COURSE:TERMAL ENGINEERING
CODE: AME013

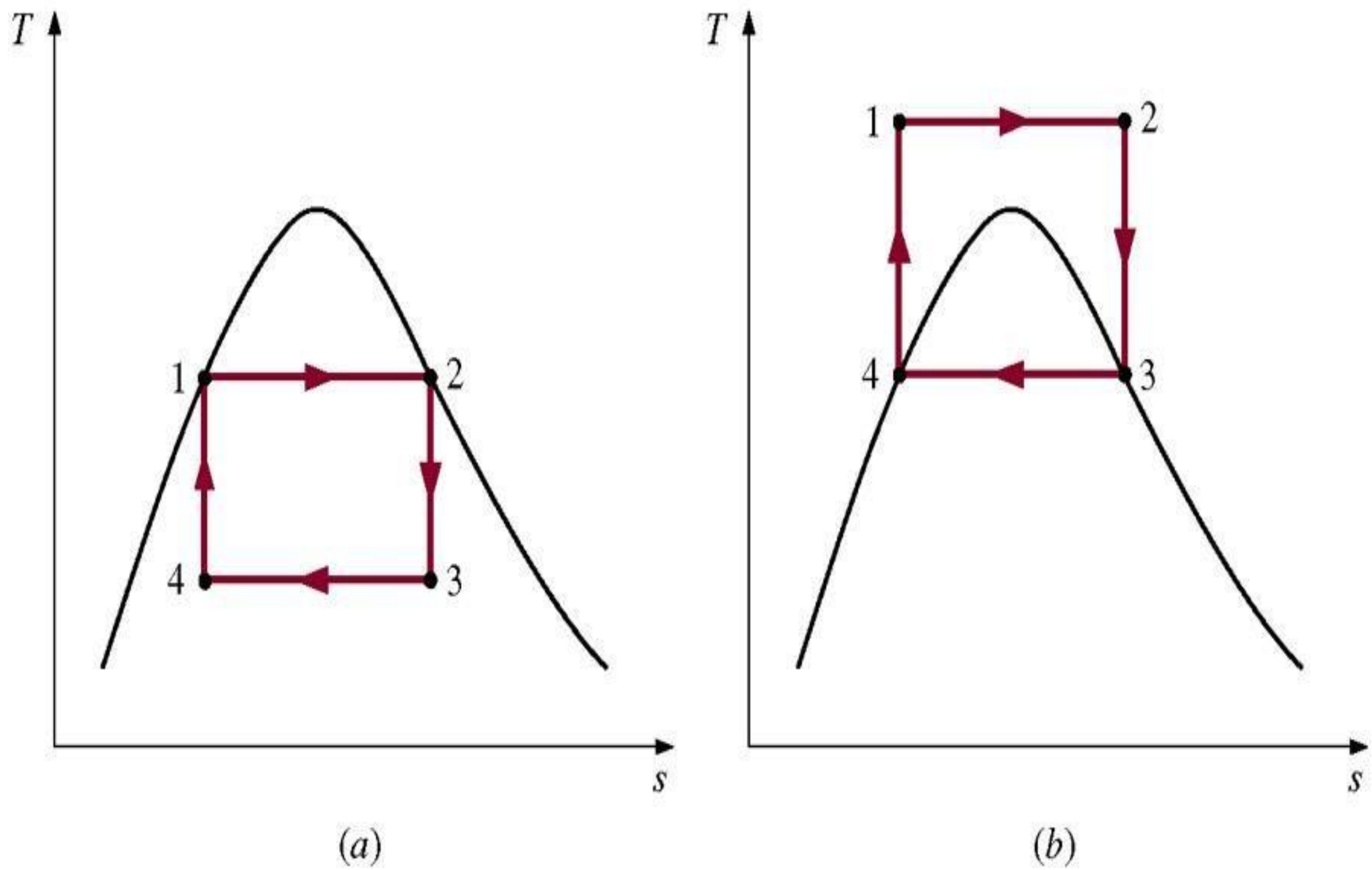
Institute of Aeronautical Engineering
(Autonomous)
Dundigal, Hyderabad – 500 043,

Prepared by
Mr. P. Sadanandam
Assistant Professor
Mechanical Department

UNIT I
THERMAL ENGINEERING

Rankine Cycle

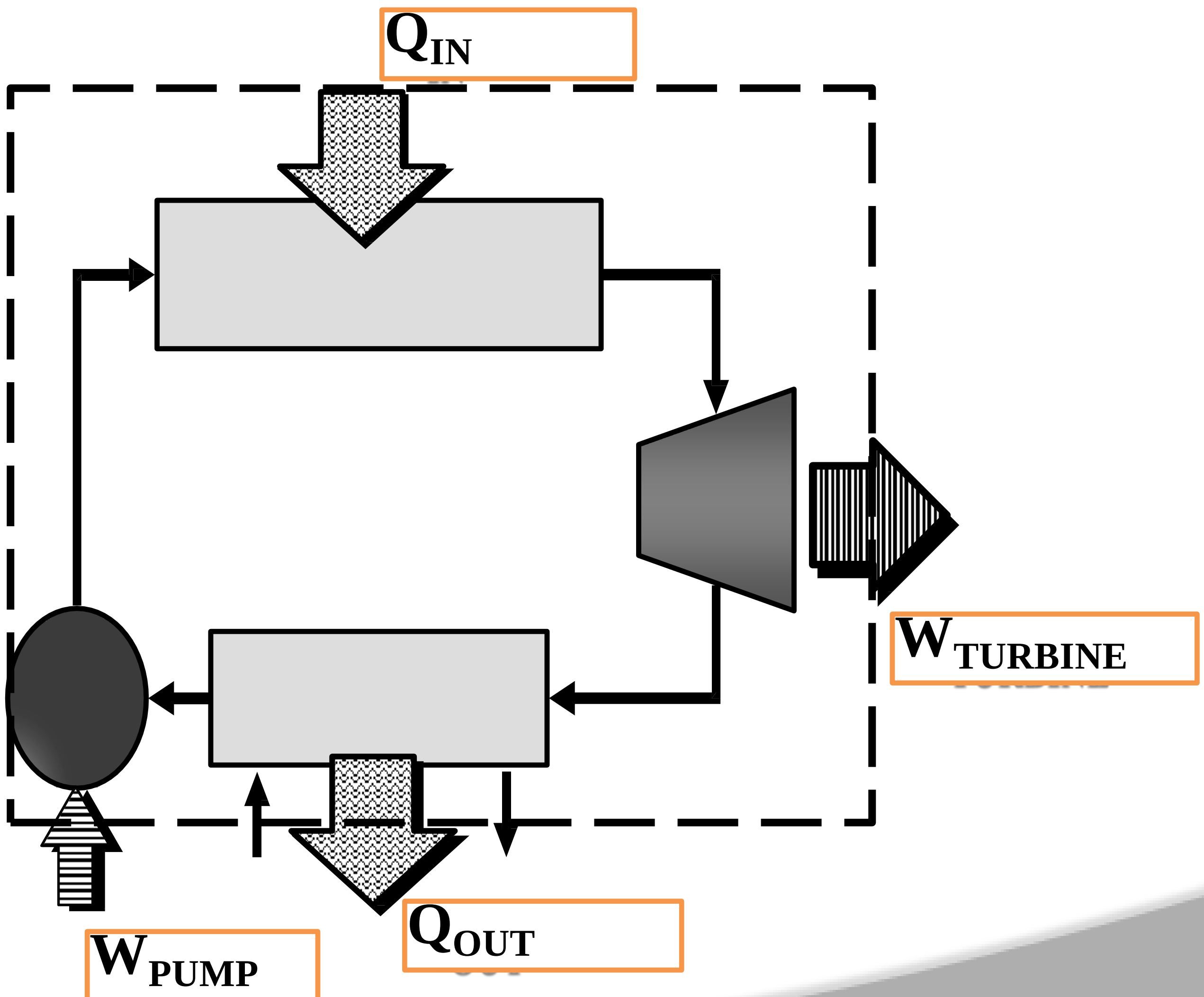
T-s diagram of two Carnot vapor cycles.



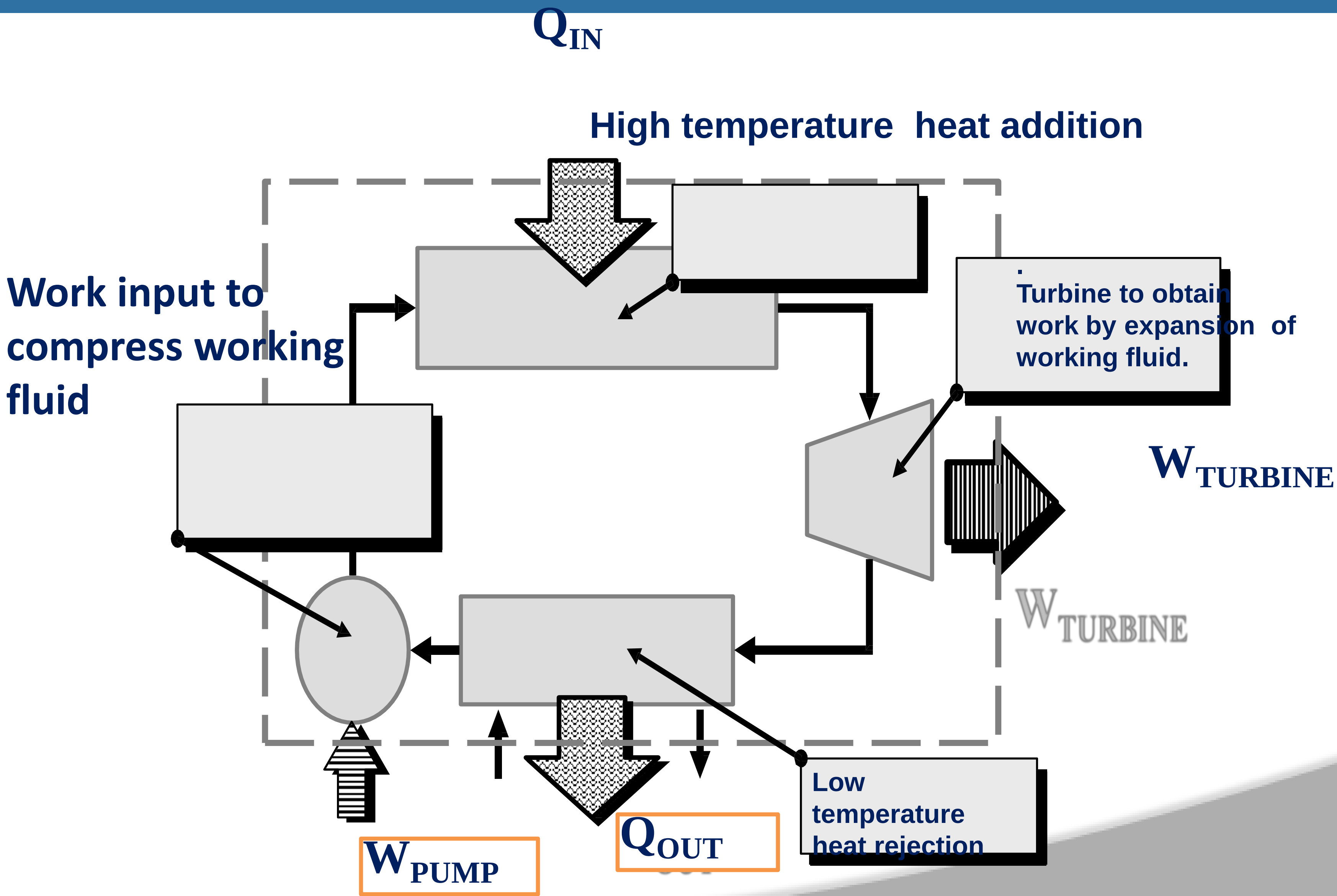
Rankine Cycle: The Ideal Cycle for Vapor Power Cycles

- **Operating principles**
- **Vapor power plants**
- **The ideal Rankine vapor power cycle**
- **Efficiency**
  - **Improved efficiency - superheat**

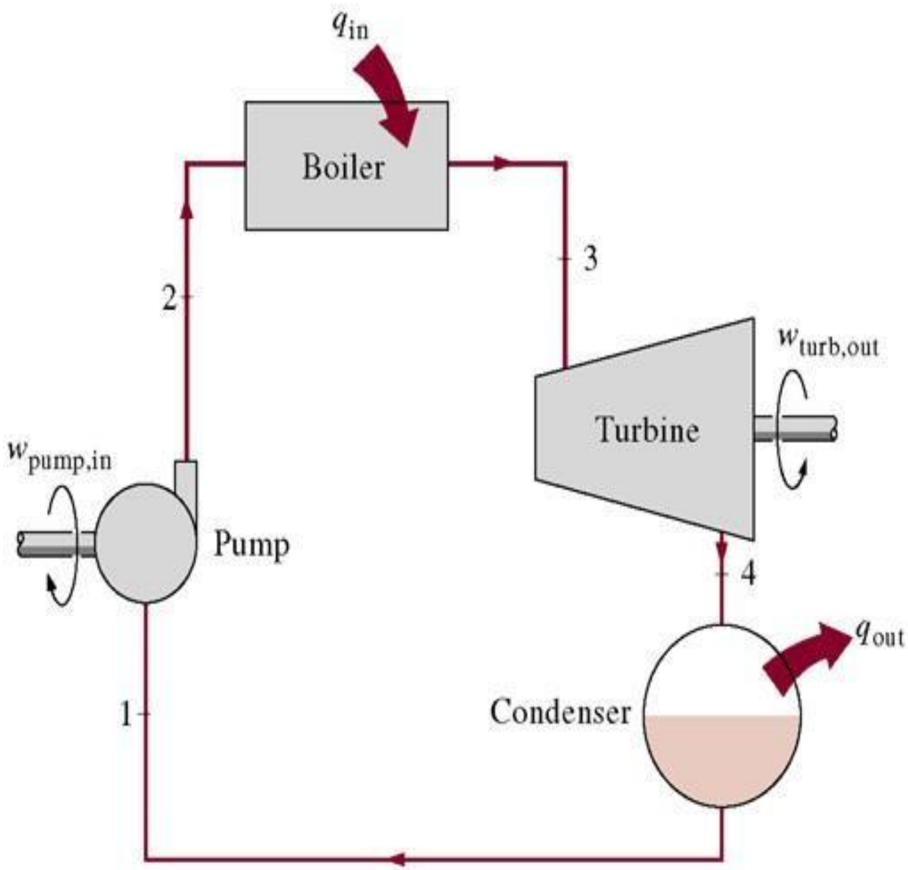
The conventional vapor power plant

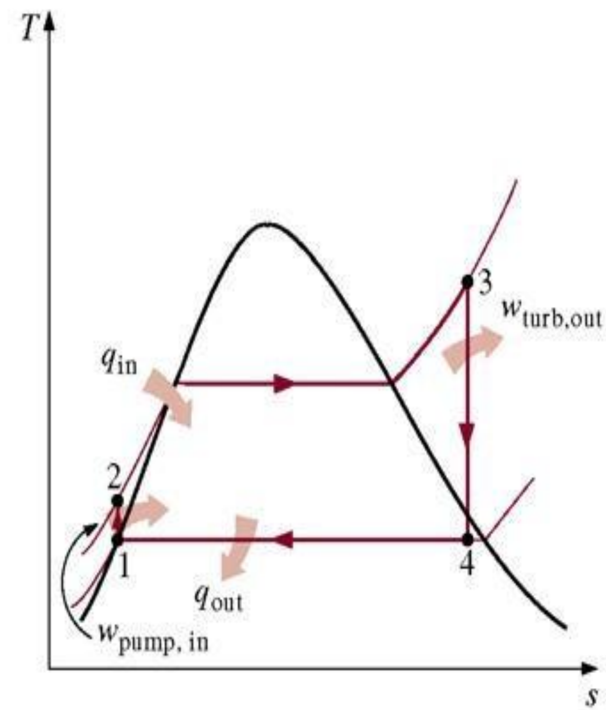


The conventional vapor power plant



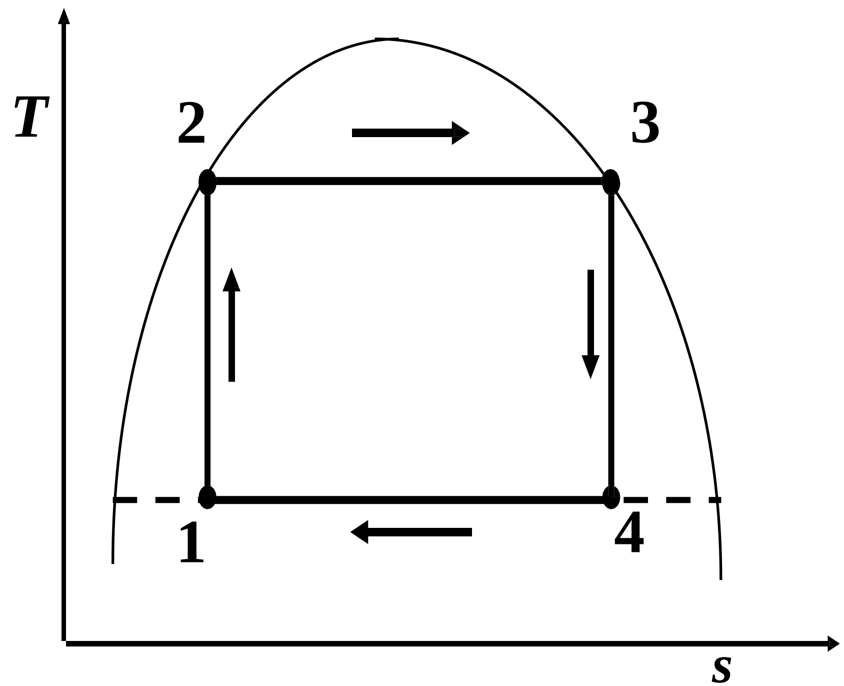
The simple ideal Rankine cycle.



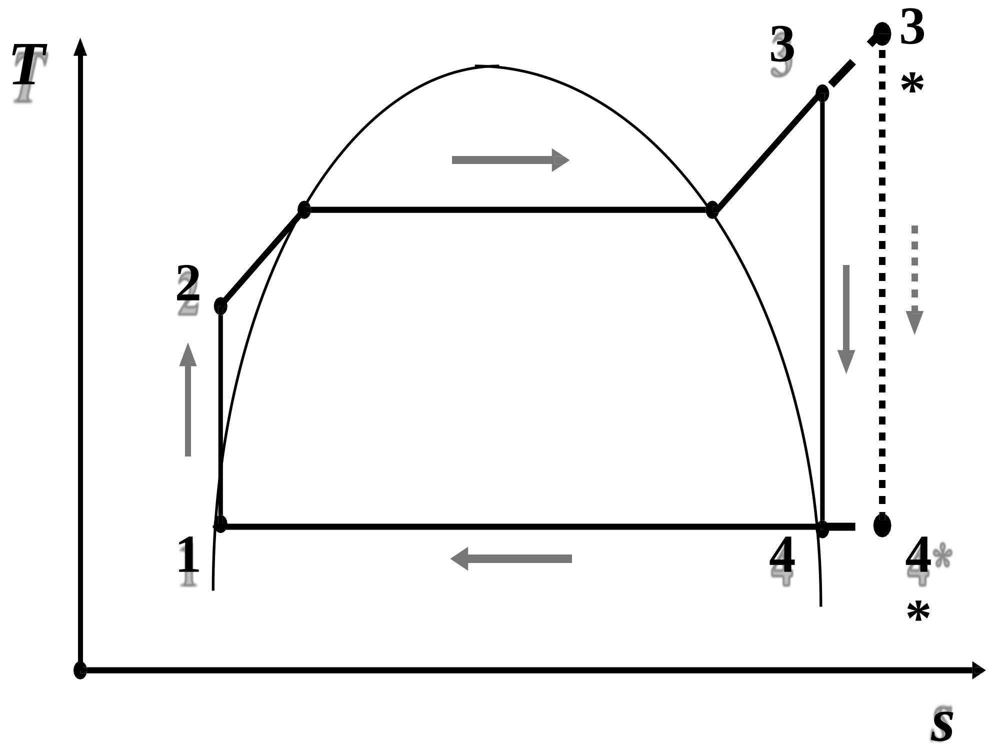


A hypothetical vapor power cycle

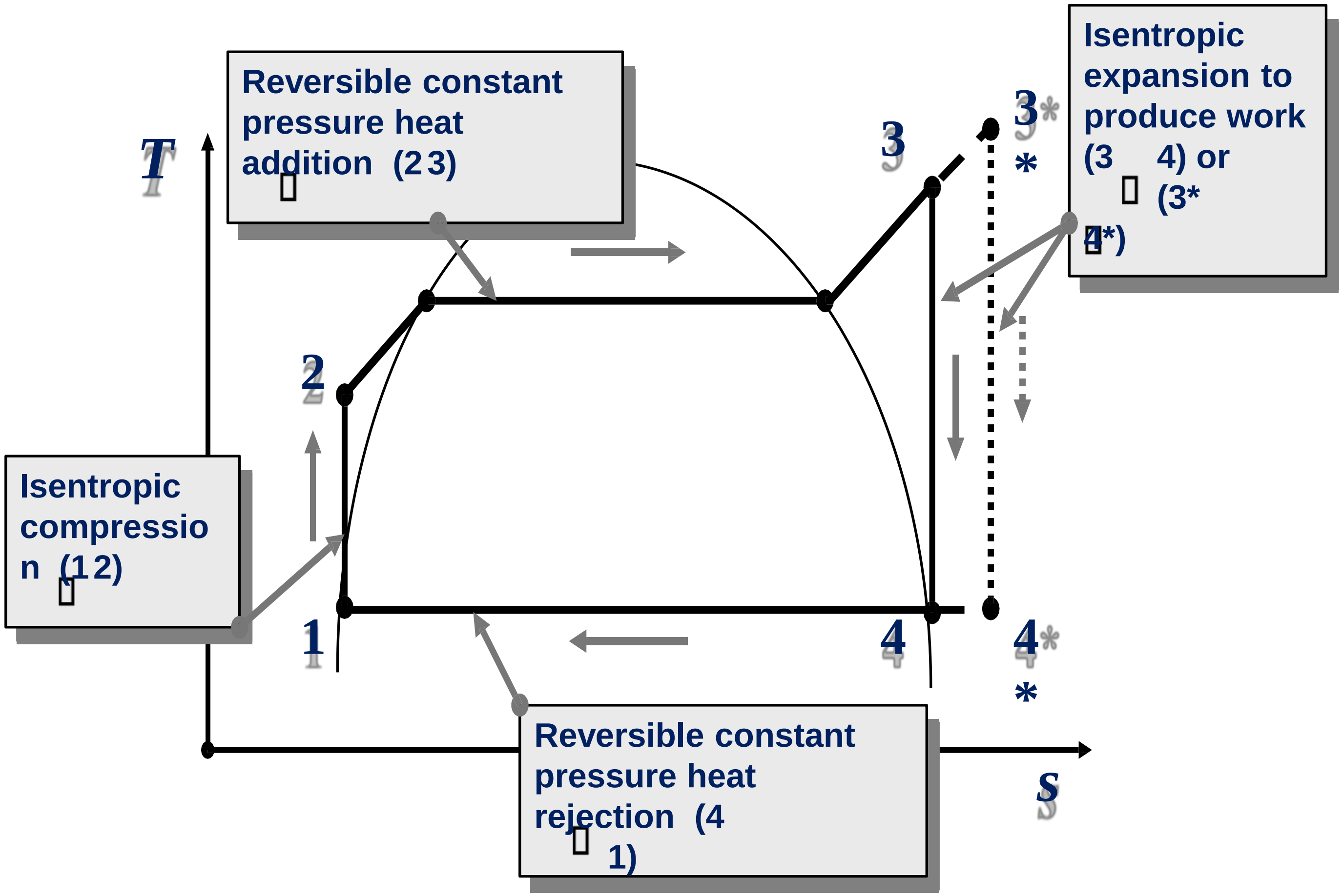
Assume a Carnot cycle operating between two fixed temperatures as shown.



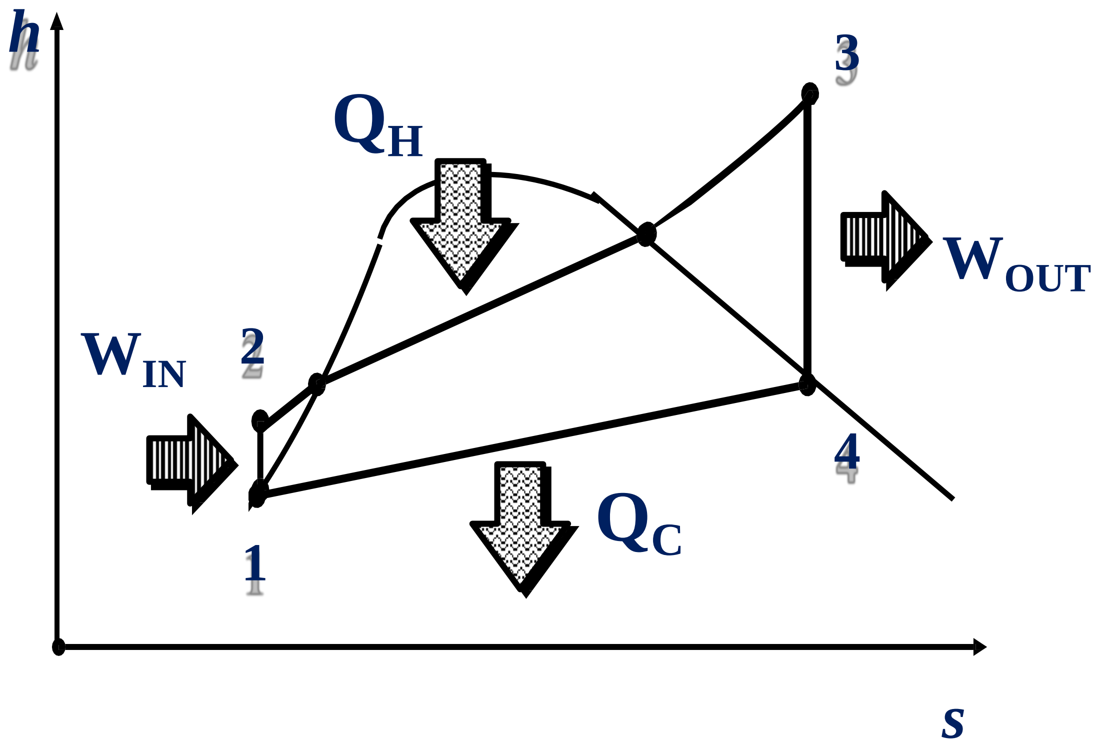
The ideal Rankine cycle



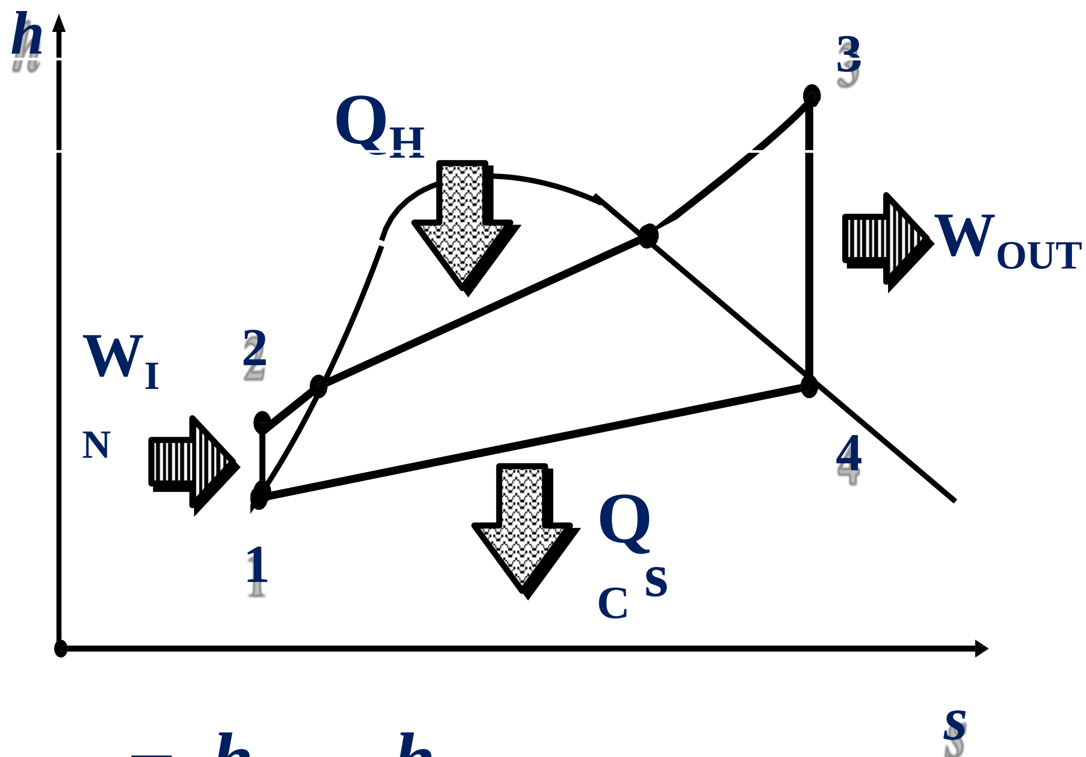
The ideal Rankine cycle



The ideal Rankine cycle (h-s diagram)



Rankine cycle efficiency



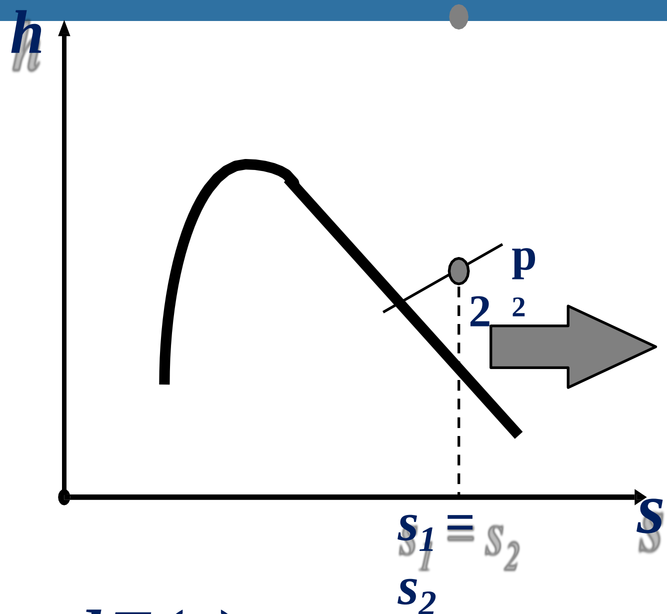
$$W_{OUT} = h_3 - h_4$$

$$W_{IN} = h_2 - h_1$$

$$Q_H = h_3 - h_4$$

$$\eta = \frac{W_{NET}}{Q_H} \quad (3)$$

Ideal Turbine Work



All accessible states lie to the right of the process (1 → 2).

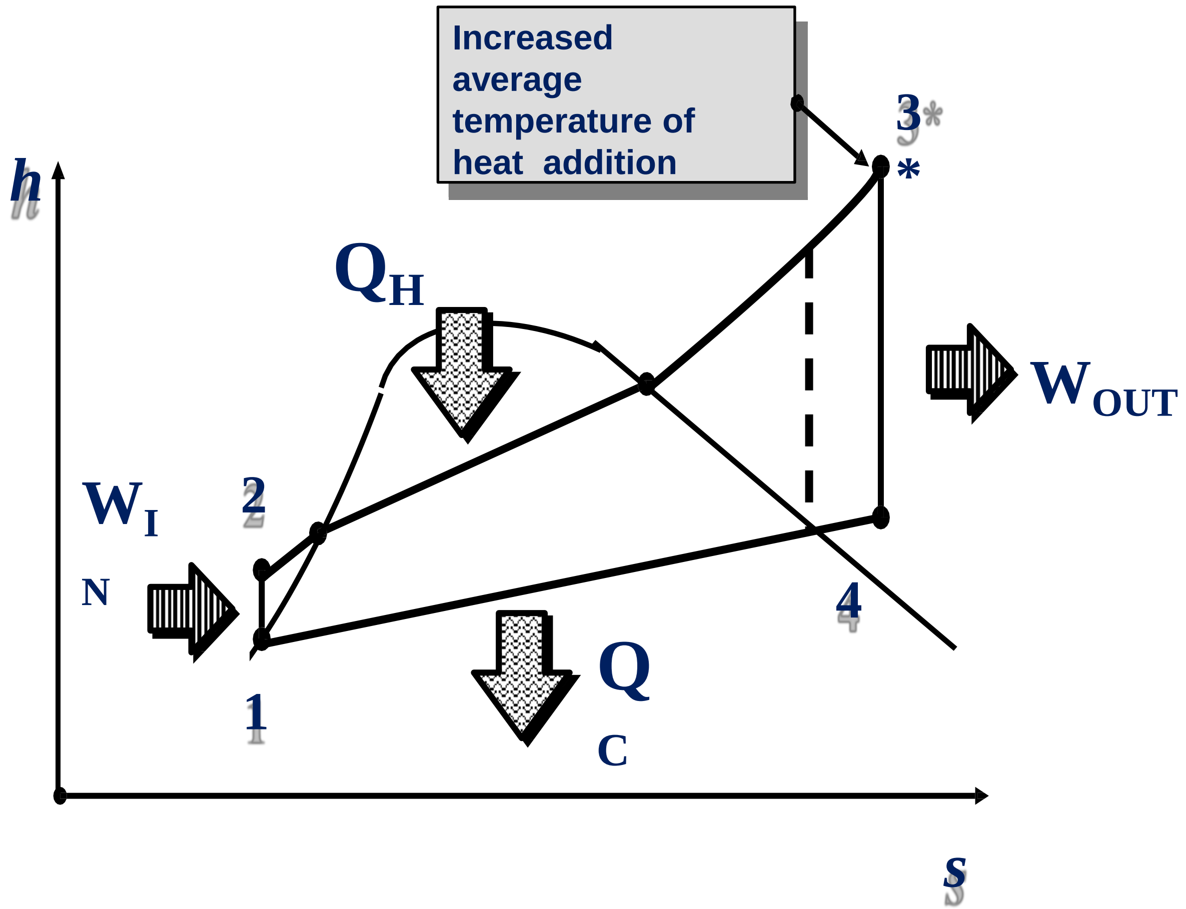
$$\frac{dE(t)}{dt} = \dot{Q}_{CS} - \dot{W}_{CS} + \sum_{i=1}^{N} \dot{m}_i \left(h + ke + pe\right)_i \qquad (4)$$

$$\frac{dS_{CV}}{dt} = \sum_j \frac{\dot{Q}_j}{T_j} + \sum_i \dot{m}_i s_i - \sum_e \dot{m}_e s_e + \dot{\sigma}_{CV}$$

Ideal turbine work

- Steady state.
- Constant mass flow
- Isentropic Expansion (s = Constant)
  - Adiabatic and reversible
  - No entropy production
- No changes in KE and PE
  - Usual assumption is to neglect KE and PE effects at inlet and outlet of turbine.

Improved Rankine cycle efficiency



Improved Rankine cycle efficiency

$$\eta = \frac{(h_{3*} - h_4) - (h_2 - h_1)}{h_{3*} - h_2} \quad (8)$$

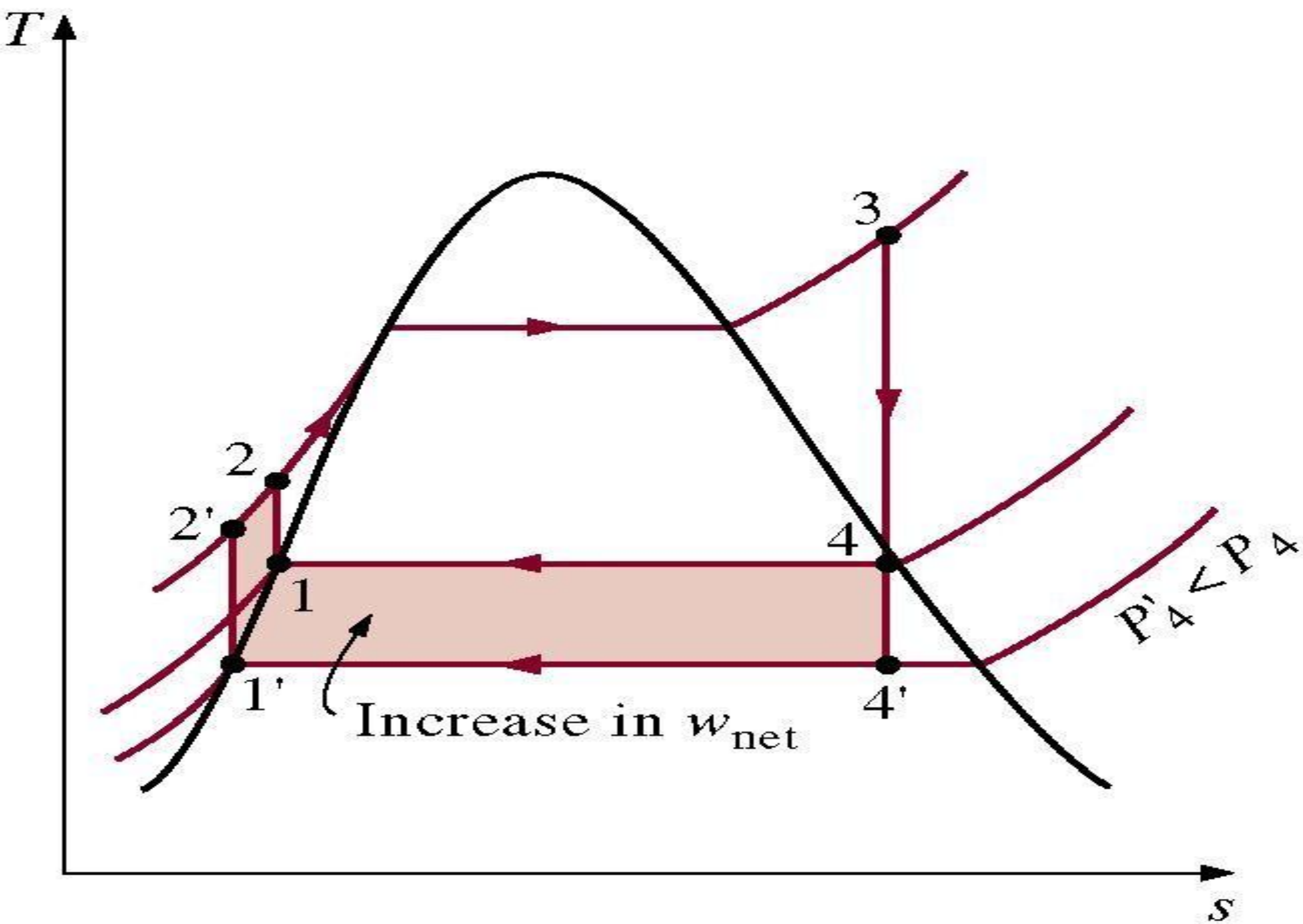
$$\frac{\partial \eta}{\partial h_{3*}} > 0 \quad (9)$$

The Improved Rankine Cycle

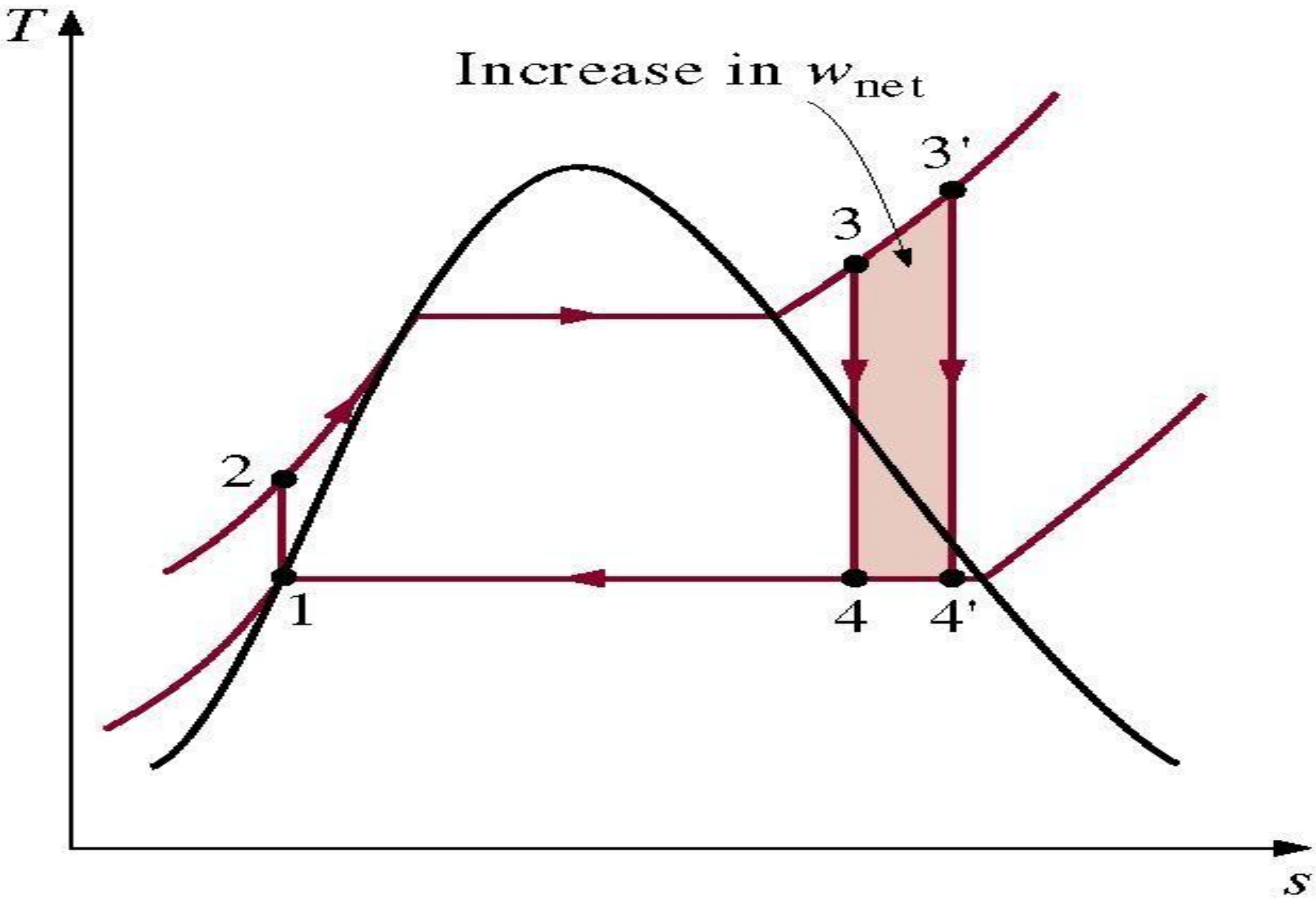
How Can We Increase the Efficiency of the Rankine Cycle

Raising the average temperature of heat addition

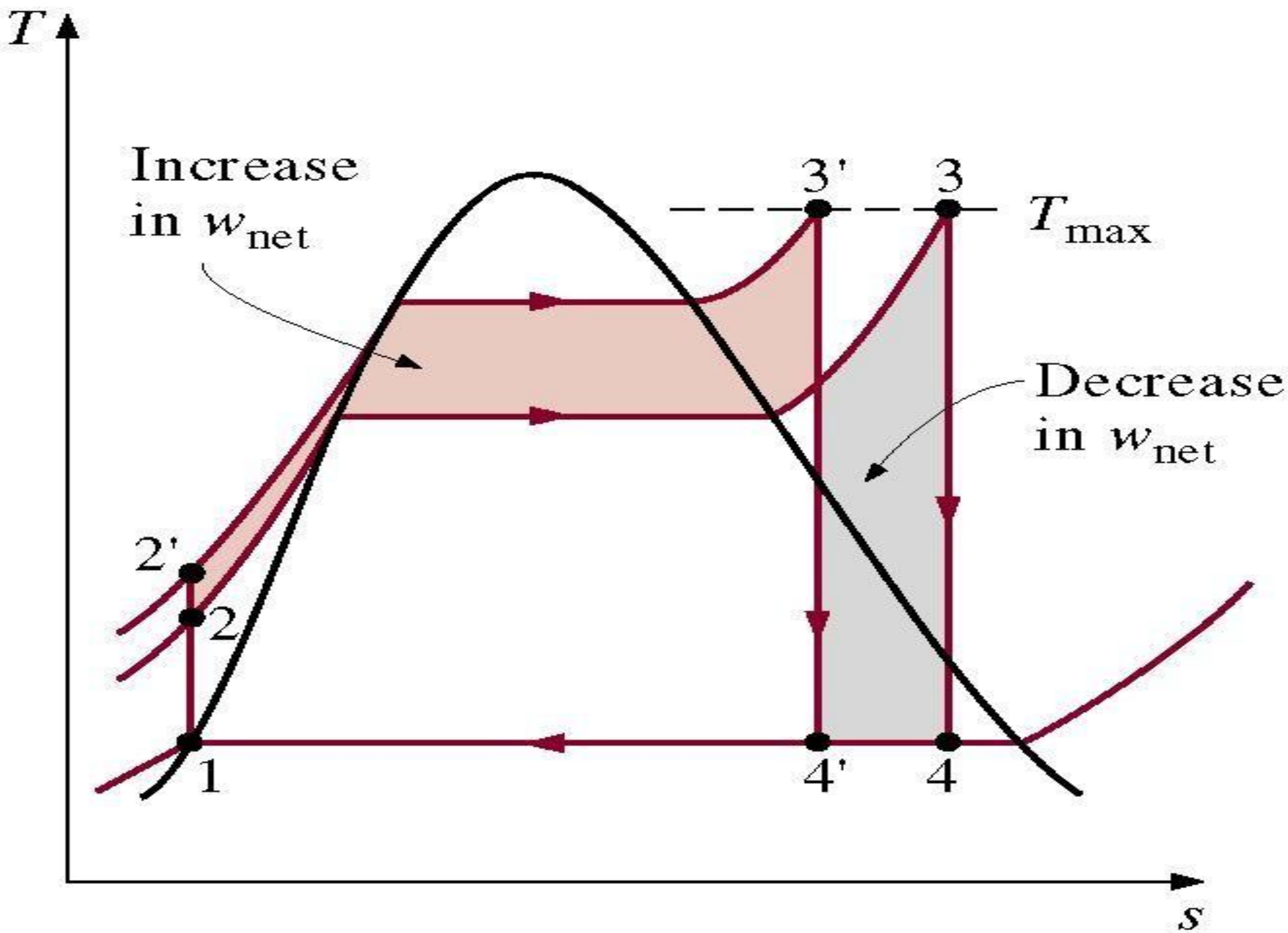
The effect of lowering the condenser pressure on the ideal Rankine cycle.



