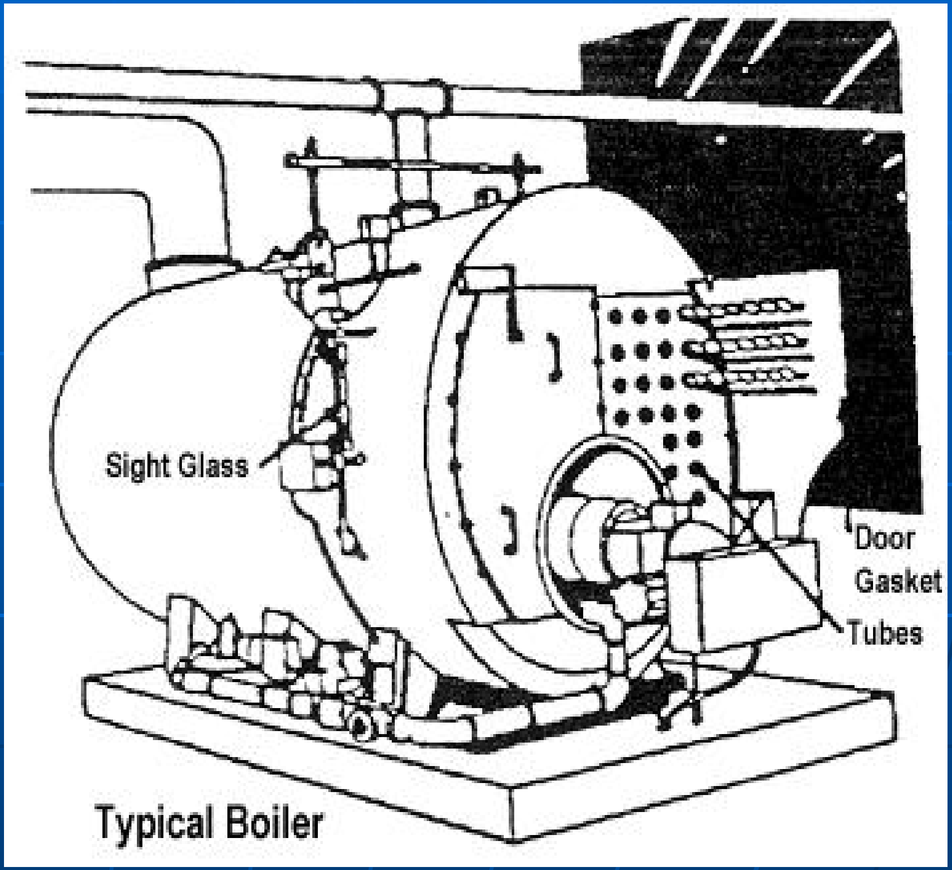
Energy Management in Thermal Systems

- Boilers

Energy Conservation in Steam Generators

Steam generator

- A major thermal system
- Heat generated by combustion of fuel is transferred to water for conversion to steam
- Hot water or steam used to transfer heat to a process
- Increase in volume 1600 times as compared to water: produces tremendous force
- Safety: critical concern

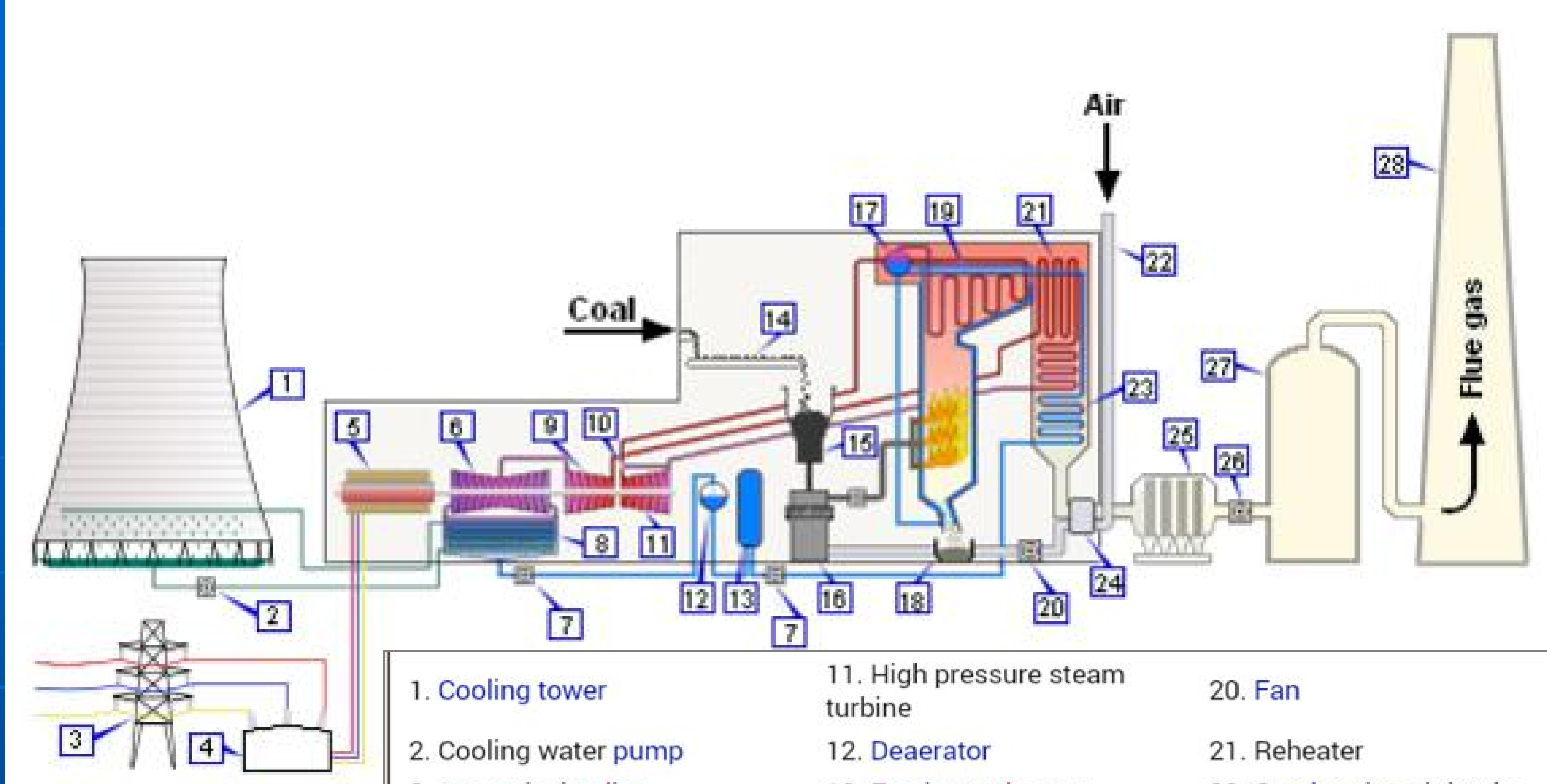


- **IBR Steam Boilers means any closed vessel exceeding 22.75 liters in capacity and which is** used expressively for generating steam under pressure and includes any mounting or other fitting attached to such vessel, which is wholly, or partly under pressure when the steam is shut off.
- **IBR Steam Pipe means any pipe through which steam passes from a boiler to a prime mover** or other user or both, if pressure at which steam passes through such pipes exceeds 3.5 kg/cm2 above atmospheric pressure or such pipe exceeds 254 mm in internal diameter and includes in either case any connected fitting of a steam pipe.

Boiler Specification

- Boiler Make & Year : XYZ & 2003
- MCR(Maximum Continuous Rating) :10TPH (F & A 100^{o}C)
- Rated Working Pressure :10.54 kg/cm^{2}(g)
- Type of Boiler : 3 Pass Fire tube
- Fuel Fired : Fuel Oil
- Heating surface : m^{2}

F & A means the amount of steam generated from water at 100 °C to saturated steam at 100 °C



1. Cooling tower
2. Cooling water pump
3. transmission line
4. transformer
5. Electrical generator
6. Low pressure steam turbines
7. Condensate and feedwater pumps
8. Surface condenser
9. Intermediate pressure steam turbine
10. Steam control valve
11. High pressure steam turbine
12. Deaerator
13. Feedwater heater
14. Coal conveyor
15. Coal hopper
16. Coal pulverizer
17. Steam drum
18. Bottom ash hopper
19. Superheater
20. Fan
21. Reheater
22. Combustion air intake
23. Economiser
24. Air preheater
25. Cold-side Electrostatic precipitator
26. Fan
27. Flue gas desulfurization scrubber
28. Flue gas stack

Main Components of Thermal Power Plants

1. Boiler
2. Super heater
3. Economizer
4. Air preheater
5. Reheater
6. Steam turbine
7. Generator
8. Condensers
9. Cooling towers
10. Pumps
11. Wagon tippler
12. Crusher house
13. Coal mills
14. FD and ID Fans
15. Ash Precipitators
16. Chimney
17. Water treatment plant
18. swtch yard
19. Control Room

Boiler Systems

- Water treatment system
- Feed water and condensate system
- Steam system
- Blow down system
- Fuel supply system
- Air supply system
- Flue gas system

Coal and Ash Handling circuit`

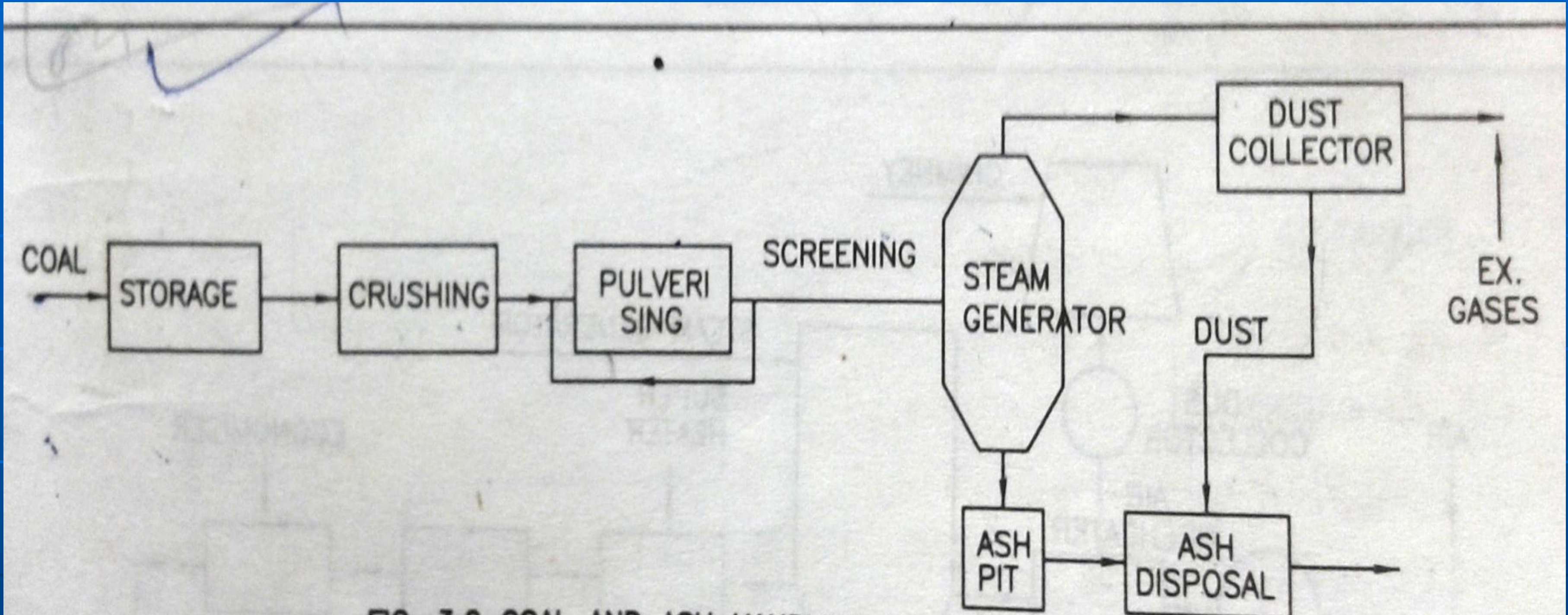


FIG. 3.2 COAL AND ASH HANDLING CIRCUIT

Air and gas circuit

- FD or ID fans are used for supply the air to combustion chamber of the boiler through air-preheater
- The air preheater is placed in the path of flue gases to preheat the air
- The flue gases produced by combustion of fuels in the boiler furnaces after passing around boiler tubes and super heater tubes
- Pass through a dust collector or precipitator where most of dust is removed before venting it of to atmosphere through chimney

Air and Gas Circuit

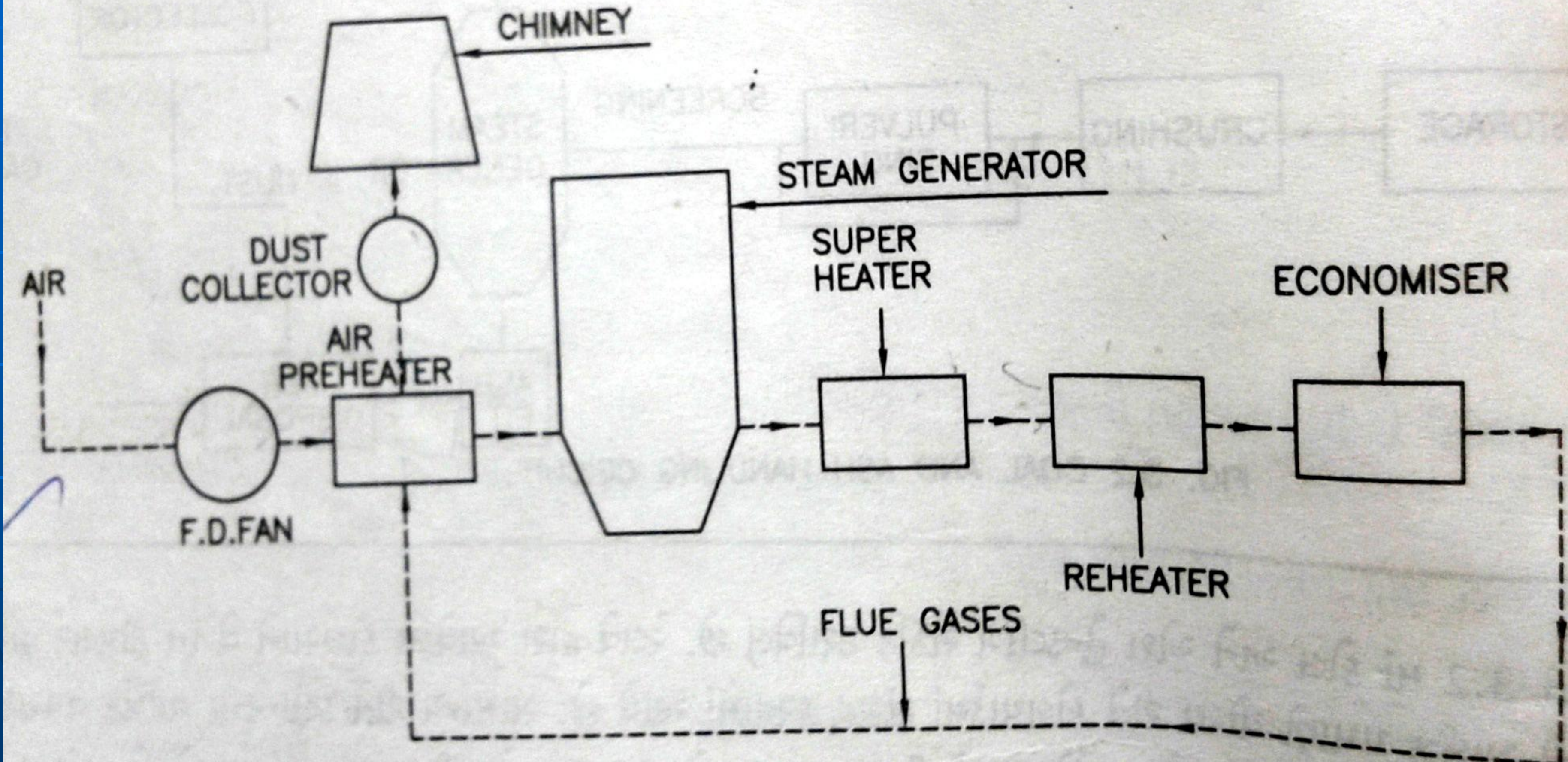


FIG. 3.3 AIR AND GAS CIRCUIT

Feed water and steam circuit:

- Prime mover develops power by utilizing steam generated in the boiler
- Then condenser is used to condense the steam coming out of prime mover
- A pump is used to feed the condensate to the boiler
- The condensate leaving the condenser is heated in feed heaters through extracted steam from lowest pressure extraction point of the turbine
- The feed water may also be supplied from external source to compensate any loss of steam and water.
- In the boiler shell and tubes water circulation is setup due to density difference of water between low and high temperature sections
- A super heater is used to super heat the wet steam from boiler drum and is then supplied to prime movers

Feed water and steam circuit

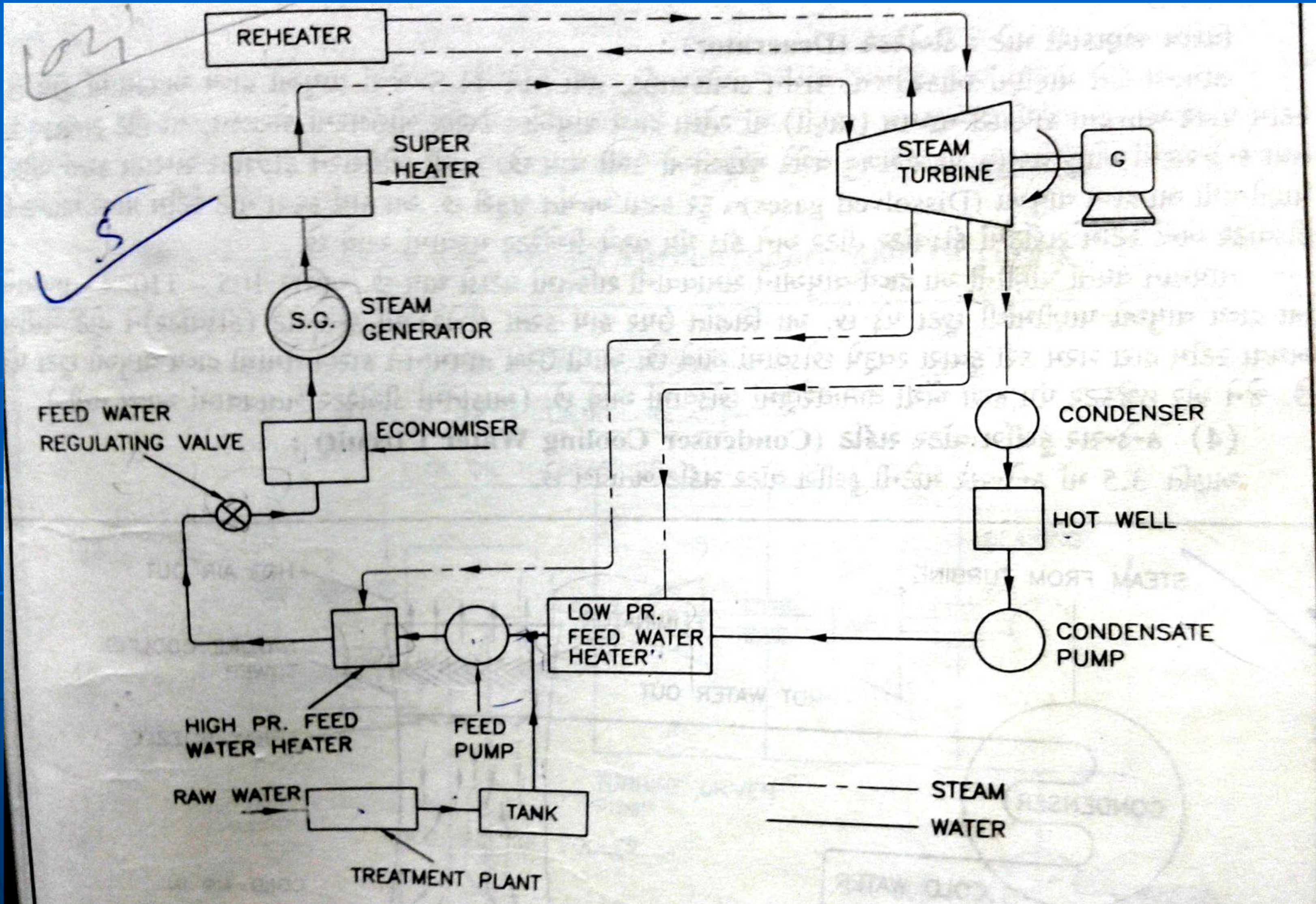


FIG. 3.4 FEED WATER AND STEAM CIRCUIT

Cooling water circuit

- In the condenser, quantity of cooling water required to condense the steam is large and is taken either from lake, river or sea
- The cooling water is taken from upper side of the river and then passed through the condenser
- The hot water is then discharged to lower side of the river
- The system is known as open system
- Where water is not available in abundant water from condenser is cooled either in cooling pond or in cooling tower the system is known as closed system