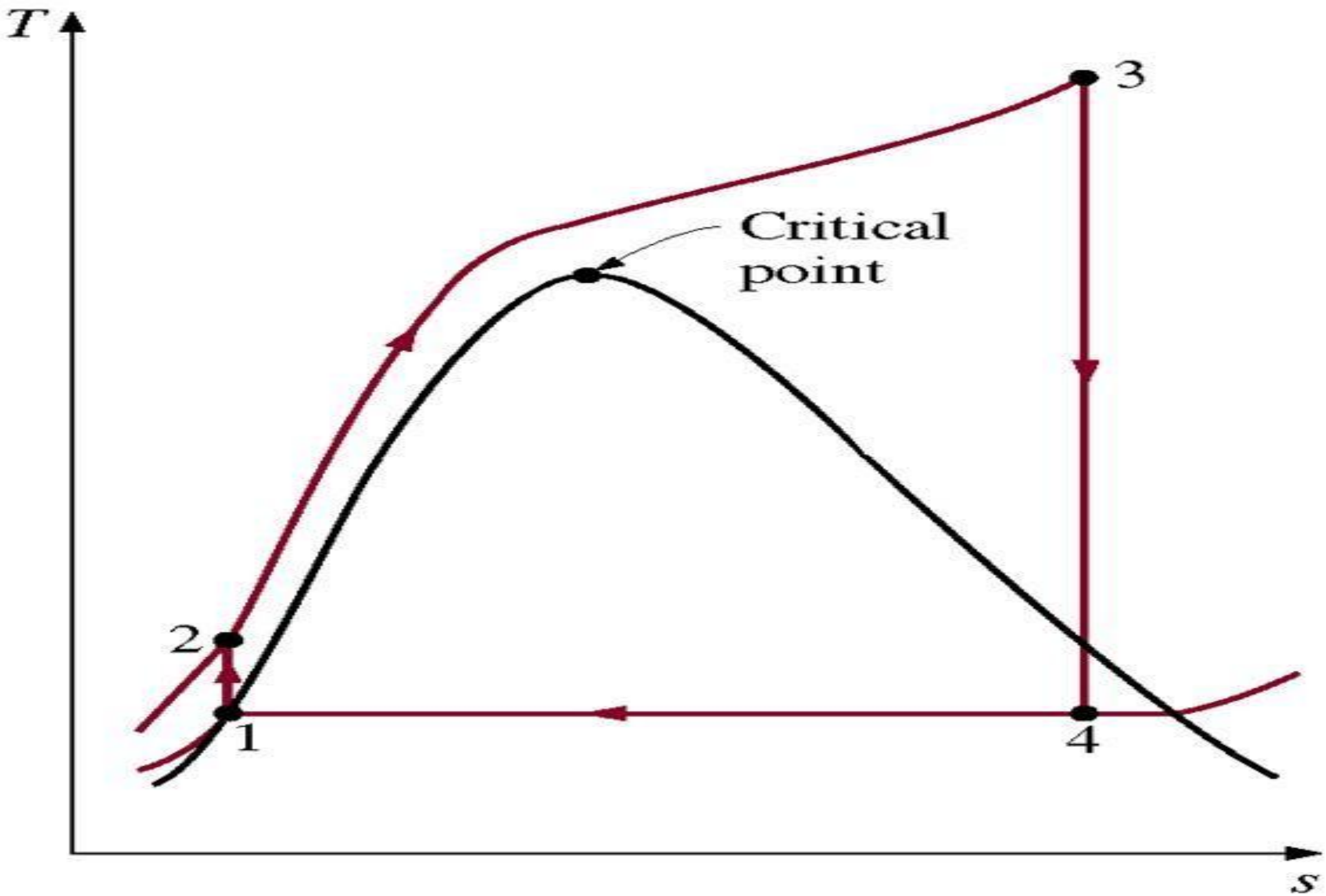
The effect of superheating the steam to higher temperatures on the ideal Rankine cycle.



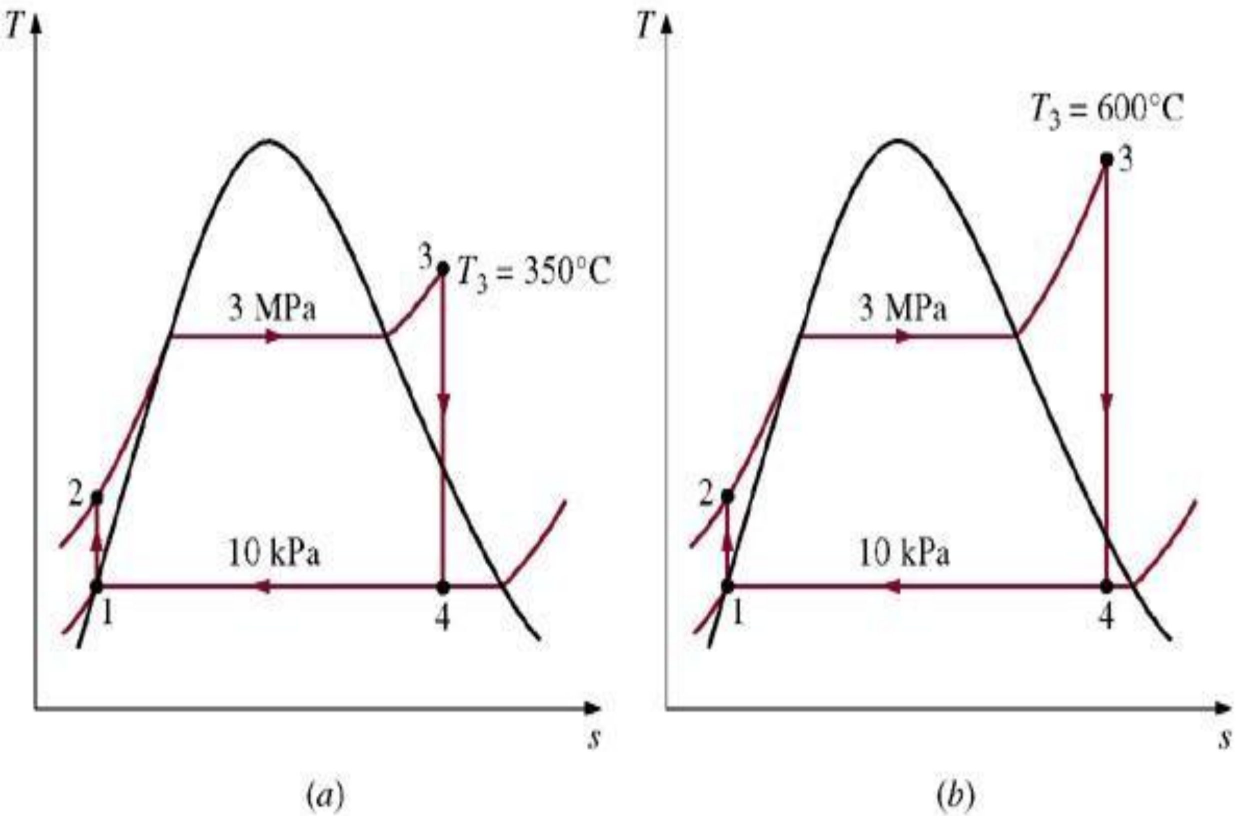
The effect of increasing the boiler pressure on the ideal Rankine cycle.



A supercritical Rankine cycle.



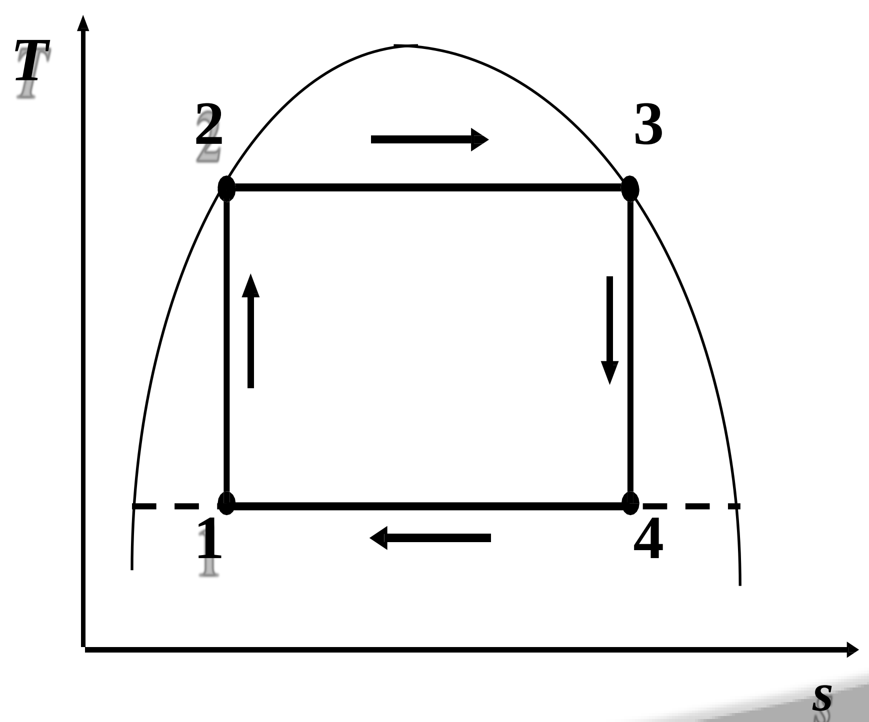
T-s diagrams of the three cycles discussed



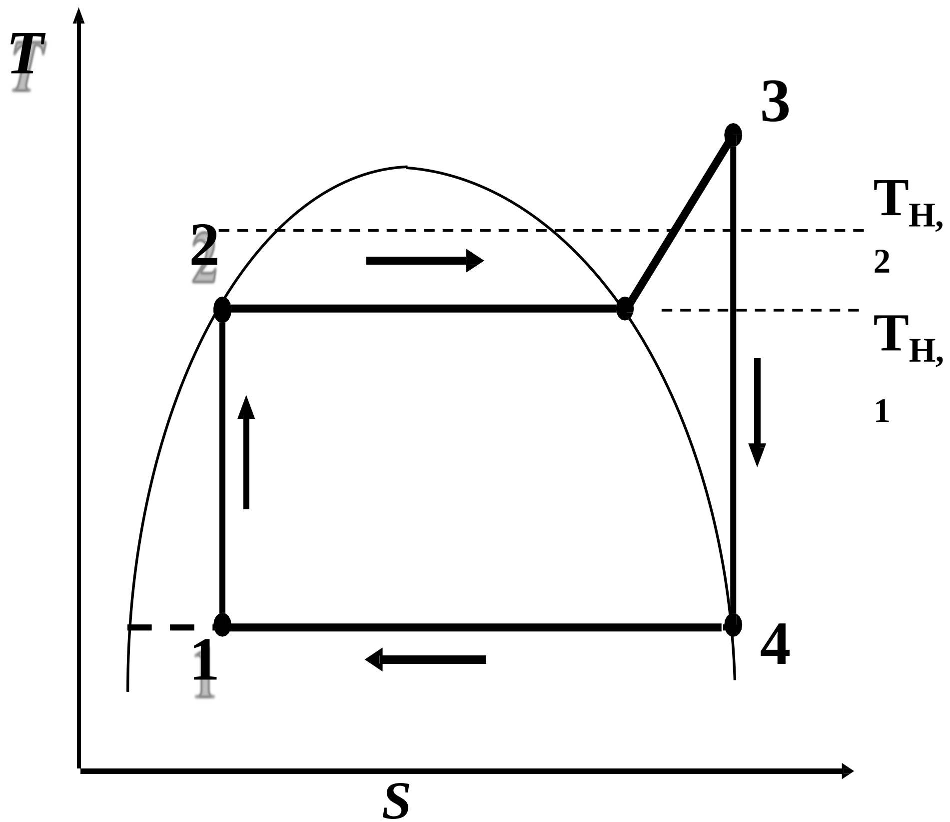
The Ideal Reheat Rankine Cycle

A hypothetical vapor power cycle

Assume a Carnot cycle operating between two fixed temperatures as shown.

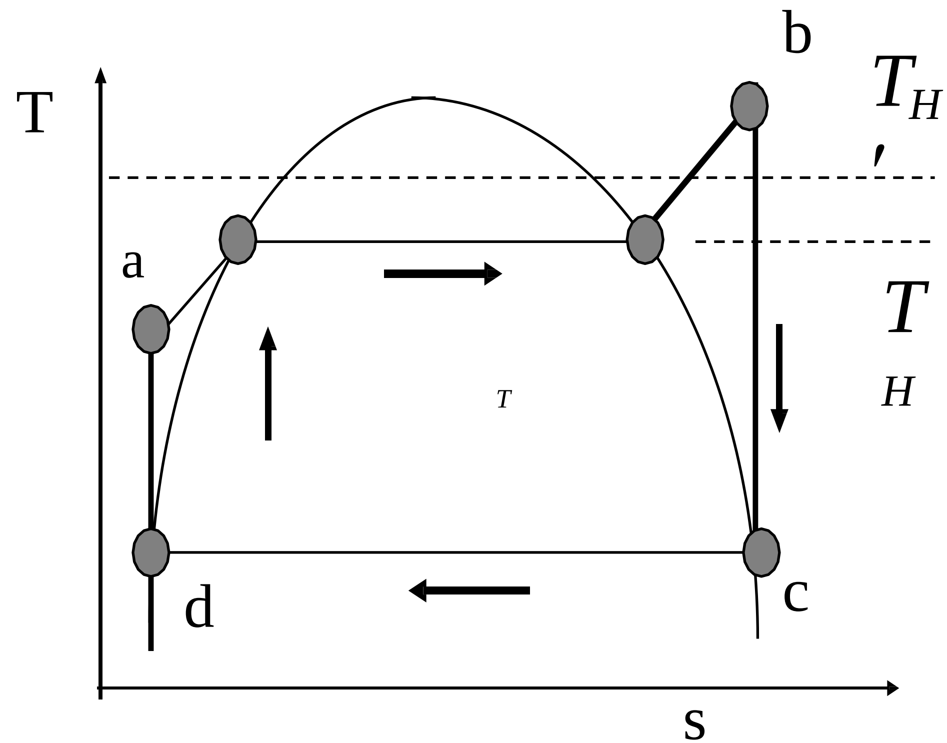


A hypothetical vapor power cycle with superheat



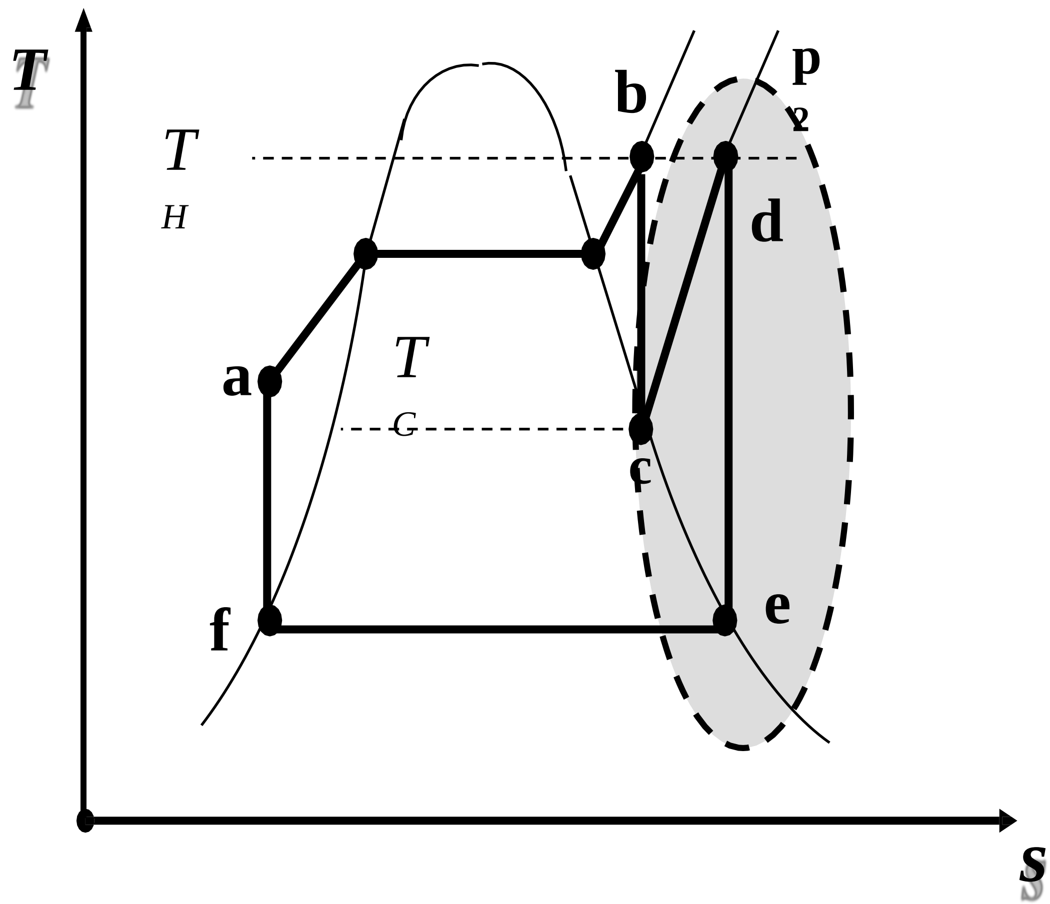
Superheating the working fluid raises the average temperature of heat addition.

A hypothetical vapor power cycle: A Rankine cycle with superheat



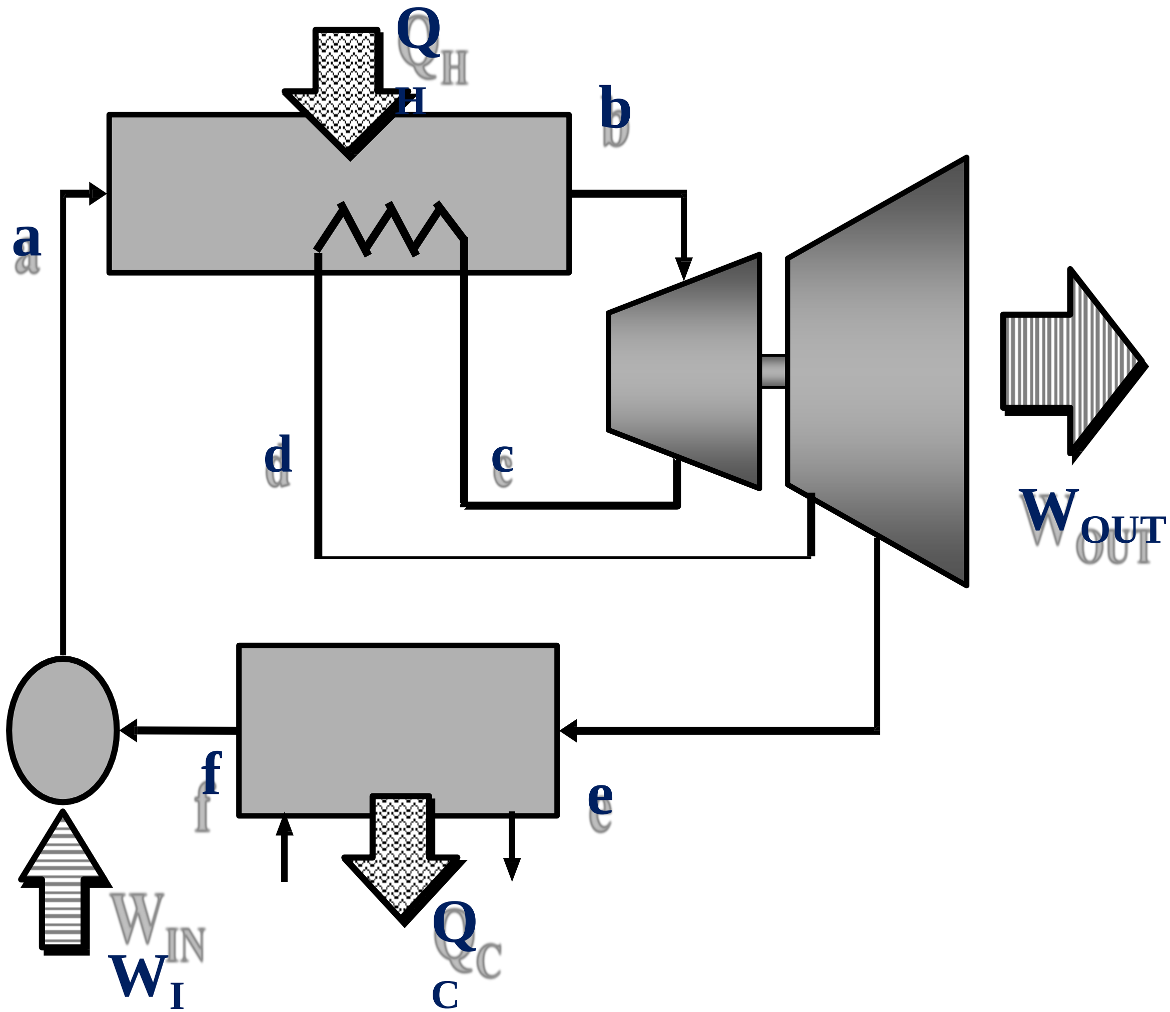
Superheating the working fluid raises the average temperature with a reservoir at a higher temperature.

The Rankine cycle with reheat



The extra expansion via reheating to state "d" allows a greater enthalpy to be released between states "c" to "e".

The reheat cycle

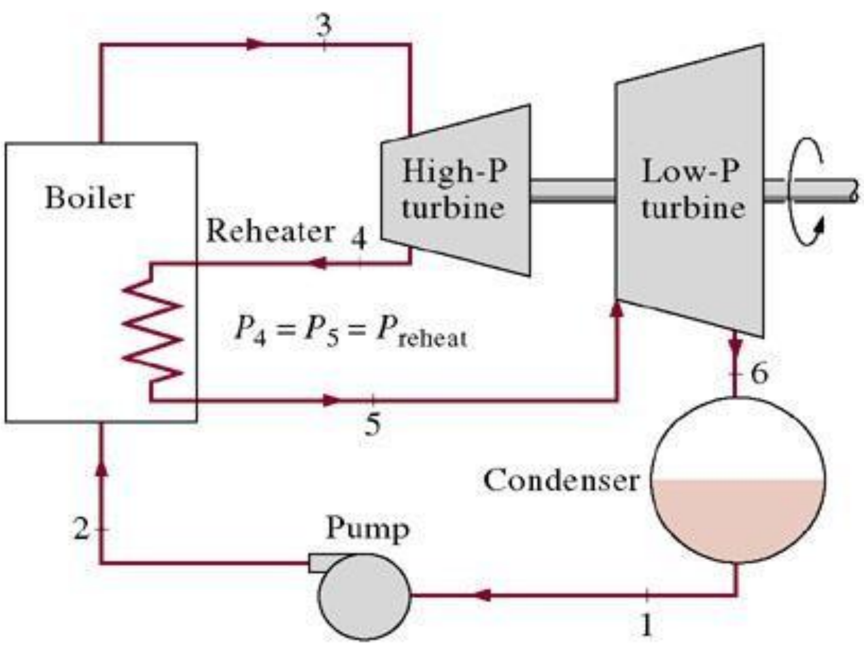


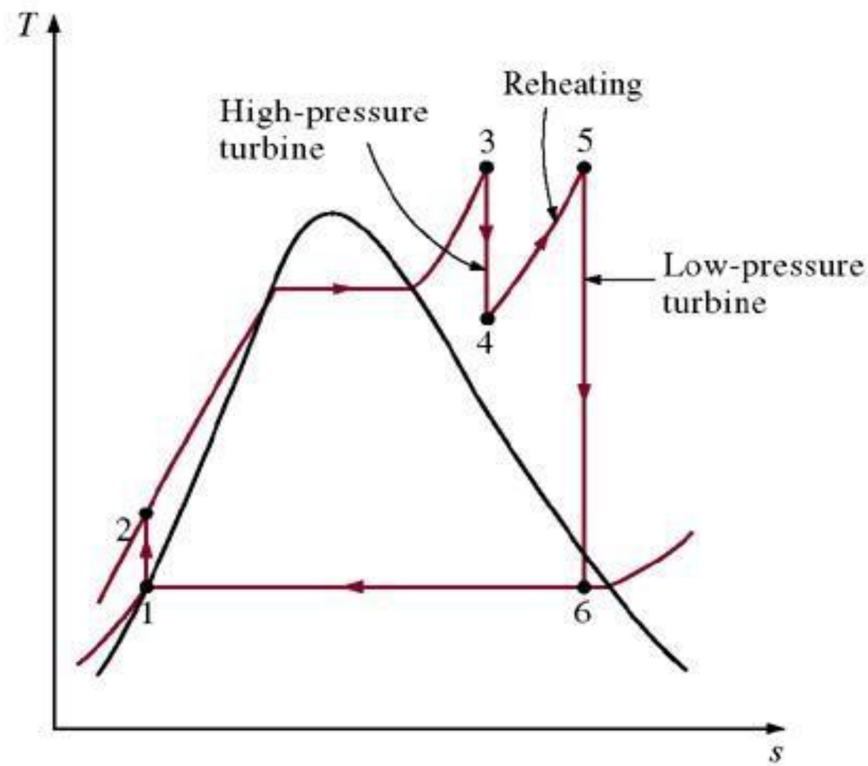
Single stage reheat. Work produced in both turbines.

Reheat Cycle Efficiency

$$\eta = \frac{W_{b-c} + W_{d-e} - W_f}{Q_{a-b} + Q_{c-d}} = \frac{(h_b - h_c) + (h_d - h_e) - (h_a - h_f)}{(h_b - h_a) + (h_d - h_c)} \quad (1)$$

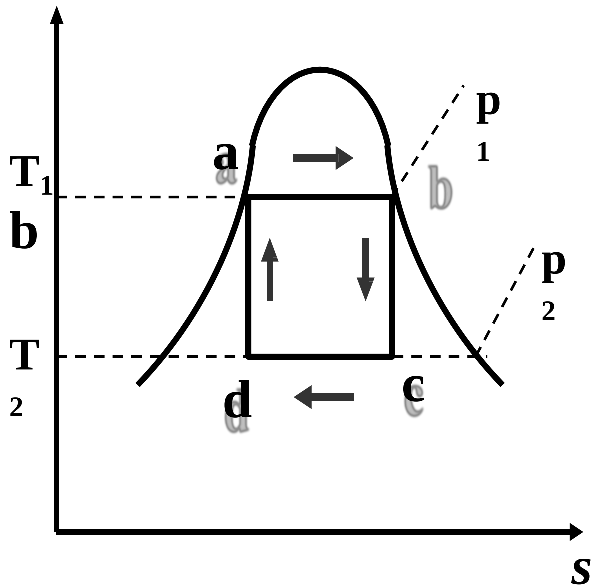
The ideal reheat Rankine cycle.

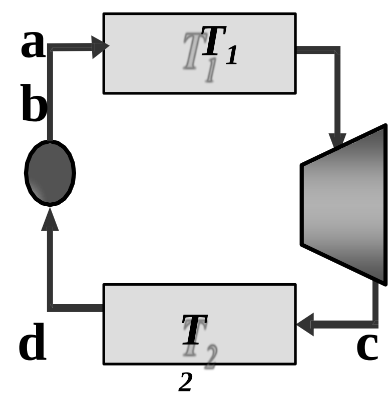




Example - 1: A Carnot cycle

To begin our analysis of Rankine cycle operations, consider a steady Carnot cycle (a-b-c-d-a) with water as the working fluid operating between to given temperature limits as shown. The given data are that the boiler pressure is 500 psi (p_a = 500 psi) and the condenser temperature is 70° F (T_c = 70° F). Determine the work output, thermal efficiency, irreversibility, and work ratio.





Example 1 - Given data

State	T R	P psi	h BTU/lbm	s BTU/ lbm-R	x
a		500			
b		500			
c	530				
d	530				

Example 1 - Process quantities

Process	ΔH BTU/lbm	δW BTU/lbm	δQ BTU/lbm	ΔS BTU/ lbm-R	$\delta Q/T$ BTU/lbm-R	σ_s BTU/ lbm-R
a-b	755	0	755	0.8147	0.8147	0
b-c	-430	430	0	0	0	0
c-d	-432	0	-432	-0.8147	-0.8147	0
d-a	107	-107	0	0	0	0
Net	0	323	323	0	0	0

To get the above process quantities, the First Law for open systems has been used assuming KE and PE effects are negligible. The entropy production was obtained from an entropy balance for an open system. Note that the cyclic heat equals the cyclic work as required by the First Law and that entropy production is zero as required by the Clausius Equality.

Example 1 - Thermal efficiency and back work ratio

Thermal efficiency

$$\eta = \frac{W}{Q_H} = \frac{323}{755} = 0.428$$

Work ratio

$$r = \frac{W_{in}}{W_{Turbine}} = \frac{107}{430} = 0.249$$

The Rankine cycle with regeneration

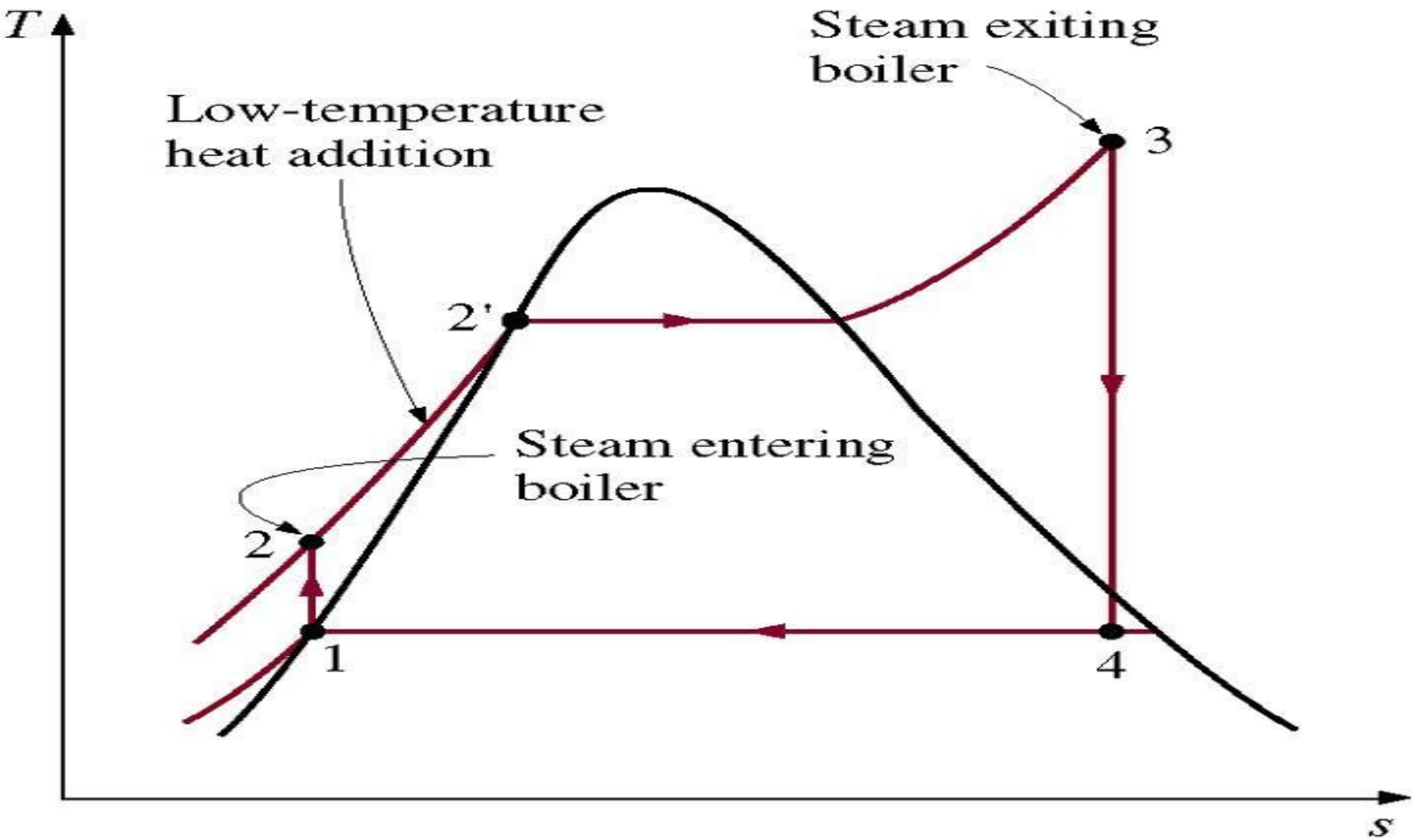
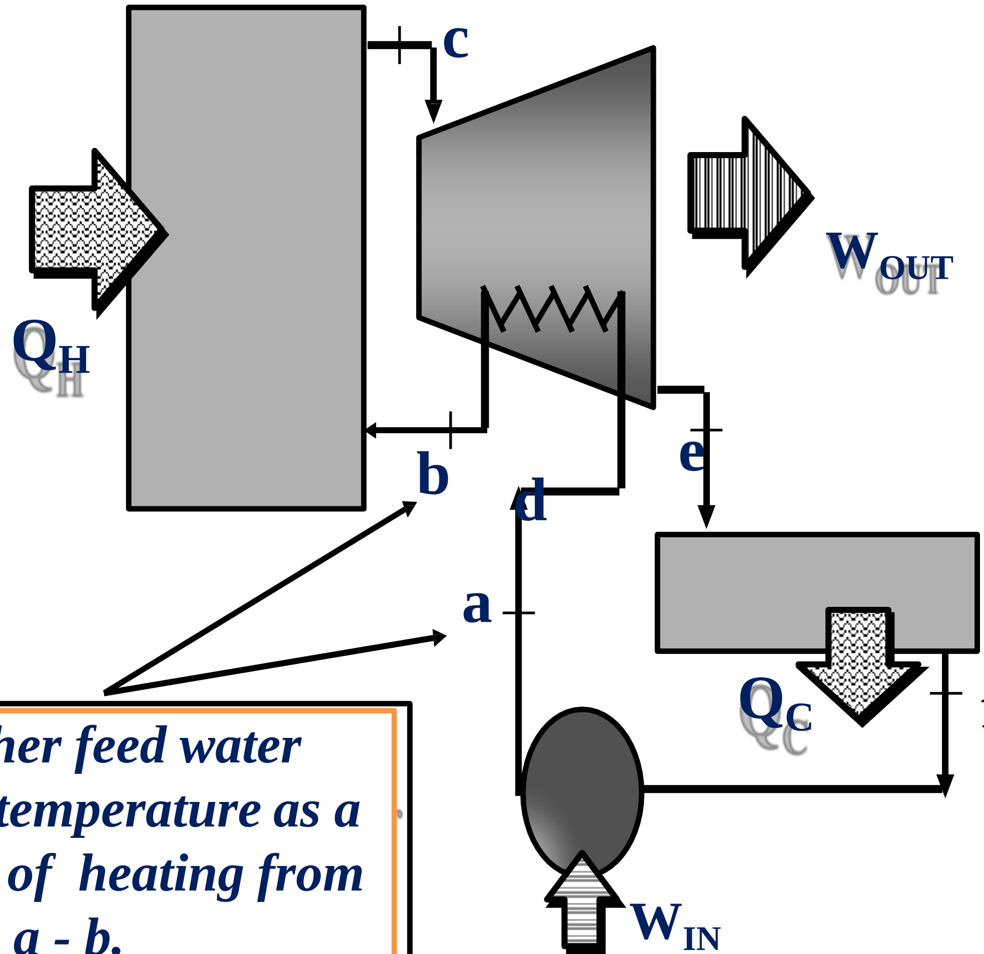


FIGURE
The first part of the heat-addition process in the boiler takes place at relatively low temperatures.