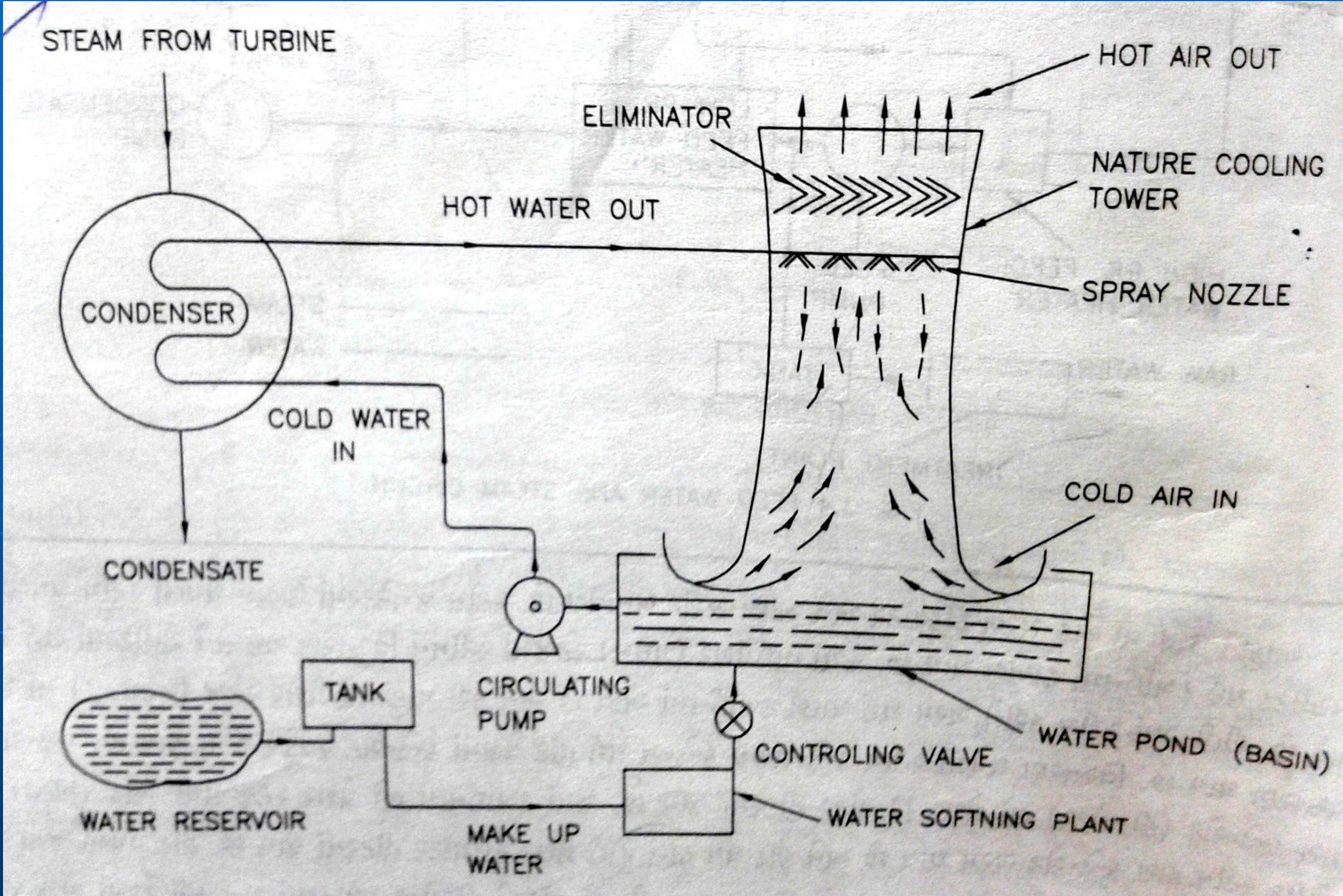


FIG. 3.5 COOLING WATER CIRCUIT

Steam turbine lubrication circuit

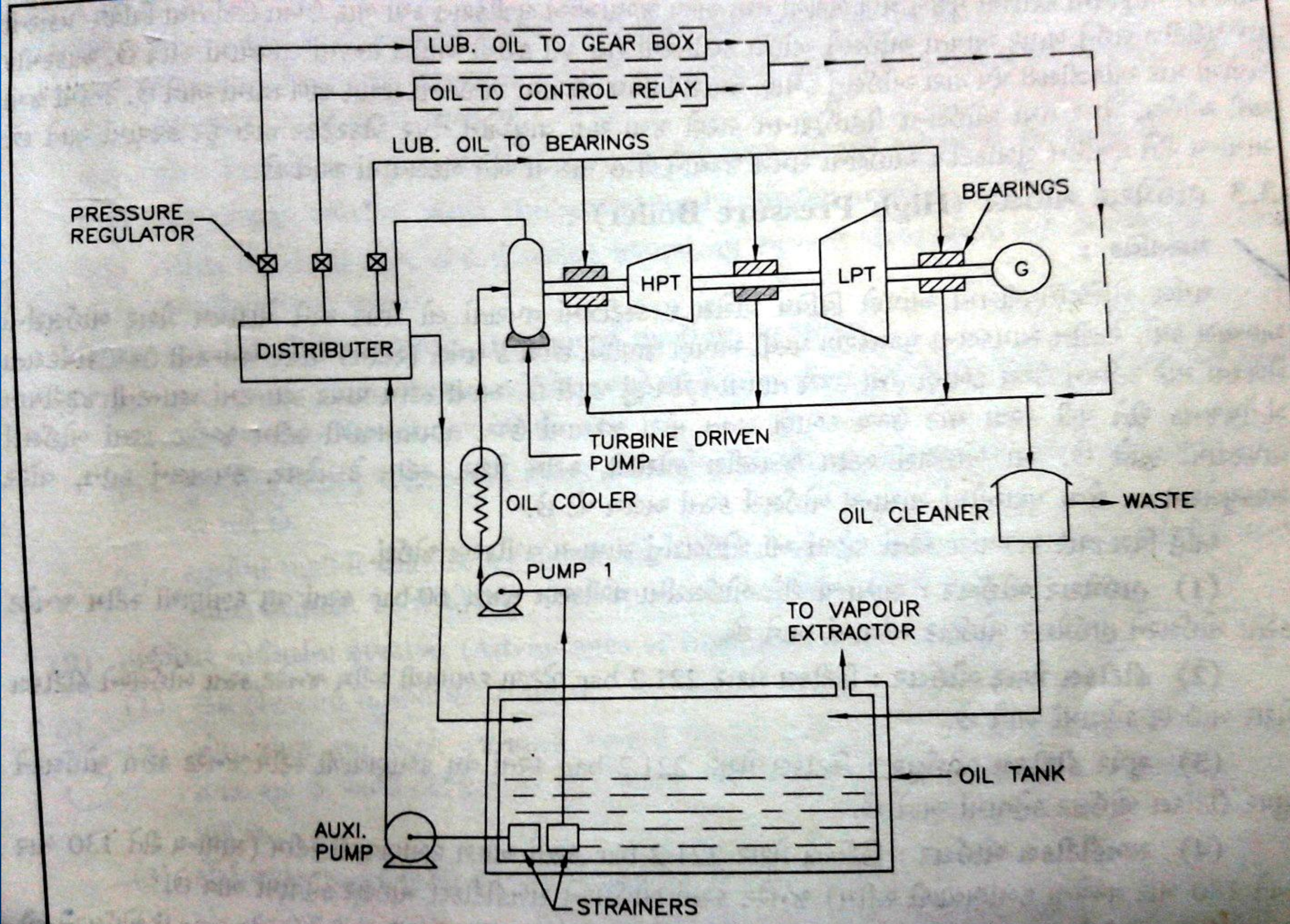


FIG. 3.6 STEAM TURBINE LUBRICATION CIRCUIT

Boiler Types and Classifications

Fire Tube Boiler

- Fire in tube or Hot gas through tubes and boiler feed water in shell side

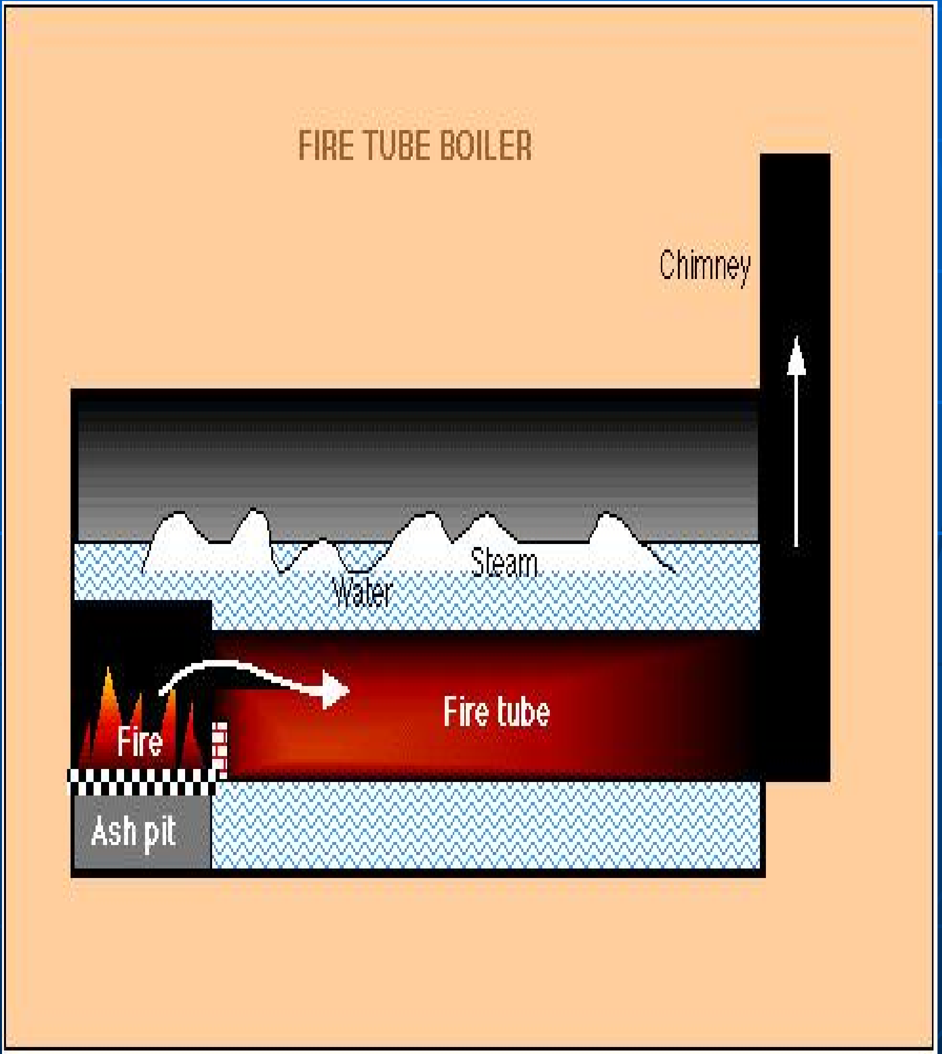
Application

- Used for small steam capacities

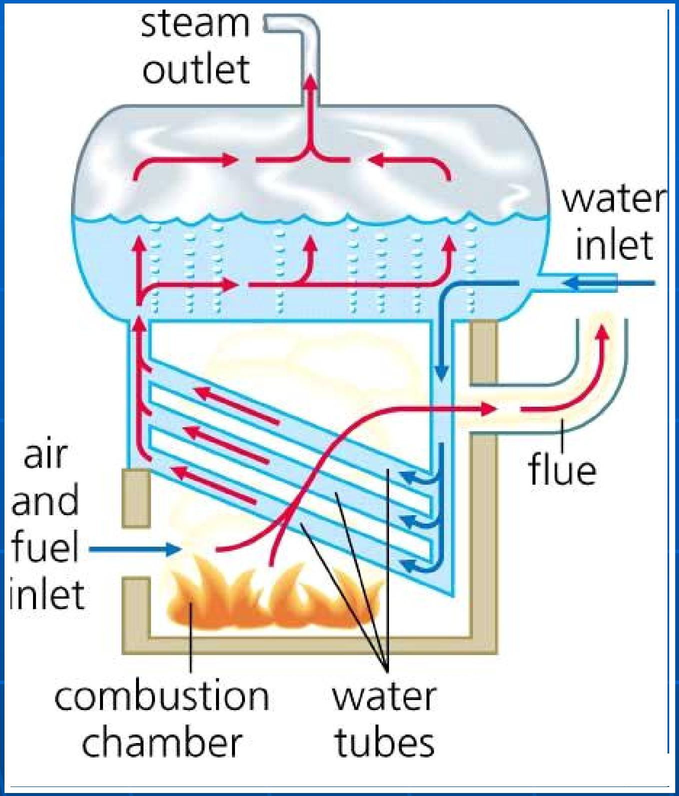
  (up to 25T/hr and $17.5 kg/cm^2$

Merits

- Lower capital cost
- Easiness in operation



Water Tube Boiler



- Water flow through tubes

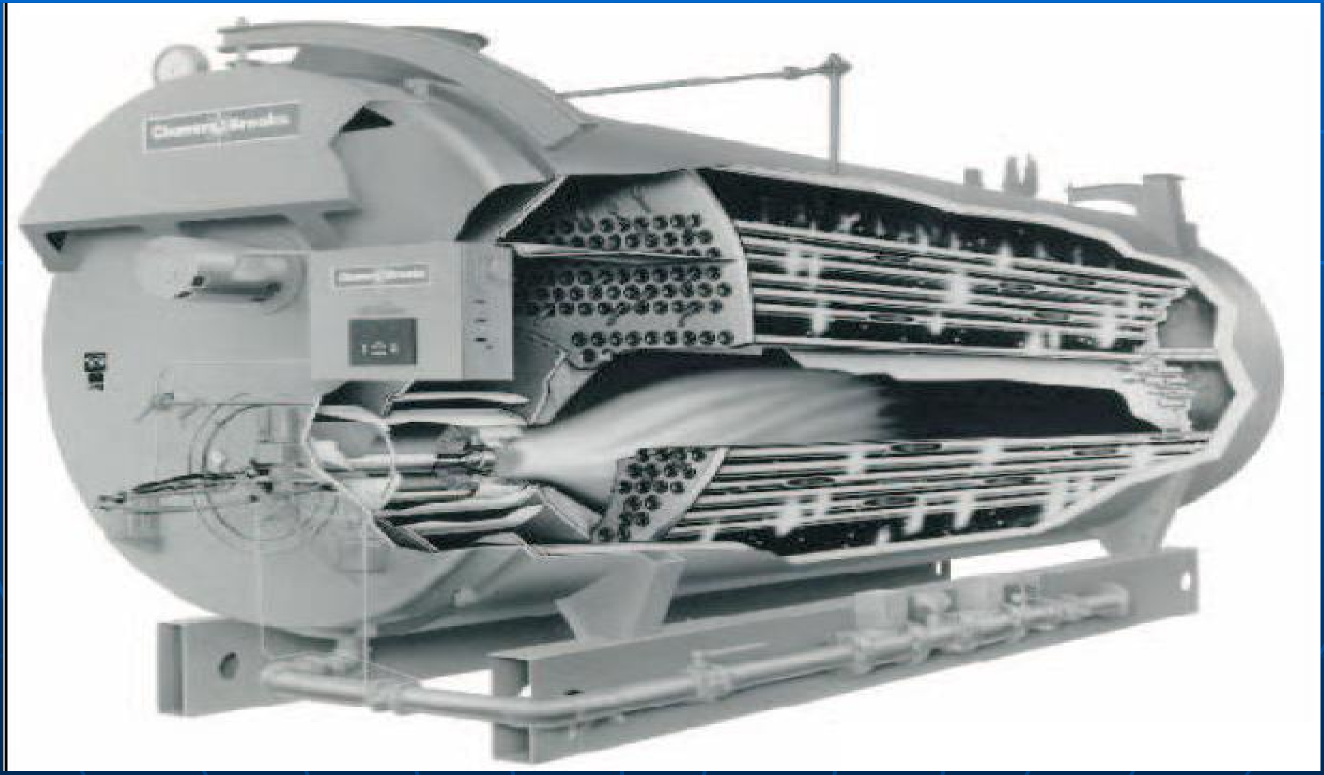
Application

- Used as process cum power boiler / power boilers
- Steam capacities range from 4.5- 120 t/hr

Characteristics

- High Capital Cost
- Used for high pressure high capacity steam boiler
- Demands more controls
- Calls for very stringent water quality

- **Packaged Boiler: The packaged boiler is so** called because it comes as a complete package. Once delivered to site, it requires only the steam, water pipe work, fuel supply and electrical connections to be made for it to become operational. Package boilers are generally of shell type with fire tube design so as to achieve high heat transfer rates by both radiation and convection



The features of package boilers are:

- Small combustion space and high heat release rate resulting in faster evaporation.
- Large number of small diameter tubes leading to good convective heat transfer.
- Forced or induced draft systems resulting in good combustion efficiency.
- Number of passes resulting in better overall heat transfer.
- Higher thermal efficiency levels compared with other boilers.

Chain-Grate or Traveling-Grate Stoker Boiler

Coal is fed onto one end of a moving steel chain grate. As grate moves along the length of the furnace, the coal burns before dropping off at the end as ash. Some degree of skill is required, particularly when setting up the grate, air dampers and baffles, to ensure clean combustion leaving minimum of unburnt carbon in the ash.

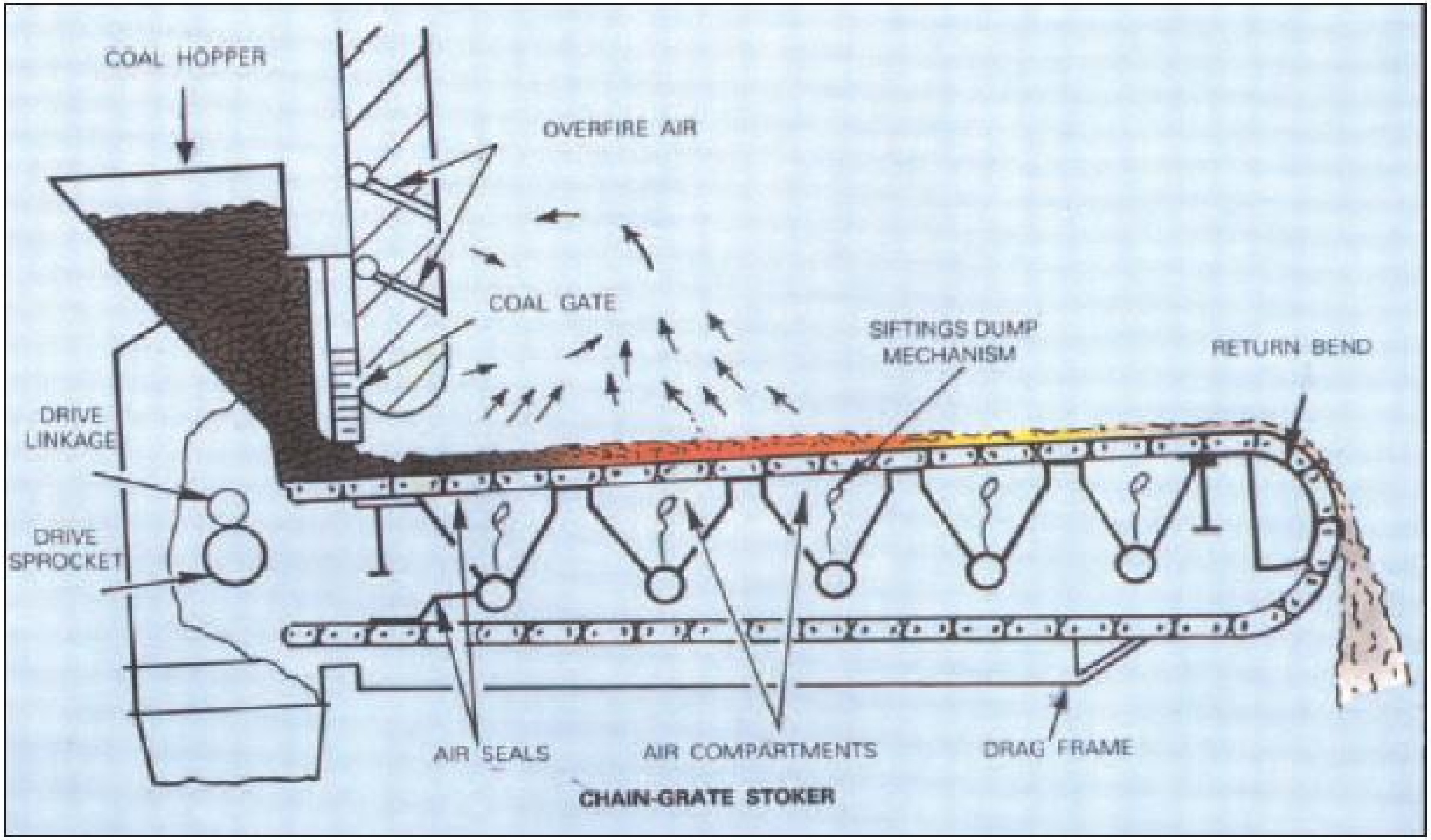


Figure 2.5 Chain Grate Stoker

Spreader Stoker Boiler

Spreader stokers (see figure 2.6) utilize a combination of suspension burning and grate burning. The coal is continually fed into the furnace above a burning bed of coal. The coal fines are burned in suspension; the larger particles fall to the grate, where they are burned in a thin, fast-burning coal bed. This method of firing provides good flexibility to meet load fluctuations, since ignition is almost instantaneous when firing rate is increased. Hence, the spreader stoker is favored over other types of stokers in many industrial applications.

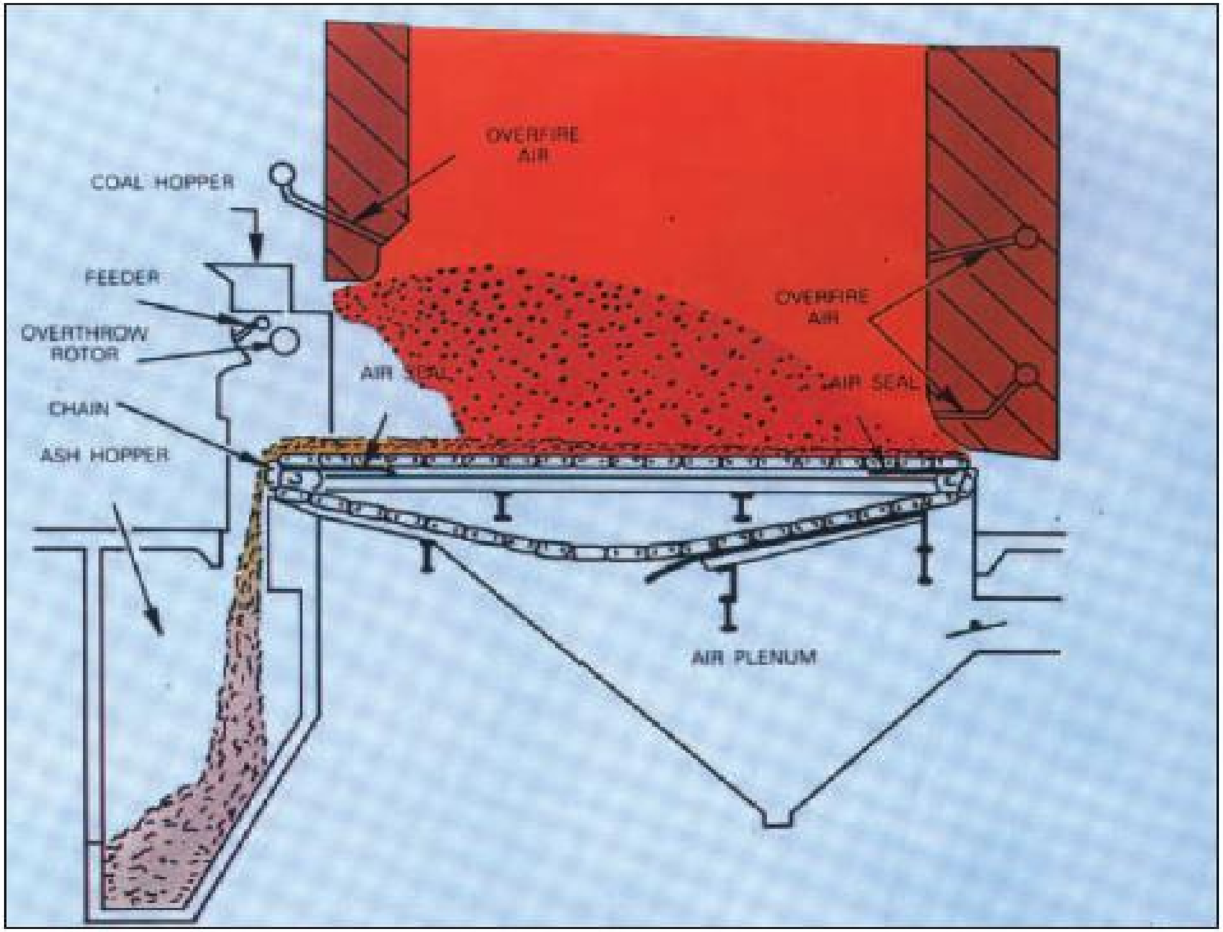


Figure 2.6 Spreader Stoker

- **Pulverized Fuel Boiler**
- Most coal-fired power station boilers use pulverized coal, and many of the larger industrial water-tube boilers also use this pulverized fuel. This technology is well developed, and there are thousands of units around the world, accounting for well over 90% of coal-fired capacity.
- The coal is ground (pulverised) to a fine powder, so that less than 2% is +300 micro metre (μm) and 70-75% is below 75 microns, for a bituminous coal. It should be noted that too fine a powder is wasteful of grinding mill power. On the other hand, too coarse a powder does not burn completely in the combustion chamber and results in higher unburnt losses.

- The pulverised coal is blown with part of the combustion air into the boiler plant through a series of burner nozzles. Secondary and tertiary air may also be added. Combustion takes place at temperatures from 1300-1700°C, depending largely on coal grade.
- Particle residence time in the boiler is typically 2 to 5 seconds, and the particles must be small enough for complete combustion to have taken place during this time

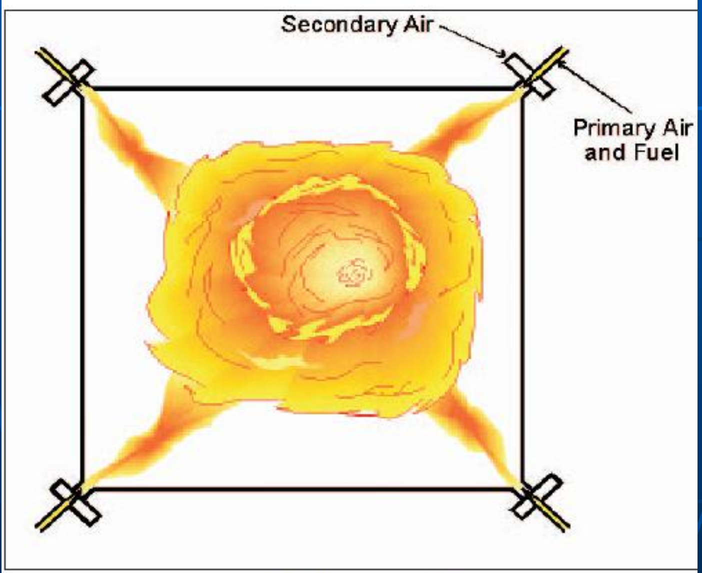


Figure 2.7 Tangential Firing

FBC Boiler

When an evenly distributed air or gas is passed upward through a finely divided bed of solid particles such as sand supported on a fine mesh, the particles are undisturbed at low velocity. As air velocity is gradually increased, a stage is reached when the individual particles are suspended in the air stream. Further, increase in velocity gives rise to bubble formation, vigorous turbulence and rapid mixing and the bed is said to be fluidized.

If the sand in a fluidized state is heated to the ignition temperature of the coal and the coal is injected continuously in to the bed, the coal will burn rapidly, and the bed attains a uniform temperature due to effective mixing. Proper air distribution is vital for maintaining uniform fluidisation across the bed.). Ash is disposed by dry and wet ash disposal systems.

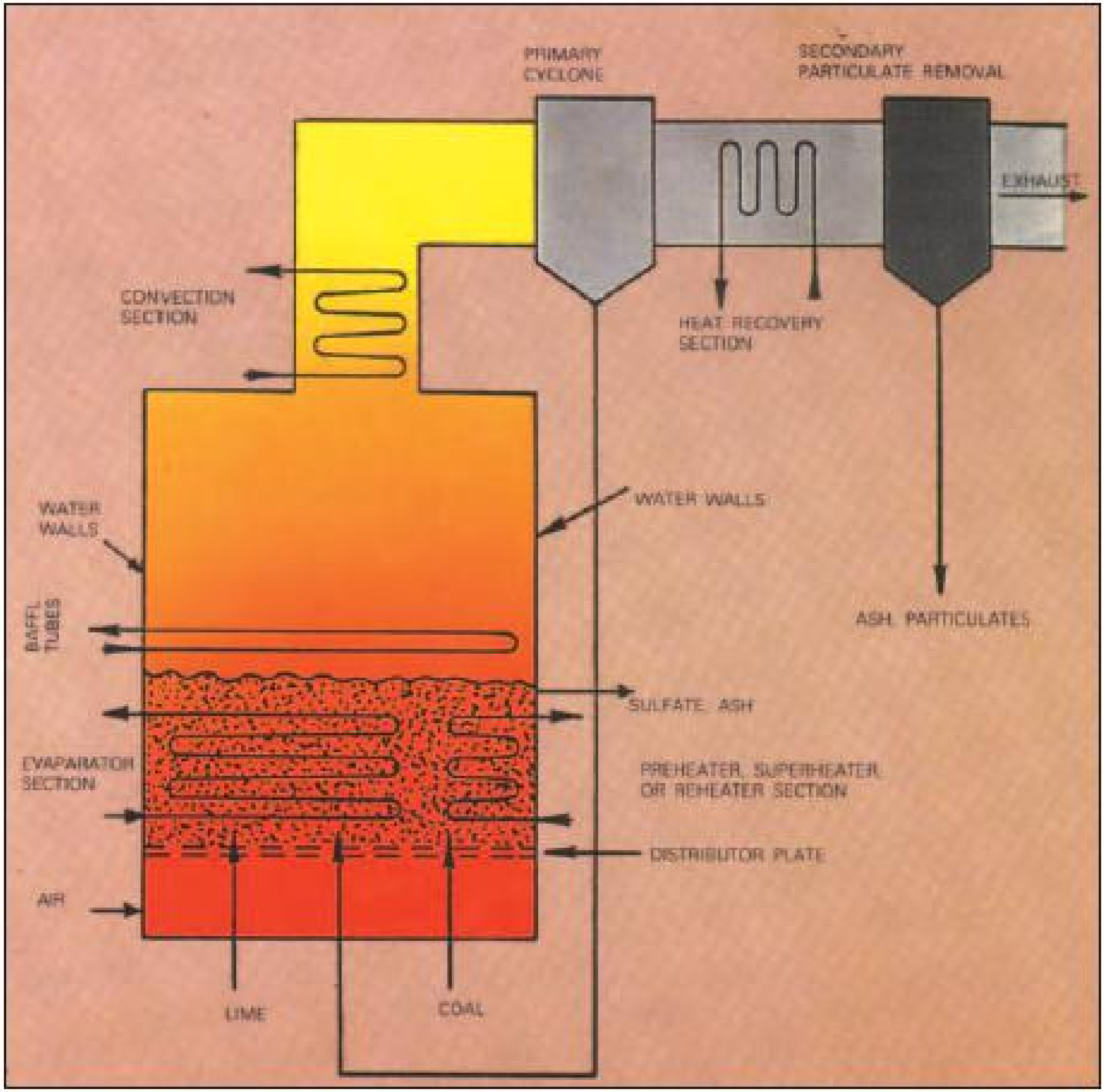


Figure 2.8 Fluidised Bed Combustion

- Fluidised bed combustion has significant advantages over conventional firing systems and offers multiple benefits namely fuel flexibility, reduced emission of noxious pollutants such as SOx and NOx, compact boiler design and higher combustion efficiency.

Assessment of a Boiler

1. Boiler performance

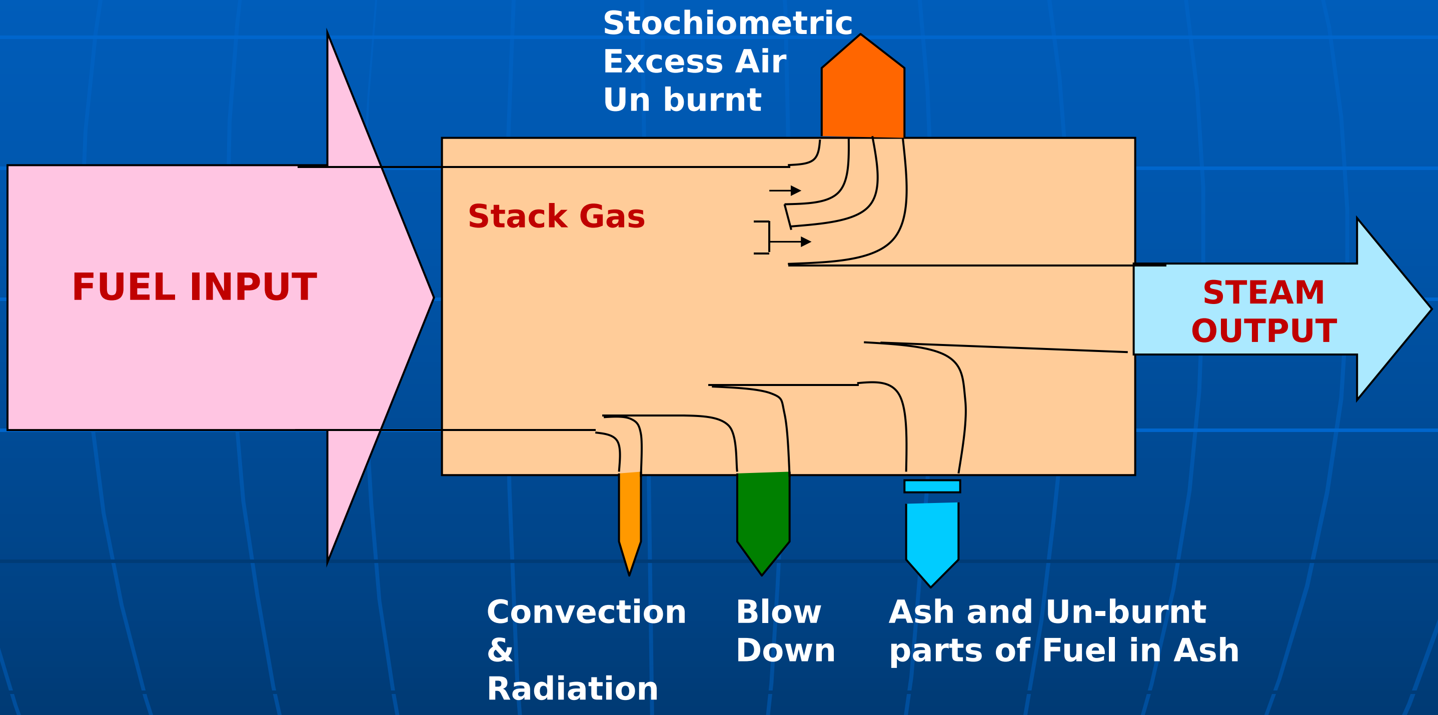
- Causes of poor boiler performance
  - -Poor Fuel and combustion quality
  - -Heat transfer surface fouling
  - -Scaling of HE surface.
  - -Poor operation and maintenance
  - -Deteriorating water quality
  - -Inadequate thermal insulation

- Heat balance: identify heat losses

- Boiler efficiency: determine deviation from best efficiency

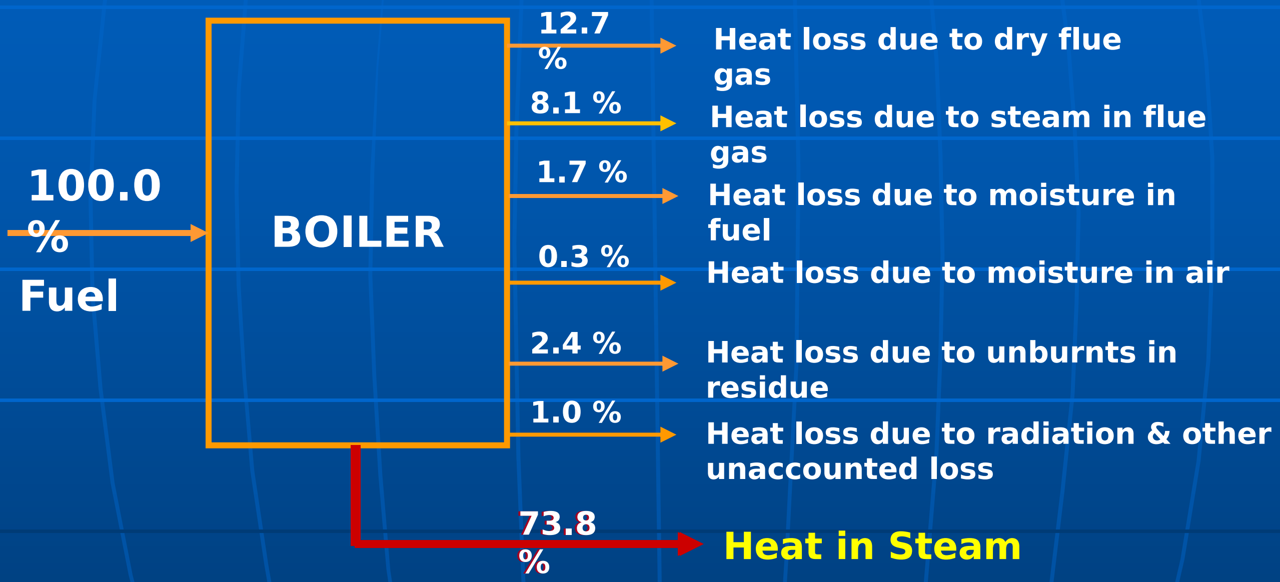
Heat Balance

An energy flow diagram describes how energy is transformed from fuel into useful energy, heat and losses



Heat Balance

Balancing total energy entering a boiler against the energy that leaves the boiler in different forms



Heat Balance

Goal: improve energy efficiency by reducing *avoidable* losses

Avoidable losses include:

- Stack gas losses (excess air, stack gas temperature)
- Losses by unburnt fuel
- Blow down losses
- Condensate losses
- Convection and radiation

Performance Evaluation of Boilers

There are two methods of assessing boiler efficiency

1) The Direct Method: Where the energy gain of the working fluid (water and steam) is compared with the energy content of the boiler fuel.

2) The Indirect Method: Where the efficiency is measured in terms of the difference between the energy losses and the energy input.