Principle of the regenerative cycle

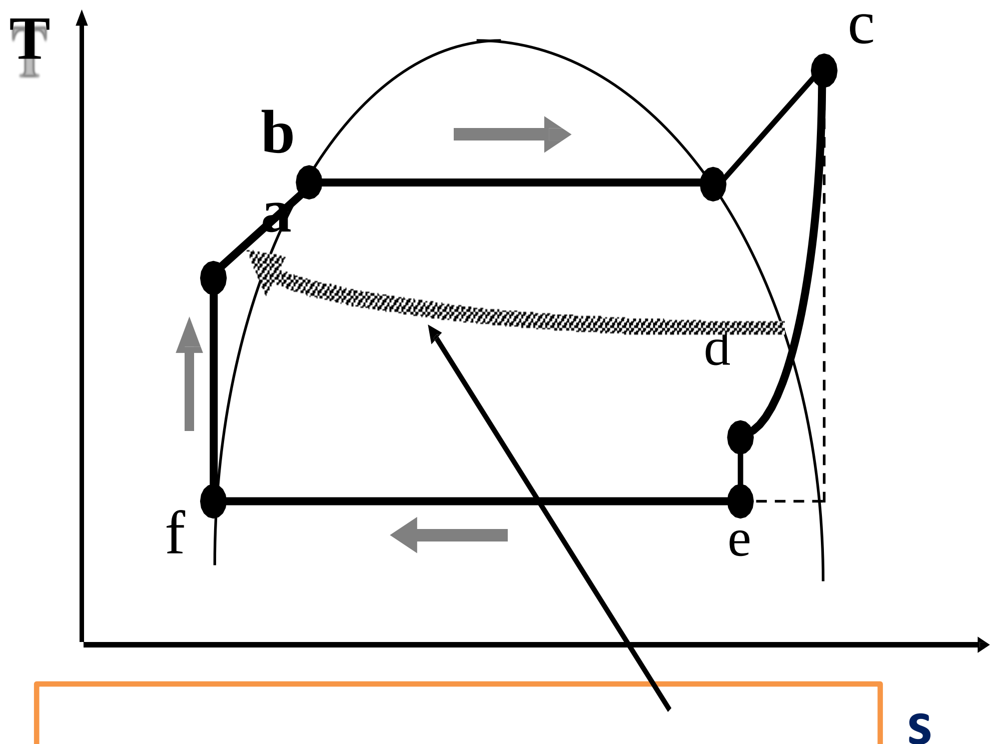


A higher feed water inlet temperature as a result of heating from States a - b.

Impacted processes

- **Heating of some of the compressed liquid is done to raise the average temperature of heat addition.**
- **Heat is supplied after the liquid is compressed to a high pressure at State a.**

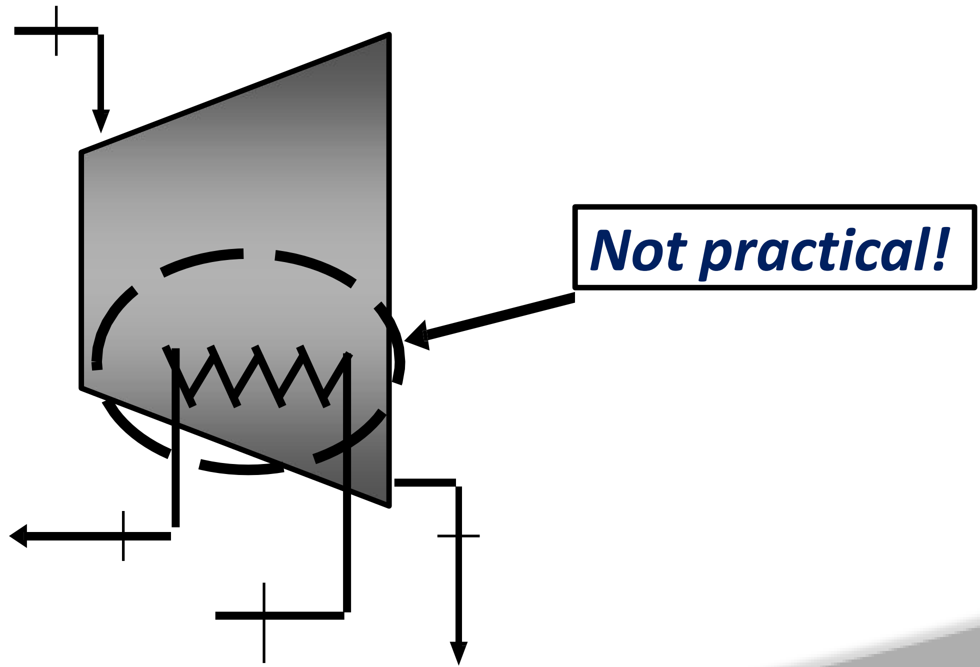
The T-s diagram for the regenerative cycle



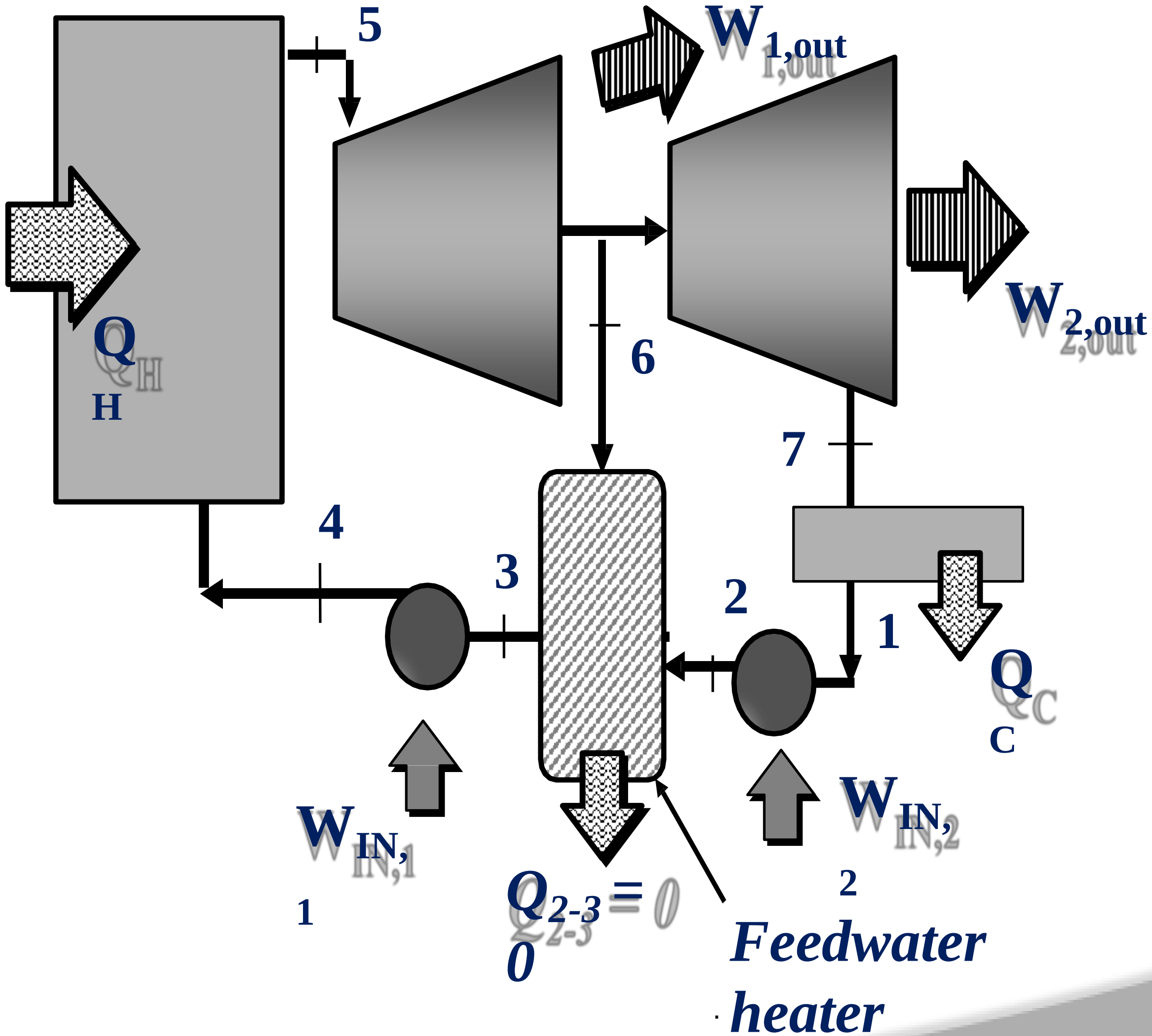
Internal heat transfer to feed water heater.

Practical considerations...

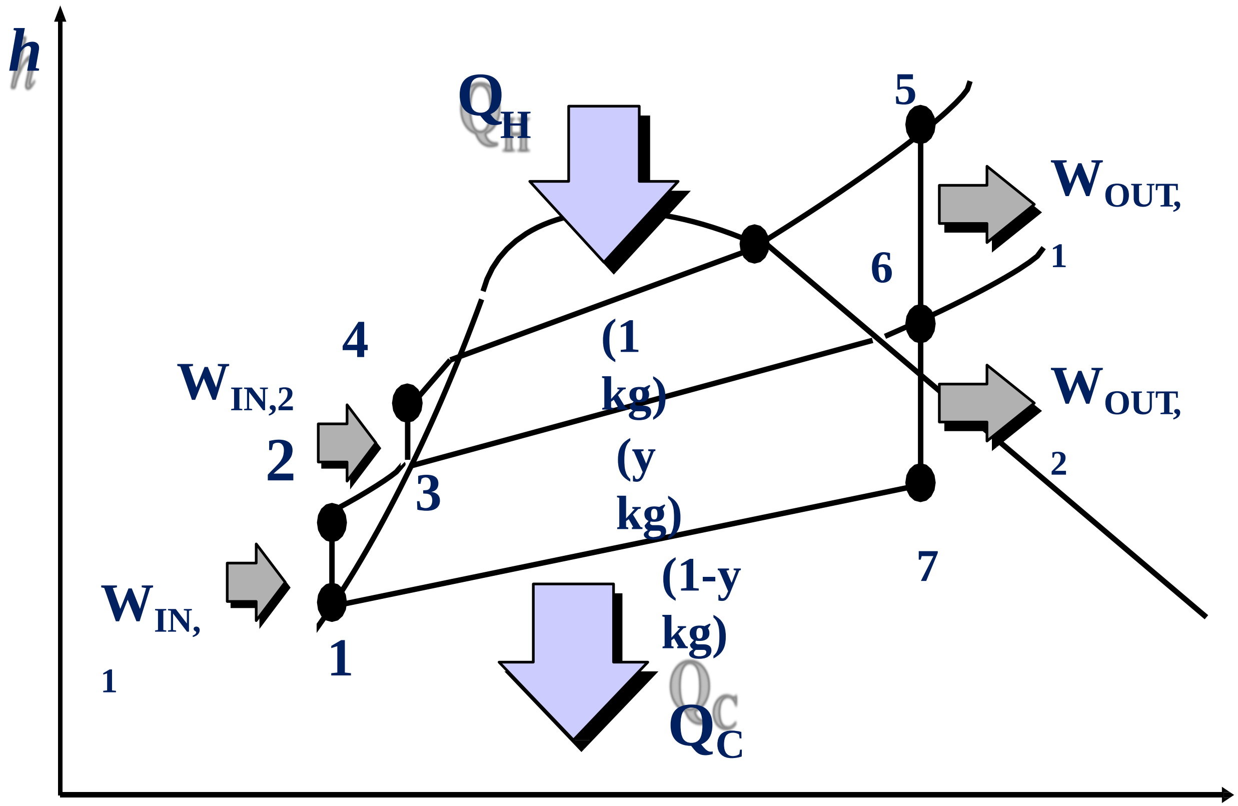
- Turbines cannot be designed economically with internal heat exchangers.
- Condensation could occur in the turbine.



The practical regenerative cycle



The h-s diagram for the regenerative cycle

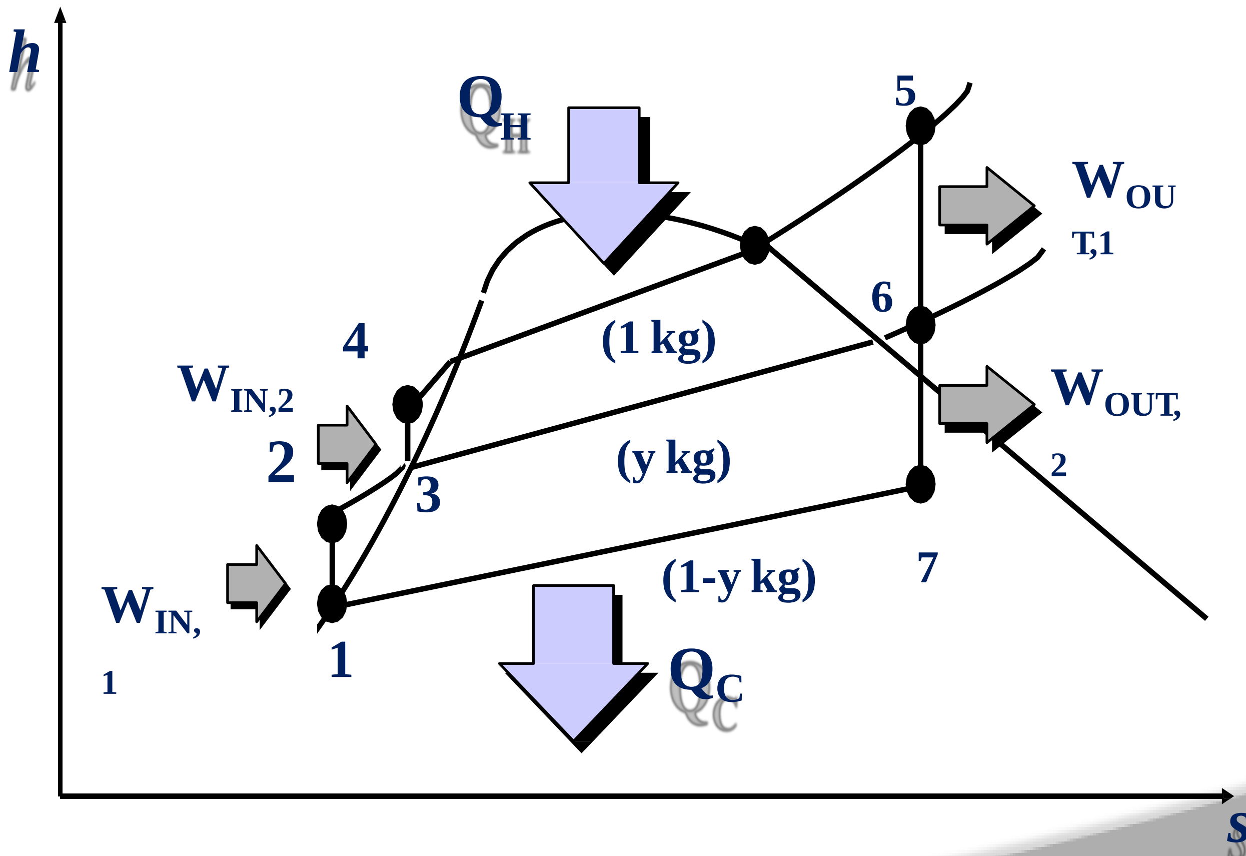


$$W_{OUT,1} = h_5 - h_6 \quad and \quad W_{OUT,2} = (1-y)(h_6 - h_7)$$

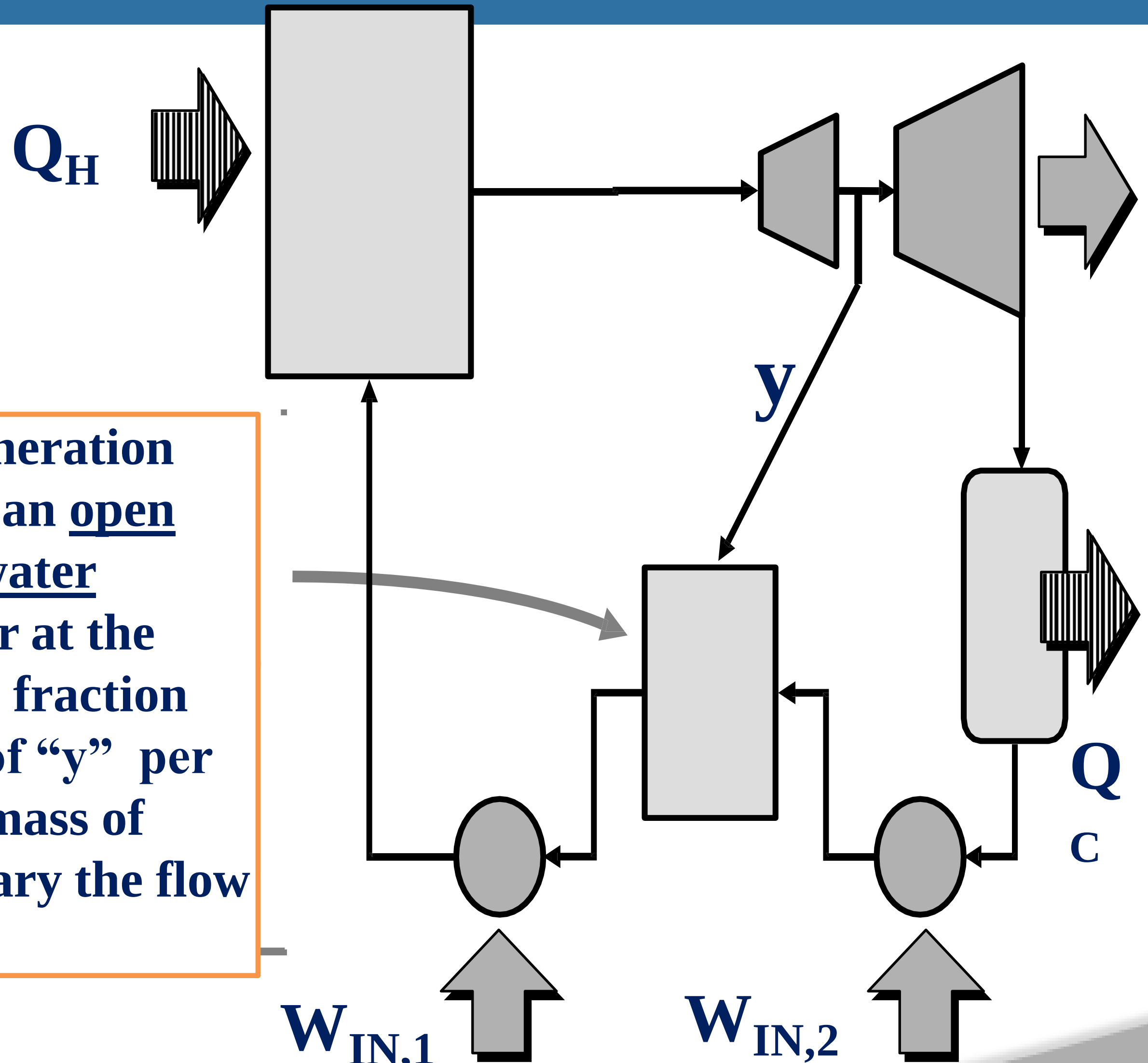
$$W_{IN,1} = h_4 - h_3 \quad and \quad W_{IN,2} = (1-y)(h_2 - h_1)$$

$$Q_H = h_5 - h_4$$

$$\eta = \frac{(h_5 - h_6) + (1-y)(h_6 - h_7) - (h_4 - h_3) - (1-y)(h_2 - h_1)}{h_5 - h_4}$$

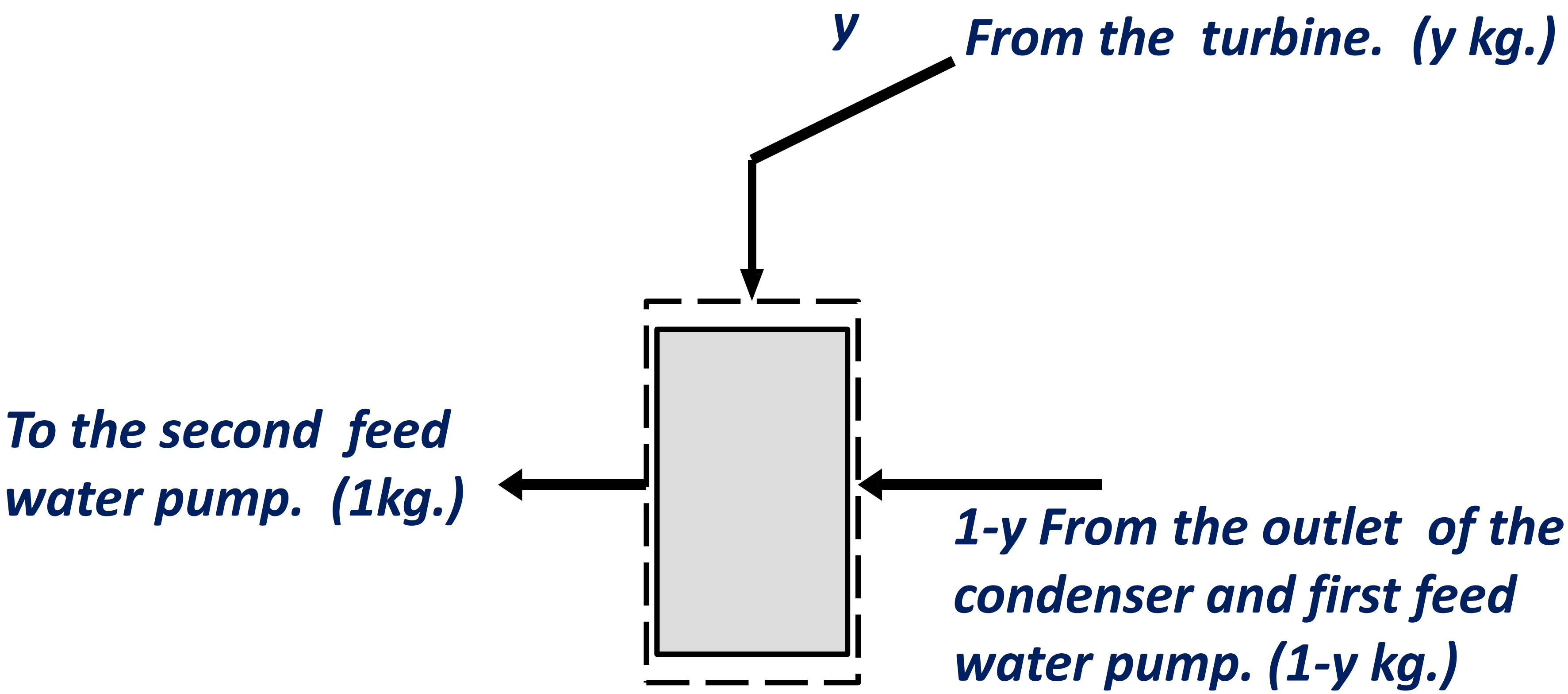


Regeneration with an open feed water heater

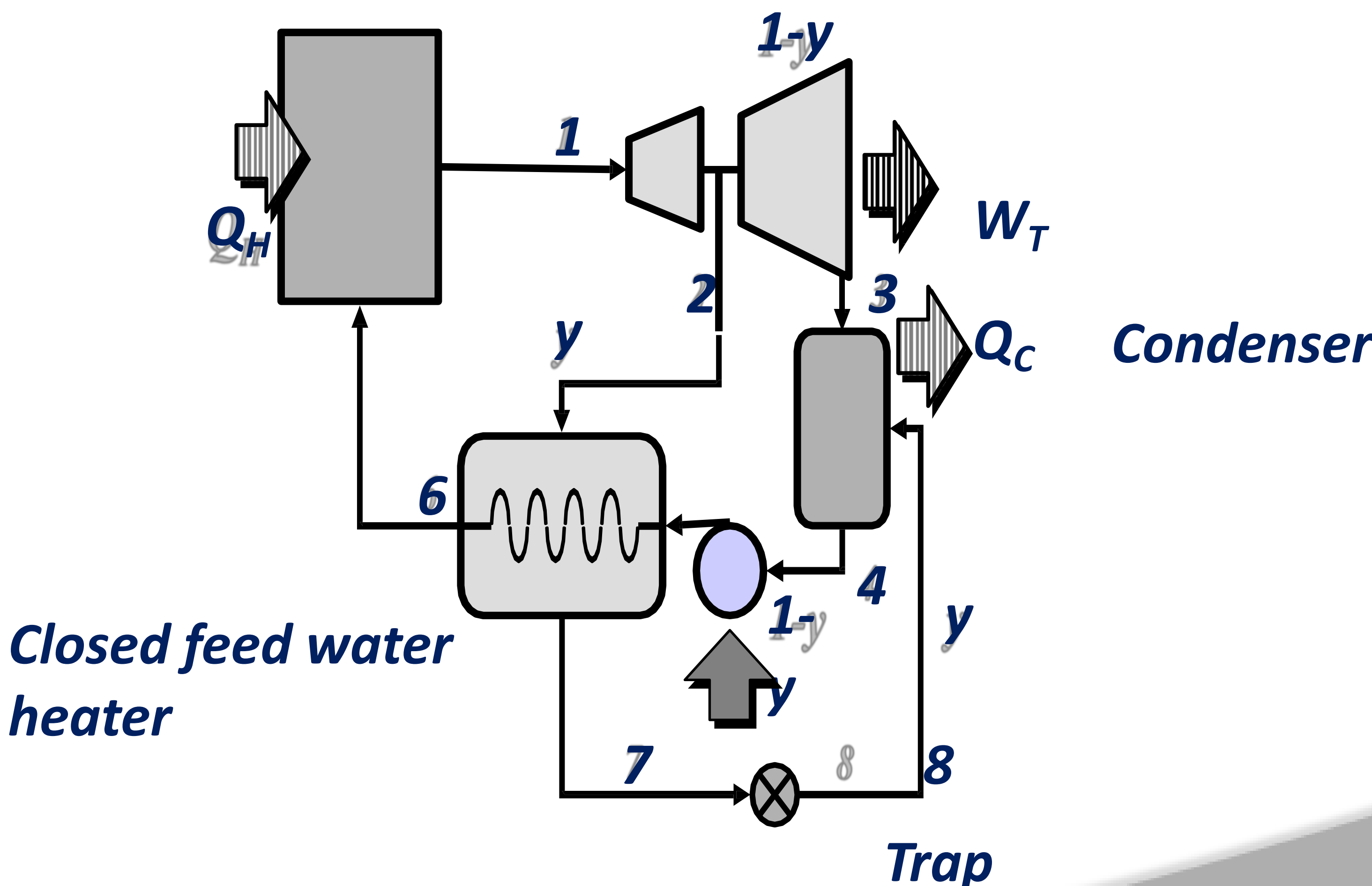


Regeneration with an open feedwater heater at the mass fraction rate of “y” per unit mass of primary the flow rate.

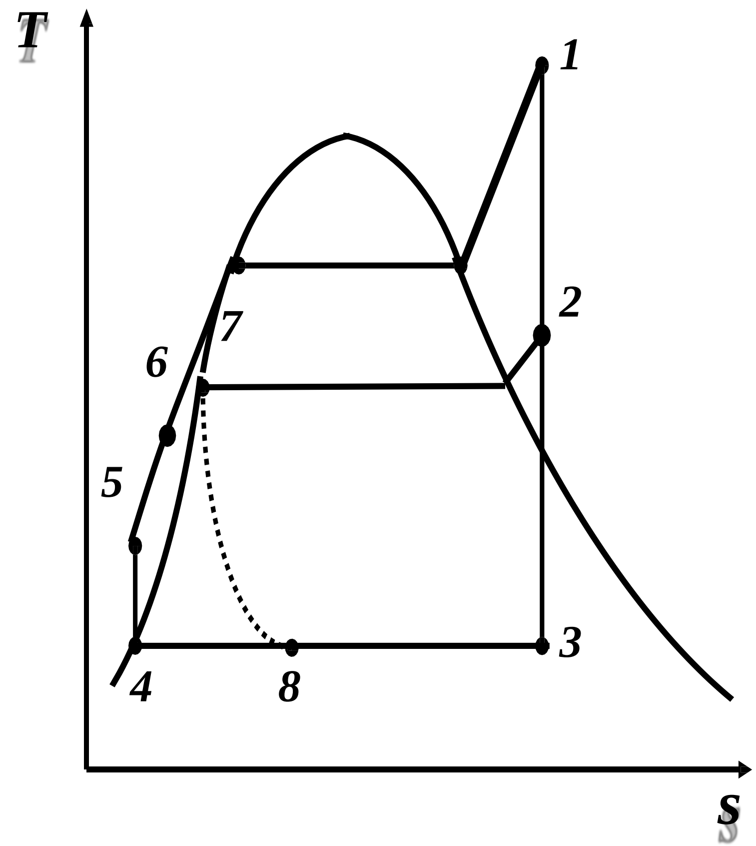
The open feed water heater



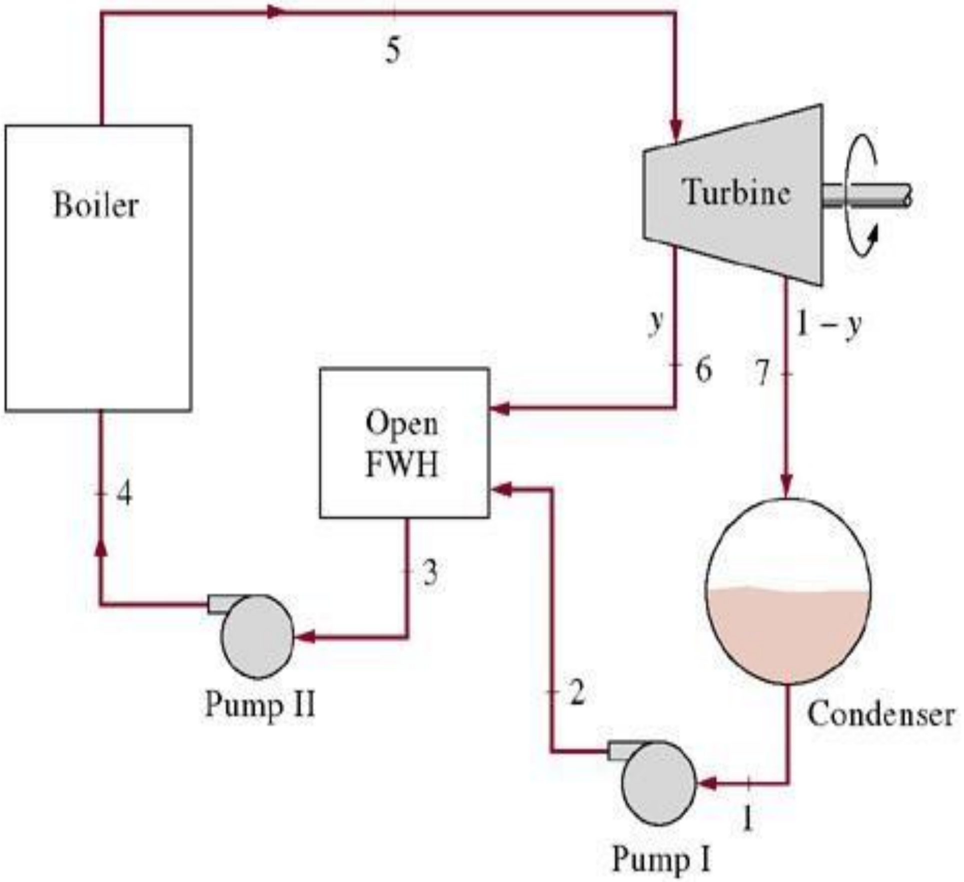
Regenerative cycle with a closed feed water heater

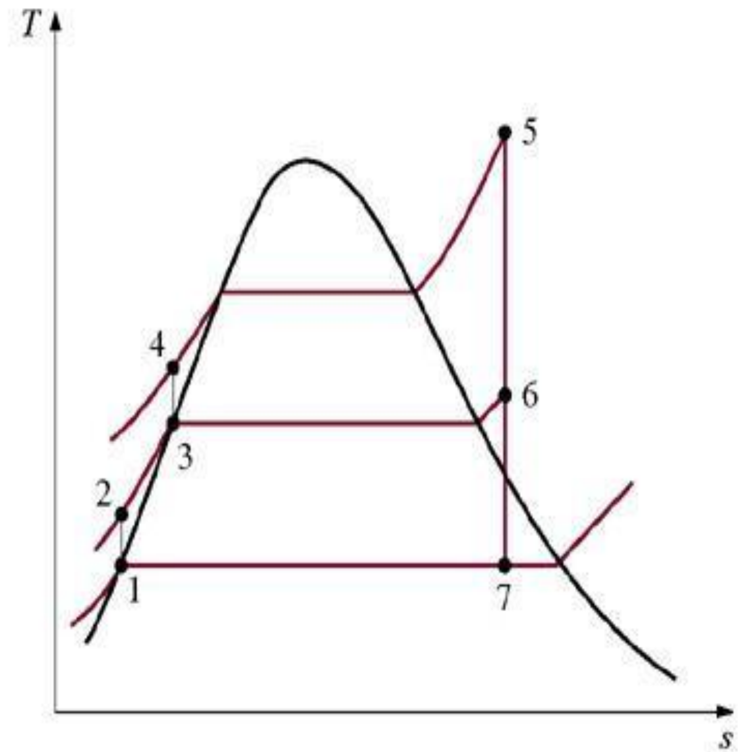


T-s diagram for a regenerative cycle with a closed Feed water heater

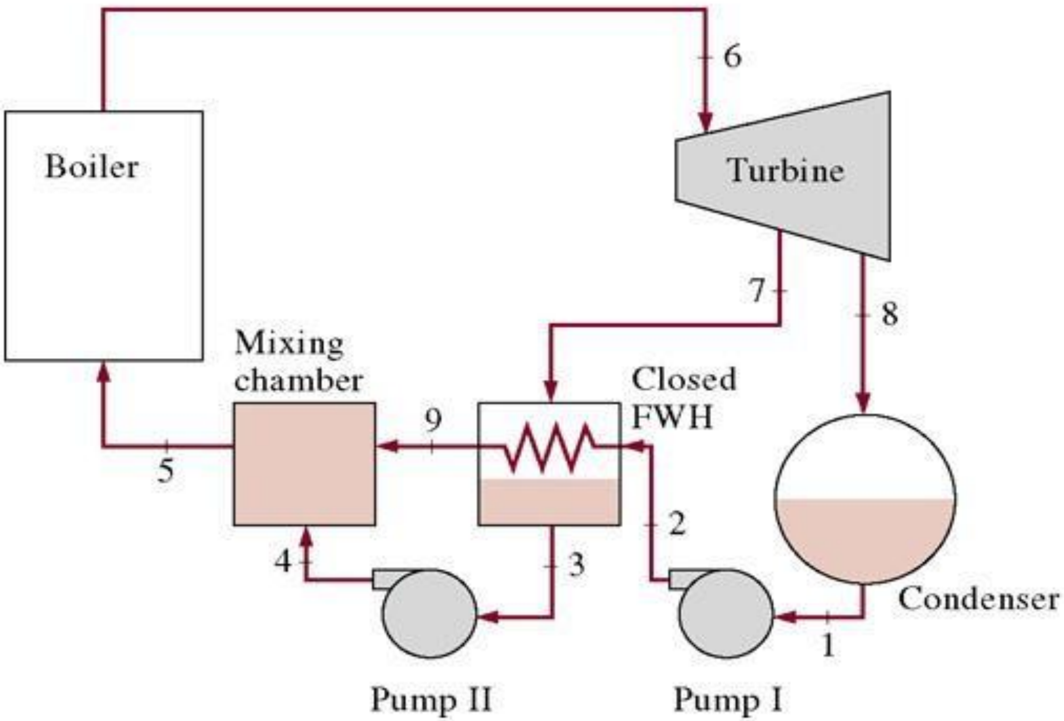


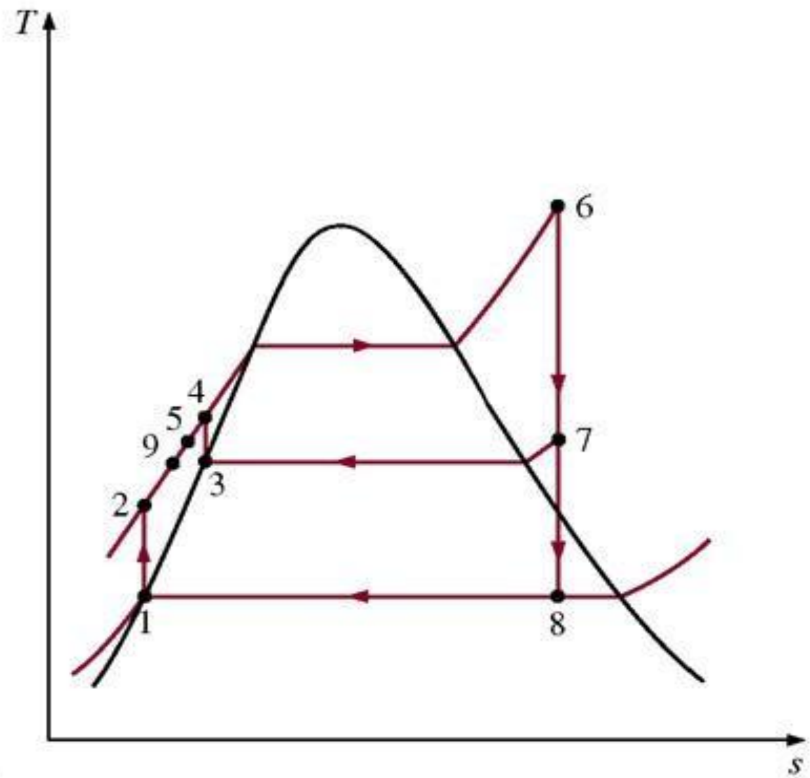
The ideal regenerative Rankine cycle with an open feed water heater.





The ideal regenerative Rankine cycle with a closed feed water heater.



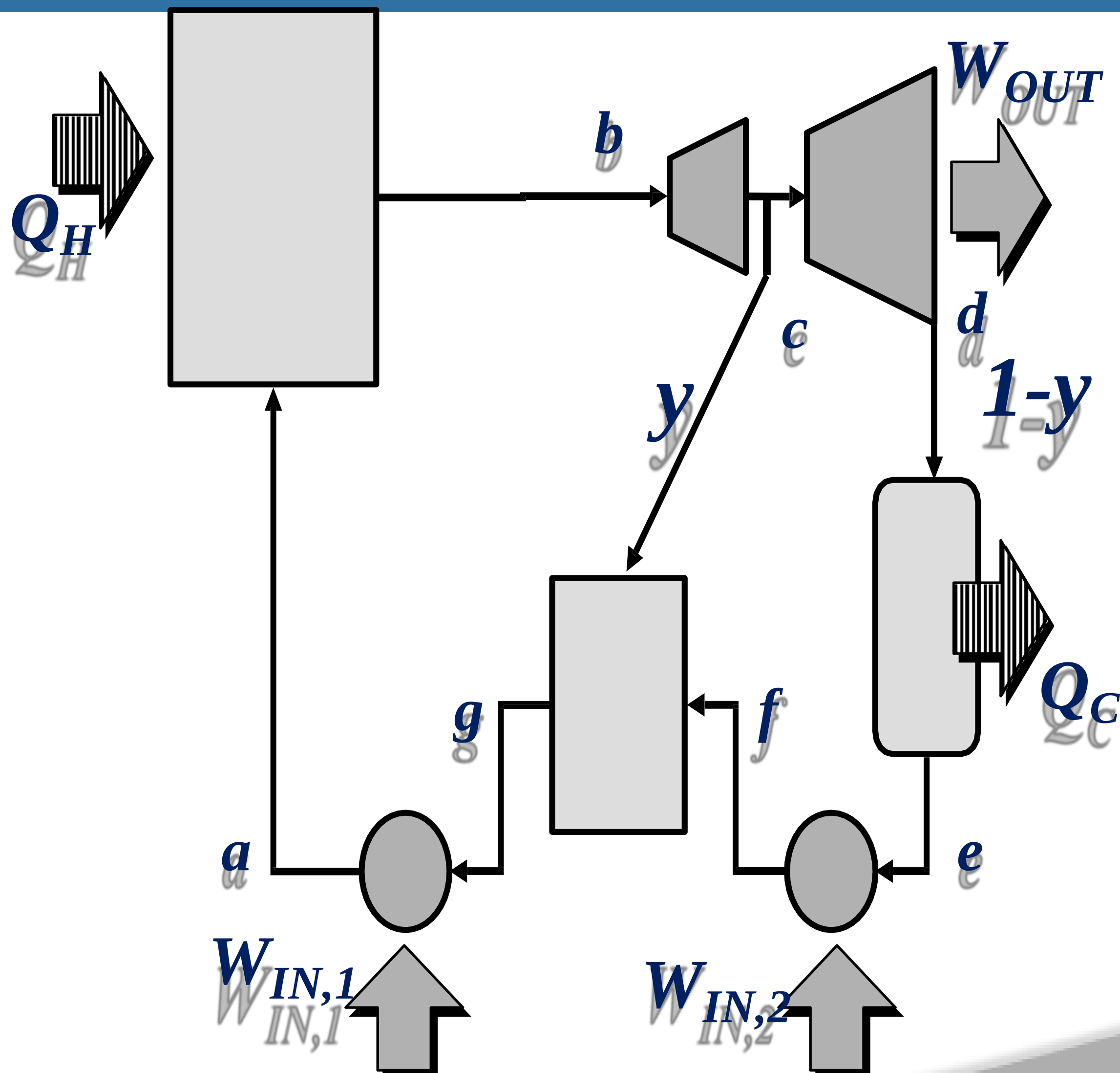


Example - Regeneration with a single extraction and an open feed water heater

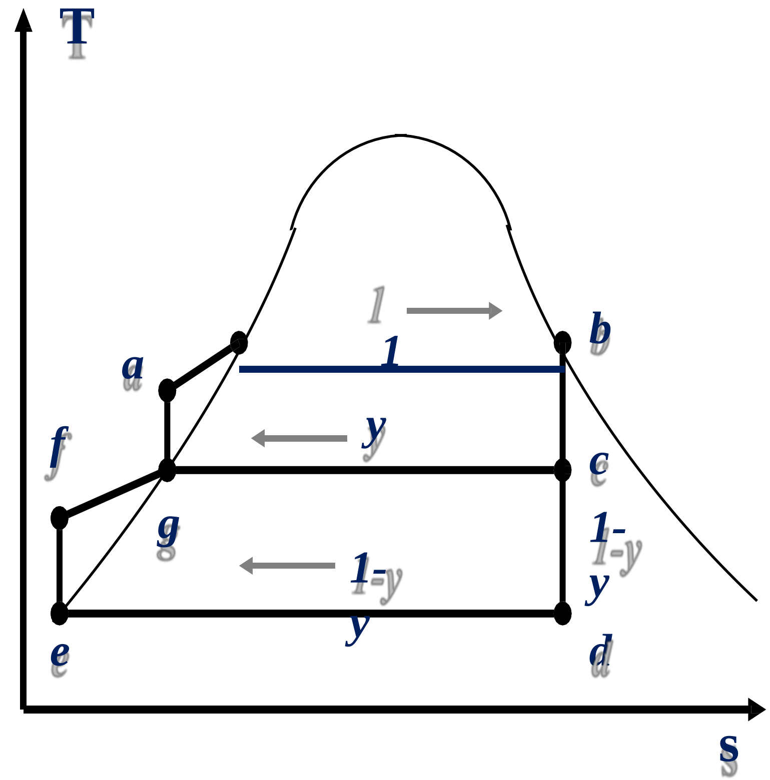
Example

A regenerative Rankine cycle with a single extraction provides saturated steam at 500 psi a the turbine inlet. Condensation takes place at 70^{o} F. One open regenerative feed water heater is included, using extracted steam at a temperature midway between the limits of the cycle. All processes are assumed to be internally reversible except that in the regenerative heater. Neglect KE and PE effects, and determine the thermal efficiency, the internal irreversibility, and the extraction pressure. Assume steady operation.

Example - Plant diagram



Example - T-s diagram

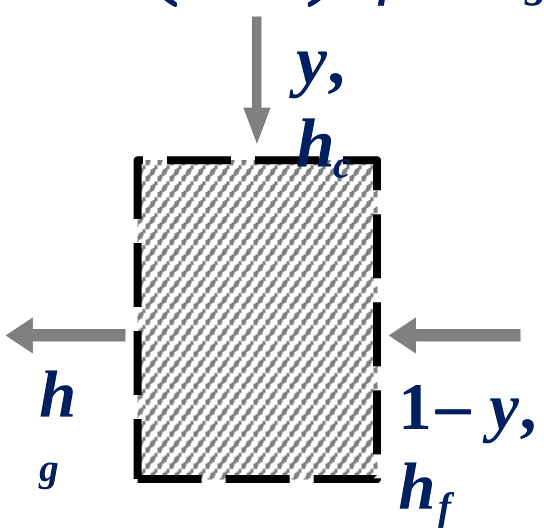


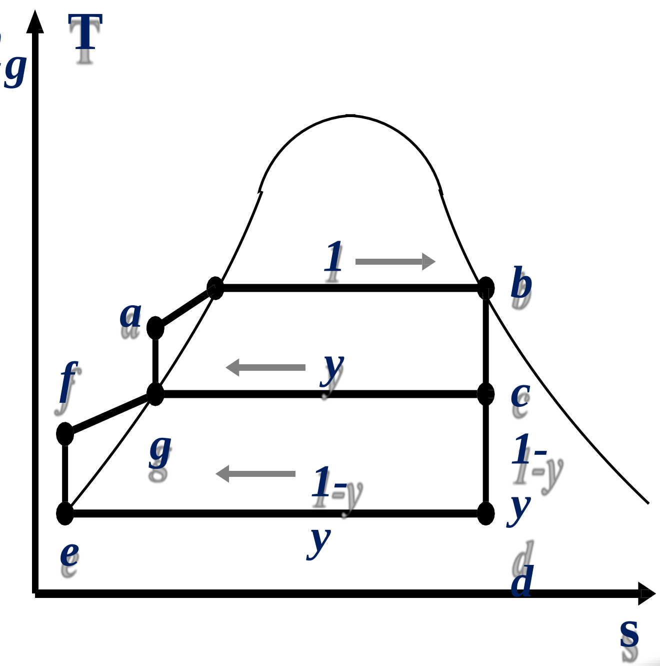
Example - Mass fraction at State “c”

The mass fraction of fluid extracted at State c is obtained from the energy balance for an open system applied to the feed water heater. Assume adiabatic mixing.

$$\dot{m}_c h_c + \left(\dot{m} - \dot{m}_c\right) h_f = \dot{m} h_g$$

$$y h_c + \left(1 - y\right) h_f = h_g$$





Example - Given data

STATE	T R	P psi	h BTU/ lbm	s BTU/lbm-R	x
a	728.7	500			…
b		500			1
c	728.5				
d	530				
e	530				0
f	530				…
g	728.7				0

Computed Data (From Tables)

STATE	TR	Ppsi	H BTU/ lbm	s BTU/lbm-R	x
a	728.7	500	239.1	0.3940	…
b	927	500	1204.4	1.4364	1
c	728.5	41	1016	1.4364	0.835
d	530	0.361	774	1.4364	0.698
e	530	0.361	38	0.0745	0
f	530	41	38.1	0.0745	…
g	728.7	41	237.6	0.3940	0

Process Quantities

Process	ΔH BTU/ lbm	m	$m\Delta h$ BTU/ lbm	δw BTU/ lbm
a-b	965	1	965	0
b-c	-188	1	-188	188
c-d	-242	0.796	-193	193
d-e	-736	0.796	-586	0
e-f	0.1	0.796	0.1	-0.1
f-g	199.5	0.796	159	0
c-g	-778	0.204	-159	
g-a	1.5	1	1.5	-1.5
Net	…	…	0	379.4

Example - Process quantities

Process Quantities

Process	δQ BTU/lbm	ds BTU/lbm-R	yds BTU/lbm-R	**δQ/T BTU/lbm-R**	**σ BTU/lbm-R**
a-b	965.3	1.0694	1.0694	**1.0694**	0
b-c	0	0	0	**0**	0
c-d	0	0	0	**0**	0
d-e	-586	-1.3889	-1.1056	**-1.1056**	0
e-f	0	0	0	**0**	0
f-g	0	0.3195	0.2543	**0**	**0.0363**
c-g		-1.0694	-0.2180		
g-a	0	0	0	**0**	0
Net	379.3	…	0	**-0.0362**	**0.0363**

Note the positive entropy production in the feed water heater.

FUELS AND COMBUSTION

TYPE OF FUEL	PRIMARY FUEL (WHICH OCCUR NATURALLY)	SECONDARY (PREPARED)
Solid	Wood	Coke
	Peat	Charcoal
	Coal	Briquettes
Liquid	Petroleum (Crude Oil)	Gasoline (Petrol)
		Kerosene
		Diesel oil
		Fuel oil
		Alcohol
		Benzol
		Shale oil
Gaseous	Natural gas	Petroleum gas (LPG)
		Producer gas
		Coal gas
		Coke-oven gas
		Blast furnace gas

Continue..

Combustion or burning is the chemical process in which the inflammable matter in a substance combines with oxygen at a temperature above the spontaneous ignition temperature of that substance and results in the evolution of heat and light.

The combustion process involves the oxidation of constituents in the fuel, that are capable of being oxidized and it can be represented by a chemical equation.

These equations indicate the required amount of oxygen combined with required amount of fuel.

In a chemical reaction the terms, reactants and the products are frequently used.

Reactants comprise of initial constituents which start the reaction while products comprise of final constituents which are formed by the chemical reaction.

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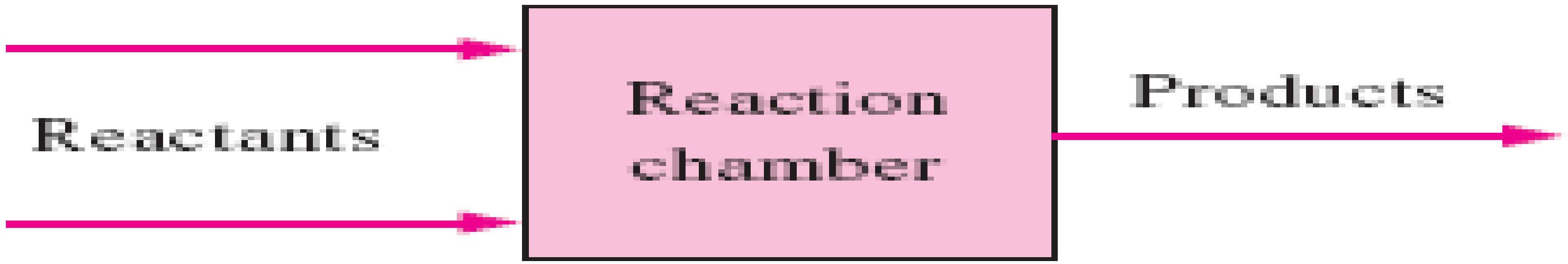


The smallest particle which can take part in a chemical change is called an atom.

It is rare to find elements to exist naturally as single atom.

Some elements have atoms which exist in pairs, each pair forming a molecule, and the atoms of each molecule are held together by stronger inter-atomic forces.

The symbols and molecular weight of some important elements, compounds and gases are given in table below:

Continue..

Elements/ Compounds/ Gases	Molecule		Atom	
	Symbol	Molecular weight	Symbol	Atomic weight
Hydrogen	H_2	2	H	1
Oxygen	O_2	32	O	16
Nitrogen	N_2	28	N	14
Carbon	C	12	C	12
Sulphur	S	32	S	32
Water	H_2O	18	-	-
Carbon monoxide	CO	28	-	-
Carbon dioxide	CO_2	44	-	-
Sulphur dioxide	SO_2	64	-	-
Methane (Marsh gas)	CH_4	16	-	-
Ethylene	C_2H_4	28	-	-
Ethane	C_2H_6	30	-	-
Acetylene	C_2H_2	26	-	-
Propane	C_3H_8	44	-	-

Continue..

Generally combustion requires reaction with an oxidant or supporter of combustion.

Oxygen is the main oxidant, but the halogens (chlorine and fluorine), hydrogen peroxide and also nitric acid, may act as oxidants as in rocket propulsion.

Air is the commonest oxidant because it is cheap and readily available. The following analysis of air is used in combustion calculations:

Air components	By volume %	By mass %
O_2	21.00	23.00
N_2	79.00	77.00
Total	100.00	100.00

Stoichiometric Air-Fuel (A/F) Ratio:

Stoichiometric (or chemically correct) mixture of air and fuel is one that contains just sufficient oxygen for complete combustion of fuel.

A weak mixture is one which has excess air.

A rich mixture is one which has a deficiency of air.

The percentage of excess air is given as under:

$$\%age\ excess\ air = \frac{Actual\frac{A}{F}ratio - Stoichiometric\frac{A}{F}\ ratio}{Stoichiometric\frac{A}{F}ratio}$$

An alternate method of expressing the same is in terms of mixture strength;

Combustion

$$Mixture\ strength\,(\%) = \frac{Stoichiometric\,\frac{A}{F}\,ratio}{Actual\,\frac{A}{F}\,ratio} \times 100$$

For a stoichiometric mixture, the mixture strength is 100%.

A weak mixture is one whose mixture strength is less than 100%, while a rich mixture has mixture strength of more than 100%.

Theoretical or stoichiometric or minimum air required for complete combustion:

We know that fuel mainly consists of constituents like carbon, hydrogen and sulphur and we also know that for combustion;

Carbon requires 2.67 times its own mass of oxygen

Hydrogen requires 8 times its own mass of oxygen

Sulphur require its own mass of oxygen

Now consider 1kg of fuel whose ultimate analysis gives:

Mass of carbon = C kg

Mass of hydrogen = H_2 kg

Mass of sulphur = S kg

Combustion

Then oxygen required to burn

C kg of carbon	= 2.67C kg
H_2 kg of hydrogen	= 8 H_2 kg
S kg of sulphur	= S kg

Therefore total oxygen required for complete combustion of 1 kg of fuel

$$= (2.67C + 8H_2 + S) \text{ kg}$$

As fuel already contains O_2 kg of oxygen which we assume can be used for combustion.

Then total oxygen required for complete combustion of 1 kg of fuel is,

$$= (2.67C + 8H_2 + S - O_2) \text{ kg}$$

Since air contains 23% of oxygen on mass basis, i.e. 1 kg of oxygen is associated with 100/23 = 4.35kg of air.

Therefore,

Minimum or theoretical air required for complete combustion of 1kg of fuel,

$$= 100/23\ (2.67C + 8H_2 + S - O_2) \text{ kg}$$

Theoretical or stoichiometric or minimum air required for complete combustion:

Consider $1m^3$ of gaseous fuel whose ultimate volume analysis is:

Volume of carbon monoxide = $CO\ m^3$

Volume of hydrogen = $H_2\ m^3$

Volume of methane = $CH_4\ m^3$

Volume of ethylene = $C_2H_4\ m^3$

Combustion

Then oxygen required to burn

CO m^3 of carbon = 0.5 CO m^3

H_2 m^3 of hydrogen = 0.5 H_2 m^3

CH_4 m^3 of sulphur = $2CH_4$ m^3

C_2H_4 m^3 of hydrogen = $3C_2H_4$ m^3

Therefore total oxygen required for complete combustion of 1 m^3 of fuel

$$= (0.5CO + 0.5H_2 + 2CH_4 + 3C_2H_4)\ m^3$$

Combustion

As fuel already contains O_2 m^3 of oxygen which we assume can be used for combustion.

Then total oxygen required for complete combustion of 1 kg of fuel is,

$$= (0.5CO + 0.5H_2 + 2CH_4 + 3C_2H_4 - O_2)\ m^3$$

Since air contains 21% of oxygen on volume basis, i.e. 1 m^3 of oxygen is associated with 100/21 = 3.76m^3 of air.

Therefore,

Minimum or theoretical air required for complete combustion of 1kg of fuel,

$$= 100/21\ (0.5CO + 0.5H_2 + 2CH_4 + 3C_2H_4 - O_2)\ kg$$

Air-fuel Ratio from analysis of products of combustion:

By making analysis of the combustion products, the air-fuel ratio can be calculated by the following methods.

1. When fuel composition is known

i) Carbon Balance Method- Quite accurate when combustion takes place with excess air and when no free (solid) carbon is present in the products.

ii) Hydrogen Balance Method- Suitable when solid carbon is suspected to be present in the products.

iii) Carbon-Hydrogen Balance Method- Used when there is some uncertainty about percentage of N_2 present.

2. When fuel composition is unknown

Only Carbon-Hydrogen Balance Method can be employed.

Adiabatic flame temperature:

In a given combustion process that takes place adiabatically and with no work or changes in kinetic or potential energy involved, the temperature of the products is referred to as adiabatic flame temperature.

With the assumption of no work and no changes in K.E or P.E, this is the maximum temperature that can be achieved for the given reactants because any heat transfer from the reacting substances and any incomplete would tend to lower the temperature of the products.

The following points to be noted:

1.The maximum temperature achieved through adiabatic complete combustion varies with the type of reaction and percent of theoretical air supplied. An increase in the Air-Fuel ratio will affect a decrease in the maximum temperature.

2.For a given fuel and given pressure and temperature of the reactants, the maximum adiabatic flame temperature that can be achieved is with a stoichiometric mixture.

3.The adiabatic flame temperature can be controlled by the amount of excess air that is used.

UNIT II
THERMAL ENGINEERING

Boilers

Boiler is an apparatus to produce steam.
Thermal energy released by combustion of fuel is used to make steam at the desired temperature and pressure.
The steam produced is used for:
(i) Producing mechanical work by expanding it in steam engine or steam turbine.
(ii) Heating the residential and industrial buildings
(iii) Performing certain processes in the sugar mills, chemical and textile industries.

Boiler properties:

(i) Safety. The boiler should be safe under operating conditions.

(ii) Accessibility. The various parts of the boiler should be accessible for repair and maintenance.

(iii) Capacity. Should be capable of supplying steam according to the requirements.

(iv) Efficiency. Should be able to absorb a maximum amount of heat produced due to burning of fuel in the furnace.

(v) It should be simple in construction .

(vi) Its initial cost and maintenance cost should be low.

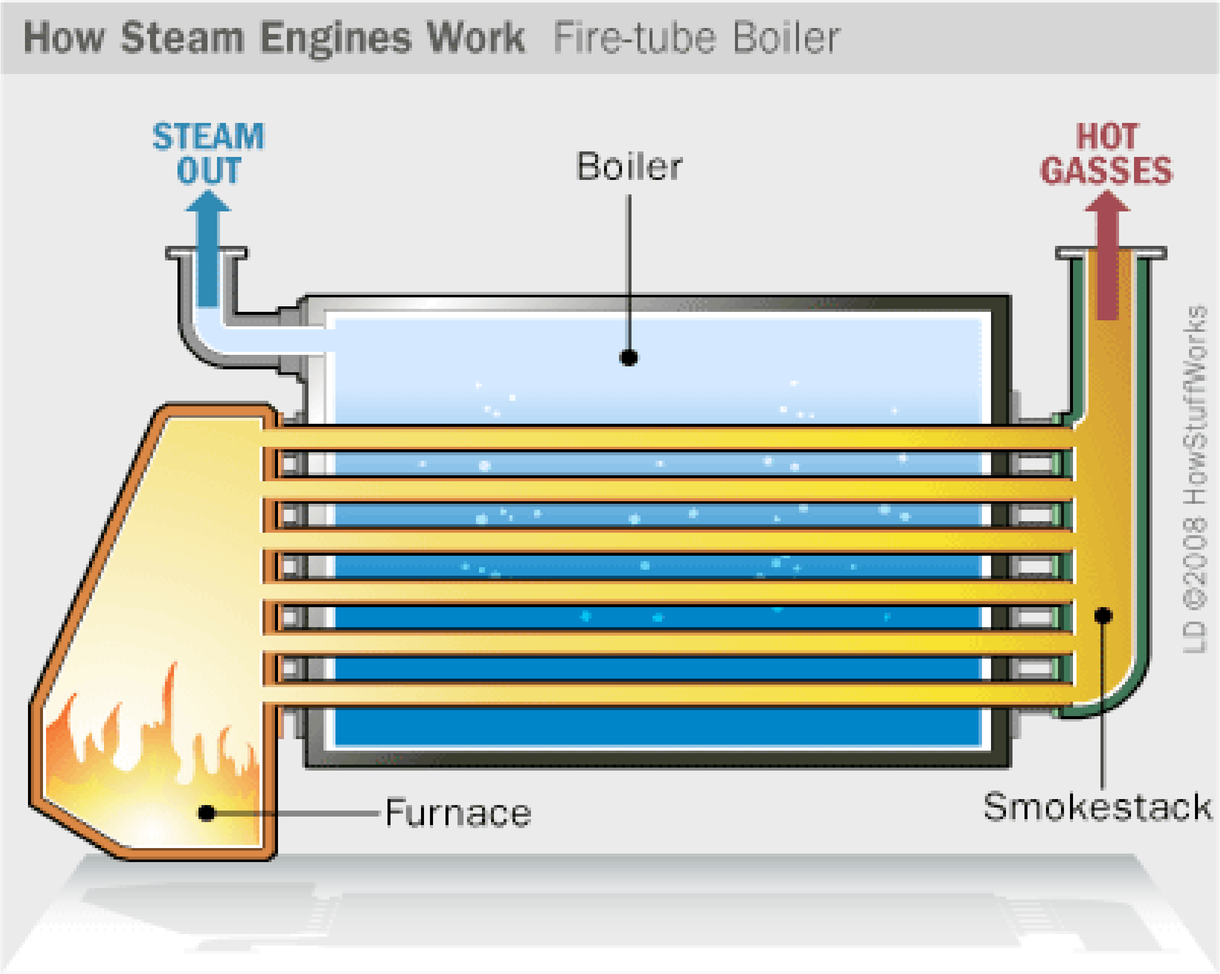
(vii) The boiler should have no joints exposed to flames.

CLASSIFICATION OF BOILERS

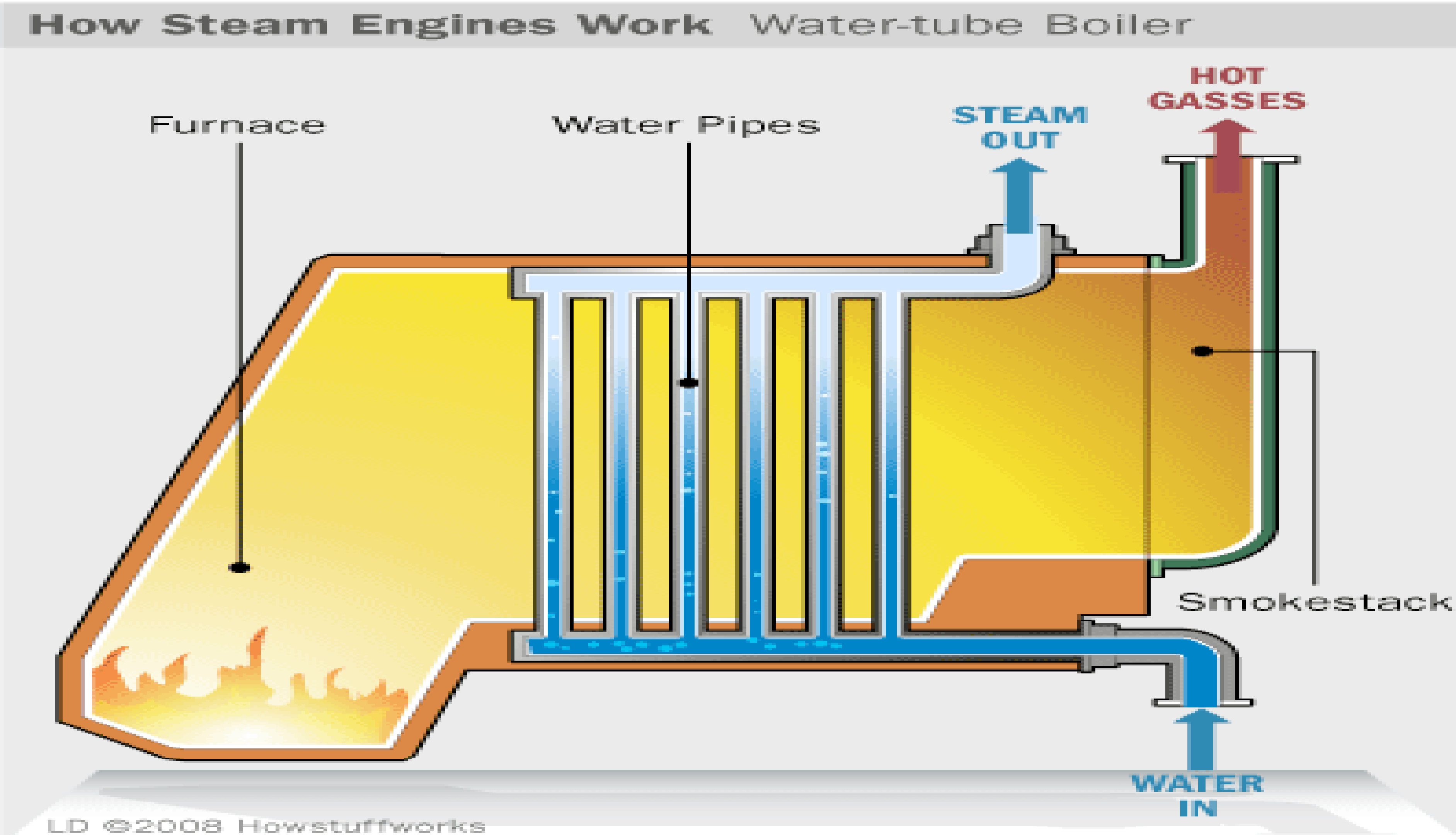
According to what flows in the TUBE

1. Water tube.
2. Fire tube.

Fire – tube Boilers



Water tube boilers



MERITS OF WATER TUBE BOILERS OVERFIRE TUBE BOILERS

1. Generation of steam is much quicker due to small ratio of water content to steam content. This also helps in reaching the steaming temperature in short time.

2. Its evaporative capacity is considerably larger and the steam pressure range is also high-200 bar.

3. Heating surfaces are more effective as the hot gases travel at right angles to the direction of

MERITS OF WATER TUBE BOILERS OVERFIRE TUBE BOILERS

4. The combustion efficiency is higher because complete combustion of fuel is possible as the combustion space is much larger.

5. The thermal stresses in the boiler parts are less as different parts of the boiler remain at uniform temperature due to quick circulation of water.

6. The boiler can be easily transported and erected as its different parts can be separated.

MERITS OF WATER TUBE BOILERS OVERFIRE TUBE BOILERS

7. Damage due to the bursting of water tube is less serious. Therefore, water tube boilers are sometimes called safety boilers.

8. All parts of the water tube boilers are easily accessible for cleaning, inspecting and repairing.

9. The water tube boiler's furnace area can be easily altered to meet the fuel requirements.

Demerits :

1. It is less suitable for impure and sedimentary water, as a small deposit of scale may cause the overheating and bursting of tube. Therefore, use of pure feed water is essential.
2. They require careful attention. The maintenance costs are higher.
3. Failure in feed water supply even for short period is liable to make the boiler over-heated.

Advantages of fire tube boilers are as follows

(i) Low cost

(ii) Fluctuations of steam demand can be met easily

(iii) It is compact in size.

Water tube boilers are classified as

1. **Horizontal straight tube boilers**

   (a) Longitudinal drum (b) Cross-drum.

2. **Bent tube boilers**

   (a) Two drum (b) Three drum

   (c) Low head three drum (d) Four drum.

3. **Cyclone fired boilers**

According to position of furnace.

(i) Internally fired (ii) Externally fired

- In internally fired boilers the grate combustion chamber are enclosed within the boiler shell
- whereas in case of extremely fired boilers and furnace and grate are separated from the boiler shell.

According to the position of principle axis.

(i) Vertical (ii) Horizontal (iii) Inclined.

According to application.

(i) Stationary (ii) Mobile, (Marine, Locomotive).

According to the circulating water.

(i) Natural circulation (ii) Forced circulation.

According to steam pressure.

(i) Low pressure (ii) Medium pressure (iii) Higher pressure.

FIRE TUBE BOILERS

- Cochran Boiler
- Lancashire Boiler
- Locomotive boiler
- Babcock Wilcox Boiler

Cochran Boiler

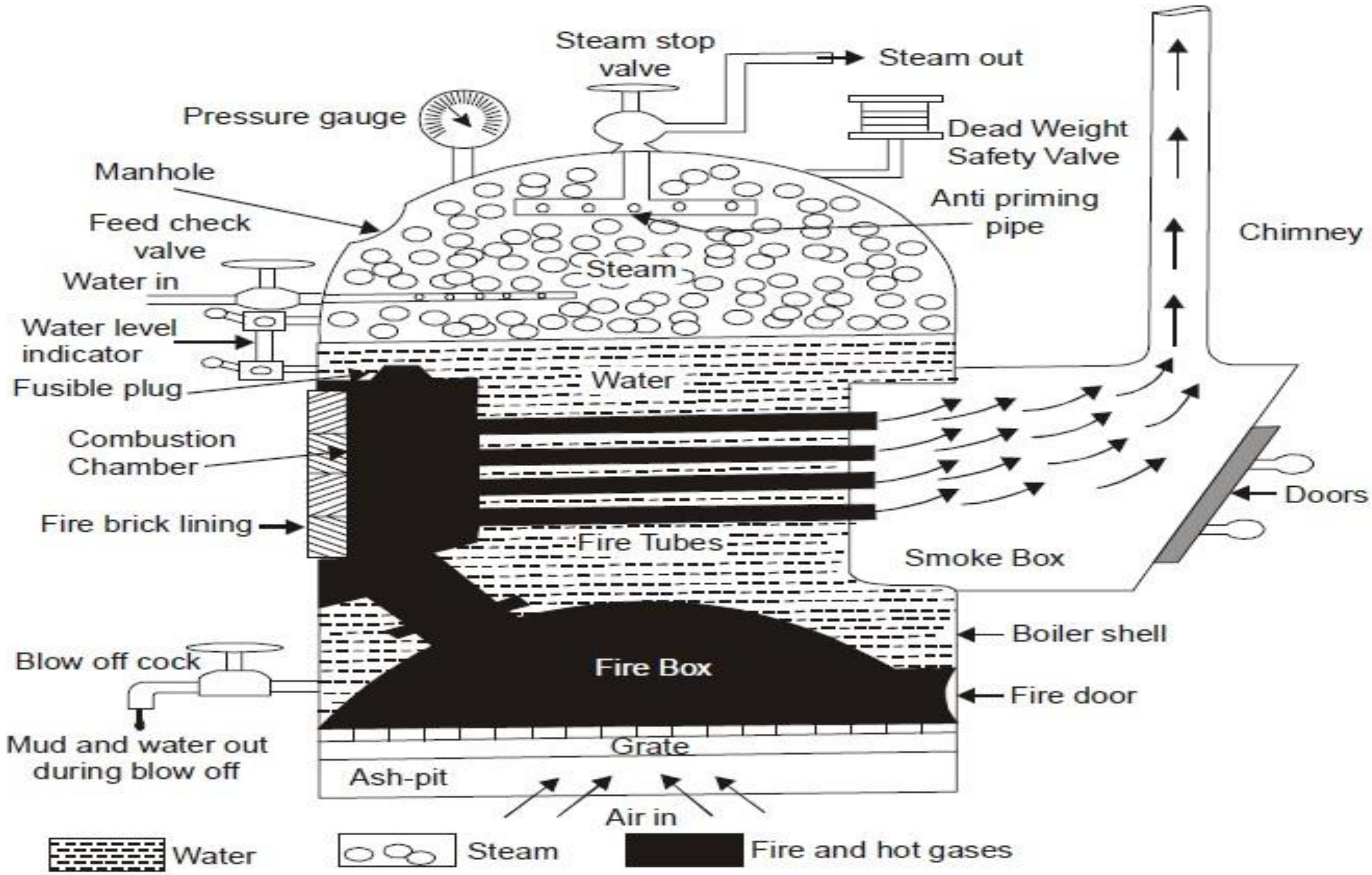
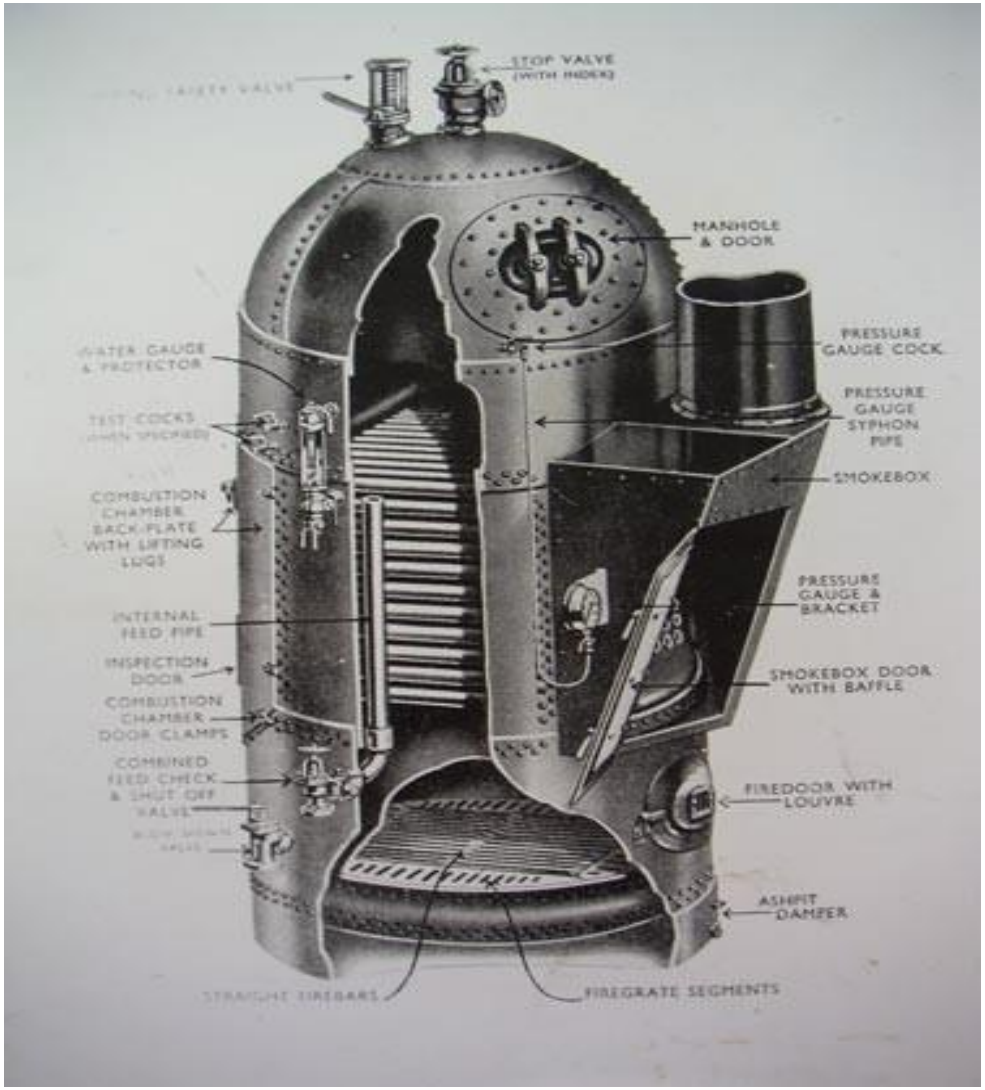
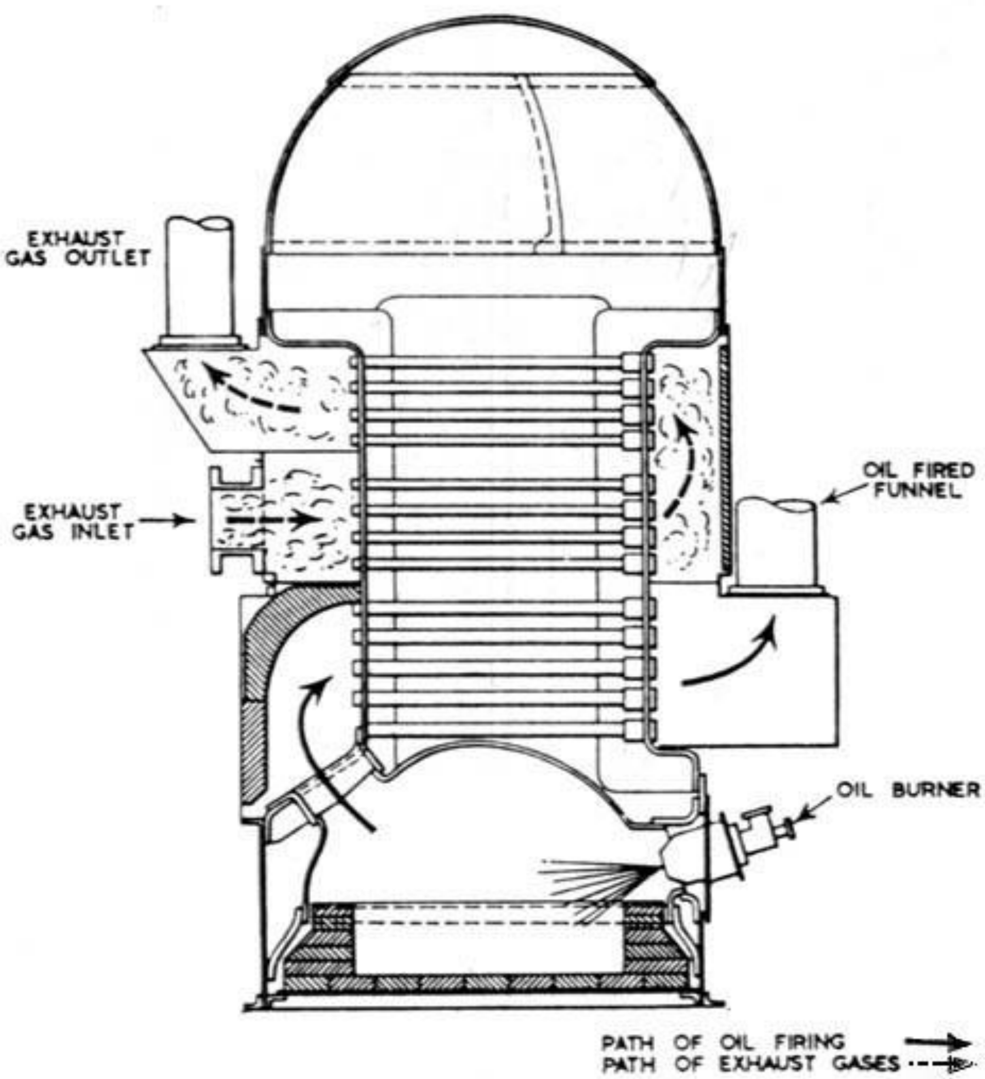


Fig. 5.1. Cochran Boiler.



Cochran Boiler

Fire – tube Boilers



Cochran Boiler

The outstanding features of this boiler are

- It is very compact and requires minimum floor area
- Any type of fuel can be used with this boiler
- Well suited for small capacity requirements
- It gives about 70% thermal efficiency with coal firing and about 75% with oil firing

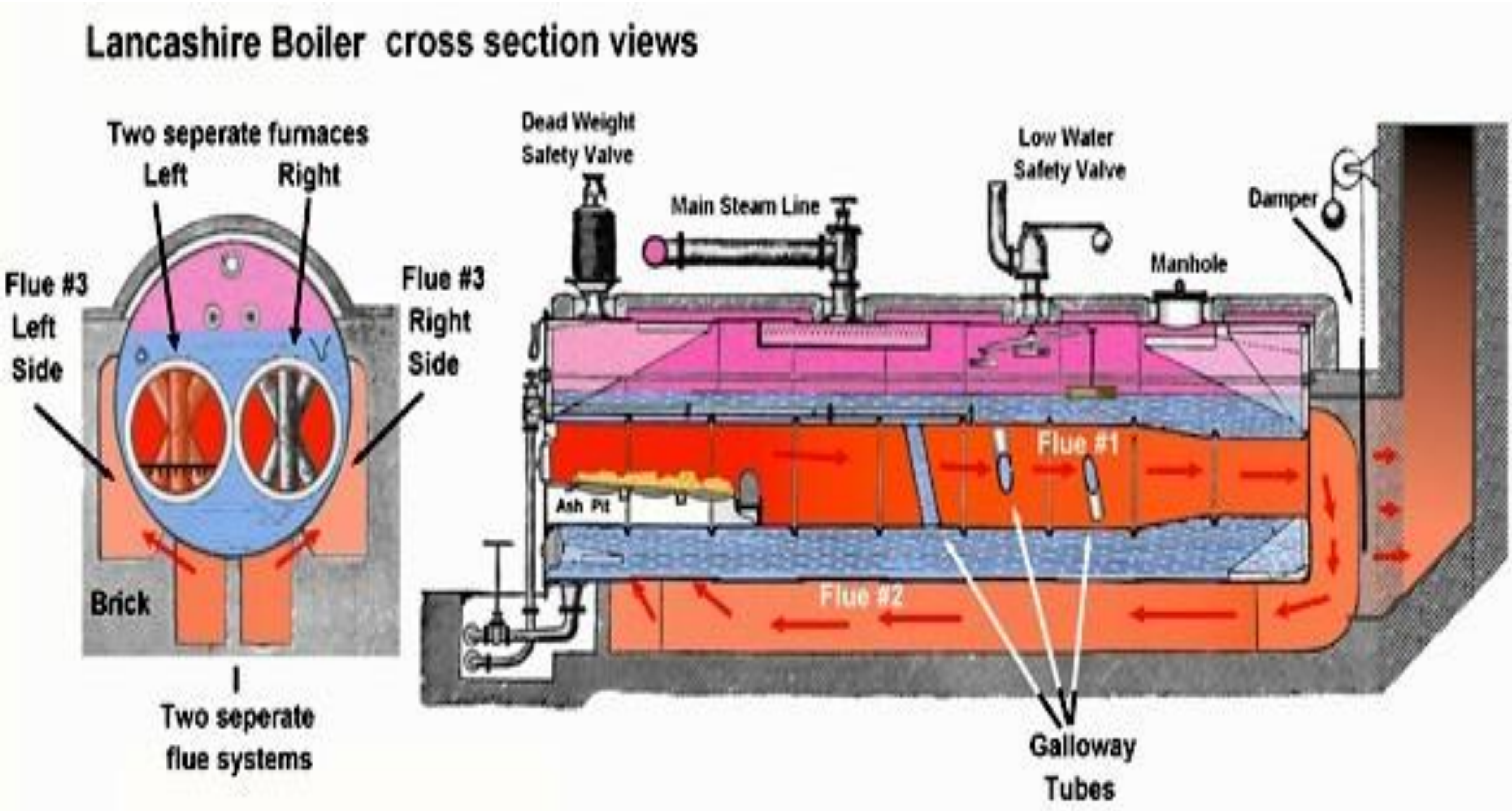
Main parts

1. Pressure Gauge. This indicates the pressure of the steam in the boiler.
2. Water Level Indicator. This indicates the water level in the boiler .
3. Safety Valve. The function of the safety valve is to prevent the increase of steam pressure in the holler above its design pressure.
4. Fusible Plug. If the water level in the boiler falls below a predetermined level, the boiler shell and tubes will be overheated.