Boiler Efficiency: Direct Method

$$\text{Boiler efficiency } (\hbar) = \frac{\text{Heat output}}{\text{Heat input}} \times 100 = \frac{Q \times (h_g - h_f)}{m \times GCV} \times 100$$

h_g -the enthalpy of saturated steam in kcal/kg of steam

h_f -the enthalpy of feed water in kcal/kg of water

Parameters to be monitored:

- Quantity of steam generated per hour (Q) in kg/hr
- Quantity of fuel used per hour (q) in kg/hr
- The working pressure (in kg/cm²(g)) and superheat temperature (°C), if any
- The temperature of feed water (°C)
- Type of fuel and gross calorific value of the fuel (GCV) in kcal/kg of fuel

Boiler Efficiency: Direct Method

Advantages

- Quick evaluation
- Few parameters for computation
- Few monitoring instruments
- Easy to compare evaporation ratios with benchmark figures

Disadvantages

- No explanation of low efficiency
- Various losses not calculated

Boiler Efficiency: Indirect Method

Efficiency of boiler ($\hbar$) = 100 – (i+ii+iii+iv+v+vi+vii)

Principle losses:

i) Dry flue gas

ii) Evaporation of water formed due to H2 in fuel

iii) Evaporation of moisture in fuel

iv) Moisture present in combustion air

v) Unburnt fuel in fly ash

vi) Unburnt fuel in bottom ash

vii) Radiation and other unaccounted losses

Boiler Efficiency: Indirect Method

Required calculation data

- Ultimate analysis of fuel (H_2, O_2, S, C, moisture content, ash content)
- % oxygen or CO_2 in the flue gas
- Fuel gas temperature in °C (T_f)
- Ambient temperature in °C (T_a) and humidity of air in kg/kg of dry air
- GCV of fuel in kcal/kg
- % combustible in ash (in case of solid fuels)
- GCV of ash in kcal/kg (in case of solid fuels)

Boiler Efficiency: Indirect Method

Advantages

- Complete mass and energy balance for each individual stream
- Makes it easier to identify options to improve boiler efficiency

Disadvantages

- Time consuming
- Requires lab facilities for analysis

Efficiency Calculation by Direct Method

Example:

Type of boiler: Coal fired Boiler

Heat input data

Qty of coal consumed :1.8 TPH

GCV of coal :3200 kCal/kg

Heat output data

- Qty of steam gen : 8 TPH
- Steam pr/temp:10 kg/cm^2(g)/180^{0}C
- Enthalpy of steam(sat) at 10 kg/cm^2(g) pressure:665 kCal/kg
- Feed water temperature : 85^0 C
- Enthalpy of feed water : 85 kCal/kg

Find out the efficiency ?

Boiler efficiency ($\hbar$): $= \dfrac{\mathbf{Q \times (H - h)}}{\mathbf{(q \times GCV)}} \mathbf{\times 100}$

Where **Q** = Quantity of steam generated per hour (kg/hr)
H = Enthalpy of saturated steam (kcal/kg)
h = Enthalpy of feed water (kcal/kg)

q = Quantity of fuel used per hour (kg/hr)
GCV = Gross calorific value of the fuel (kcal/kg)

Boiler efficiency ($\hbar$)= $\dfrac{\text{8 TPH x1000Kg/Tx (665–85) x 100}}{\text{1.8 TPH x 1000Kg/T x 3200}}$
= 80.0%

Evaporation Ratio = 8 Tonne of steam/1.8 Ton of coal
= 4.4

Example:

The following are the data collected for a typical oil fired boiler. Find out the efficiency of the boiler by indirect method

Ultimate analysis of Oil

C : 84.0 % H_2: 12.0 %

S: 3.0 % O_2: 1.0 %

GCV of Oil : 10200 kcal/kg

Steam Generation Pressure : 7kg/cm^2(g)-saturated

Enthalpy of steam : 660 kCal/kg

Feed water temperature : 60^{o}C

Percentage of Oxygen in flue gas: 7

Percentage of CO_2 in flue gas: 11

Flue gas temperature (T_f) : 220 ^{0}C

Ambient temperature (T_a) : 27 ^{0}C

Humidity of air : 0.018 kg/kg of dry air

Solution

Step-1: Find the theoretical air requirement

$$[(11.6\,x\,C)+\{34.8\,x\,(H_2 - O_2/8)\}+(4.35\,x\,S)]/100$$

= kg/kg of oil

=[(11.6 x 84) + [{34.8 x (12 – 1/8)} + (4.35 x 3)]/100 kg/kg of oil

=14 kg of air/kg of oil

Step-2: Find the %Excess air supplied

Excess air supplied (EA) = $\dfrac{O_2\%}{21 - O_{2\%}} x100$ = $\dfrac{7\%}{21 - 7} x100$ = 50%

Step-3: Find the Actual mass of air supplied

Actual mass of air supplied /kg of fuel = [1 + EA/100] x Theoretical Air

(AAS) = [1 + 50/100] x 14

= 1.5 x 14

= 21 kg of air/kg of oil

Step-4: Estimation of all losses

i. Dry flue gas loss

Percentage heat loss due to dry flue gas = $\dfrac{m \, x \, C_p \, x \, (T_f - T_a)}{GCV \; of \; fuel} \; x \, 100$

m= mass of CO_2 + mass of SO_2 + mass of N_2 + mass of O_2

$$m = \frac{0.84 \, x \, 44}{12} + \frac{0.03 \, x \, 64}{32} + \frac{21 \, x \, 77}{100} + \left((21 - 14) \, x \, \frac{23}{100} \right)$$

m = 21 kg / kg of oil

$$\frac{21 \, x \, 0.23 \, x \, (220 - 27)}{10200} \; x \, 100$$ = 9.14 %

Alternatively a simple method can be used for determining the dry flue gas loss as given below.

Percentage heat loss due to dry flue gas = $$\frac{m \, x \, C_p \, x \, (T_f - T_a)}{GCV \; of \; fuel} \; x \, 100$$

Total mass of flue gas (m) = mass of actual air supplied + mass of fuel supplied **= 21 + 1=22**

%Dry flue gas loss = $$\frac{22 \, x \, 0.23 \, x \, (220 - 27)}{10200} \; x \, 100 = 9.57\%$$

ii. Heat loss due to evaporation of water formed due to H_2 in fuel

$$= \frac{9 \times H_2 \times \{584 + C_p (T_f - T_a)\}}{\text{GCV of fuel}} \times 100$$

Where, H_2 – percentage of H_2 in fuel

$$= \frac{9 \times 12 \times \{584 + 0.45 (220 - 27)\}}{10200} \times 100$$

= 7.10%

iii. Heat loss due to moisture present in air

$$= \frac{AAS \times humidity \times C_p \times (T_f - T_a)}{GCV\ of\ fuel} \times 100$$

$$\frac{21 \times 0.018 \times 0.45 \times (220 - 27)}{10200} \times 100$$

= 0.322%

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

Boiler Efficiency
i. Heat loss due to dry flue gas : 9.14%
ii. Heat loss due to evaporation of water formed due to H_2 in fuel : 7.10 %
iii. Heat loss due to moisture present in air : 0.322 %
iv. Heat loss due to radiation and other unaccounted loss : 2%

Boiler Efficiency = 100- [9.14 + 7.10 + 0.322 + 2]
= 100 – 18.56 = 81 %(app)

Boiler Blow down

- Boiler Blow down used to control solids (TDS) in the boiler feed water.
- Solids in feed water will deposit lead to scale formation and result in localized overheating and tube failure

TABLE 2.1 RECOMMENDED TDS LEVELS FOR VARIOUS BOILERS

	Boiler Type	Maximum TDS (ppm)*
1.	Lancashire	10,000 ppm
2.	Smoke and water tube boilers (12 kg/cm^2)	5,000 ppm
3.	Low pressure Water tube boiler	2000–3000
4.	High Pressure Water tube boiler with superheater etc.	3,000–3,500 ppm
5.	Package and economic boilers	3,000 ppm
6.	Coil boilers and steam generators	2000 (in the feed water

Note: Refer guidelines specified by manufacturer for more details
*parts per million

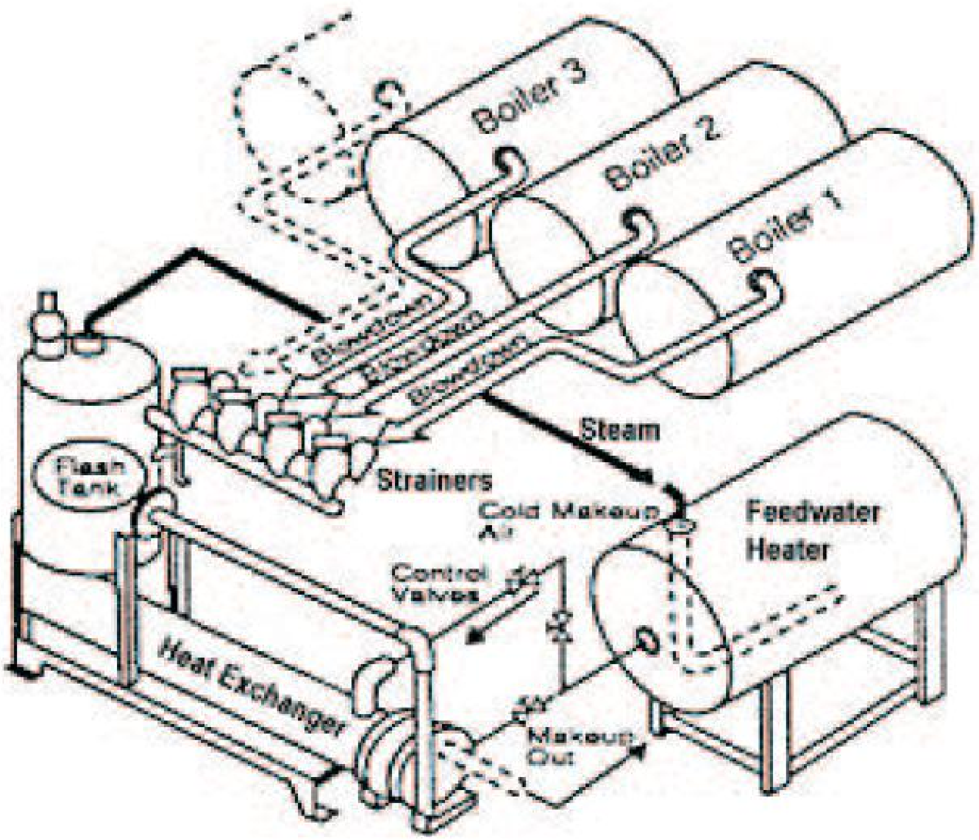
Intermittent(Manual or Bottom) Blow down

- 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.
- 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.
- 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.

Continuous Blowdown

- Steady and constant dispatch of small stream of concentrated boiler water, and replacement by steady and constant inflow of feed water. This ensures constant TDS and steam purity at given steam load. Once blow down valve is set for a given

ed for regular operator



flash tank and generating flash steam. This flash steam can be used for preheating boiler feed water or for any other purpose.

Blowdown Calculation

The quantity of blowdown required to control boiler water solids concentration is calculated by using the following formula:

$$\text{Blow down (\%)} = \frac{\text{Feed water TDS} \times \text{\% Make up water}}{\text{Maximum Permissible TDS in Boiler water}}$$

If maximum permissible limit of TDS as in a package boiler is 3000 ppm, percentage make up water is 10% and TDS in feed water is 300 ppm, then the percentage blow down is given as:

$$= 300 \times 10 / 3000$$

$$= 1\%$$

If boiler evaporation rate is 3000 kg/hr then required blow down rate is:

$$\frac{3000 \times 1}{100}$$

$$= 30 \text{ kg/hr}$$

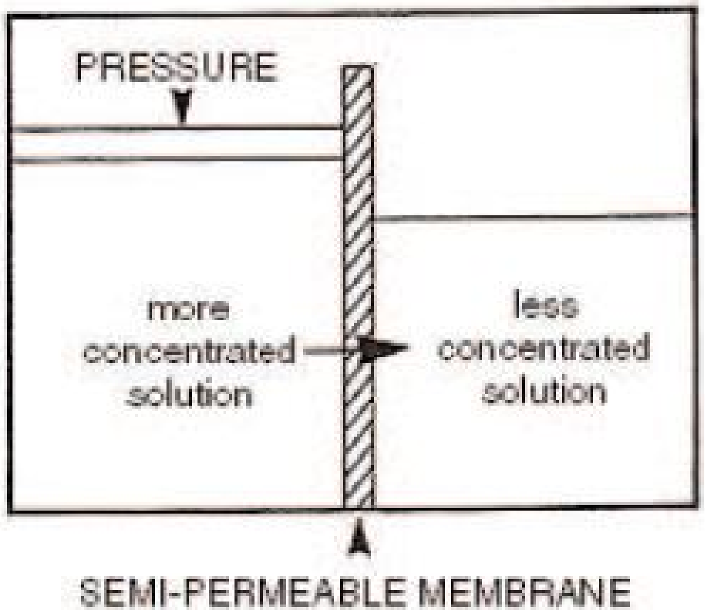
Benefits of Blowdown

Good boiler blow down control can significantly reduce treatment and operational costs that include:

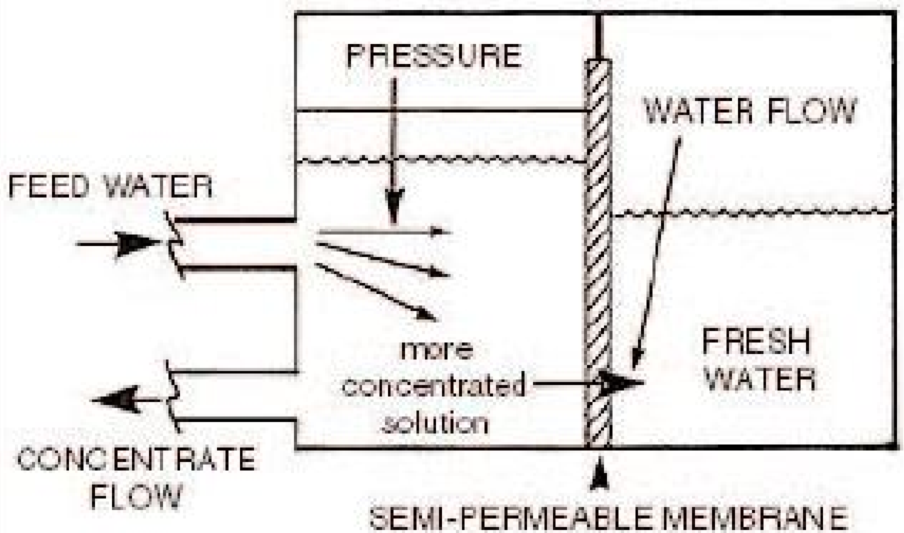
- Lower pretreatment costs
- Less make-up water consumption
- Reduced maintenance downtime
- Increased boiler life
- Lower consumption of treatment chemicals

Boiler Feed Water Treatment

- Deposits Control **Impurities Causing Deposits**
- **Silica -** formation of hard silicate scales
- **Internal Water Treatment- a**dding chemicals to boiler to prevent the formation of scale by converting the scale-forming compounds to free-flowing sludges, which can be removed by blowdown.
- **External Water Treatment-** External treatment is used to remove suspended solids, dissolved solids (particularly the calcium and magnesium ions which are a major cause of scale formation) and dissolved gases (oxygen and carbon dioxide). The external treatment processes available are: ion exchange; demineralization; reverse osmosis and de-aeration.
  - **Ion-exchange process (Softener Plant)**
  - **De-aeration -** dissolved gases, such as oxygen and carbon dioxide, are expelled by preheating the feed water before it enters the boiler. **Mechanical de-aeration, Chemical de-**



When a pressure is applied to the concentrated solution which is great that the osmotic pressure difference, the direction of water passage through the membrane is reversed and the process that we refer to as reverse osmosis is established. That is, the membrane's ability to selectively pass water is unchanged, only the direction of the water flow is changed.