Main parts

5. Blow-off Cock. The water supplied to the boiler always contains impurities like mud, sand and, salt Due to heating, these are deposited at the bottom of the boiler, they have to be removed using blow off cock.
6. Steam Stop Valve. It regulates the flow of steam supply outside. The steam from the boiler first enters into an ant-priming pipe where most of the water particles associated with steam are removed
7. Feed Check Valve. The high pressure feed water is supplied to the boiler through this valve. This valve opens towards the boiler only and feeds the water to the boiler.

Lancashire Boiler

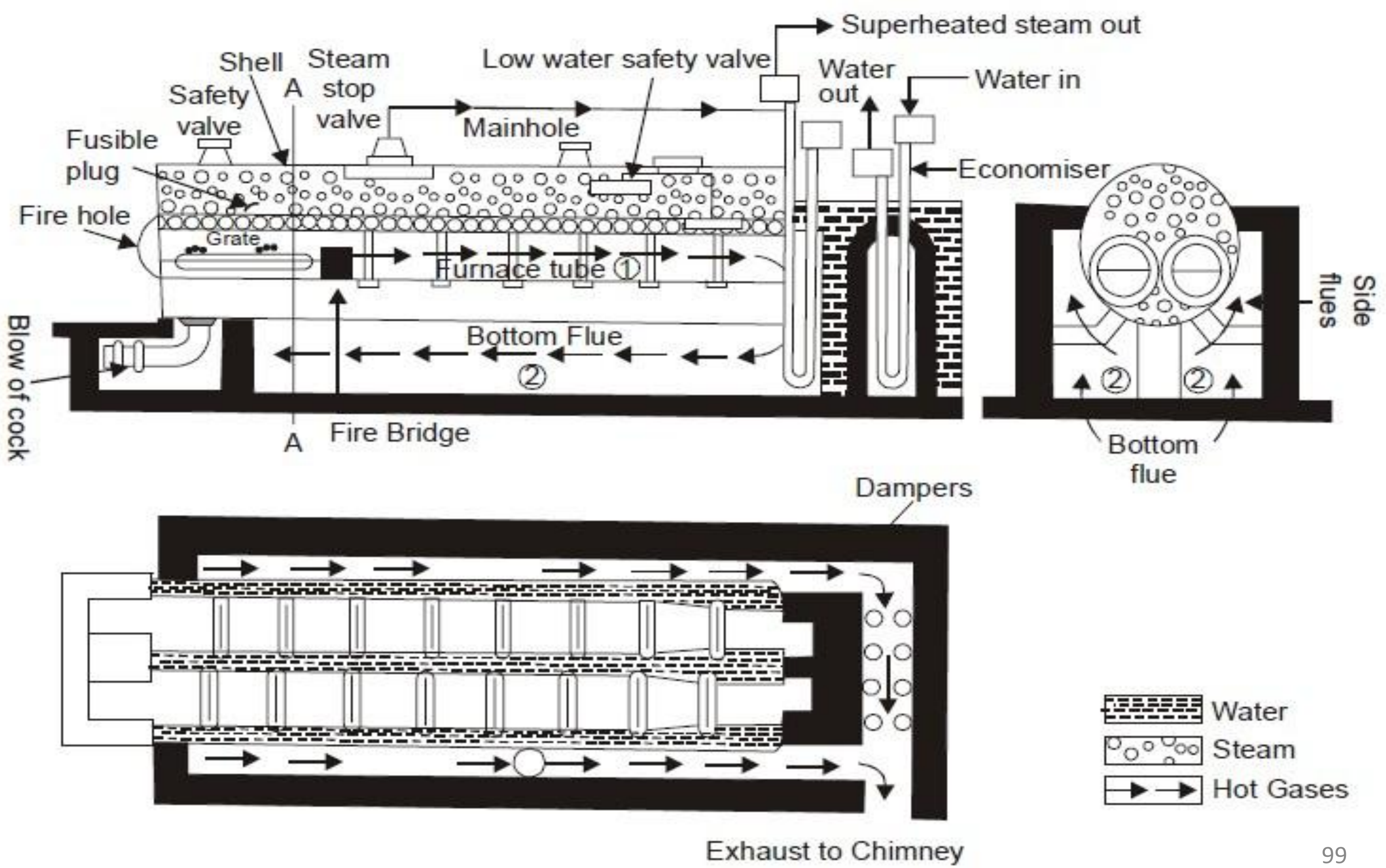


Lancashire Boiler

It is stationary fire tube, internally fired, horizontal, natural circulation boiler. This is a widely used boiler because of its good steaming quality and its ability to burn coal of inferior quality. These boilers have a cylindrical shell 2 m in diameters and its length varies from 8 m to 10m.

It has two large internal flue tubes having diameter between 80 cm to 100 cm in which the grate is situated. This boiler is set in brickwork forming external flue so that the external part of the shell forms part of the heating surface.

Lancashire Boiler



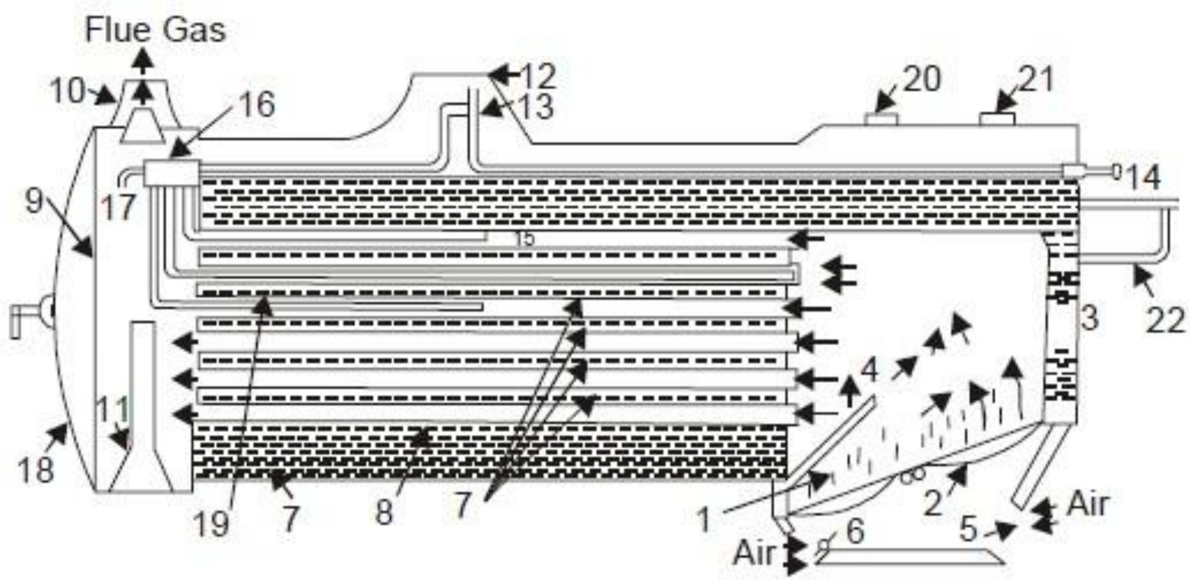
Advantages

- The feed pipe projecting into the boiler is perforated to ensure uniform water distribution.
- Its heating surface area per unit volume at the boiler is considerably large.
- Its maintenance is easy.
- It is suitable where a large reserve of hot water is needed. This boiler due to the large reserve capacity can easily meet load fluctuations.
- Super-heater and economizer can be easily incorporated into the system, therefore; overall efficiency of the boiler can be considerably increased (80-85%).

LOCOMOTIVE BOILER

- **Locomotive boiler is a horizontal fire tube type mobile boiler. The main requirement of this boiler is that it should produce steam at a very high rate. Therefore, this boiler requires a large amount of heating surface and large grate area to burn coal at a rapid rate. In order to provide the large heating surface area, a large number of fire tubes are setup and heat transfer rate is increased by creating strong draught by means of steam jet.**

LOCOMOTIVE BOILER



1. Fire box	2. Grate	3. Fire hole	4. Fire bride arch
5. Ash pit	6. Damper	7. Fine tubes	8. Barrel or shell
9. Smoke box	10. Chimney (short)	11. Exhaust steam pipe	12. Steam dome
13. Regulator	14. Lever	15. Superheater tubes	16. Superheater header
17. Superheater exist pipe	18. Smoke box door	19. Feed check valve	20. Safety valve
21. Whistle	22. Water gauge		

LOCOMOTIVE BOILER

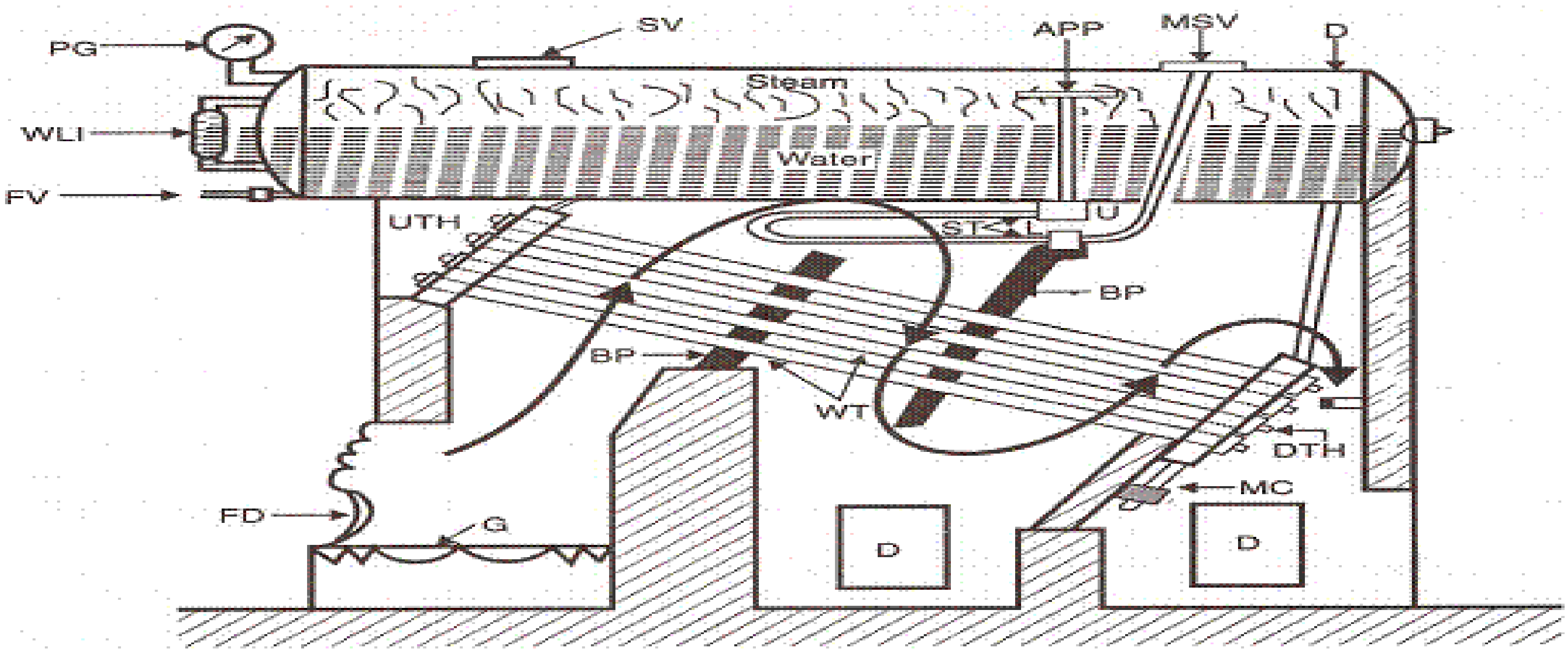
Advantages

- 1. Large rate of steam generation per square metre of heating surface. To some extent this is due to the vibration caused by the motion.
- 2. It is free from brickwork, special foundation and chimney. This reduces the cost of installation.
- 3. It is very compact.

The pressure of the steam is limited to about 20 bar.

LOCOMOTIVE BOILER

BABCOCK WILCOX BOILER



D = Drum	*PG* = Pressure gauge
DTH = Down take header	*ST* = Superheater tubes
WT = Water tubes	*SV* = Safety valve
BP = Baffle plates	*MSV* = Main stop valve
D = Doors	*APP* = Antipriming pipe
G = Grate	*L* = Lower junction box
FD = Fire door	*U* = Upper junction box
MC = Mud collector	*FV* = Feed valve
WLI = Water level indicator	

Features

1. The evaporative capacity of this boilers is high compared with other boilers (20,000 to 40,000kg/hr). The operating pressure lies between 11.5 to 17.5 bar.
2. The draught loss is minimum compared with other boilers.
3. The defective tubes can be replaced easily.
4. The entire boiler rests over an iron structure, independent of brick work, so that the boiler may expand or contract freely. The brick walls which form the surroundings of the boiler are only to enclose the furnace and the hot gases.

Boiler performance

1) **Evaporative capacity**

can be expressed in terms of:

a) kg of steam/hr

b) kg of hour/hr/m^2 of heating surface

c) kg of steam/kg of fuel fired

Equivalent evaporation

But different boilers give out steam at different temperature and pressure,

Evaporative capacity expressed in terms of mass of water getting converted to steam doesn't give a good comparison

$m_e = m_a(h - h_f)/h_{fg}$

Factor of evaporation

It is defined as the ratio of the heat received by 1 kg of water at the working conditions to that received by 1 kg of water evaporated from and at 100^0C

$$F_e \quad = (h - h_f)/2257 \text{ KJ}$$

Boiler efficiency

Ratio of heat actually utilized in the generator to the heat supplied by the fuel.

Efficiency= $m_a(h-h_f)/C$ Where C is the calorific value

BOILER MOUNTINGS

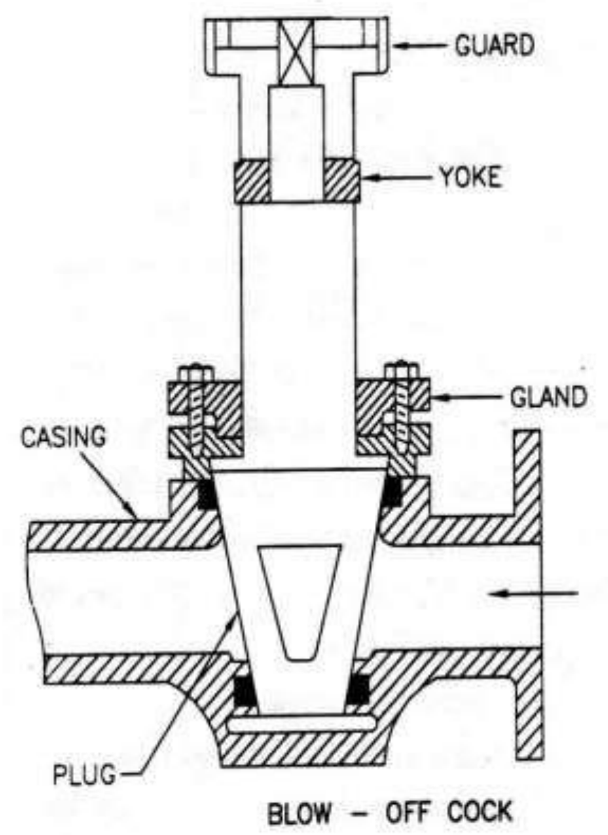
Mainly seven (7) mountings are required and essential to a Boiler :

1. **Water level indicator. (Water gauge)**
2. **Main steam stop valve.**
3. **Pressure gauge.**
4. **Feed check valve.**
5. **Fusible plug.**
6. **Blow down valve. (Blow off cock)**
7. **Safety valve.**

Blow-Off Cock

Function:

The function of blow-off cock is to discharge mud and other sediments deposited in the bottom most part of the water space in the boiler, while boiler is in operation. It can also be used to drain-off boiler water. Hence it is mounted at the lowest part of the boiler. When it is open, water under the pressure rushes out, thus carrying sediments and mud.



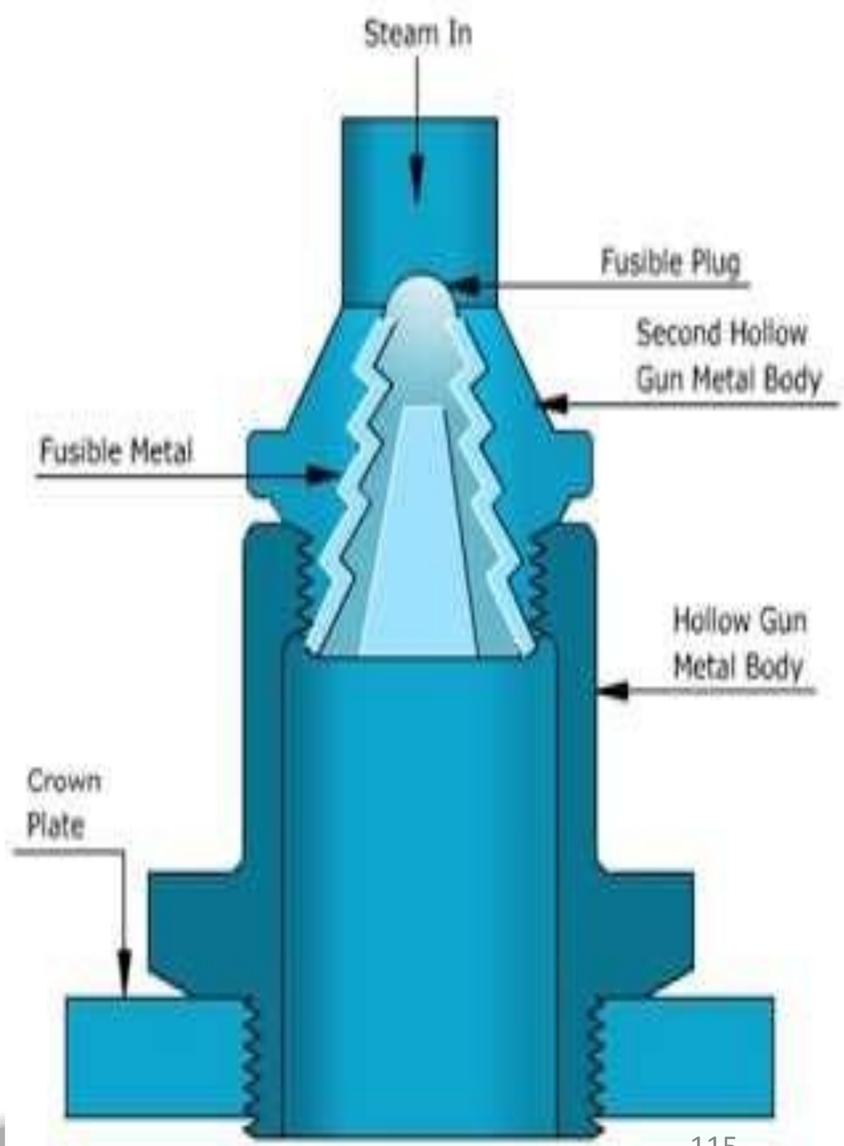
Working

When rectangular hole of plug is brought in line with casing hole by rotating spindle, the water flow out. When the solid portion of the plug is in front of casing hole (this position shown in the fig.) the water cannot flow out of boiler.

Fusible plug

Function :

It is use to protect the boil against damage due to overheating caused by low water level in the boiler.



Working

- In normal working condition, the upper surface of fusible plug is covered with water which keeps the temperature of the plug below its melting point while other end of plug is exposed to fire or hot gases. The low melting point (tin or lead) does not melt till the upper surface of plug is submerged in water. But in case of water level in boiler falls below the danger levels, the fusible plug uncovered by the water and get exposed to steam. This overheats the plug and the fusible metal having low melting point which melts quickly.

Feed check valve

- **Function: It controls the supply of water from the boiler when the feed pump pressure is less than boiler pressure or pump is stopped.**

WORKING

Inlet and outlet pipe of valve expose different pressure .at inlet of valve the feed pump pressure acts and outlet pipe of the valve the boiler pressure act . When feed pump is in operation,

The pressure on the feed pump side(inlet) is more than pressure on the boiler side(outlet).This pressure difference lifts the non return valve, And allows water flow into boiler.

WATER LEVEL INDICATOR

Function:-

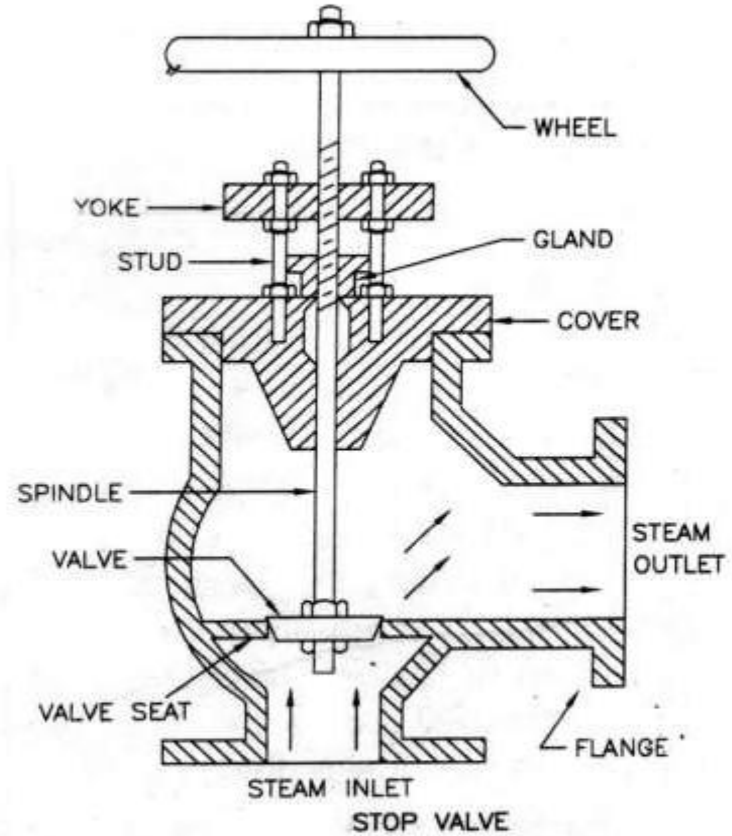
It indicate the water level inside the boiler vessel. It shows the level in the boiler drum.

WORKING

- When steam cock and water cock opened, steam rushes from upper passage and water rushed from lower from passage to the glass tube. This will indicate the level of water in the boiler. Two ball are places at the junction of metal tube. Under normal operating condition the ball are kept. full line circle in case the glass tube is broken, steam will rushes from upper passage and water from lower passage due to pressure difference between boiler pressure at atmospheric pressure. the ball are carrier

Steam Stop Valve

- **Function:- It regulate the flow of steam from boiler to the steam pipe or from one steam pipe to the other.**



WORKING

- The spindle it rotated by help of hand wheel due to rotation of spindle the valve move up and down. When the valve sits over the valve seat, the passage of steam is completely closed. The steam passage may be partially or fully opened by moving the valve up, help of rotating the hand wheel the clearance (passage) between valve and valve seat regulates the flow of steam out of boilers. in locomotive boilers, the supply of the steam is regulated by means of a regulator which is placed inside boiler cell and operated by a handle from driver's cabin.

Pressure Gauge

- **Function : It indicates the pressure of steam in boiler.**

Working

- When pressure is applied to inside of oval bourdon tube. It cross section tends to becomes circular, and free end of bourdon tube try to becomes straight, so turning the spindle by the links and gearing. This causes the needle to move and indicate pressure on graduated dial.

Safety valves

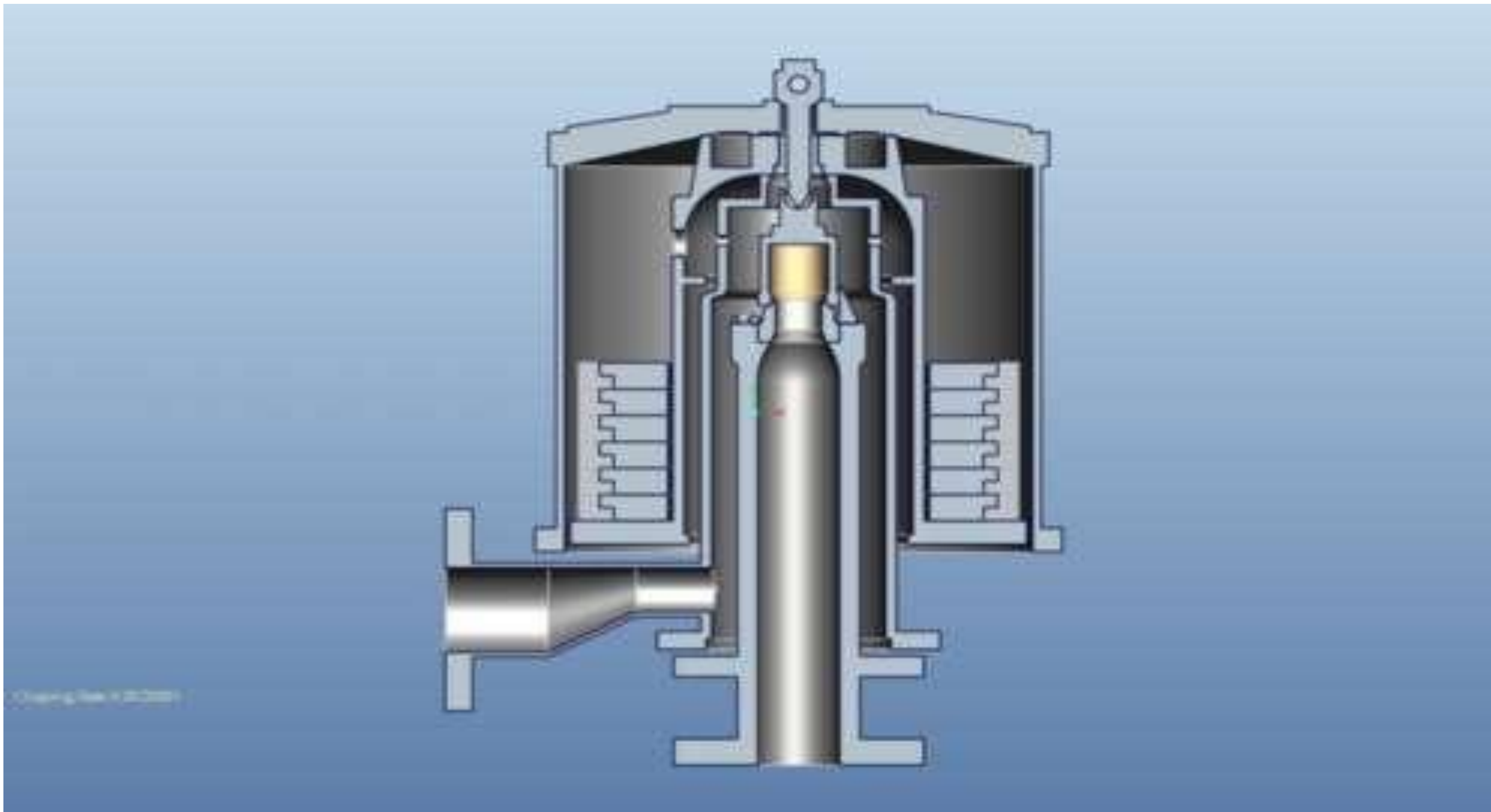
- **Function : Safety valves are located on the top of the boiler. They guard the boiler against the excessive high pressure of steam inside the drum. If the pressure of steam in the boiler drum exceeds the working pressure then the safety valve allows blow-off the excess quantity of steam to atmosphere. Thus the pressure of steam in the drum falls. The escape of steam makes a audio noise to warm the boiler attendant.**

Safety valves

:There are four types of safety valve:

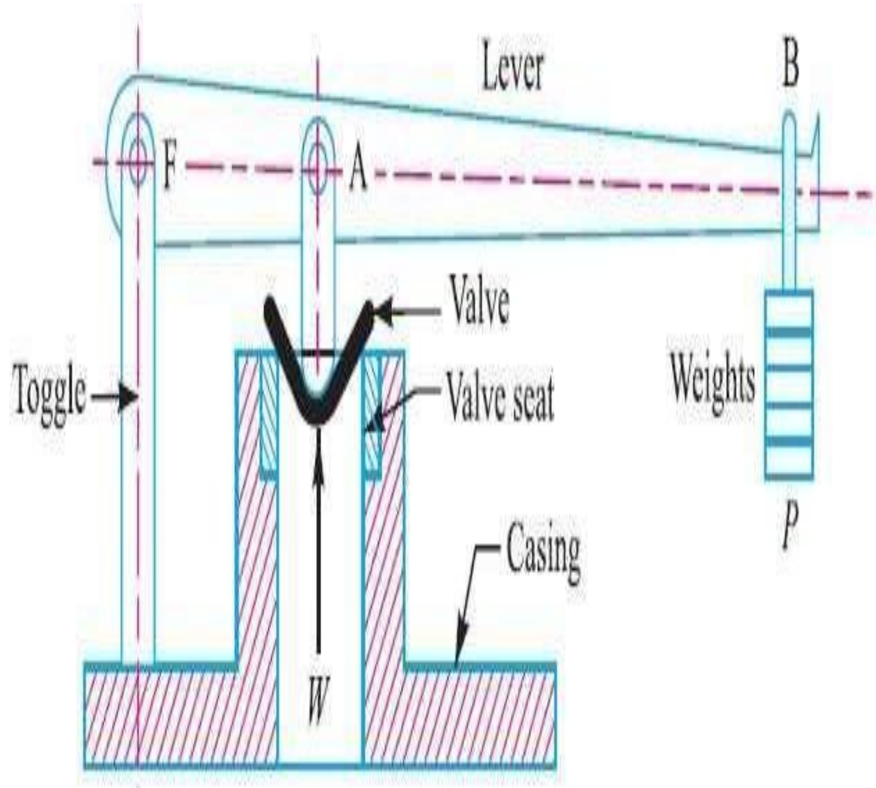
1. Dead weight safety valve.
2. Spring loaded safety valve
3. Lever loaded safety valve
4. High steam and low water safety valve

Dead weight safety valve



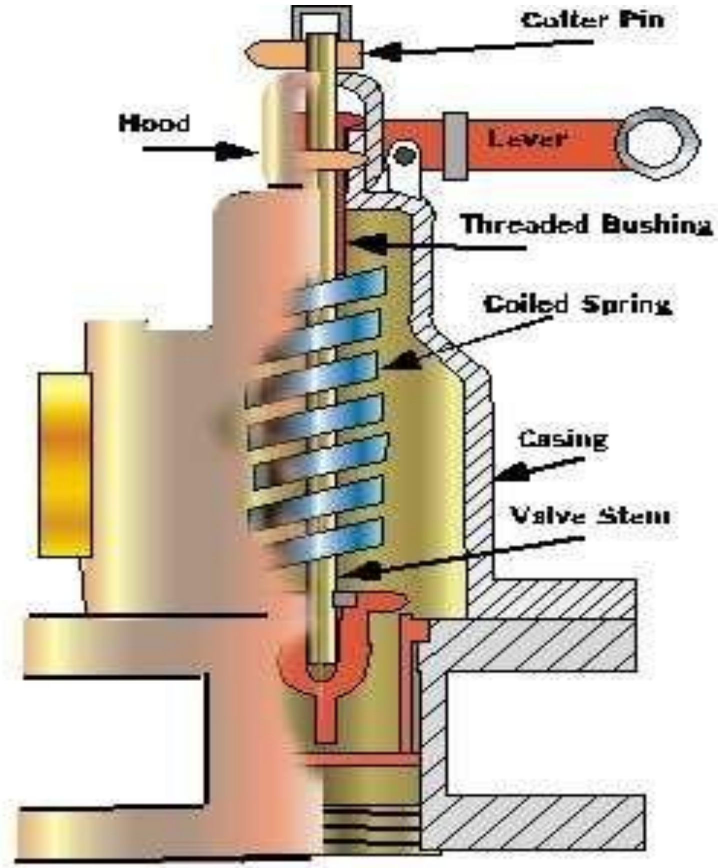
Lever safety valve

- **The main disadvantages of dead weight safety valve as heavy weights required for high pressure boiler is eliminated in a lever safety valve by use of a lever.**



Spring loaded safety valve

- There are various types of sprir loaded safety valve use on different boilers.



Spring Loaded Safety Valve

High steam & low water safety valve

Function

1) The steam automatically escapes out when the of water falls below a normal level.
2) It automatically discharges the excess steam when the pressure of steam rises above a normal pressure.

- This valve is generally used in Cornish or Lancashire boiler.

Boiler Accessories

Boilers Accessories are as under:

(1) Feed pump

(2) Injector

(3) Economiser

(4) Air preheater

(5) Superheater

(6) Steam Separator

(7) Steam trap

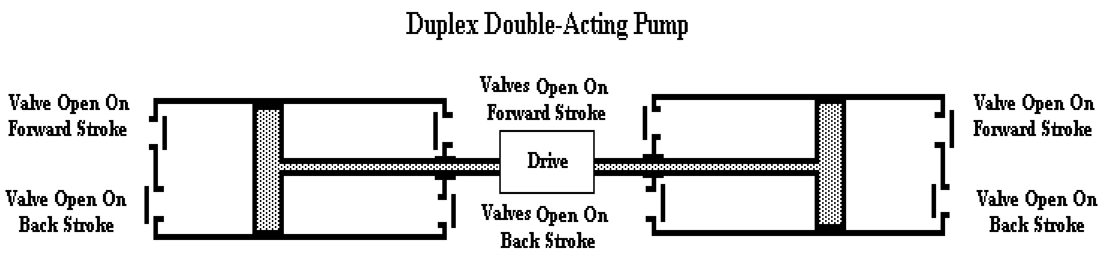
Feed Pump

- **Function:**
- **The feed pump is a pump which is used to deliver feed water to the boiler.**
- **Double feed pump is commonly employed for medium size boilers.**

Types of Feed pumps

- There are Three types of feed Pumps mainly:
- Reciprocating pumps-simplex,duplex,Triplex
- Rotary pumps
- Centrifugal pumps

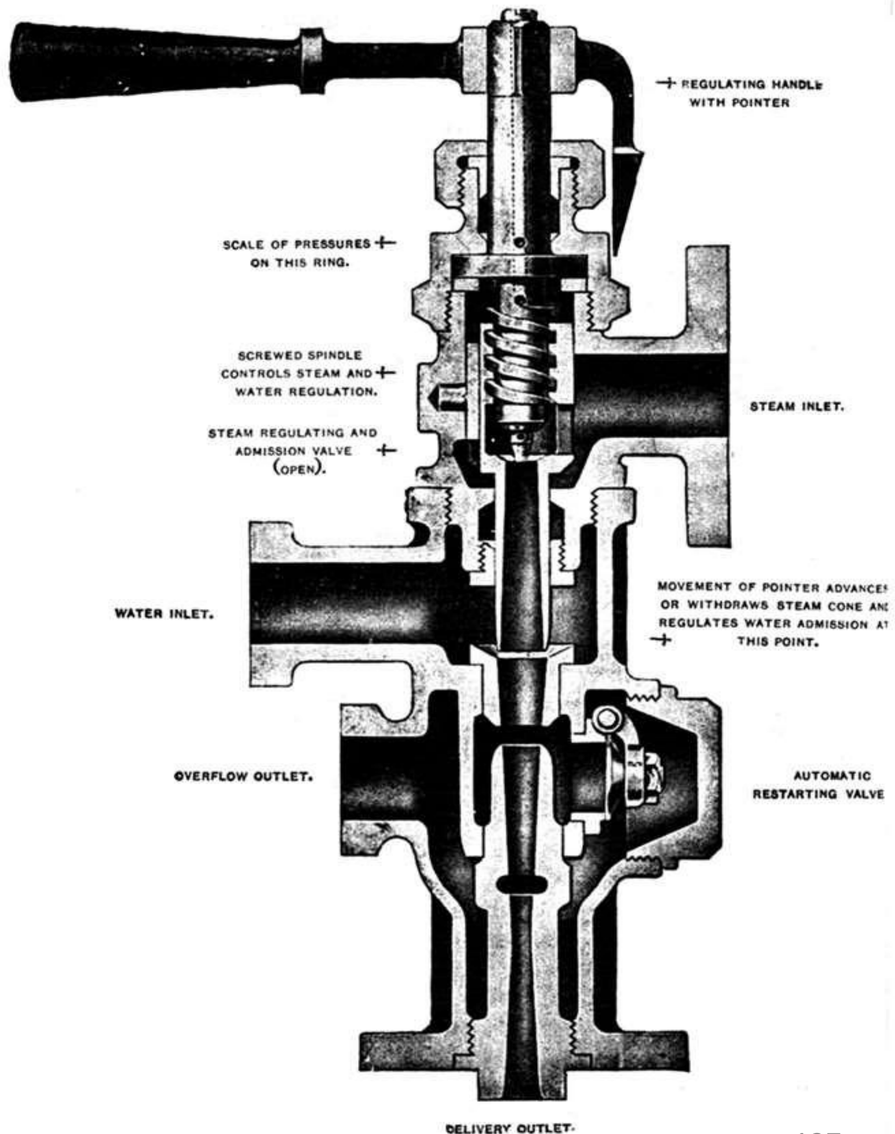
Reciprocating Duplex Pump



Duplex pump is very common steam driven reciprocating pump. It consist of two steam cylinder placed side by side. There are two steam ports for each of the cylinders.

Injector

- Function : Injector is used to feed water in the boiler .
- It is commonly employees for vertical boiler and does not find its application in large capacity high pressure boilers . it also uses more space is not available for the installation for feed pump.



Economiser

- **Function: Economizer increases the temperature of feed water using waste of heat to flue gases leaving the boiler through chimney.**

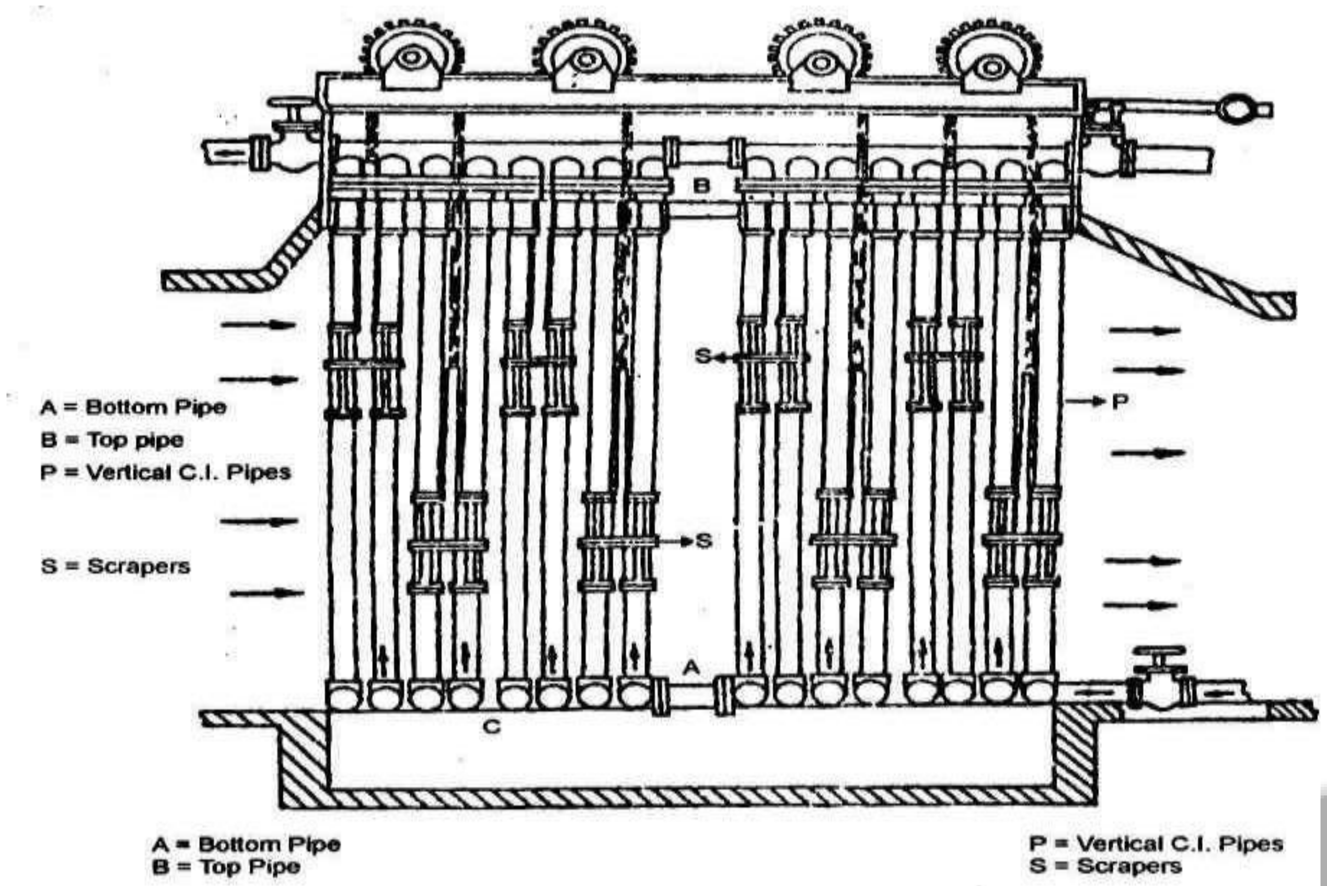
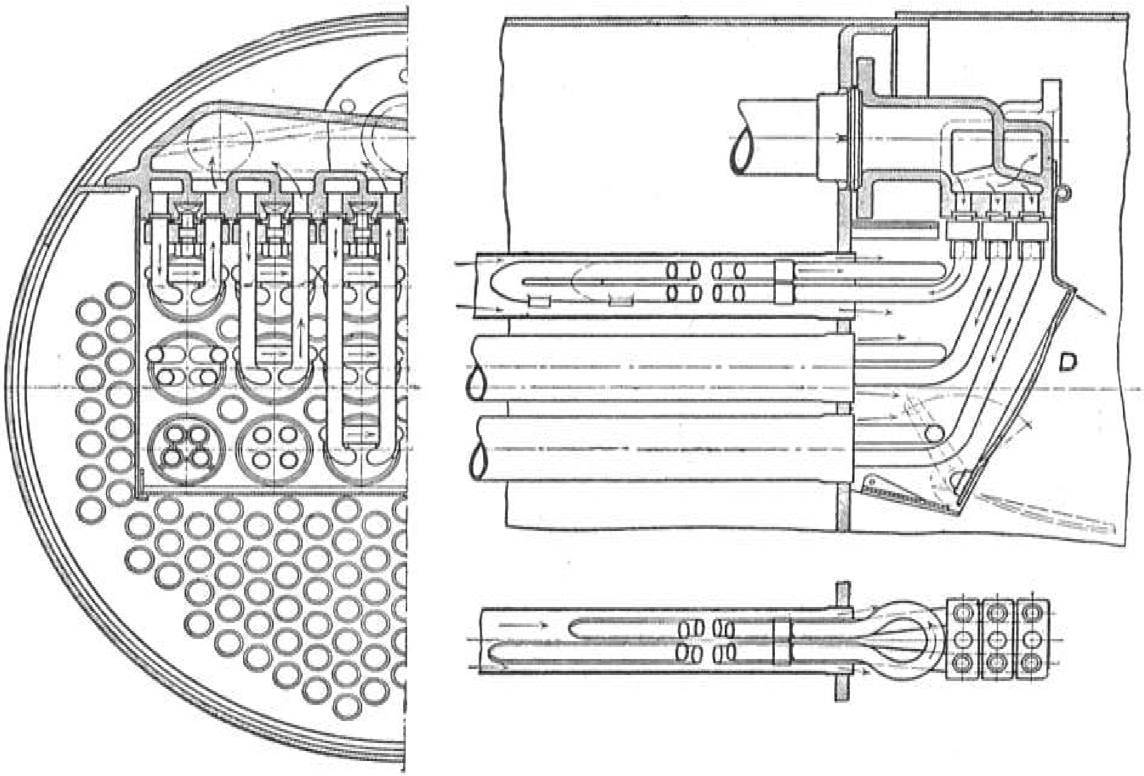


Fig. Economiser

Super heater

- The function of super heater is to increase the temperature of the steam above its saturation point.



Working

- To superheat the steam generated by boiler.
- Super heaters are heat exchangers in which heat is transferred to the saturated steam to increase its temperature.
- Superheated steam has the following advantages :

i)Steam consumption of the engine or turbine is reduced.

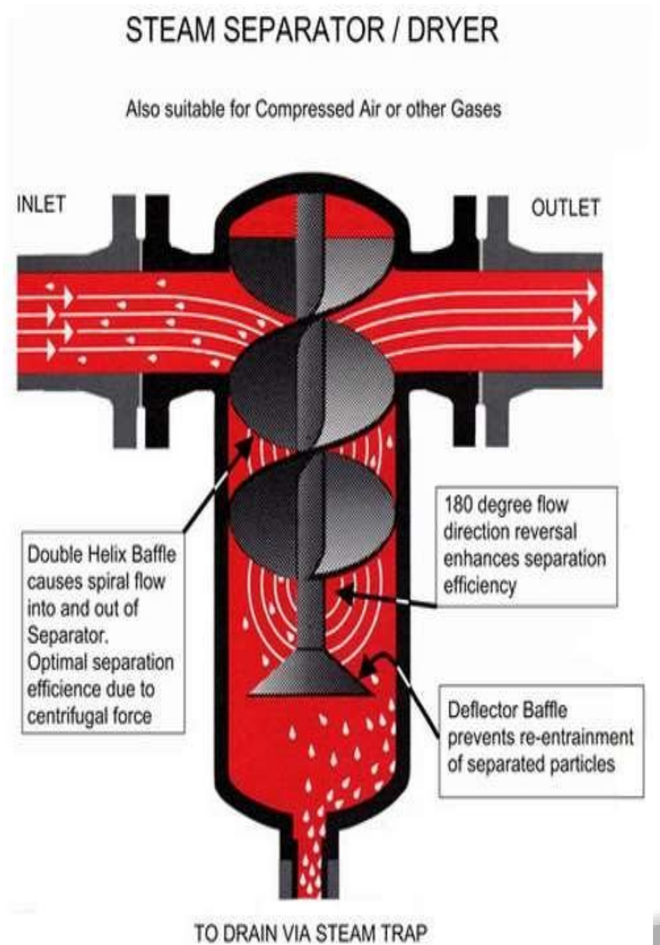
ii)Losses due to condensation in the cylinders and the steam pipes are reduced.

iii)Erosion of turbine blade is eliminated.

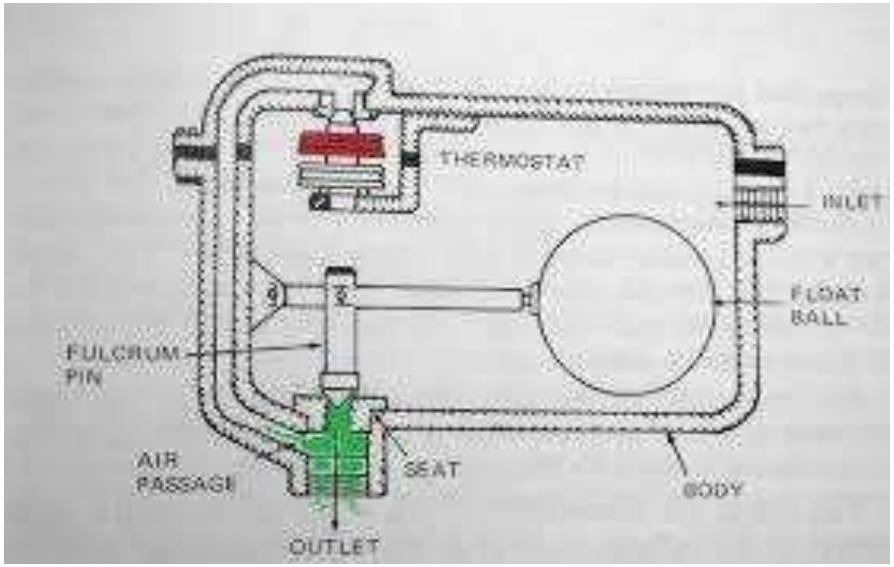
iv)Efficiency of steam plant is increased

Steam Separator

A Steam separator, sometimes referred to as a moisture separator, is a device for separating water droplets from steam. The simplest type of steam separator is the steam dome on a steam locomotive. Stationary boilers and nuclear reactors may have more complex devices which impart a "spin" to the steam so that water droplets are thrown outwards by centrifugal force and collected.



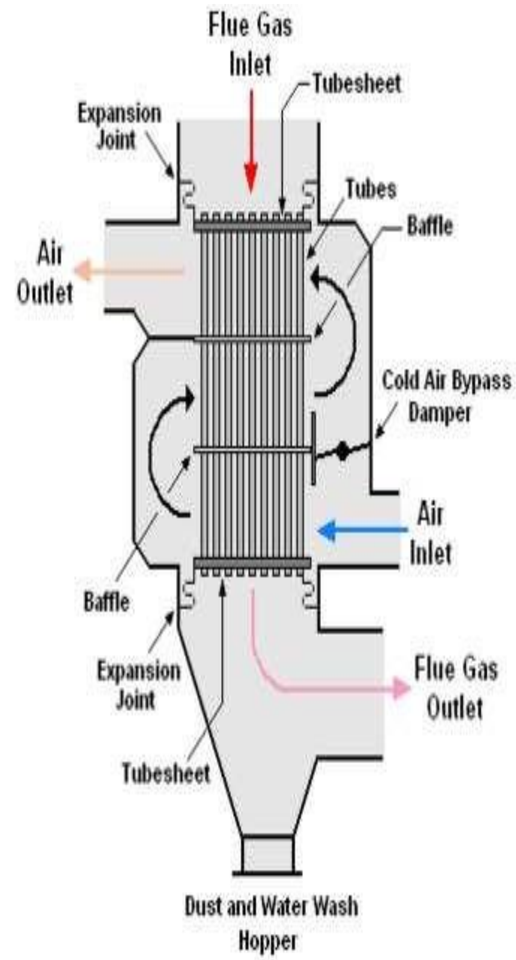
Steam Trap



:: A steam trap is a device used to discharge condensate and non condensable gases with a negligible consumption or loss of live steam. Most steam traps are nothing more than automatic valves. They open, close or modulate automatically. Others, like venture traps, are based on turbulent 2-phase flows to obstruct the steam flow.::

Air Preheater

An air preheater is a general term to describe any device designed to heat air before another process (for example, combustion in a boiler) with the primary objective of increasing the thermal efficiency of the process. They may be used alone or to replace a recuperative heat system or to replace a steam coil.



Nozzle

- Nozzle is duct of smoothly varying cross-sectional area in which a steadily flowing fluid can be made to accelerate by a pressure drop along the duct.

Applications:

- steam and gas turbines
- Jet engines
- Rocket motors
- Flow measurement

Diffuser

- When a fluid is decelerated in a duct causing a rise in pressure along the stream, then the duct is called a diffuser.

- Two applications in practice in which a diffuser is used are :

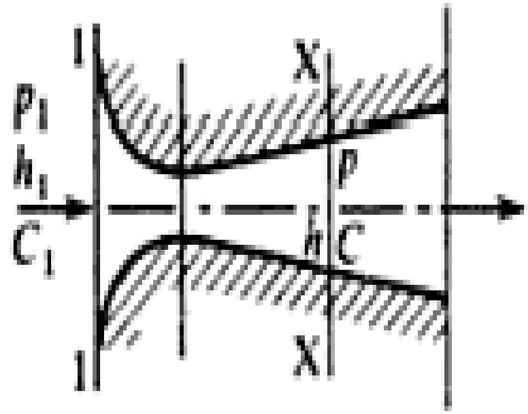
- The centrifugal compressor
- Ramjet

One dimensional flow

- In one dimensional flow it is assumed that the fluid velocity, and the fluid properties, change only in the direction of the flow.
- This means that the fluid velocity is assumed to remain constant at a mean value across the cross section of the duct.

Applying Steady flow energy equation:

$$h_1 + \frac{C_1^2}{2} = h + \frac{C^2}{2}$$



$$C^2 = 2(h_1 - h) + C_1^2$$

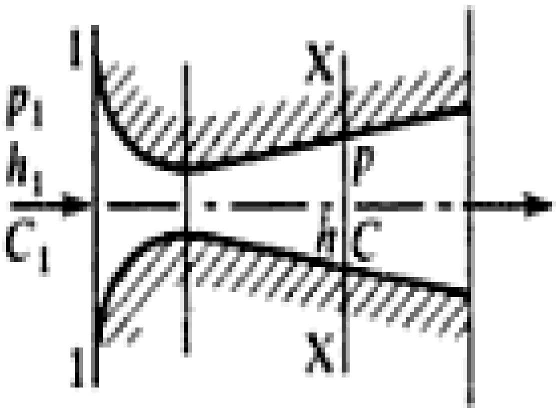
$$C = \sqrt{\{2(h_1 - h) + C_1^2\}} \quad \text{.................................} \quad \textbf{(1)}$$

Critical pressure ratio:

Ratio of pressure at the section where sonic velocity is attained to the inlet pressure of a nozzle is called the critical pressure ratio.

Consider convergent divergent nozzle,

- **Inlet conditions of Nozzle be:** (P1 ; h1 ; C1)
- **Conditions at any other section X-X:** (P ; h ; C)

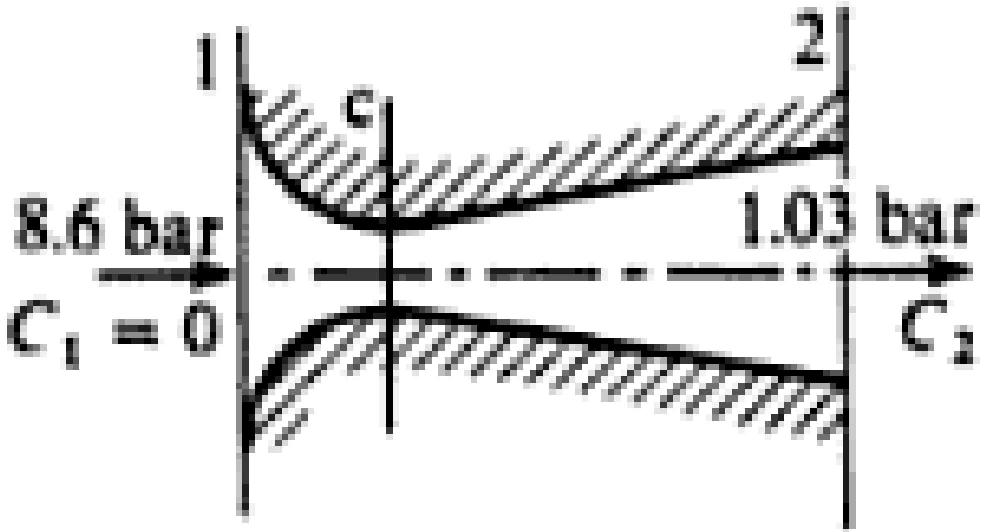


Problem:01

Air at 8.6 bar and 190 °C expands at the rate of 4.5 kg/s through a convergent–divergent nozzle into a space at 1.03 bar. Assuming that the inlet velocity is negligible, calculate the throat and the exit cross-sectional areas of the nozzle.

DATA:

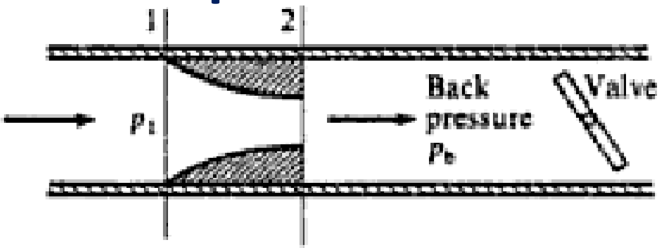
P1 = 8.6 bar
T1 = 190 ‘c
m’ = 4,5kg/s P = 1.03 bar



Calculate:

➢**Throat and exit cross-sectional areas.**

Consider a convergent nozzle expanding into a space, the pressure of which can be varied, while the inlet pressure remains fixed.



When,

<u>Pb = P1</u> : then no fluid can flow through the nozzle

<u>As Pb is reduced</u> : mass flow through the nozzle increases, since the
enthalpy drops and hence the velocity increases.

<u>When the Pb = Pc:</u> no further reduction in back pressure can affect the mass flow and velocity at the exit is sonic.

Convergent nozzle with back pressure variation

CHOCKING

- **Maximum mass flow through a convergent nozzle is obtained when the pressure ratio across the nozzle is the critical pressure ratio.**

- **Also for a convergent – divergent nozzle , with sonic velocity at the throat, the cross-sectional area of the throat fixes the mass flow through the nozzle for fixed inlet conditions.**

- ***When a nozzle operates with the maximum mass flow it is said to be choked.***

CHOCKING

FOR EXAMPLE :

- ***When air at 10 bar expands in a nozzle, the critical pressure can be***

shown to be 5.283 bar.

- ***When the Pb = 4 bar then nozzle is chocked and is passing the maximum mass flow.***
- ***If the Pb is reduced to 1 bar, the mass flow through the nozzle is unchanged***

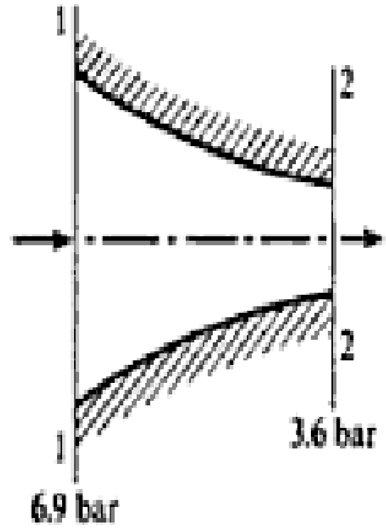
PROBLEM NO: 02

A fluid at 6.9 bar and 93 °C enters a convergent nozzle with negligible velocity, and expands isentropically into a space at 3.6 bar. Calculate the mass flow per square metre of exit area:

(i) when the fluid is helium ($c_p = 5.19$ kJ/kg K);
(ii) when the fluid is ethane ($c_p = 1.88$ kJ/kg K).

Assume that both helium and ethane are perfect gases, and take the respective molar masses as 4 kg/kmol and 30 kg/kmol.

$$\dot{m} = \frac{A_2 C_2}{v_2}$$ .... eq no: 1

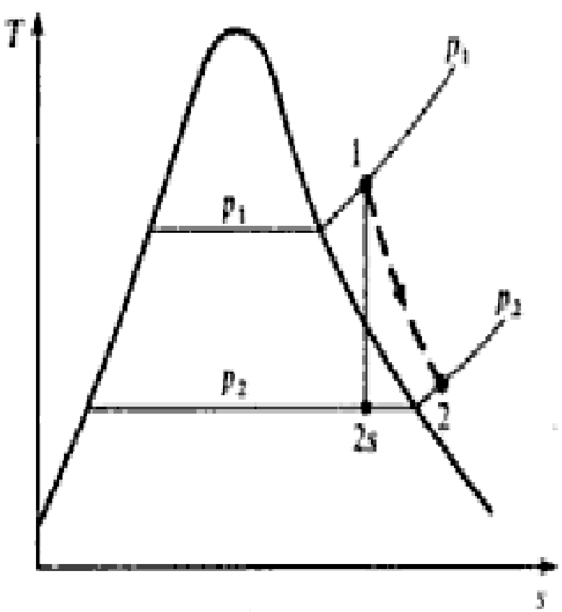


NOZZLE OFF THE DESIGN PRESSURE RATIO (Under expansion & overexpansion)

- **When the back pressure of a nozzle is below the design value the nozzle is said to *under expand.***
- **When the back pressure of a nozzle is above the design value the nozzle is said to *over expand.***

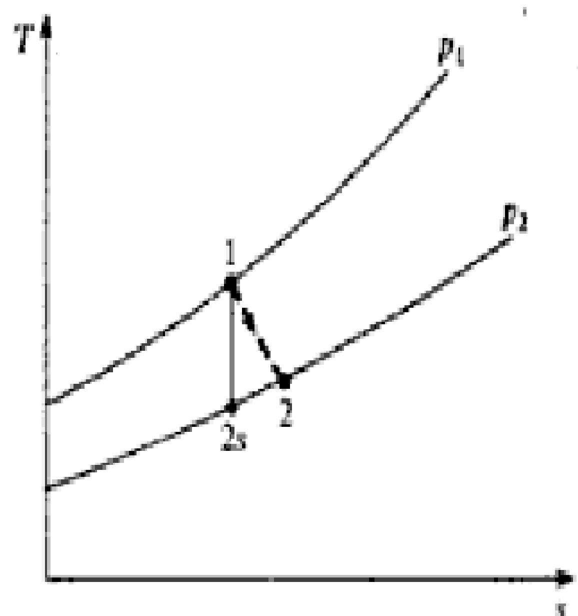
T-S DIAGRAM Expansion between P1 and P2 in a nozzle (For a vapour and for a perfect gas respectively)

- **The line 1-2s represents the ideal isentropic expansion,**
- **The line 1-2 represents the actual irreversible adiabatic expansion.**



(a)

(a) for a vapour



(b)

(b) for a perfect gas

Velocity Co-efficient:

It is the ratio of actual exit velocity to the velocity when the flow is isentropic b/w the same pressures.

Velocity Co-efficient is square root of the nozzle efficiency when the inlet velocity is assumed to be negligible.

Co-efficient of discharge :

" Ratio of the actual mass flow through the nozzle m', to the mass flow which would be passed if the flow were isentropic, m's. "

Angle of divergence:

The included angle of divergent duct is usually kept below about 20*.

If the angle of divergence of a convergent – divergent nozzle is made too large, then breakaway of the fluid from the duct is liable to occur, with consequent increased friction losses.

Example : 3

Gases expand in propulsion nozzle from 3.5 bar and 425 C down to a back pressure of 0.97 bar, at the rate of 18 kg/s. Taking a coefficient of discharge of 0.99 and a nozzle efficiency of 0.94, Calculate the required throat and exit areas of the nozzle. For the gases take $\gamma = 1.333$ and Cp = 1.11 kJ/ kg K, Assume that the inlet velocity is negligible.

Data

P1 = 3.5 bar; T1 = 425 C P2 = 0.97 bar

m' =18 kg/s

Cd = 0.99

Efficiency = 0.94 Cp = 1.11 *kJ/ kg K* $\gamma = 1.333$

Calculate:

Throat and exit areas =?

Steam Nozzle

- Properties of steam can be obtained from tables or from h-s chart.

- But in order to find the
  - critical pressure ratio
  - critical velocity
  - maximum mass flow rate,

approximate formulae may be used.

- We assume that steam follows an isentropic law = PV^K

- k = isentropic index for steam
  - For dry saturated steam k = 1.135,
  - for superheated steam k = 1.3

Supersaturation or Supersaturated expansion

- The type of expansion in which expansion of vapour after the saturated vapour line continues as if it did not exist, and then at a certain point it condenses suddenly and irreversibly.

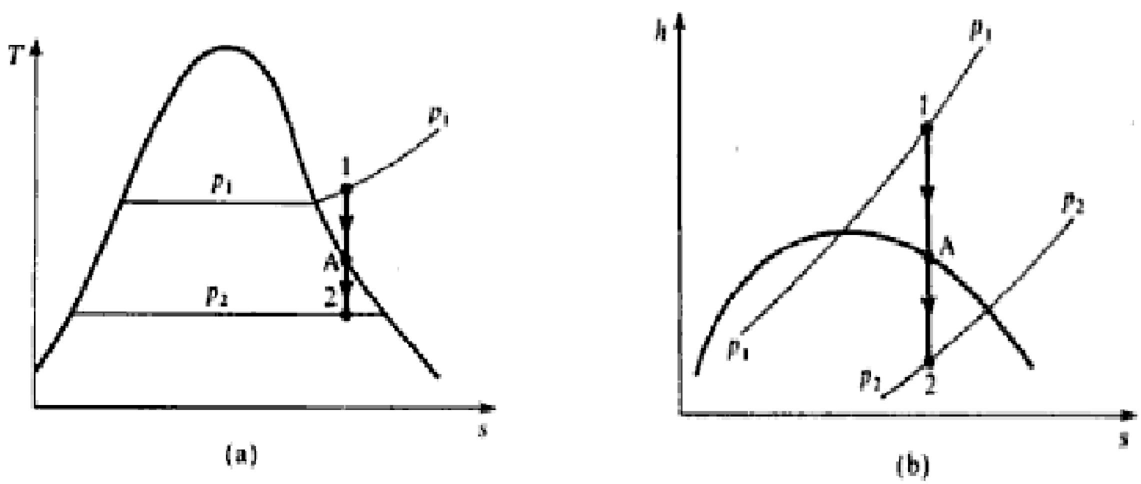
- The state of vapour during this type of expansion is called metastable state.

- mass flow with super saturation flow is greater than the mass flow with equilibrium flow.

Generally

- Condensation with in the vapour begins to form when the saturated vapour line is reached.

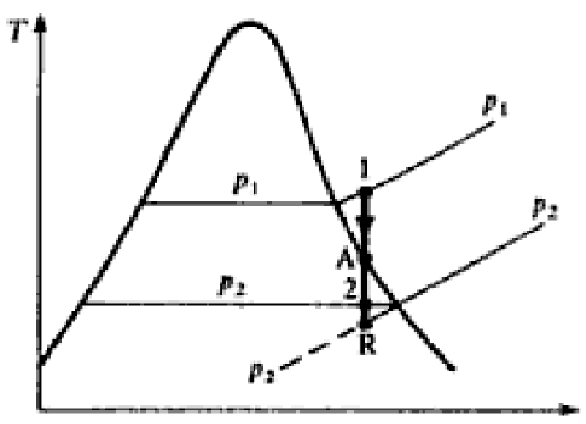
- Below the saturated vapour line (in wet region) Dryness fraction becomes smaller.

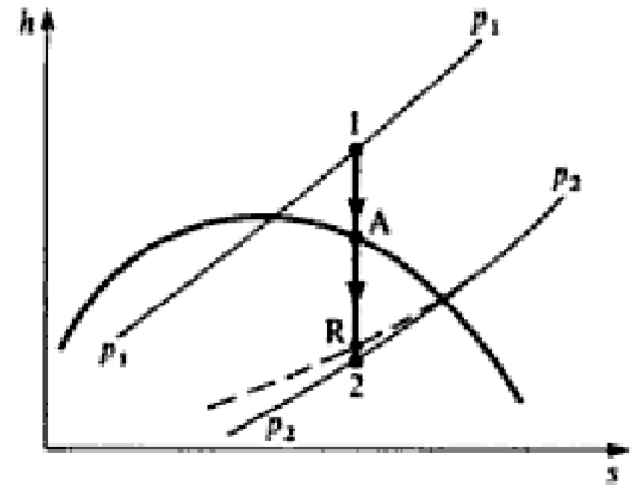


Superheated steam expanding into the wet region on
(a) T-S and (b) h – S diagrams

In case of Nozzle:

- ***Expansion is so quick that condensation does not occur at point A.***
- **Then it suddenly condenses irreversibly at certain point.**
- **That point may be outside or within the nozzle.**

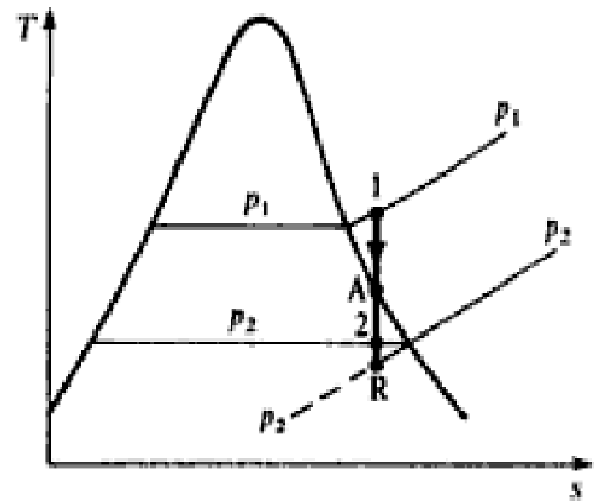




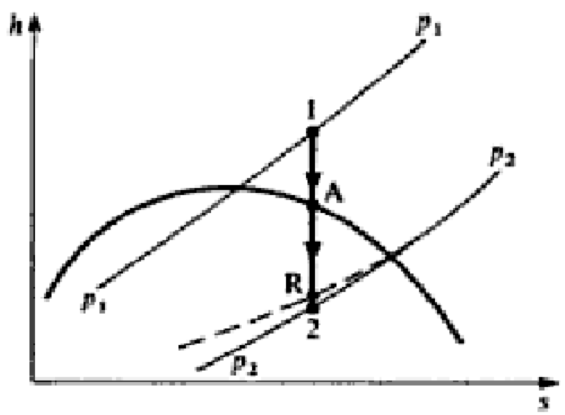
Supersaturated expansion of steam on (a) T-s and (b) h-as diagram

Assuming the isentropic flow,

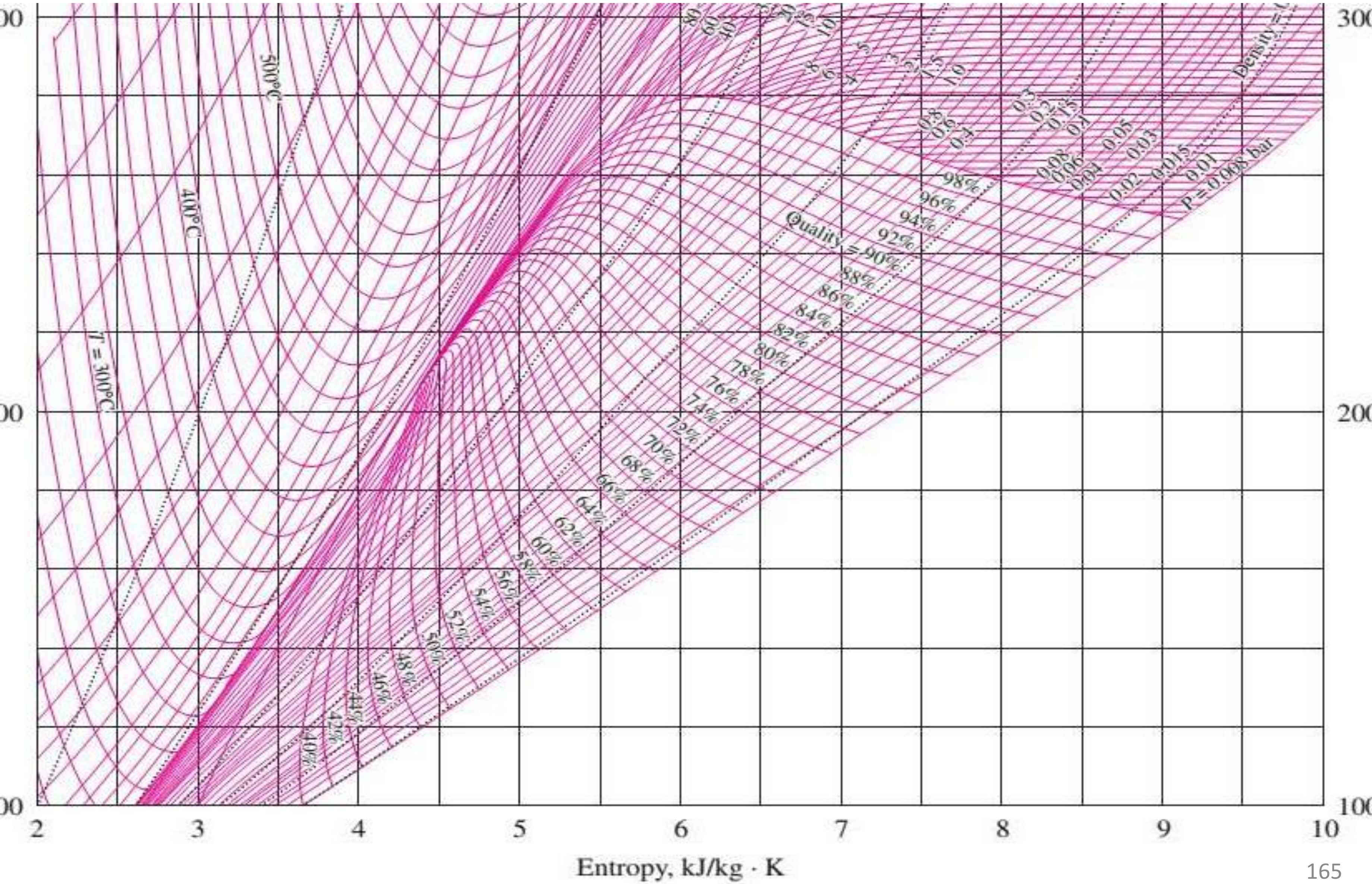
- Line 1-2 represents expansion with equilibrium.
- Line 1-R represents supersaturated expansion
- Line 1-R intersects the pressure line P2 produced from superheat region.


(a)

- It can be seen that the temperature of the super-saturated vapour at P2 is tr, which is less than the saturation temperature t2 corresponding to P2.


(b)

Mollier diagram



UNIT III
THERMAL ENGINEERING

DEFINITION

A steam turbine is a prime mover in which the potential energy of the steam is transformed into kinetic energy and later in its turn is transformed into the mechanical energy of rotation of the turbine shaft.

APPLICATIONS OF STEAM TURBINES

- **Power Generation**
- **Transport**

CLASSIFICATION OF STEAM TURBINES

According to the action of steam:

- **Impulse turbine: In impulse turbine, steam coming out through a fixed nozzle at a very high velocity strikes the blades fixed on the periphery of a rotor. The blades change the direction of steam flow without changing its pressure. The force due to change of momentum causes the rotation of the turbine shaft. Ex: De-Laval, Curtis and Rateau Turbines**
- **Reaction turbine: In reaction turbine, steam expands both in fixed and moving blades continuously as the steam passes over them. The pressure drop occurs continuously over both moving and fixed blades.**
- **Combination of impulse and reaction turbine**

CLASSIFICATION OF STEAM TURBINES

According to the number of pressure stages:

➢ **Single stage turbines: These turbines are mostly used for driving centrifugal compressors, blowers and other similar machinery.**

➢ **Multistage Impulse and Reaction turbines: They are made in a wide range of power capacities varying from small to large.**

According to the type of steam flow:

➢ **Axial turbines: In these turbines, steam flows in a direction parallel to the axis of the turbine rotor.**

➢ **Radial turbines: In these turbines, steam flows in a direction perpendicular to the axis of the turbine, one or more low pressure stages are made axial.**

CLASSIFICATION OF STEAM TURBINES

According to the number of shafts:

- **Single shaft turbines**
- **Multi-shaft turbines**

According to the method of governing:

- **Turbines with throttle governing: In these turbines, fresh steam enter through one or more (depending on the power developed) simultaneously operated throttle valves.**
- **Turbines with nozzle governing: In these turbines, fresh steam enters through one or more consecutively opening regulators.**
- **Turbines with by-pass governing: In these turbines, the steam besides being fed to the first stage is also directly fed to one, two or even three intermediate stages of the turbine.**

CLASSIFICATION OF STEAM TURBINES

According to the heat drop process:

- ***Condensing turbines with generators:*** **In these turbines, steam at a pressure less than the atmospheric is directed to the condenser. The steam is also extracted from intermediate stages for feed water heating). The latent heat of exhaust steam during the process of condensation is completely lost in these turbines.**
- ***Condensing turbines with one or more intermediate stage extractions:*** **In these turbines, the steam is extracted from intermediate stages for industrial heating purposes.**
- ***Back pressure turbines:*** **In these turbines, the exhaust steam is utilized for industrial or heating purposes. Turbines with deteriorated vacuum can also be used in which exhaust steam may be used for heating and process purposes.**

CLASSIFICATION OF STEAM TURBINES

According to the steam conditions at inlet to turbine:

- ***Low pressure turbines:*** **These turbines use steam at a pressure of 1.2 ata to 2 ata.**
- ***Medium pressure turbines:*** **These turbines use steam up to a pressure of 40 ata.**
- ***High pressure turbines:*** **These turbines use steam at a pressure above 40 ata.**
- ***Very high pressure turbines:*** **These turbines use steam at a pressure of 170 at a and higher and temperatures of 550°C and higher.**
- ***Supercritical pressure turbines:*** **These turbines use steam at a pressure of 225 ata and higher.**

CLASSIFICATION OF STEAM TURBINES

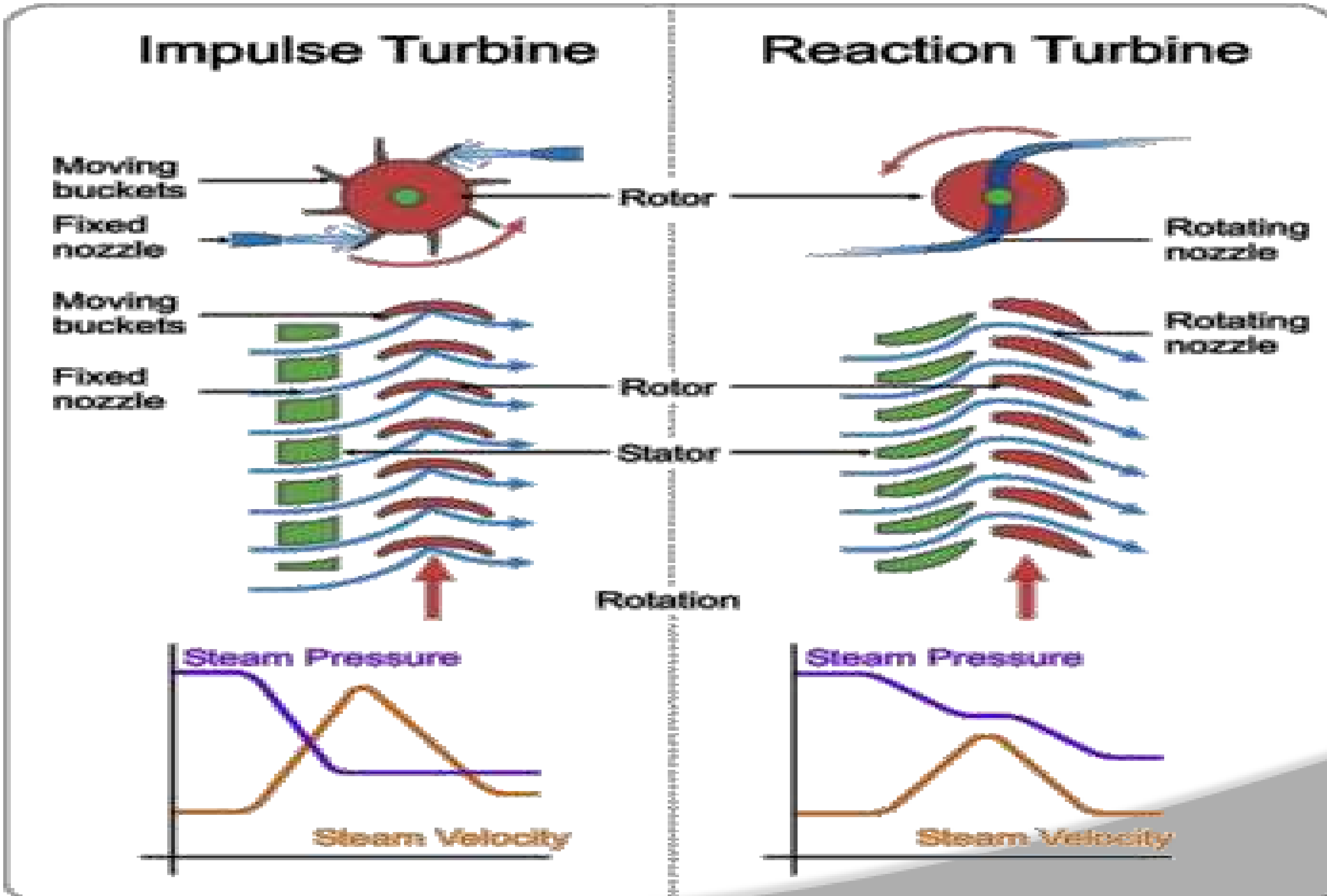
According to their usage in industry:

- ➢**Stationary turbines with constant speed of rotation: These turbines are primarily used for driving alternators.**
- ➢**Stationary turbines with variable speed of rotation: These turbines are meant for driving turbo-blowers, air circulators, pumps, etc.**
- ➢**Non-stationary turbines with variable speed: These turbines are usually employed in steamers, ships and railway locomotives.**

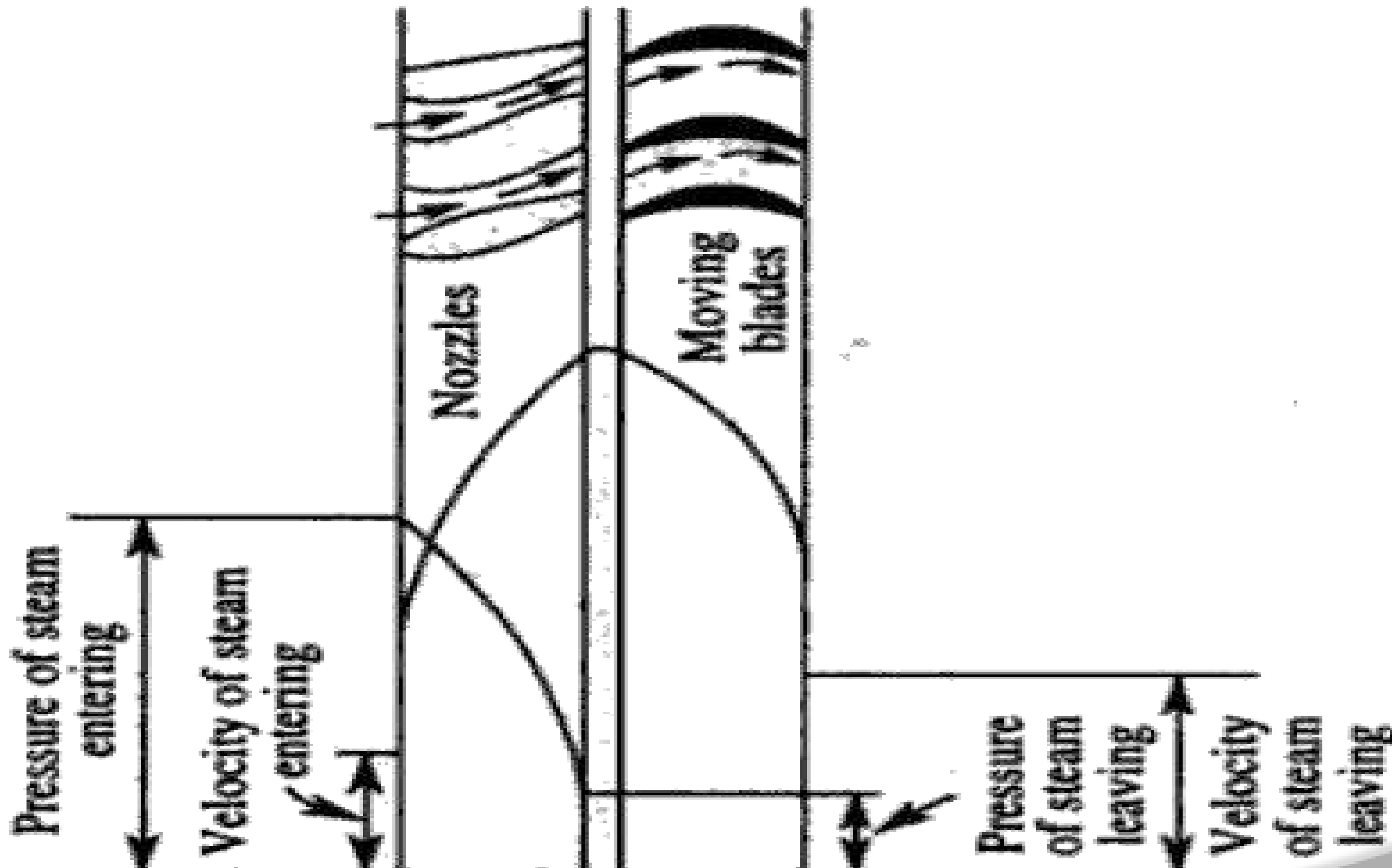
ADVANTAGES OF STEAM TURBINES OVER STEAM ENGINES

1. The thermal efficiency is much higher.
2. As there is no reciprocating parts, perfect balancing is possible and therefore heavy foundation is not required.
3. Higher and greater range of speed is possible.
4. The lubrication is very simple as there are no rubbing parts.
5. The power generation is at uniform rate & hence no flywheel is required.
6. The steam consumption rate is lesser.
7. More compact and require less attention during operation.
8. More suitable for large power plants.
9. Less maintenance cost as construction and operation is highly simplified due to absence of parts like piston, piston rod, cross head, connecting rod.