The feed water and concentrate (reject stream) ports illustrates a continuously operating RO system.

Figure 2.11 Reverse Osmosis

TABLE 2.2 RECOMMENDED FEED WATER LIMITS

Factor	Upto 20 kg/cm^2	21 – 39 kg/cm^2	41 – 59 kg/cm^2
Total iron (max) ppm	0.05	0.02	0.01
Total copper (max) ppm	0.01	0.01	0.01
Total silica (max) ppm	1.0	0.3	0.1
Oxygen (max) ppm	0.02	0.02	0.01
Hydrazine residual ppm	–	–	-0.02-0.04
pH at 25°C	8.8-9.2	8.8-9.2	8.2-9.2
Hardness, ppm	1.0	0.5	–

TABLE 2.3 RECOMMENDED BOILER WATER LIMITS (IS 10392, YEAR 1982)

Factor	Upto 20 kg/cm^2	21 – 39 kg/cm^2	40 – 59 kg/cm^2
TDS, ppm	3000–3500	1500–2500	500–1500
Total iron dissolved solids ppm	500	200	150
Specific electrical conductivity at 25°C (mho)	1000	400	300
Phosphate residual ppm	20-40	20-40	15-25
pH at 25°C	10–10.5	10–10.5	9.8–10.2
Silica (max) ppm	25	15	10

Heat Loss Sources

Stack gas

- Minimizing excess air
- Keeping heat transfer surfaces clean
- Adding flue gas heat recovery equipment
  where justified
- Controlling air infiltration

Heat Loss Sources

Combustible heat losses

- Carbon in the bottom ash
- Carbon in the fly ash
- Combustible gases in the flue gas (this can happen in oil and gas-fired units as well)

Energy Conservation Opportunities

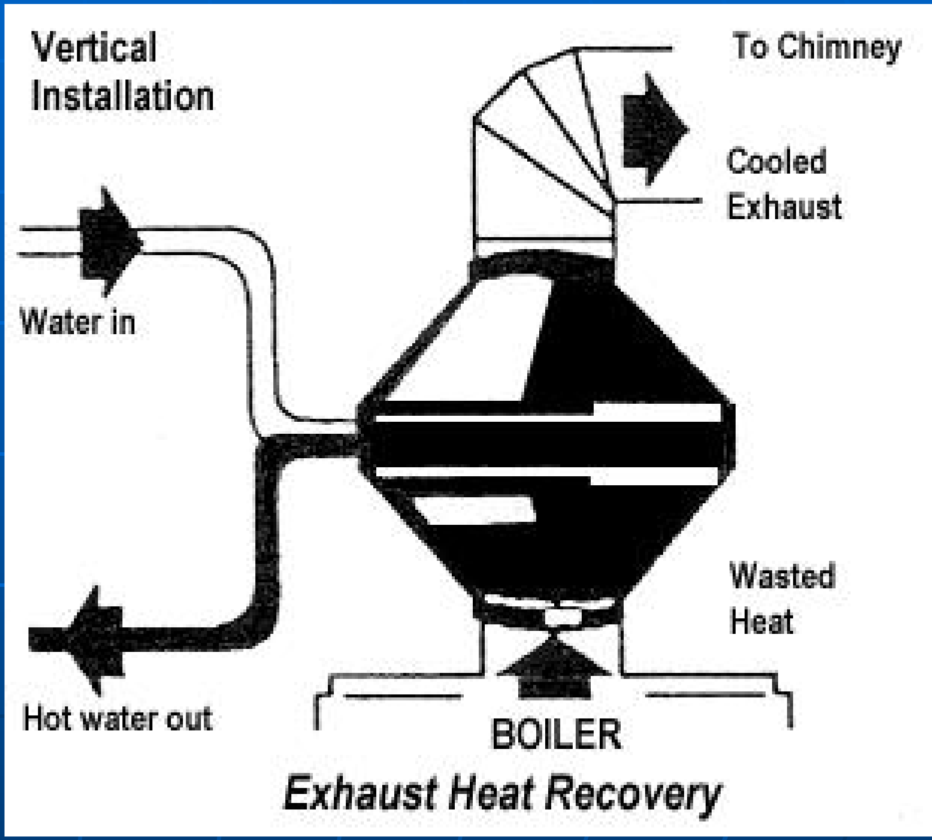
1. Reduce Stack Temperature

- Stack temperatures greater than 200°C indicates potential for recovery of waste heat.
- It also indicate the scaling of heat transfer/recovery equipment and hence the urgency of taking an early shut down for water / flue side cleaning.

22^{o} C reduction in flue gas temperature increases boiler efficiency by 1%

2. Feed Water Preheating using Economiser

- For an older shell boiler, with a flue gas exit temperature of 260°C, an economizer could be used to reduce it to 200°C
- Increase in overall thermal efficiency would be in the order of 3%



6°C raise in feed water temperature, by economiser/condensate recovery, corresponds to a 1% saving in fuel consumption

3. Combustion Air Preheating

- Combustion air preheating is an alternative to feedwater heating.
- In order to improve thermal efficiency by 1%, the combustion air temperature must be raised by 20 ^{o}C.

4. Avoiding Incomplete Combustion

- Incomplete combustion can arise from a shortage of air or surplus of fuel or poor distribution of fuel.
- **<u>In the case of oil and gas fired systems,</u>** CO or smoke with normal or high excess air indicates burner system problems.

  Example: Poor mixing of fuel and air at the burner. Poor oil fires can result from improper viscosity, worn tips, carbonization on tips etc.
- **<u>With coal firing</u>**: Loss occurs as grit carry-over or carbon-in-ash (2% loss).

  Example :In chain grate stokers, large lumps will not burn out completely, while small pieces and fines may block the air passage, thus causing poor air distribution.

TABLE 2.4 THEORETICAL COMBUSTION DATA – COMMON BOILER FUELS

Fuel	kg of air req./kg of fuel	kg of flue gas/kg of fuel	m^3 of flue/kg of fuel	Theoretical CO_2% in dry flue gas	CO_2% in flue gas achieved in practice
Solid Fuels					
Bagasse	3.2	3.43	2.61	20.65	10–12
Coal (bituminous)	10.8	11.7	9.40	18.70	10–13
Lignite	8.4	9.10	6.97	19.40	9–13
Paddy Husk	4.6	5.63	4.58	19.8	14–15
Wood	5.8	6.4	4.79	20.3	11.13
Liquid Fuels					
Furnace Oil	13.90	14.30	11.50	15.0	9–14
LSHS	14.04	14.63	10.79	15.5	9–14

5. Excess Air Control

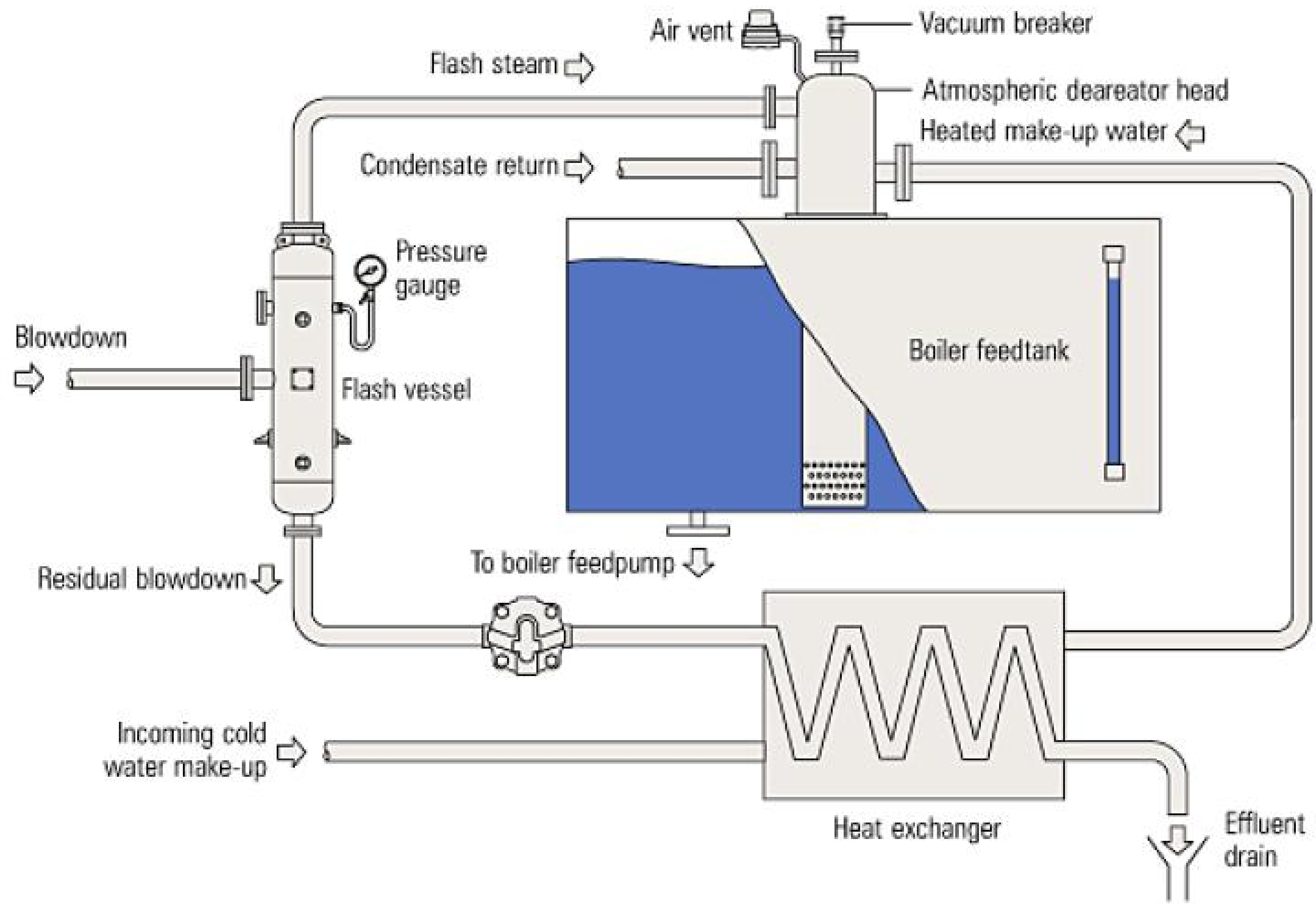
For every 1% reduction in excess air ,0.6% rise in efficiency

The optimum excess air level varies with furnace design, type of burner, fuel and process variables

TYPICAL VALUES OF EXCESS AIR LEVELS FOR DIFFERENT FUELS (National Productivity Council, field experience)		
Fuel	**Type of Furnace or Burners**	**Excess Air (percent by wt)**
Pulverized coal	Completely water-cooled furnace for slag-tap or dry-ash removal	15-20
	Partially water-cooled furnace for dry-ash removal	15-40
Coal	Spreader stoker	30-60
	Water-cooler vibrating-grate stokers	30-60
	Chain-grate and traveling-grate stokers	15-50
	Underfeed stoker	20-50
Fuel oil	Oil burners, register type	15-20
	Multi-fuel burners and flat-flame	20-30
Natural gas	High pressure burner	5-7

6. Blow down Heat Recovery

- **Efficiency Improvement - Up to 2 %**
- The amount of blowdown should be minimized by following a good water treatment program, but installing a heat exchanger in the blowdown line allows this waste heat to be used in preheating makeup and feedwater
- Heat recovery is most suitable for continuous blowdown operations which in turn provides the best water treatment program.


Air vent
Vacuum breaker
Flash steam
Atmospheric deareator head
Heated make-up water
Condensate return
Pressure
gauge
Blowdown
Boiler feedtank
Flash vessel
Residual blowdown
To boiler feedpump
Incoming cold
water make-up
Heat exchanger
Effluent
drain

7. Radiation and Convection Heat Loss Minimization

- The external surfaces of a shell boiler are hotter than the surroundings

- The surfaces thus lose heat to the surroundings depending on the surface area and the difference in temperature between the surface and the surroundings.

- The heat loss from the boiler shell is normally a fixed energy loss, irrespective of the boiler output.

- With modern boiler designs, this may represent only 1.5 percent on the gross calorific value at full rating, but will increase to around 6 percent, if the boiler operates at only 25 percent output.

- Repairing or augmenting insulation can reduce heat loss through boiler walls and piping.

8. Reduction of Scaling and Soot Losses

- In oil and coal-fired boilers, soot buildup on tubes acts as an insulator against heat transfer.
- Any such deposits should be removed on a regular basis. Elevated stack temperatures may indicate excessive soot buildup. Also same result will occur due to scaling on the water side.
- This condition can result from a gradual build-up of gas-side or waterside deposits. Waterside deposits require a review of water treatment procedures and tube cleaning to remove deposits.
- Stack temperature should be checked and recorded regularly as an indicator of soot deposits. When the flue gas temperature rises about 20^{o}C above the temperature for a newly cleaned boiler, it is time to remove the soot deposits
- It is estimated that 3 mm of soot can cause an increase in fuel consumption by 2.5 percent due to increased flue gas

9. Reduction of Boiler Steam Pressure

- This is an effective means of reducing fuel consumption, if permissible, by as much as 1 to 2 percent. Lower steam pressure gives a lower saturated steam temperature and without stack heat recovery, a similar reduction in the temperature of the flue gas temperature results.

- Steam is generated at pressures normally dictated by the highest pressure / temperature requirements for a particular process.

- But it must be remembered that any reduction of boiler pressure effectively de-rates the boiler output.

- Pressure should be reduced in stages, and no more than a 20 percent reduction should be considered.

10. Variable Speed Control for Fans, Blowers and Pumps

- 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.
- If the load characteristic of the boiler is variable, the possibility of replacing the dampers by a VSD should be evaluated.

11. Effect of Boiler Loading on Efficiency

- 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.
- However, below half load, most combustion appliances need more excess air to burn the fuel completely and increases the sensible heat loss.
- Operation of boiler below 25% should be avoided
- Optimum efficiency occurs at 65-85% of full loads
- Proper boiler scheduling

12. Boiler Replacement

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 replacement option should be explored.
- Since boiler plants traditionally have a useful life of well over 25 years, replacement must be carefully studied.

2.8 Case Study

Installing Boiler Economiser

A paper mill retrofitted an economiser to existing boiler. The general specification of the boiler is given below:

Boiler Capacity (T/h)	Feed Water Temp (°C)	Steam Pressure (bar)	Fuel oil
8	110	18	Furnace oil

The thermal efficiency of the boiler was measured and calculated by the indirect method using flue gases analyser and data logger. The result is summarised below:

Thermal efficiency	:	81%
Flue gas temperature	:	315°C
CO_2%	:	13
CO (ppm)	:	167

The temperature in the flue gas is in the range of 315 to 320 °C. The waste heat in the flue gas is recovered by installing an economizer, which transfers waste heat from the flue gases to the boiler feed water. This resulted in a rise in feed water temperature by about 26 °C.

Basic Data

- Average quantity of steam generated ..... : 5 T/hr
- Average flue gas temperature .... : 315 °C
- Average steam generation / kg of fuel oil : 14 kg
- Feed water inlet temperature .... : 110 °C
- Fuel oil supply rate.................................. : 314 kg/hr
- Flue gas quantity .... : 17.4 kg/kg of fuel

Cost Economics

- Quantity of flue gases .... : $314 \times 17.4 = 5463.6$ kg/h
- Quantity of heat available in the flue gases : $5463.6 \times 0.23 \times (315\text{-}200) = 144512$ kCal/h
- Rise in the feed water temperature .... : 26 °C.
- Heat required for pre-heating the feed water : $5000 \times 1 \times 26 = 130000$ kCal/h
- Saving in terms of furnace oil ....: $130000/10000 = 13$ kg/h
- Annual operating hours .... : 8600
- Annual savings of fuel oil .... : $8600 \times 13 = 111800$ kg

Conclusion

Through recovery of waste heat by installation of an economizer, the paper mill was able to save 13 kg/hr. of furnace oil, which amounts to about 1,11,800 kg of furnace oil per annum.

Heat Recovery

Why Recovery?

- Heat which is generated in a process by way of fuel combustion or chemical reaction, and then "dumped" into the environment even though it could still be reused for some useful and economic purpose

Sources for Heat Recovery

- Boilers
- Kilns
- Ovens
- Furnaces
- DG Sets
- Thermic Fluid Heaters
- Low temperature process streams

Benefits of Heat Recovery

- Direct benefits
- Indirect benefits

Reduction in Pollution

Reduction in equipment sizes

Reduction in auxiliary energy consumption

Classification and Application

Source	Quality
Heat in flue gases.	The higher the temperature, the greater the potential value for heat recovery
Heat in vapour streams.	As above but when condensed, latent heat also recoverable.
Convective and radiant heat lost from exterior of equipment	Low grade – if collected may be used for space heating or air preheats.
Heat losses in cooling water.	Low grade – useful gains if heat is exchanged with incoming fresh water.
Heat in gaseous and liquid	Poor if heavily contaminated and thus requiring alloy heat exchanger. effluents leaving process.
Heat stored in products leaving the process	Quality depends upon temperature.

High ,medium and low Temperature Heat Recovery

Types of Device -High Temperature	**Temperature, °C**
Nickel refining furnace	1370 –1650
Aluminium refining furnace	650-760
Cement kiln (Dry process)	620- 730
Glass melting furnace	1000-1550

Types of Device- Medium Temperature	**Temperature, °C**
Steam boiler exhausts	230-480
Gas turbine exhausts	370-540
Diesel engine exhausts	315-600
Heat treatment furnace, Catalytic crackers, Annealing furnace	425 - 650

Low Temperature		Temperature, ºC
Process steam condensate		55-88
Cooling water from	Air compressors	27-50
R and AC condensers		32–43

Development of Heat Recovery System

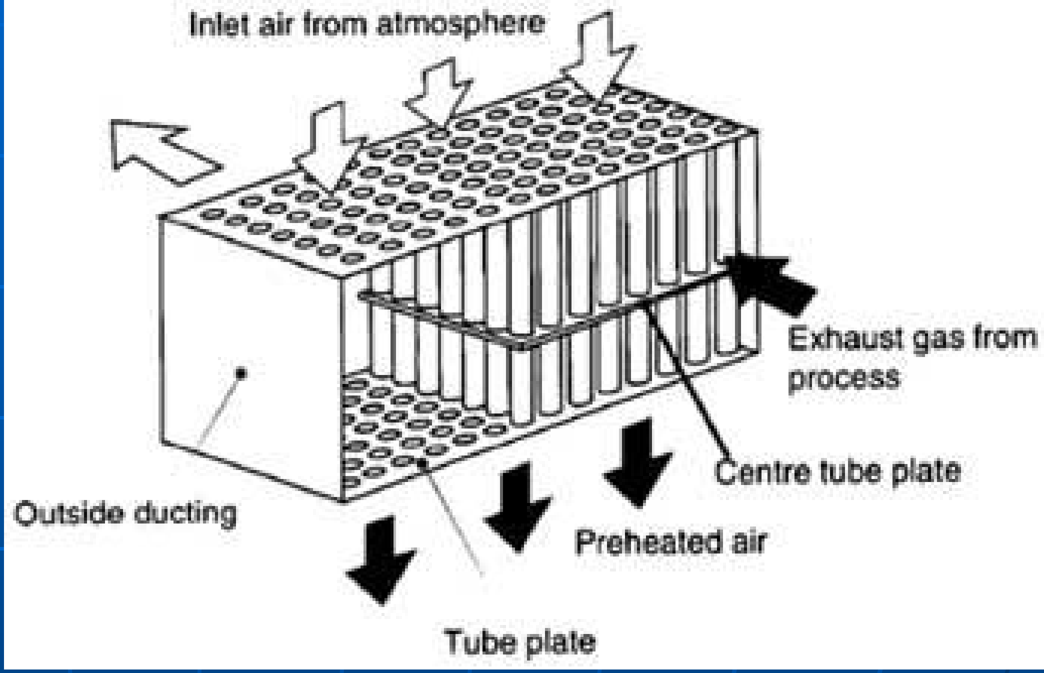
- **Understand the process**
  - Sources and uses of heat
  - Conditions occurring in the plant due to heat recovery
  - Availability of space
  - Any other constraint, such as dew point occurring in an equipment, etc.
- **Economic evaluation**

Devices

- Recuperator
- Heat Wheel
- Heat Pipe
- Shell and tube heat exchanger
- Heat Pump

Recuperator

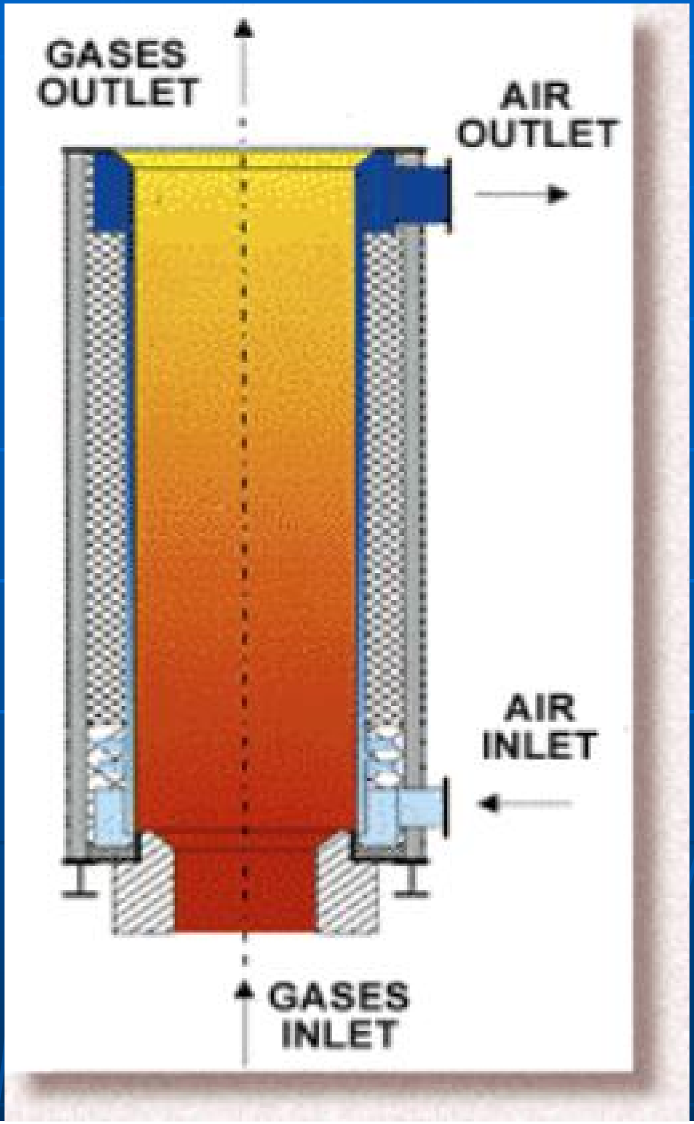
In a recuperator, heat exchange takes place between the flue gases and the air through metallic or ceramic walls. Duct or tubes carry the air for combustion to be pre-heated, the other side contains the waste heat stream.



- In order to overcome the temperature limitation of metallic recuperators which is about 1000°C on the gas side, ceramic tube recuperators have been developed. Ceramic recuperators allow operation on the gas side up to 1300 °C and on the preheated air side up to 850 °C.

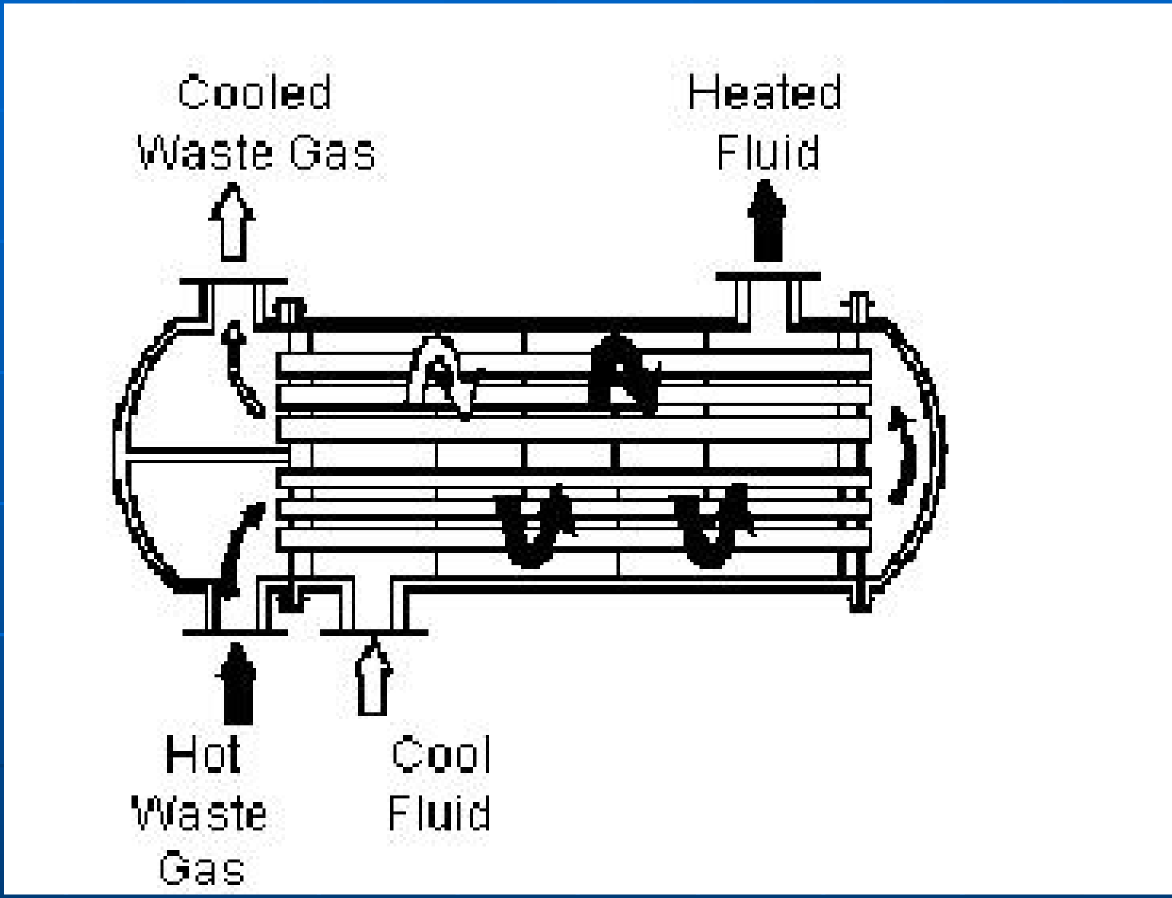
Metallic Radiation Recuperat

The radiation recuperator gets its name from the fact that a substantial portion of the heat transfer from the hot gases to the surface of the inner tube takes place by radiative heat transfer



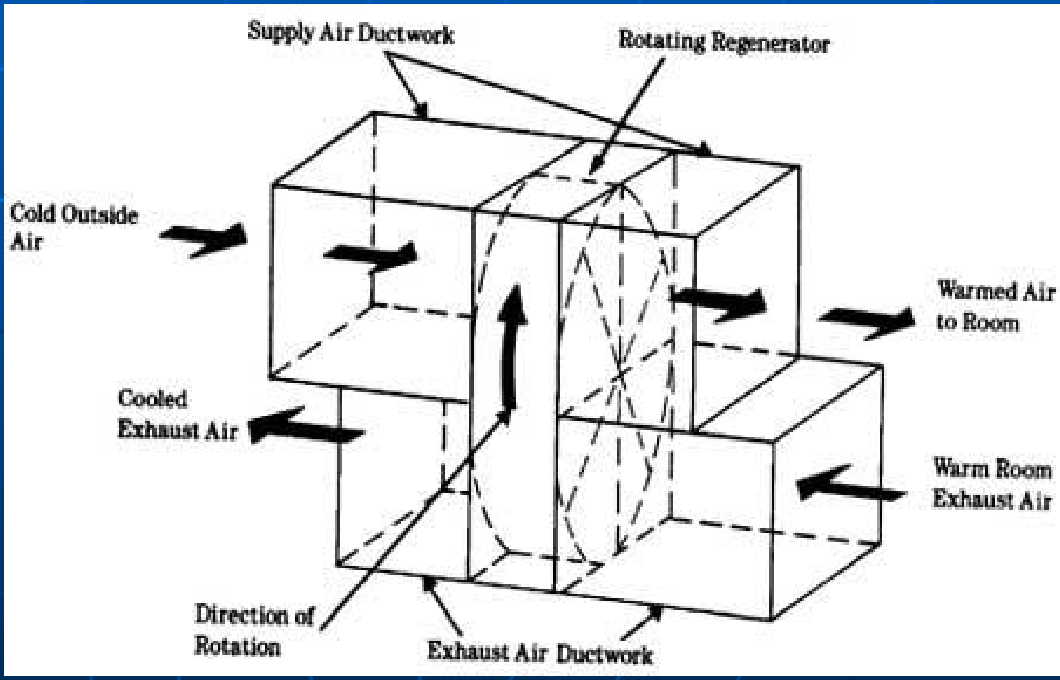
Convective Recuperator

The hot gases are carried through a number of parallel small diameter tubes, while the incoming air to be heated enters a shell surrounding the tubes and passes over the hot tubes one or more times in a direction normal to their axes.