IMPULSE TURBINE VS REACTION TURBINE



SIMPLE IMPULSE TURBINE



Diagrammatic sketch of a simple impulse turbine

IMPULSE PRINCIPLE

- The outer rim of the rotor carries a set of curved blades, and the whole assembly is enclosed in an airtight case.
- Nozzles direct steam against the blades and turn the rotor. The energy to rotate an impulse turbine is derived from the kinetic energy of the steam flowing through the nozzles.
- The term impulse means that the force that turns the turbine comes from the impact of the steam on the blades.

IMPUSLE PRINCIPLE

- The toy pinwheel can be used to study some of the basic principles of turbines. When we blow on the rim of the wheel, it spins rapidly. The harder we blow, the faster it turns.
- The steam turbine operates on the same principle, except it uses the kinetic energy from the steam as it leaves a steam nozzle rather than air.
- Steam nozzles are located at the turbine inlet. As the steam passes through a steam nozzle, potential energy is converted to kinetic energy.
- This steam is directed towards the turbine blades and turns the rotor.

The velocity of the steam is reduced in passing over the blades.

- Some of its kinetic energy has been transferred to the blades to turn the rotor.

BASICS OF IMPULSE TURBINE

- **In impulse turbine, steam coming out through a fixed nozzle at a very high velocity strikes the blades fixed on the periphery of a rotor.**
- **The blades change the direction of steam flow without changing its pressure.**
- **The force due to change of momentum causes the rotation of the turbine shaft.**
- **Examples: De-Laval, Curtis and Rateau turbines.**

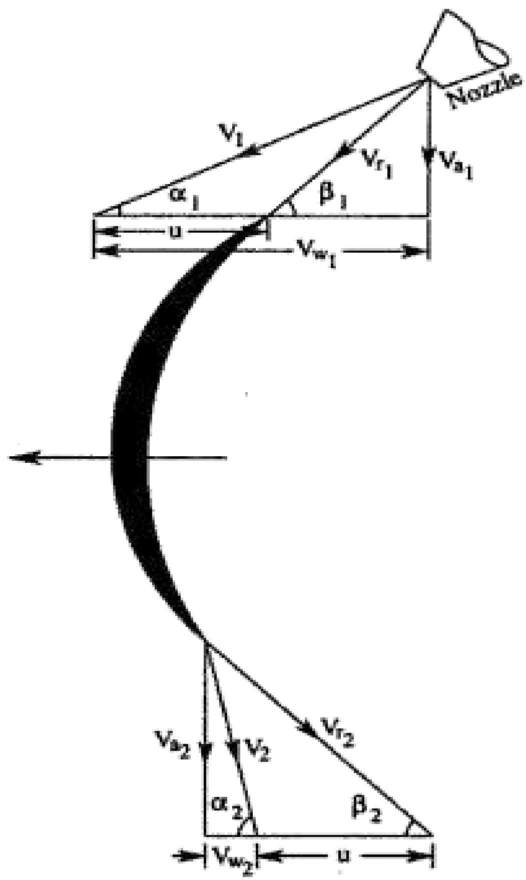
CONSTRUCTION & WORKING PRINCIPLE OF IMPULSE PRINCIPLE

- It primarily consists of a nozzle or a set of nozzles, a rotor mounted on a shaft, one set of moving blades attached to the rotor and a casing.
- A simple impulse turbine is also called De-Laval turbine, after the name of its inventor
- This turbine is called *simple* impulse turbine since the expansion of the steam takes place in one set of nozzles.

DISADVANTAGES OF IMPULSE TURBINE

1. **Since all the KE of the high velocity steam has to be absorbed in only one ring of moving blades, the velocity of the turbine is too high i.e. up to 30000 RPM for practical purposes.**

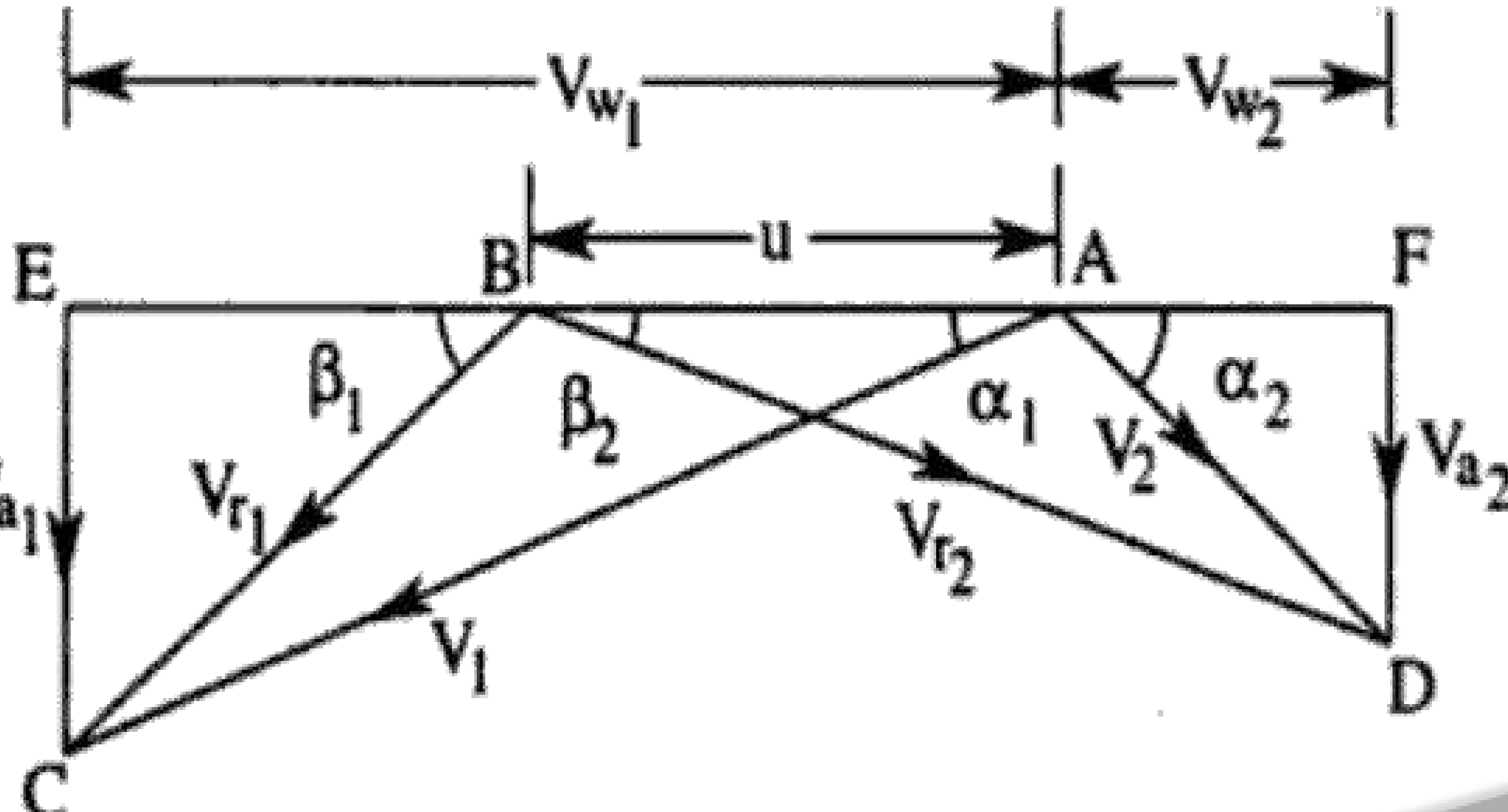
2. **The velocity of the steam at exit is sufficiently high which means that there is a considerable loss of KE.**



INLET VELOCITY TRIANGLE

OUTLET VELOCITY TRIANGLE

COMBINED VELOCITY TRIANGLE



Combined Velocity Triangle

METHODS OF REDUCING ROTOR SPEED (COMPOUNDING OF TURBINES)

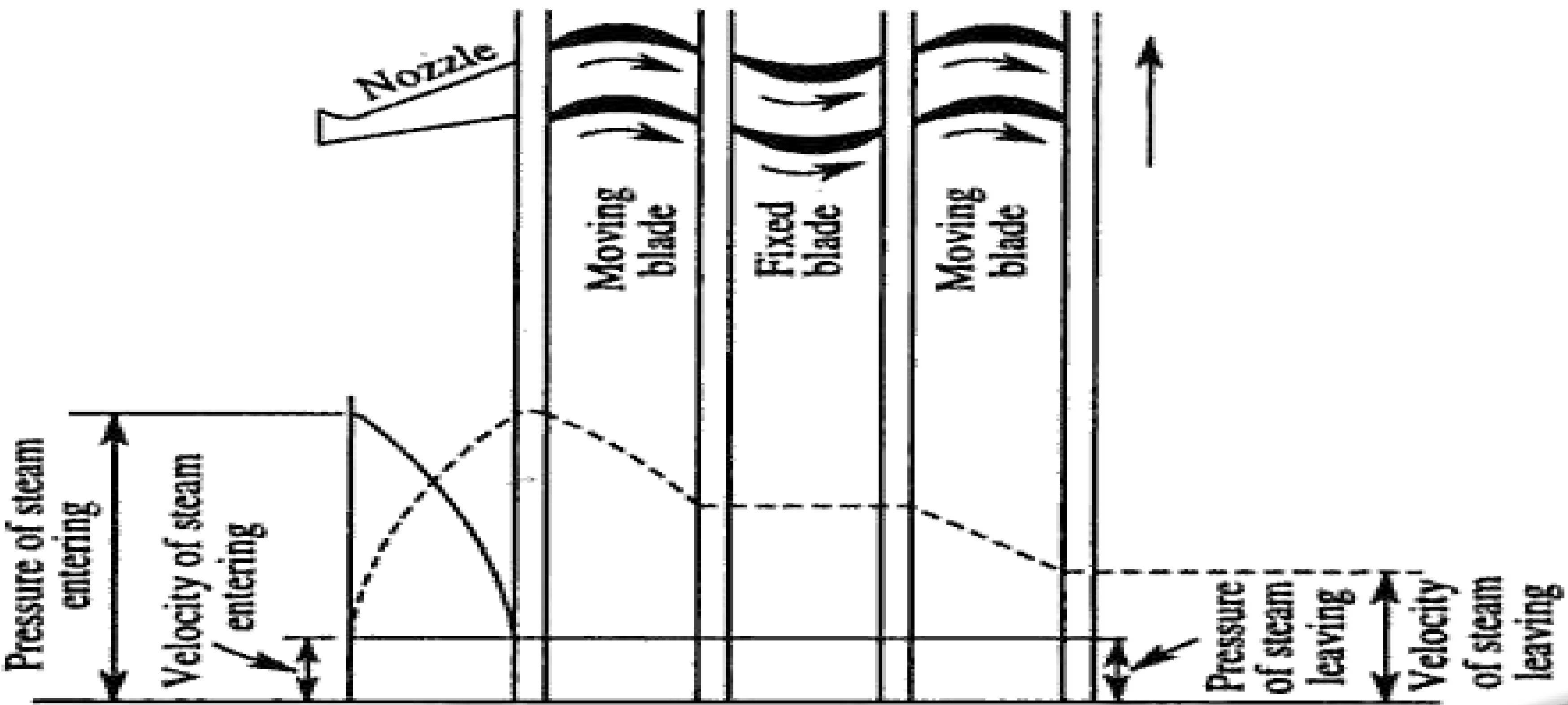
- If high velocity of steam is allowed to flow through one row of moving blades, it produces a rotor speed of about 30000 rpm which is too high for practical use.
- It is therefore essential to incorporate some improvements for practical use and also to achieve high performance.
- This is possible by making use of more than one set of nozzles,

and rotors, in a series, keyed to the shaft so that either the steam pressure or the jet velocity is absorbed by the turbine in stages.

This is called *compounding of turbines*.

- The high rotational speed of the turbine can be reduced by the following methods of compounding:
    1) Velocity compounding
    2) Pressure compounding, and
    3) Pressure-Velocity compounding

METHODS OF REDUCING ROTOR SPEED (VELOCITY COMPOUNDING)

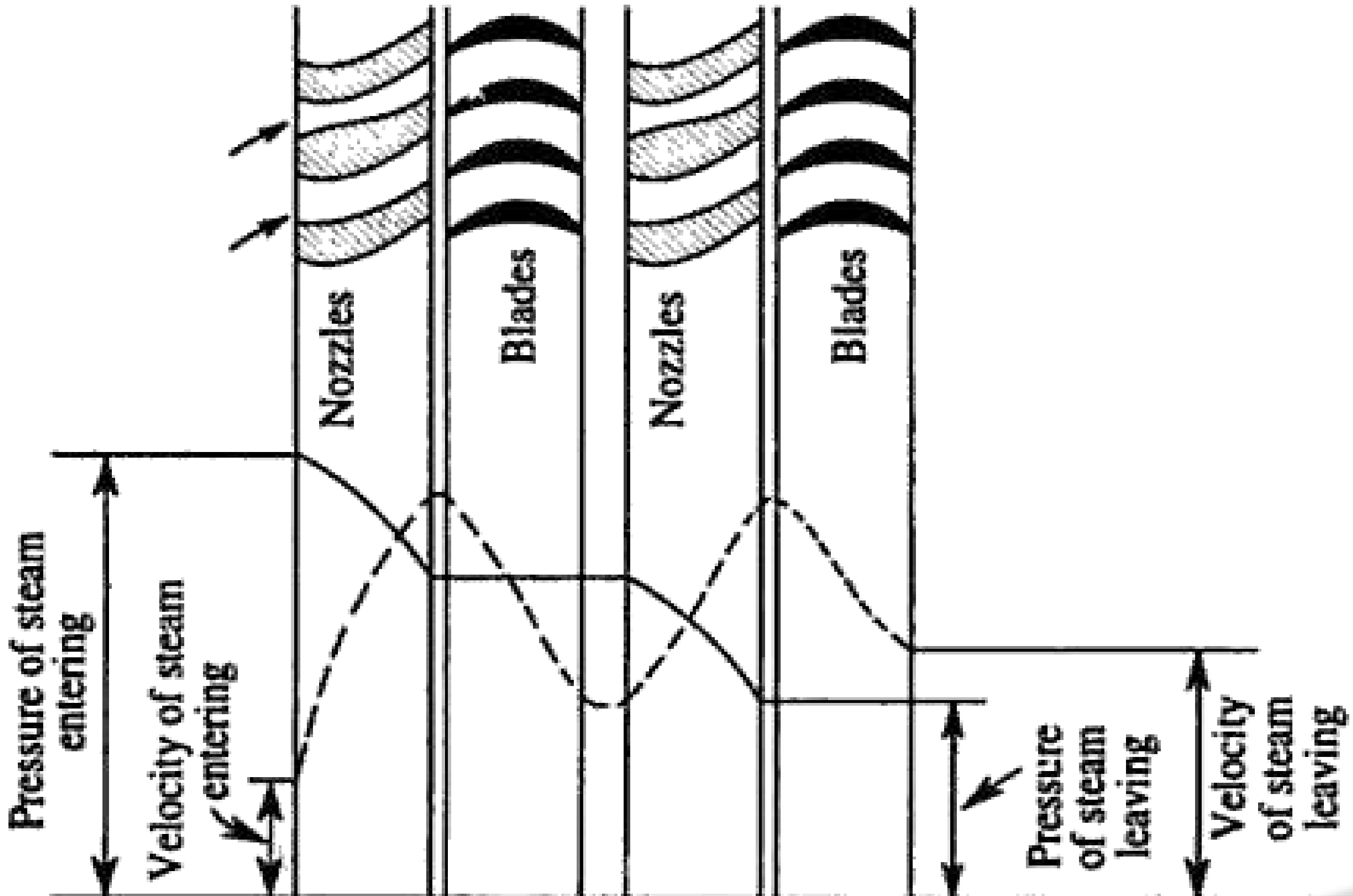


Velocity compounding

METHODS OF REDUCING ROTOR SPEED (VELOCITY COMPOUNDING)

- It consists of a set of nozzles and a few rows of moving blades which are fixed to the shaft and rows of fixed blades which are attached to the casing.
- As shown in figure, the two rows of moving blades are separated by a row of fixed blades.
- The high velocity steam first enters the first row of moving blades, where some portion of the velocity is absorbed.
- Then it enters the ring of fixed blades where the direction of steam is changed to suit the second ring of moving blades. There is no change in the velocity as the steam passes over the fixed blades.

METHODS OF REDUCING ROTOR SPEED (PRESSURE COMPOUNDING)



Pressure Compounding

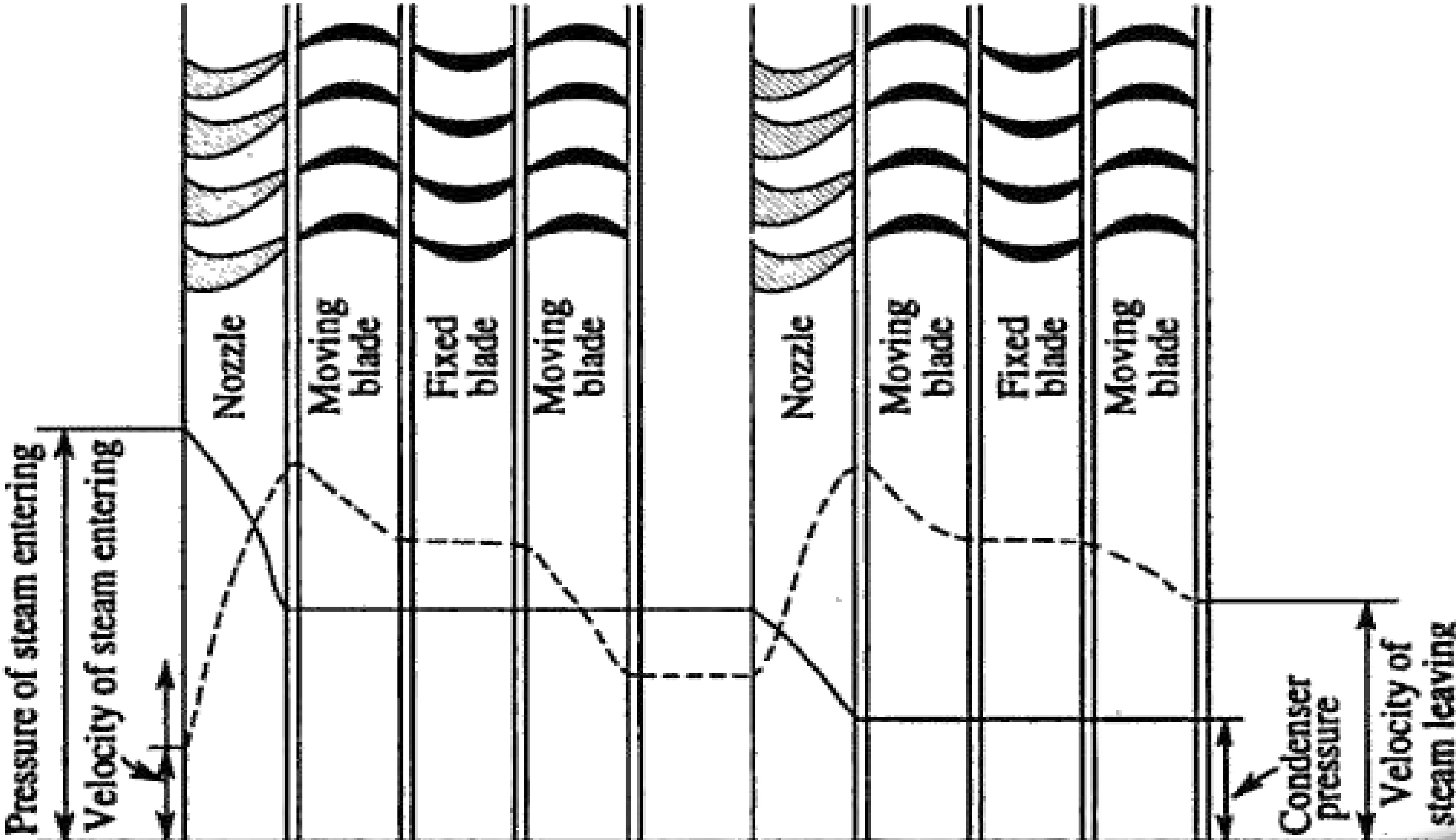
METHODS OF REDUCING ROTOR SPEED

- It consists of a number of fixed nozzles which are incorporated between the rings of moving blades. The moving blades are keyed to the shaft.
- Herethe pressure drop is done in a number of stages. Each stage consists of a set of nozzles and a ring of moving blades.
- Steam from the boiler passes through the first set of nozzles where it expands partially. Nearly all its velocity is absorbed when it passes over the first set of moving blades.
- It is further passed to the second set of fixed nozzles where it is partially expanded again and through the second set of moving blades where the velocity of steam is almost absorbed. This process is repeated till steam leaves at condenser pressure.

METHODS OF REDUCING ROTOR SPEED (PRESSURE-VELOCITY COMPOUNDING)

1)In this method of compounding, both pressure and velocity compounding methods are utilized.
2)The total drop in steam pressure is carried out in two stages and the velocity obtained in each stage is also compounded.
3)The ring of nozzles are fixed at the beginning of each stage and pressure remains constant during each stage.
4)Thismethod ofcompounding is used in *Curtis*
and *More* turbines.

METHODS OF REDUCING ROTOR SPEED *(PRESSURE-VELOCITY COMPOUNDING)*

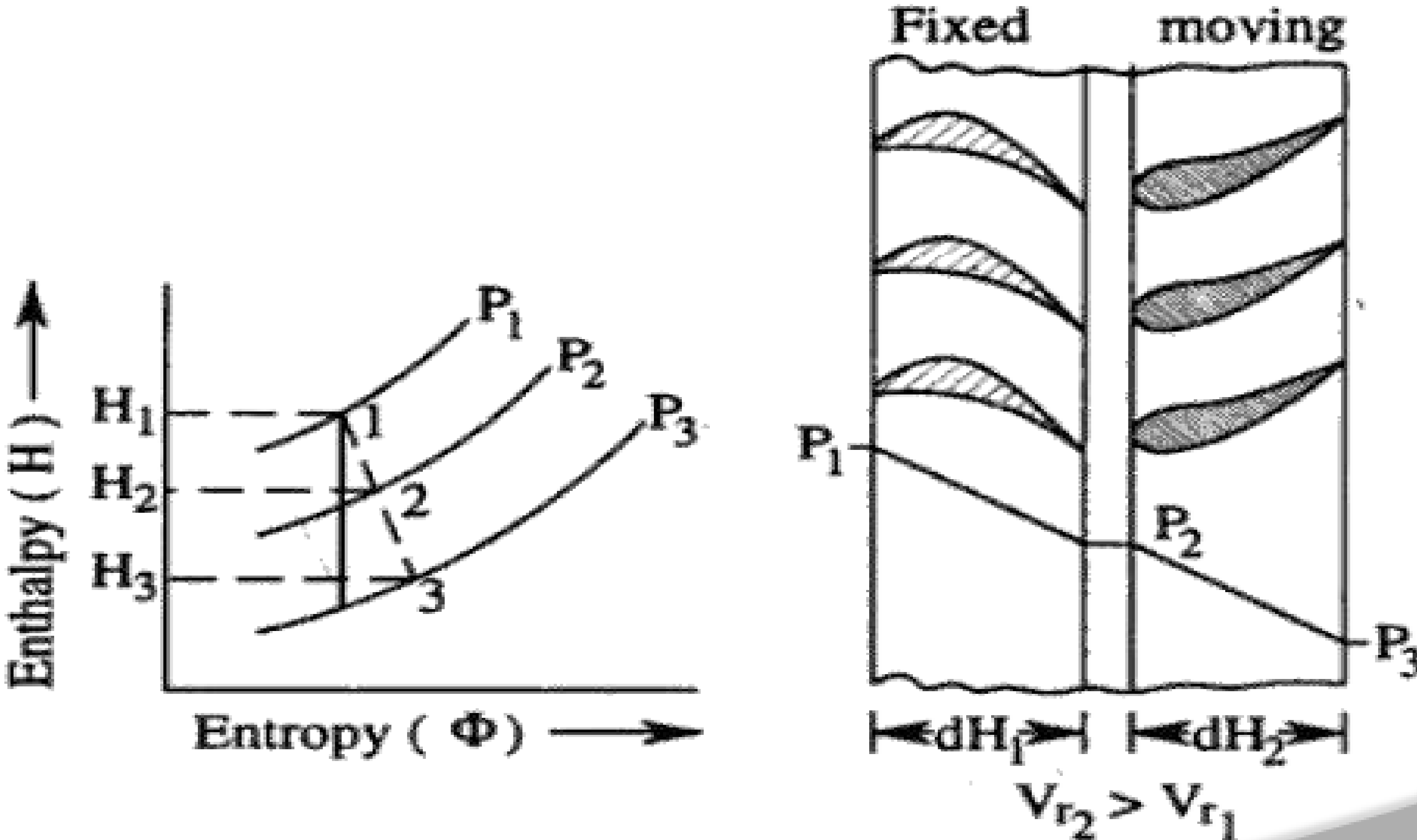


Pressure-Velocity Compounding

REACTION TURBINE

- A turbine in which steam pressure decreases gradually while expanding through the moving blades as well as the fixed blades is known as *reaction turbine.*
- It consists of a large number of stages, each stage consisting of set of fixed and moving blades. The heat drop takes place throughout in both fixed and moving blades.
- No nozzles are provided in a reaction turbine. The fixed blades act both as nozzles in which velocity of steam increased and direct the steam to enter the ring of moving blades. As pressure drop takes place both in the fixed and moving blades, all the blades are nozzle shaped.
- The steam expands while flowing over the moving blades and thus gives reaction to the moving blades. Hence the turbine is called *reaction turbine*.

REACTION TURBINE

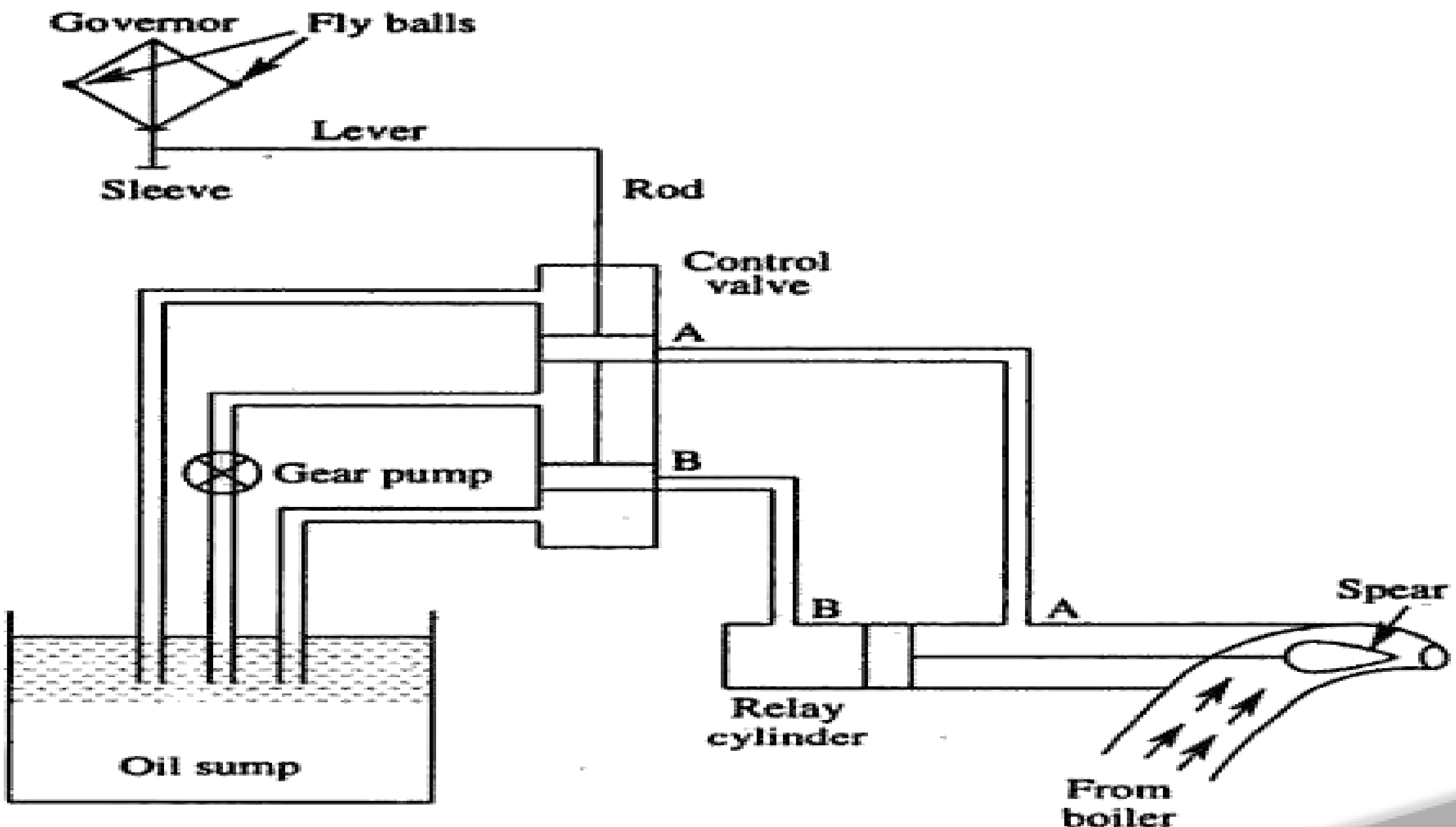


Isentropic expansion in Reaction Turbine

GOVERNING OF TURBINES

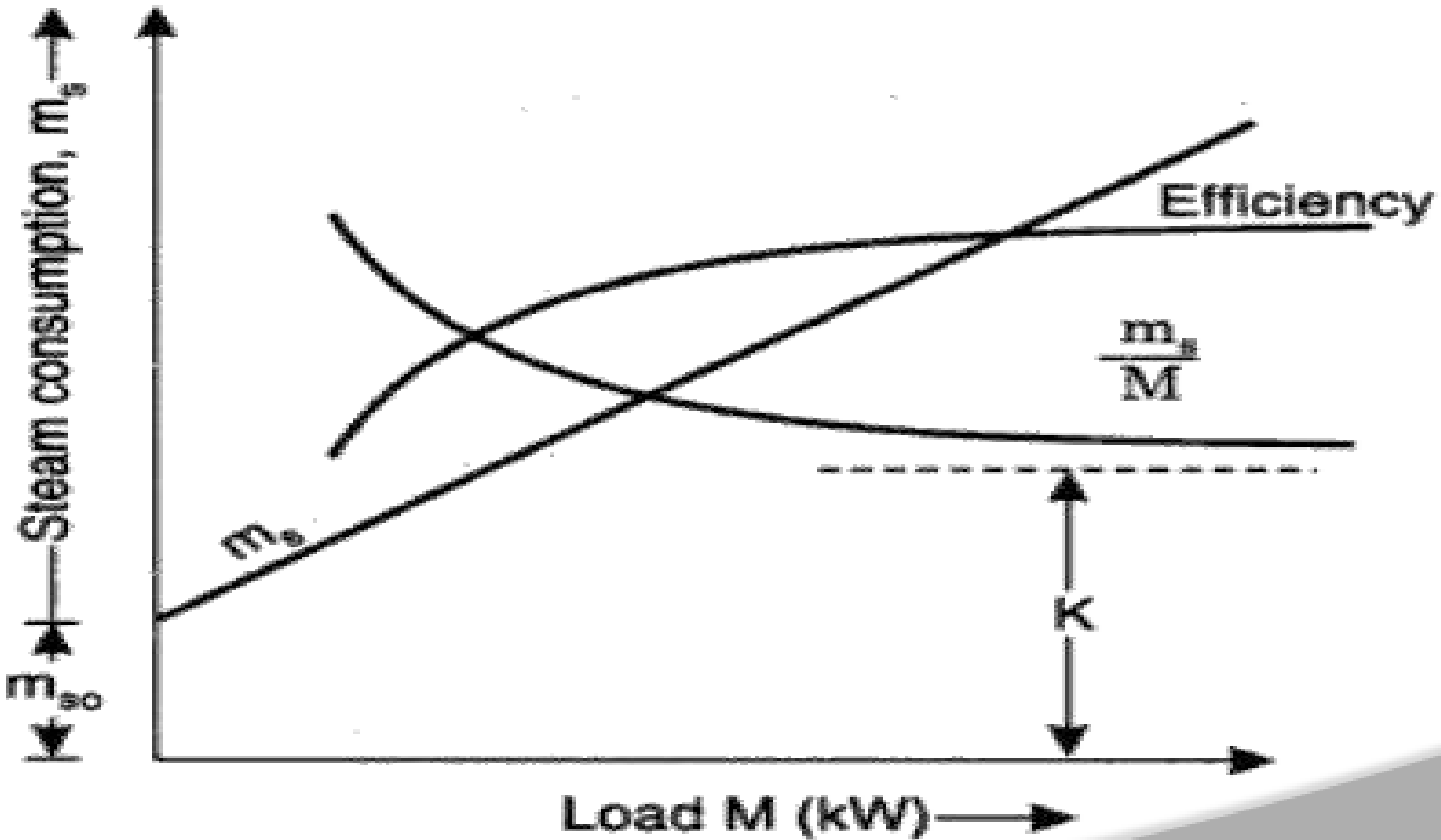
- ***Governing*** **is the method of maintaining the speed of the turbine constant irrespective of variation of the load on the turbine.**
- **A *governor* is used for achieving this purpose which regulates the supply of steam to the turbine in such a way that the speed of the turbine is maintained as far as possible a constant under varying load conditions.**
- **The various methods of governing of steam turbines are:**
  1) **Throttle governing**
  2) **Nozzle governing**
  3) **By-pass governing**
  4) **Combination of (1) & (2) or (2) & (3)**

GOVERNING OF TURBINES (THROTTLE GOVERNING)



Throttle Governing

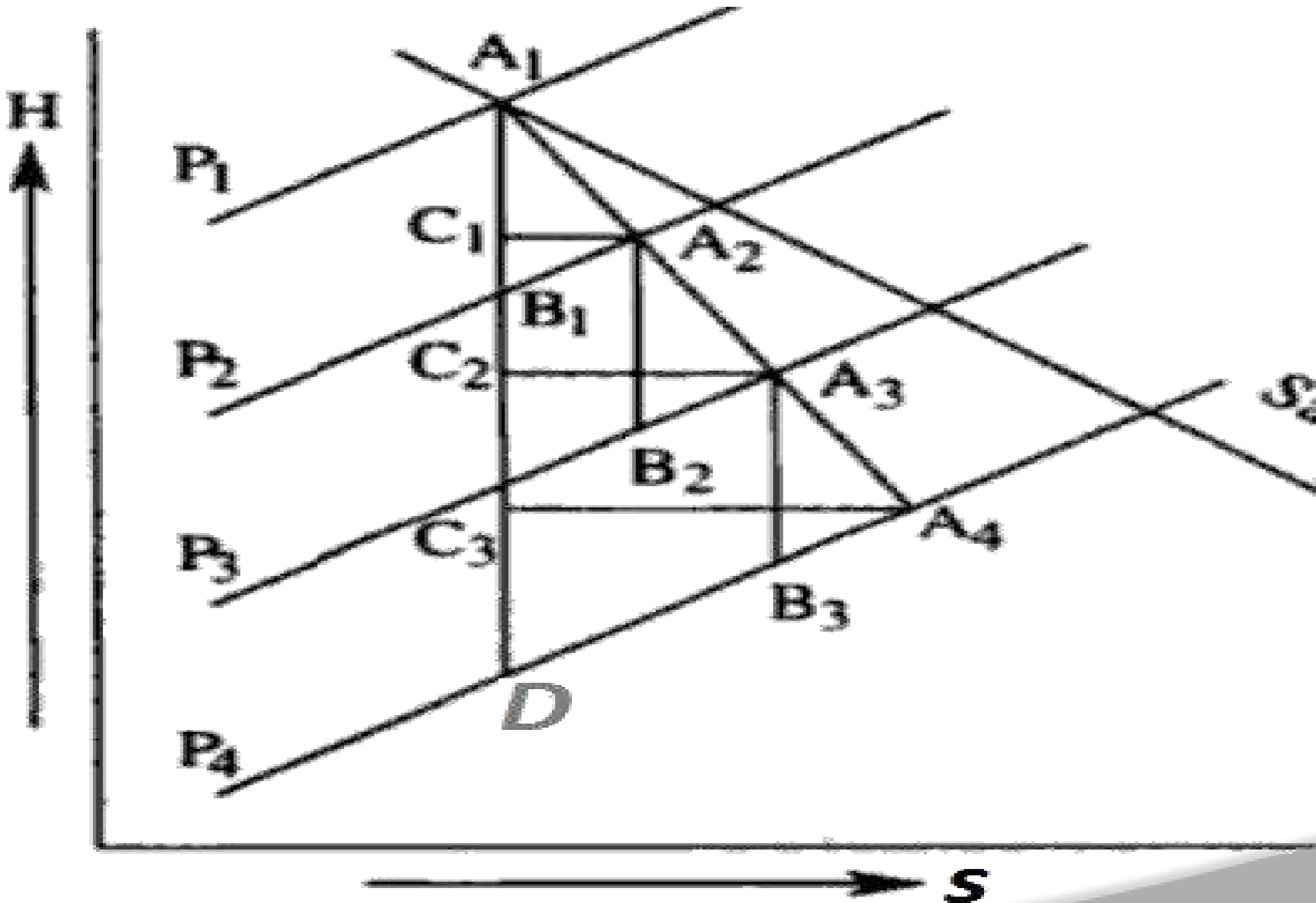
WILLIAN'S LINE



LOSSES IN STEAM TURBINES

- Residual velocity loss
- Losses in regulating valves
- Loss due to steam friction in nozzle
- Loss due to leakage
- Loss due to mechanical friction
- Loss due to wetness of steam
- Radiation loss

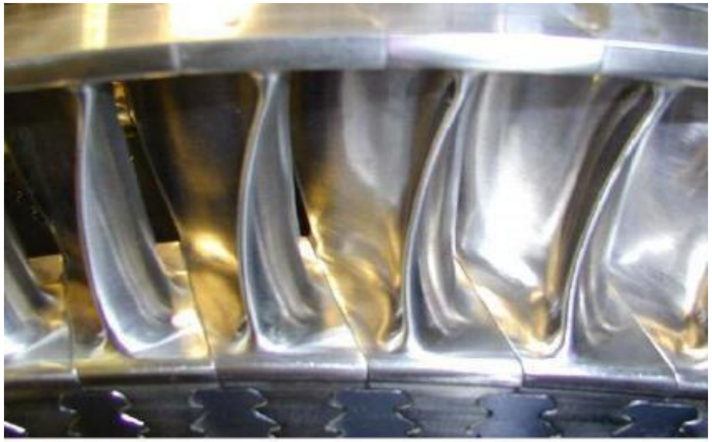
EFFECT OF BLADE FRICTION IN *STEAM TURBINES*



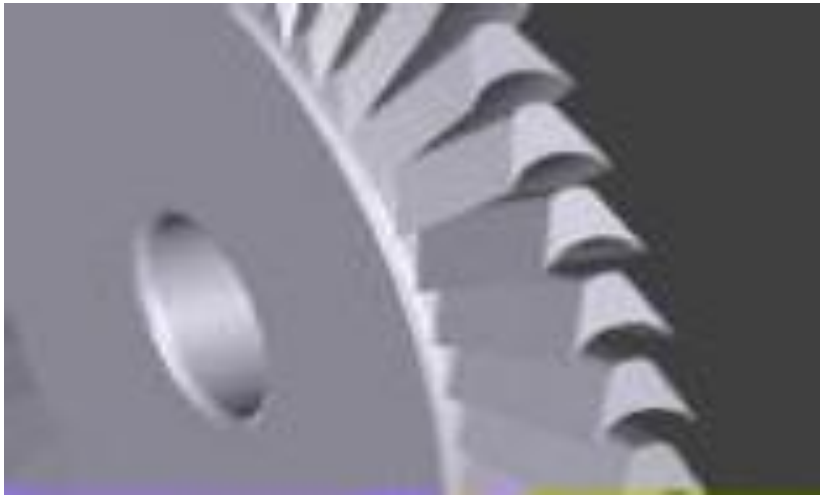
Theories of operations of turbines

A flowing or working fluid contains kinetic as well as potential energy and the fluid may be compressible as well as incompressible. The energy of these fluids is trapped by turbines in several ways.