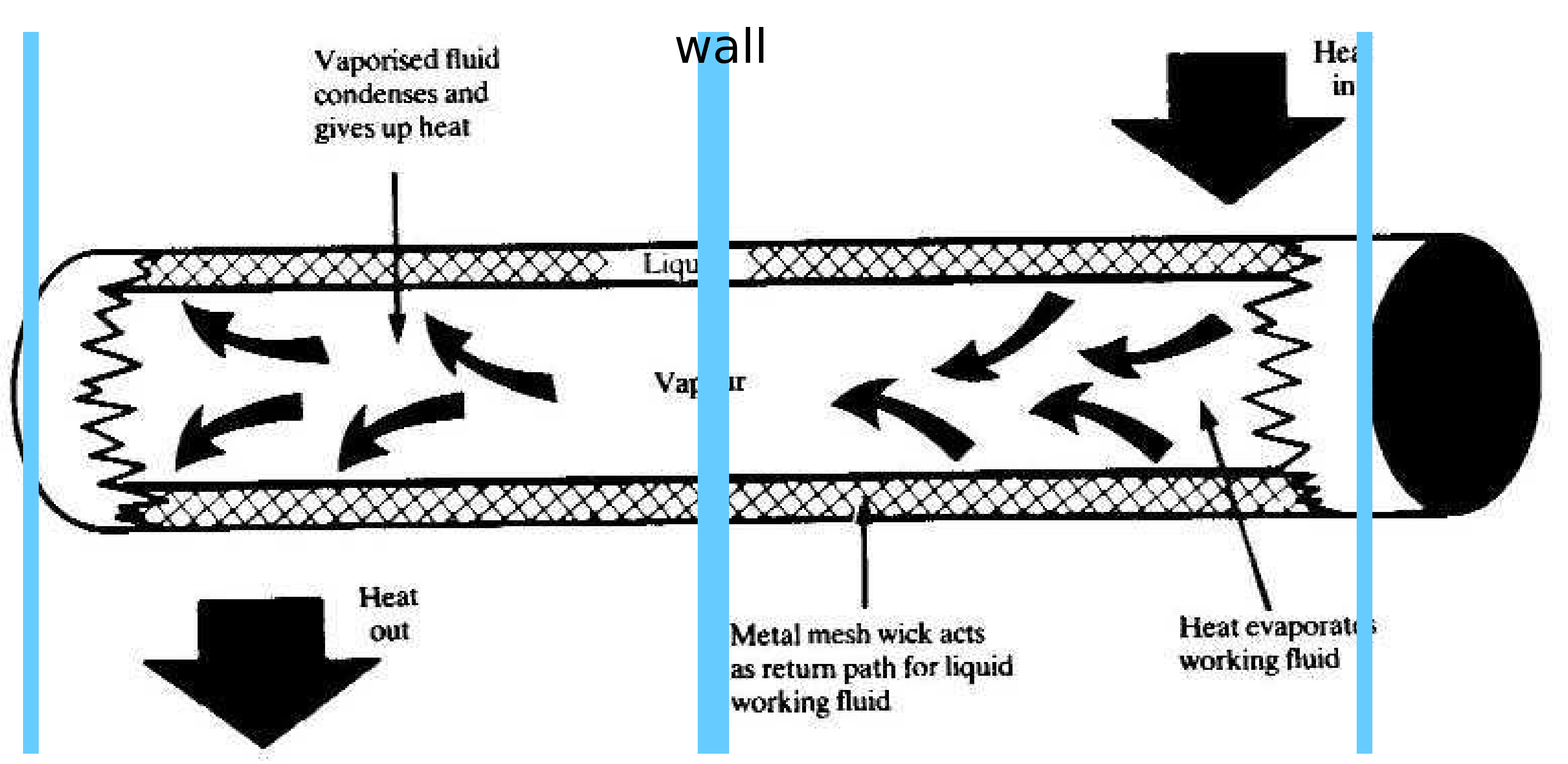


Heat Wheels

Widely used in low to medium temperature waste heat recovery systems.
A disk rotates between two side-by-side ducts: one a cold gas duct, the other a hot gas duct.
As the disk slowly rotates, sensible heat (moisture that contains latent heat) is transferred to the disk by the hot air and, as the disk rotates, from the disk to the cold air.



Heat Pipe



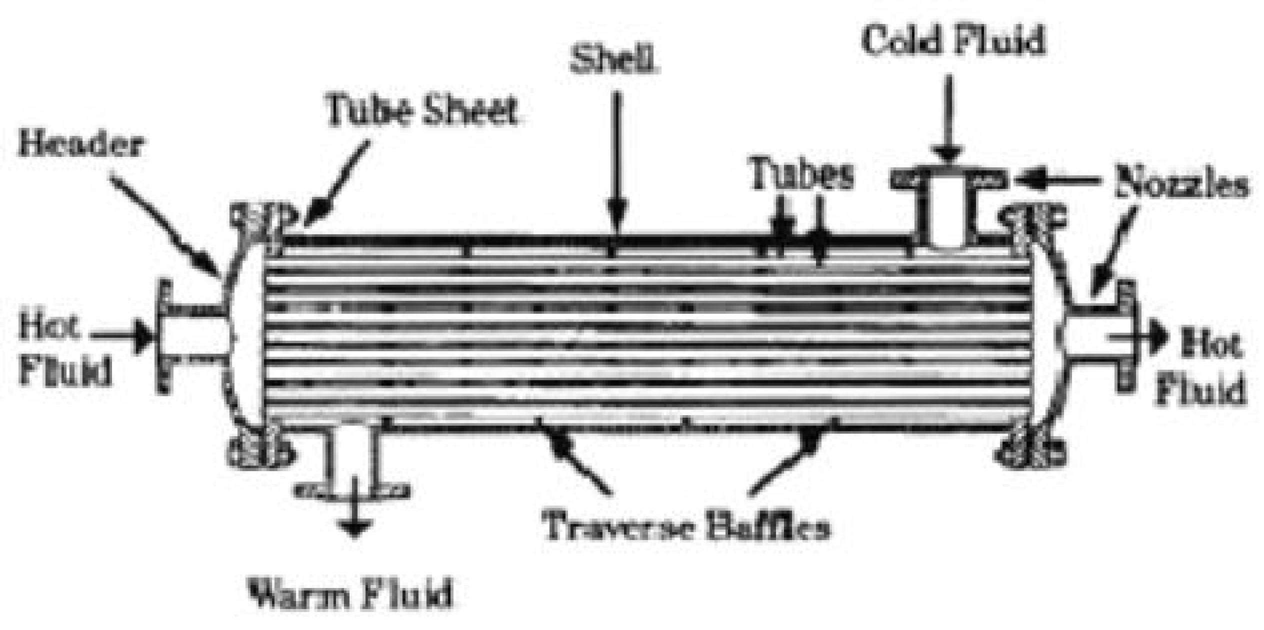
Heat pipe is a thermal energy absorbing and transferring system and have no moving parts and hence require minimum maintenance.

- The heat pipe exchanger is a lightweight compact heat recovery system

- It does not need mechanical maintenance, as there are no moving parts to wear out

- It does not need input power for its operation and is free from cooling water and lubrication systems.

Shell and Tube Heat Exchange

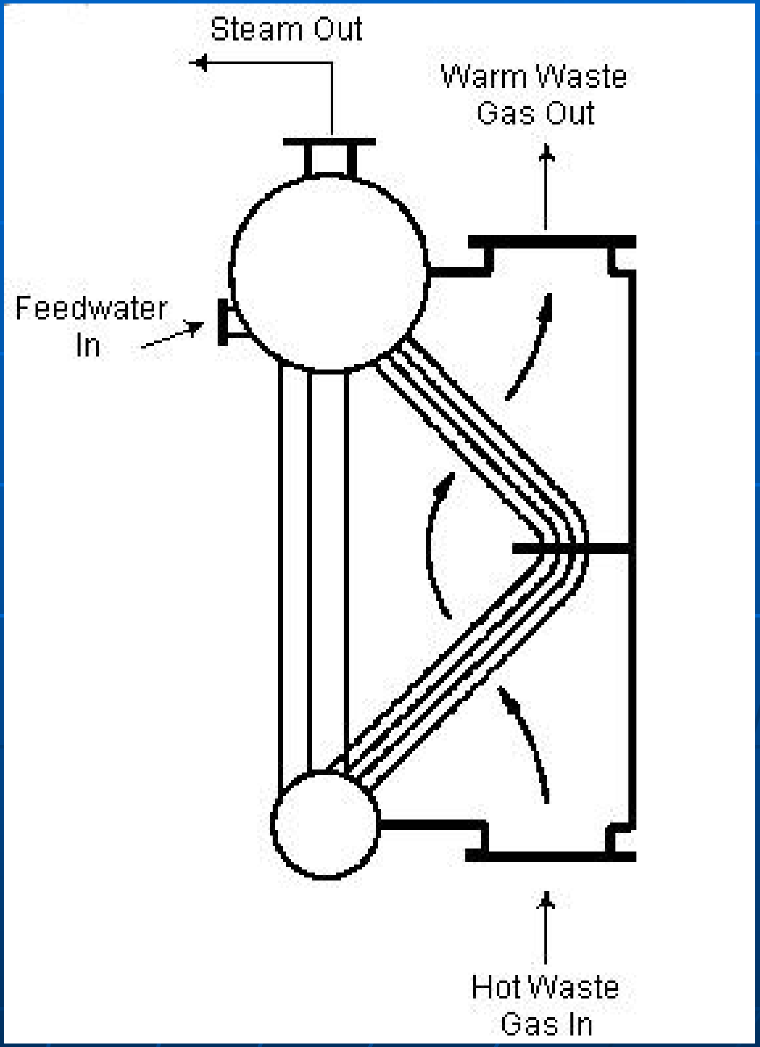


When the medium containing waste heat is a liquid or a vapor which heats another liquid, then the shell and tube heat exchanger must be used since both paths must be sealed to contain the pressures of their respective fluids.

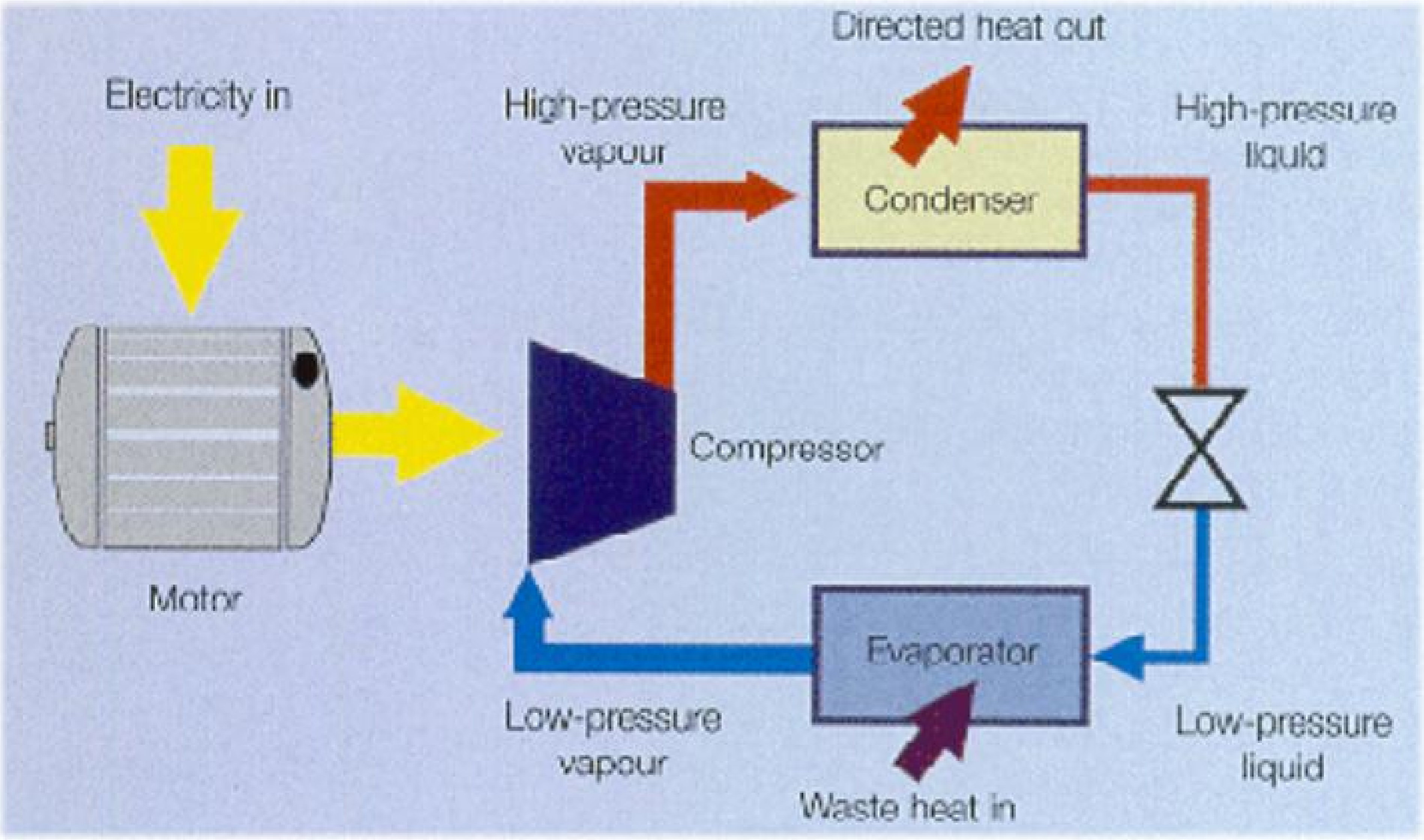
Waste Heat Boilers

Waste heat boilers are ordinarily water tube boilers in which the hot exhaust gases from gas turbines, incinerators, etc., pass over a number of parallel tubes containing water.

The water is vaporized in the tubes and collected in a steam drum from which it is drawn off for use as heating or processing steam



Heat Pumps


Directed heat out
Electricity in
High-pressure vapour
High-pressure liquid
Condenser
Compressor
Motor
Evaporator
Low-pressure vapour
Low-pressure liquid
Waste heat in

Concluding Remarks

- Eliminate steam leakages by trap improvements
- Maximise condensate recovery
- Adopt combustion controls for maximizing combustion efficiency
- Replace pumps, fans, air compressors, refrigeration compressors, boilers, furnaces, heaters and other energy consuming equipment, wherever significant energy efficiency margins exist.
- Shuffling of compressors to match needs.
- Periodic review of insulation thickness
- Identify potential for heat exchanger networking and process integration.

Concluding Remarks…

- Substituting existing fossil fuel with more efficient and less cost/less polluting fuel such as natural gas, biogas and locally available agro-residues
- Natural gas is increasingly the fuel of choice as fuel and feedstock in the fertilizer, petrochemicals, power and sponge iron industries.
- Replacement of coal by coconut shells, rice husk etc.
- Replacement of LDO by LSHS

Few examples of energy substitution

- Replacement of electric heaters by steam heaters
- Replacement of steam based hot water by solar systems

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Questions

1. Name three factors affecting the boiler efficiency and explain briefly?
2. Discuss the various types of heat losses in a boiler?
3. How do you measure boiler efficiency using direct method?
4. What do you understand by term evaporation ratio? What are the typical values for coal and oil-fired boiler?
5. What do you understand by the term ‘Turn Down Ratio’ ?
6. What are the methods available for assessing the boiler efficiency and explain briefly?
7. What is mean by blowdown of boiler? Why it is needed? Discuss about methods of blowdown of boiler.
8. What is the function of de-aerator in boiler?
9. List the 5 energy conservation measures in improving the boiler efficiency without investment.
10. Is moisture in coal wasteful?
11. What is atomisation of fuel oil in combustion?
12. What are the causes for heavy black smoke in a boiler?

Questions

13. For boiler at 8 kg/cm2 (g) steam pressure. The following details are given Saturation temperature of steam = 170°C

- Sensible heat of water = 171 kCal/kg
- Latent heat of evaporation = 490 kCal/kg
- Moisture content in the steam = 4%

What is the total heat content of the steam?

14. The following are the ultimate analysis for coal: Calculate the stoichiometric air requirement.

- Carbon-38%, Ash-35%, Hydrogen-5% , Sulphur-2%.
- For the same data, calculate the theoretical CO2.
- If the actual measured CO2 is 8%, find out the excess air levels?

THANK YOU