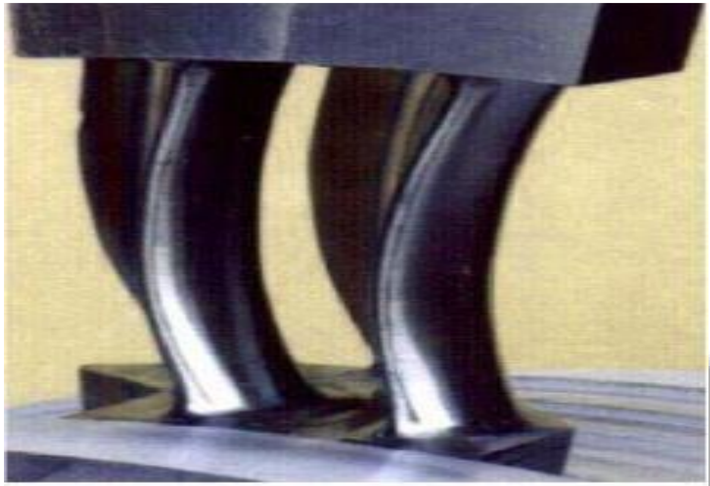
IMPULSE TURBINE BLADE



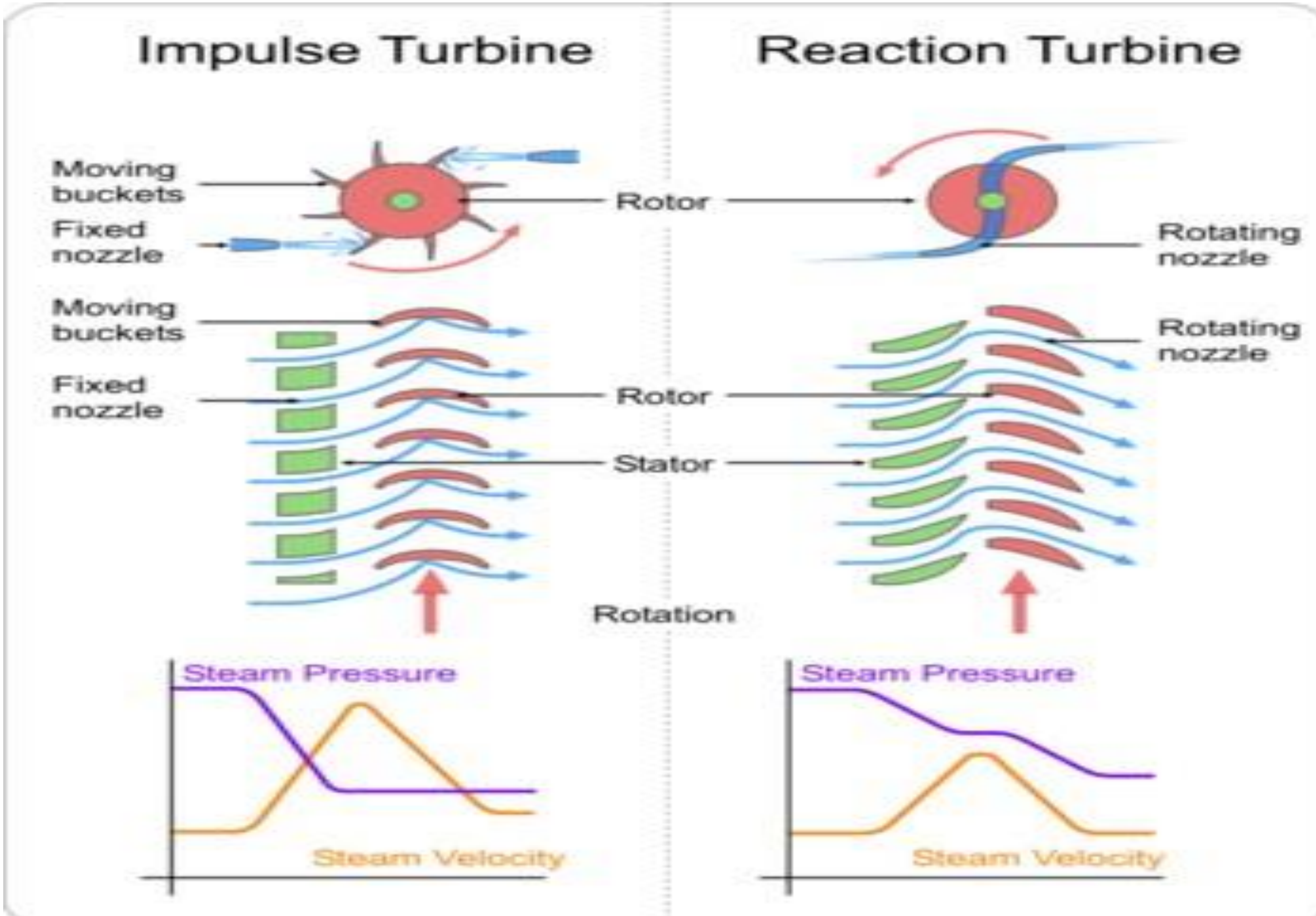
Rotating Blade



REACTION TURBINE BLADE



Stationary blade



Impulse Turbine
Reaction Turbine
Moving buckets
Fixed nozzle
Rotor
Rotating nozzle
Moving buckets
Fixed nozzle
Rotor
Stator
Rotating nozzle
Rotation
Steam Pressure
Steam Velocity
Steam Pressure
Steam Velocity

Reaction turbines-

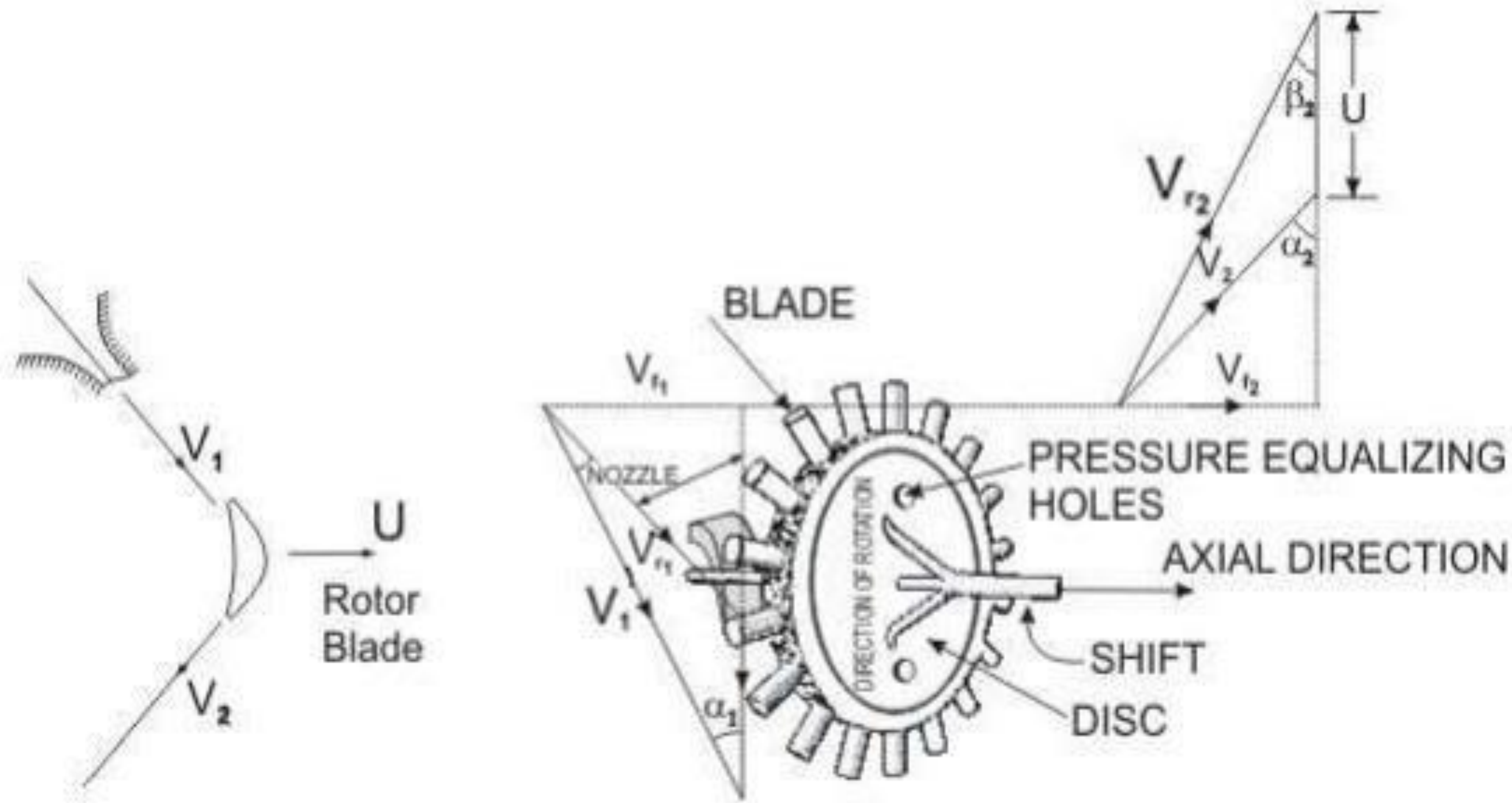
A torque is developed in these turbines when they react to the gas or the fluid pressure or the mass. When the gas or fluid passes through the turbine rotor blades, the pressures in the system changes. The turbine must be fully immersed in the flowing fluid and the pressure casement is also provided for a working fluid. The primary function of the working fluid is to contain and direct the working fluid. It also maintains the functions imparted by the draft tubes in water turbines.

This concept is used in most steam turbines including the Francis turbine. Newton's third law is used to describe the transfer of energy in reaction turbines.

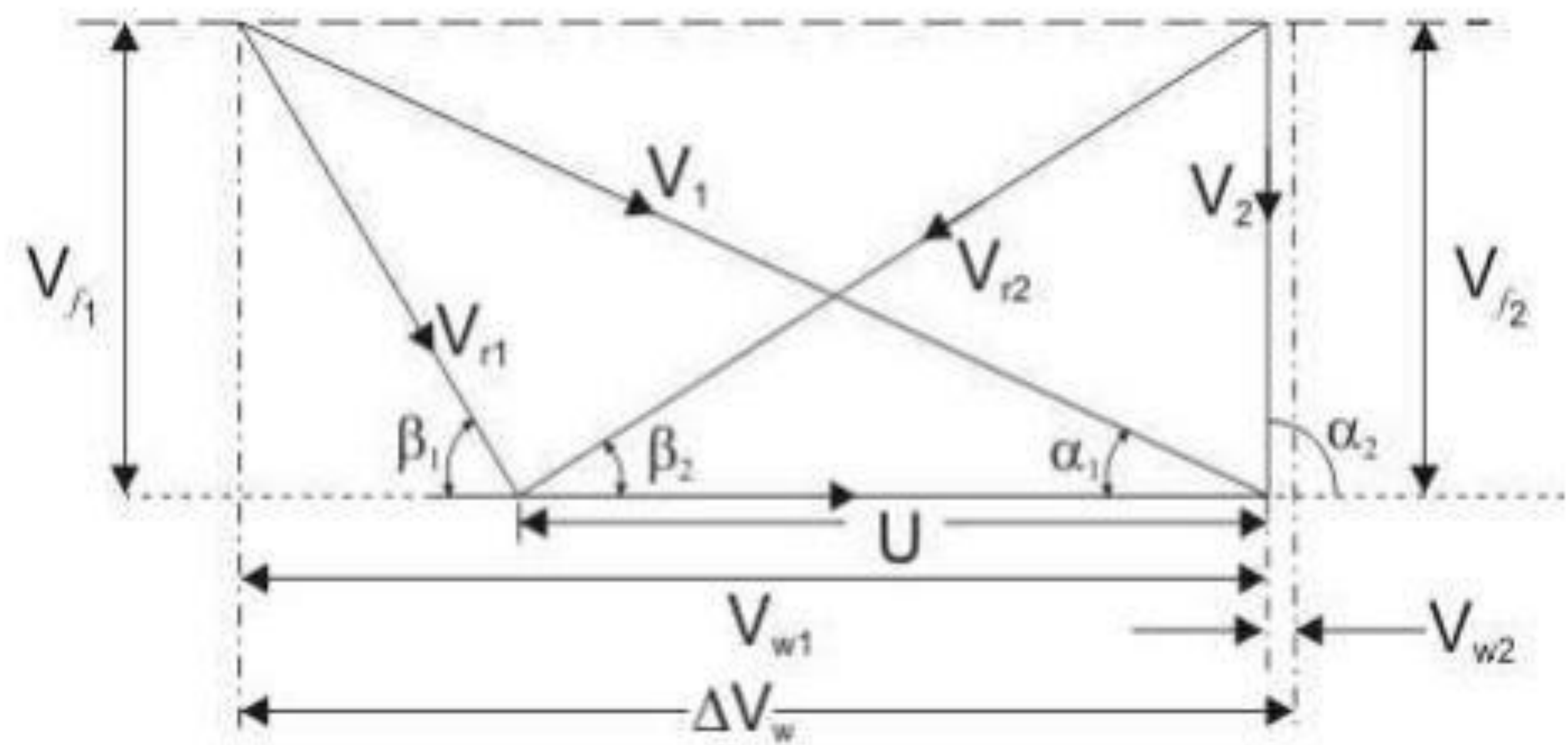
CLASSIFICATIONS OF TURBINES

1.Steam turbine
2.Gas turbine
3.Transonic turbine
4.Contra Rotating Turbine 5.Ceramic Turbine
6.Shrounded Turbine
7.Bladeless turbine
8. Wind turbine
9.Water Turbine

Schematic diagram of an Impulse Turbine



Velocity diagram of an Impulse Turbine



Compounding in Impulse Turbine

If high velocity of steam is allowed to flow through one row of moving blades, it produces a rotor speed of about 30000 rpm which is too high for practical use.

It is essential to incorporate some improvements for practical use and also to achieve high performance.

This is called compounding.

Two types of compounding can be accomplished: (a) velocity compounding and (b) pressure compounding

Compounding in Steam Turbine

The compounding is the way of reducing the wheel or rotor speed of the turbine to optimum value.

Different methods of compounding are:

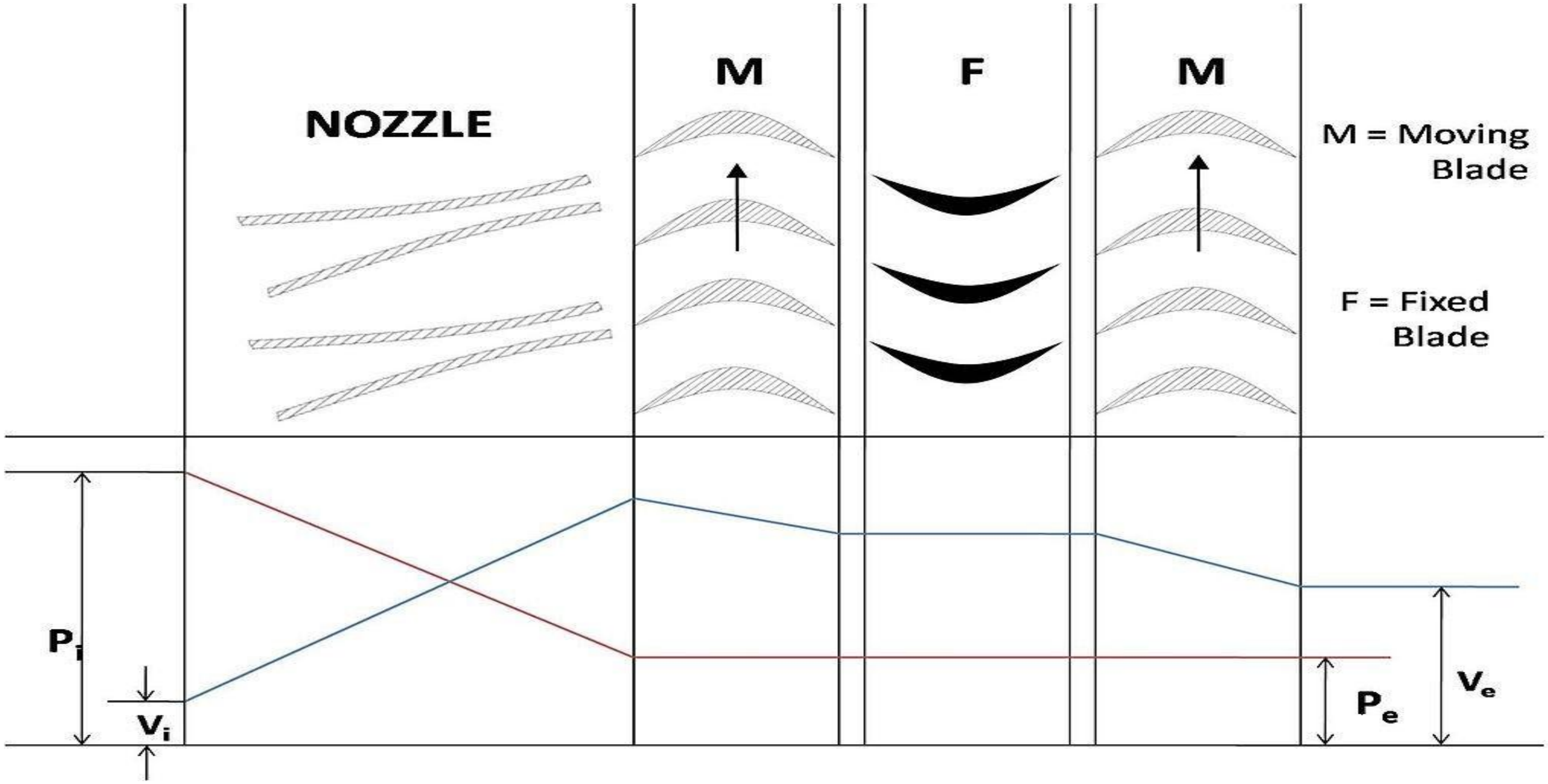
1.Velocity Compounding
2.Pressure Compounding
3.Pressure Velocity Compounding.

In a Reaction turbine compounding can be achieved only by Pressure compounding.

Velocity Compounding

There are number of moving blades separated by rings of fixed blades as shown in the figure. All the moving blades are keyed on a common shaft. When the steam passed through the nozzles where it is expanded to condenser pressure. It's Velocity becomes very high. This high velocity steam then passes through a series of moving and fixed blades. When the steam passes over the moving blades it's velocity decreases. The function of the fixed blades is to re-direct the steam flow without altering it's velocity to the following next row moving blades where a work is done on them and steam leaves the turbine with allow velocity as shown in diagram.

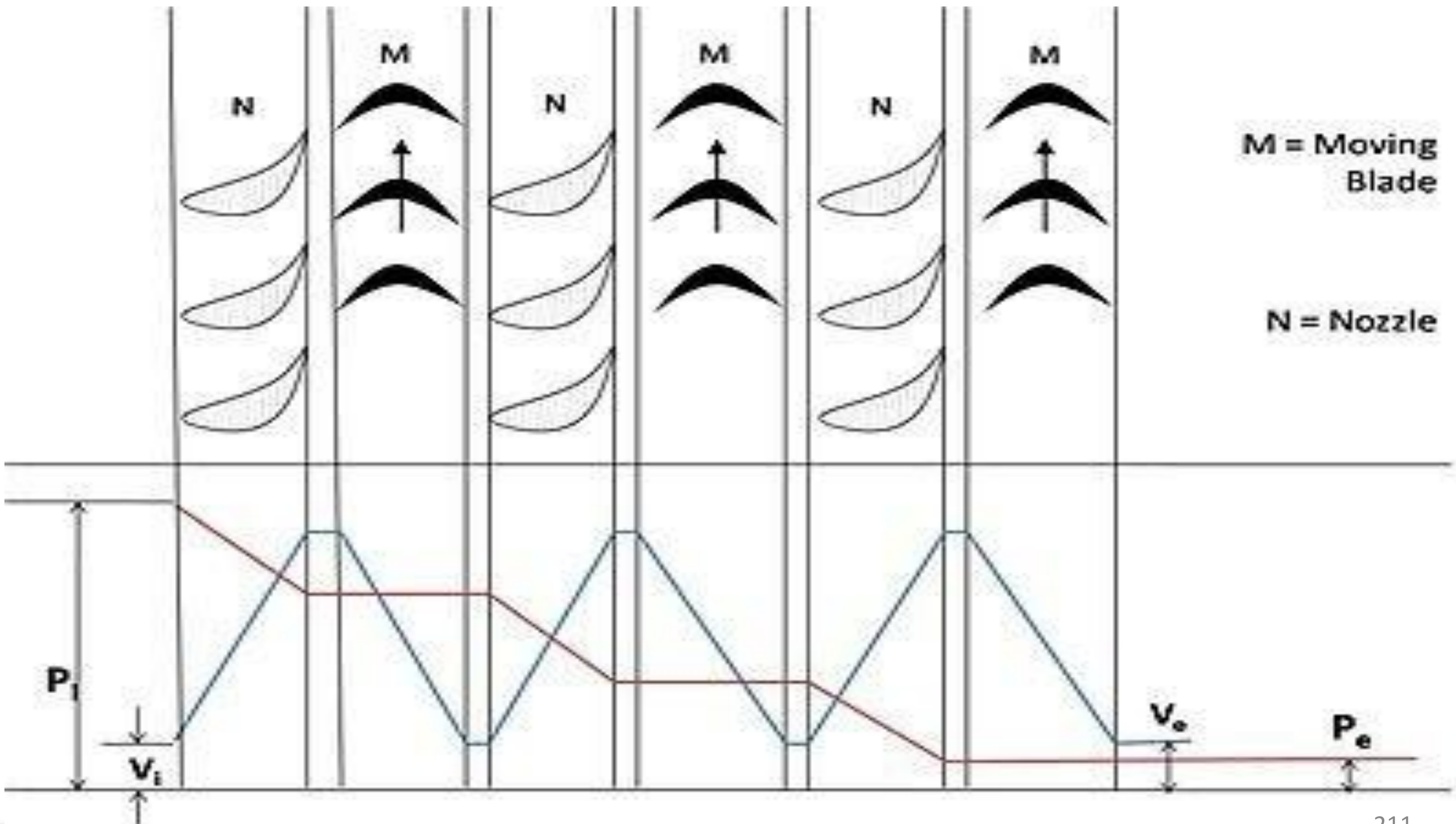
Velocity Compounding



Pressure Compounding

- These are the rings of moving blades which are keyed on a same shaft in series, are separated by the rings of fixed nozzles.
- The steam at boiler pressure enters the first set of nozzles and expanded partially. The kinetic energy of the steam thus obtained is absorbed by moving blades.
- The steam is then expanded partially in second set of nozzles where it's pressure again falls and the velocity increase the kinetic energy so obtained is absorbed by second ring of moving blades.

Pressure Compounding



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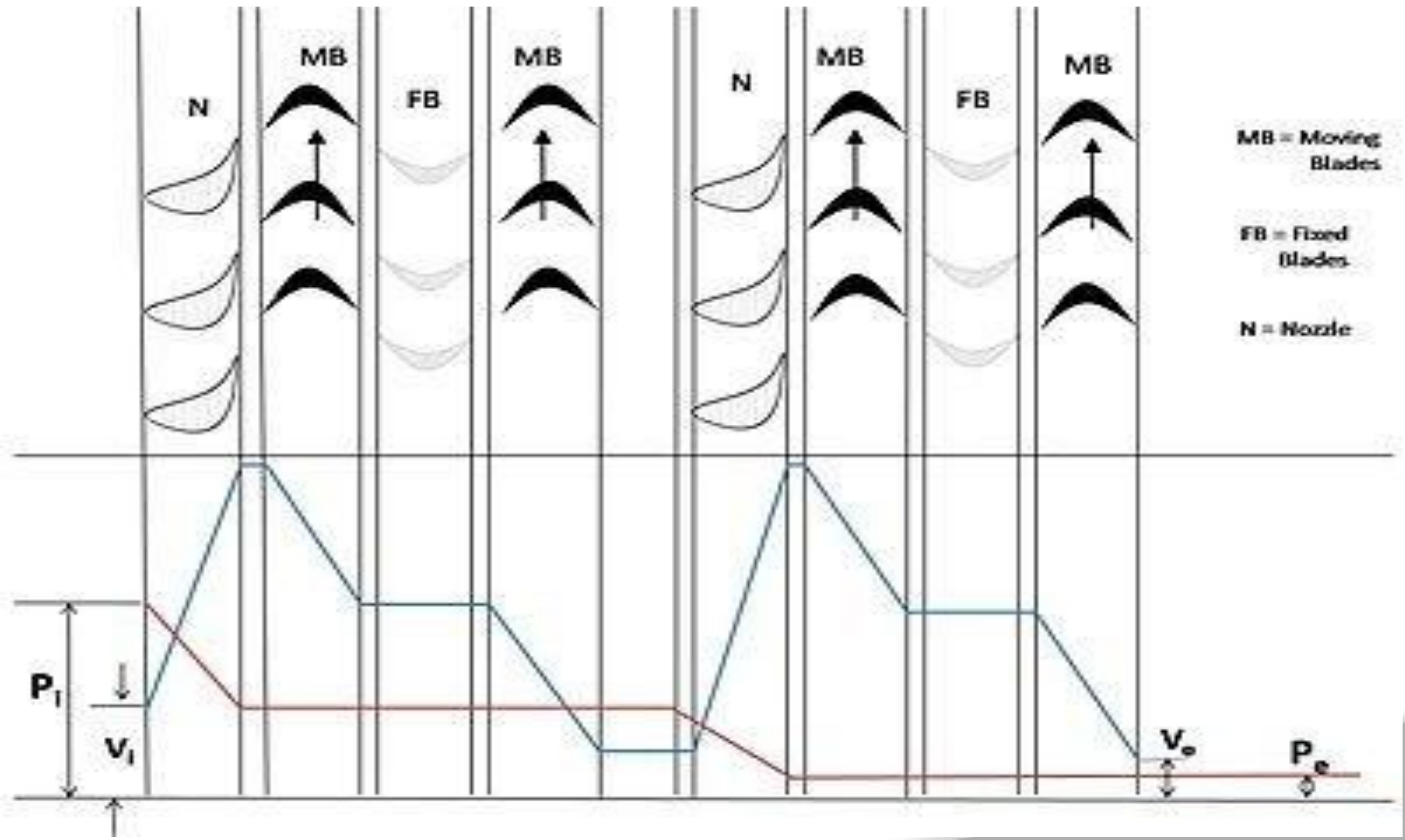
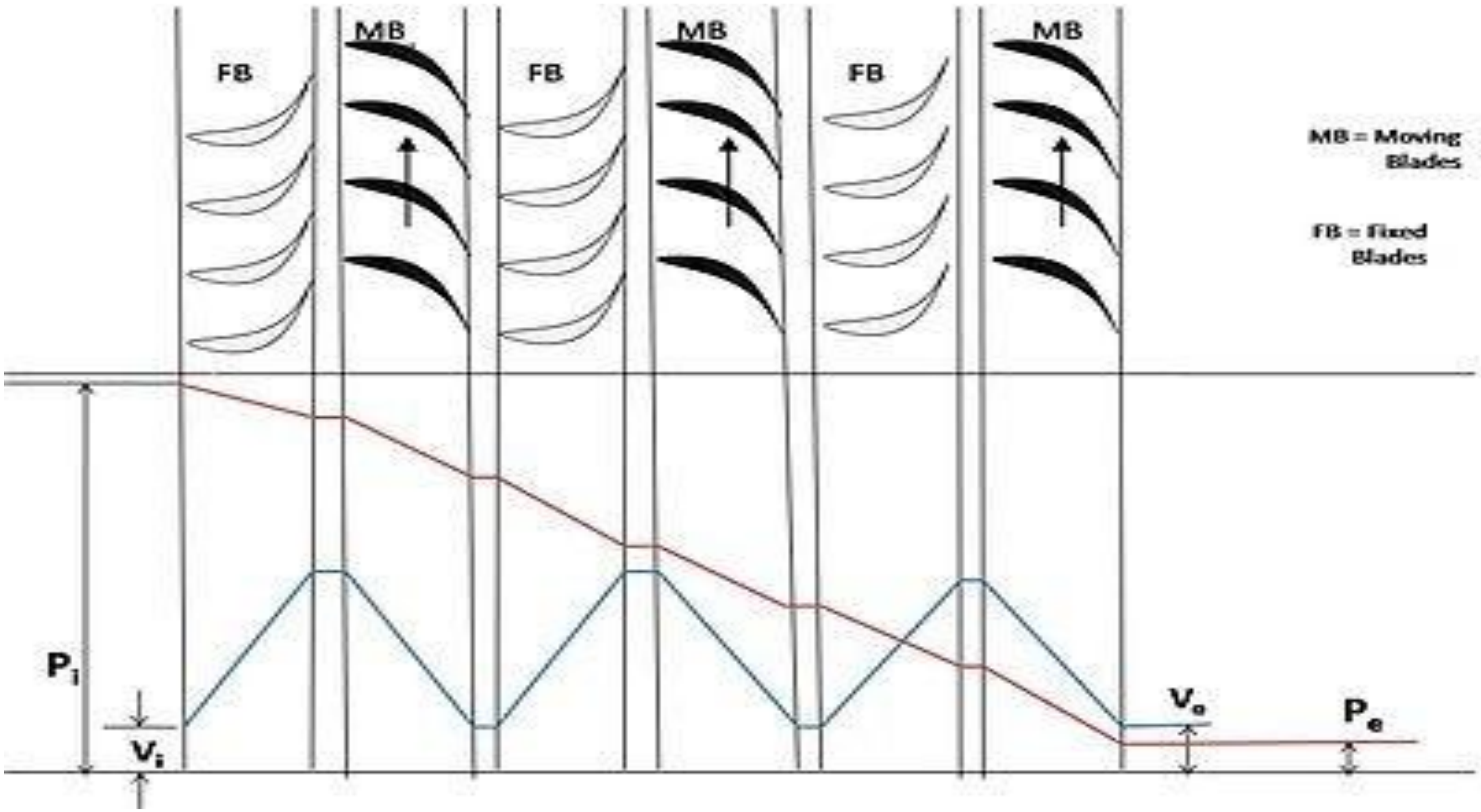
Pressure velocity compounding

This method of compounding is the combination of two previously discussed methods. The total drop in steam pressure is divided into stages and the velocity obtained in each stage is also compounded. The rings of nozzles are fixed at the beginning of each stage and pressure remains constant during each stage as shown in figure. The turbine employing this method of compounding may be said to combine many of the advantages of both pressure and velocity staging By allowing a bigger pressure drop in each stage, less number stages are necessary and hence a shorter turbine will be obtained for a given pressure drop.

PRESSURE-VELOCITY COMPOUNDED



REACTION TURBINE PRESSURE COMPOUNDING



REACTION TURBINE

- A *reaction turbine*, therefore, is one that is constructed of rows of fixed
and rows of moving blades.
- The fixed blades act as nozzles.
- The moving blades move as a result of the impulse of steam received (caused by change in momentum) and also as a result of expansion and acceleration of the steam relative to them.
- The pressure drops will not be equal.
- They are greater for the fixed blades and greater for the high-pressure than the low-pressure stages.
- The absolute steam velocity changes within each stage as shown and repeats from stage to stage

Governing of Steam Turbine

- The method of maintaining the turbine speed constant irrespective of the load is known as governing of turbines. The device used for governing of turbines is called Governor. There are 3 types of governors in steam turbine,
- 1. Throttle governing
- 2. Nozzle governing
- 3. By-pass governing

THROTTLE GOVERNING

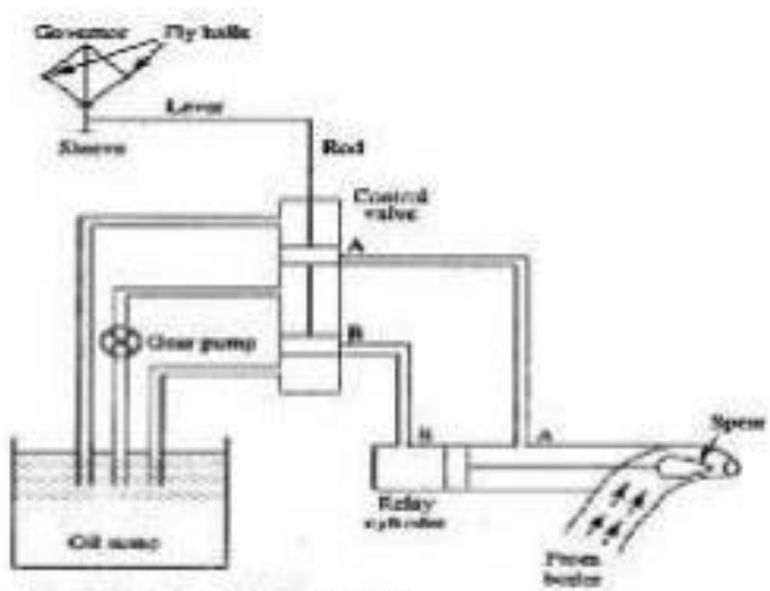


Fig 3.1 Throttle Governing

APPLICATIONS

- Locomotives
- Power generations
- Industrial application for producing steam

UNIT IV
THERMAL ENGINEERING

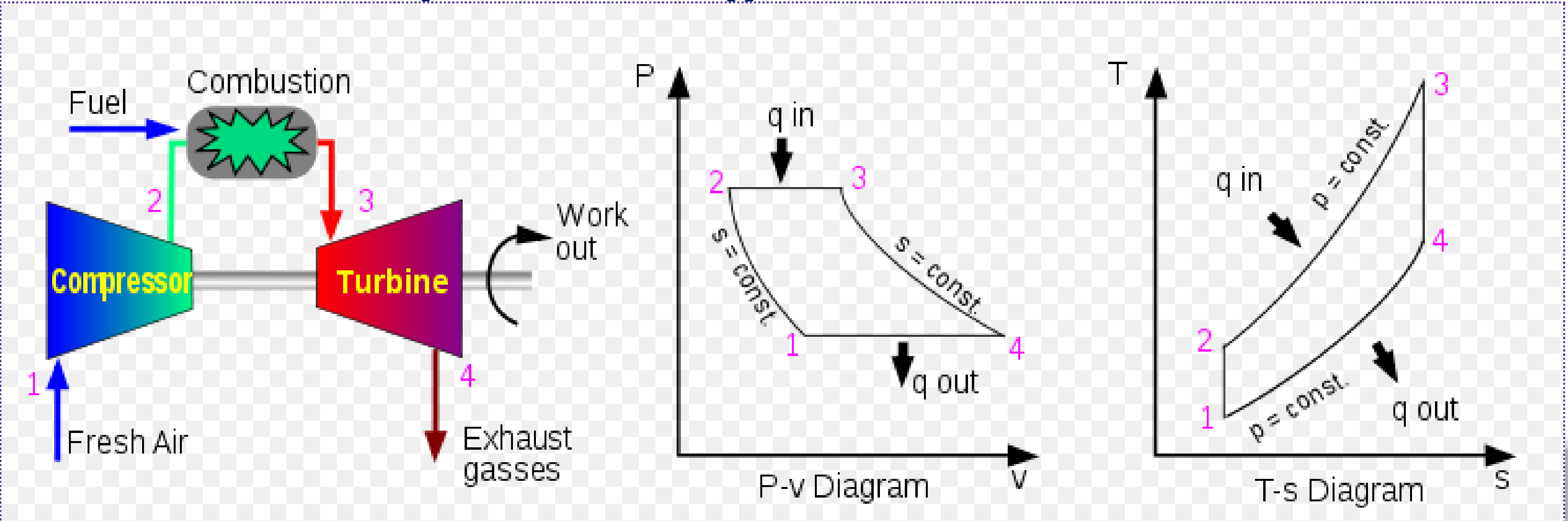
UNIT 4 – Gas Turbines

How they work

- Energy is added to the gas stream
- Combustion increases the temperature, velocity, and volume of the gas flow
- Turbine rotates, powering the compressor
- Energy is then extracted in the form of shaft power, compressed air and thrust

Brayton Cycle

- Gas turbines are described thermodynamically by the Brayton cycle
- In this cycle:
  1. air is compressed isentropically
  2. combustion occurs at constant pressure
  3. heated air expands through the turbine



Idealized Brayton Cycle

Advantages of gas turbine engines

- Very high power-to-weight ratio
- More size efficient
- Moves in one direction only, with fewer moving parts
- Low operating pressures
- High operation speeds
- Low lubricating oil cost and consumption

Disadvantages of gas turbine engines

- More expensive compared to a similar-sized reciprocating engine
- More complex machining operations
- Usually less efficient than reciprocating engines, especially at idle
- Delayed response to changes in power settings

Gas Turbines

- A gas turbine is a machine delivering mechanical power or thrust. It does this using a gaseous working fluid. The mechanical power generated can be used by, for example, an industrial device.
- The outgoing gaseous fluid can be used to generate thrust. In the gas turbine, there is a continuous flow of the working fluid.

Efficiency is 20 to 30% whereas that of steam power plant is 38 To 48% Major Applications of Gas Turbine

1. Aviation(self contained, light weight don't require cooling
2. Power Generation
3. Oil and Gas industry(cheaper supply of fuel and low installation cost)
4. Marine propulsion

Gas Turbine

Hot gases move through a multistage gas turbine.

Like in steam turbine, the gas turbine also has stationary and moving blades.

The stationary blades

- ✓guide the moving gases to the rotor blades
- ✓adjust its velocity.

The shaft of the turbine is coupled to a generator.

WORKING PRINCIPLE

- Air is compressed(squeezed) to high pressure by a compressor.
- Then fuel and compressed air are mixed in a combustion chamber and ignited.
- Hot gases are given off, which spin the turbine wheels.
- Gas turbines burn fuels such as oil, naturalgas and pulverized(powdered) coal.
- Gas turbines have three main parts:

i) Air compressor

ii)Combustion chamber

iii)Turbine

Advantages of Gas turbine power plants.

- Storage of fuel requires less area and handling is easy.
- The cost of maintenance is less.
- It is simple in construction. There is no need for boiler, condenser and other accessories as in the case of steam power plants.
- Cheaper fuel such as kerosene , paraffin, benzene and powdered coal can be used which are cheaper than petrol and diesel.
- Gas turbine plants can be used in water scarcity areas.
- Less pollution and less water is required.

Disadvantages of Gas turbine power plants.

- **Disadvantages of gas turbine power plant**

1. 66% of the power developed is used to drive the compressor. Therefore the gas turbine unit has a low thermal efficiency.
2. The running speed of gas turbine is in the range of (40,000 to 100,000 rpm) and the operating temperature is as high as 1100 – 1260^{0}C. For this reason special metals and alloys have to be used for the various parts of the turbine.
3. High frequency noise from the compressor is objectionable.

PERFORMANCE TERMS

- Pressure Ratio- Ratio of the cycle's highest pressure to its lowest pressure.
- Work Ratio: Ratio of network output to the total work developed in the turbine.
- Air Ratio: kg of air entering the compressor inlet per unit of cycle net output, Kg/kWh
- Compression efficiency: Ratio of work needed for ideal air compressor through a given pressure range to work actually used by the compressor.
- Engine Efficiency: It is the ratio of the work actually developed by the turbine expanding hot power gas through a given pressure range to that would be yeilded for ideal expansion conditions
- Machine Efficiency: Collective term of engine efficiency and compressor efficiency of turbine and compressor.
- Combustion Efficiency: It is the ratio of heat actually released by 1 g of the fuel to heat that would be released by complete perfect combustion.
- Thermal Efficiency: It is the percentage of total energy input appearing as net work output of the cycle.

OPEN CYCLE GAS TURBINE AND ITS CHARACTERISTICS

Gas turbines usually operate on an open cycle

Air at ambient conditions is drawn into the compressor, where its temperature and pressure are raised. The high pressure air proceeds into the combustion chamber, where the fuel is burned at constant pressure. The high-temperature gases then enter the turbine where they expand to atmospheric pressure while producing power output.

Some of the output power is used to drive the compressor.

The exhaust gases leaving the turbine are thrown out (not re-circulated), causing the cycle to be classified as an open cycle

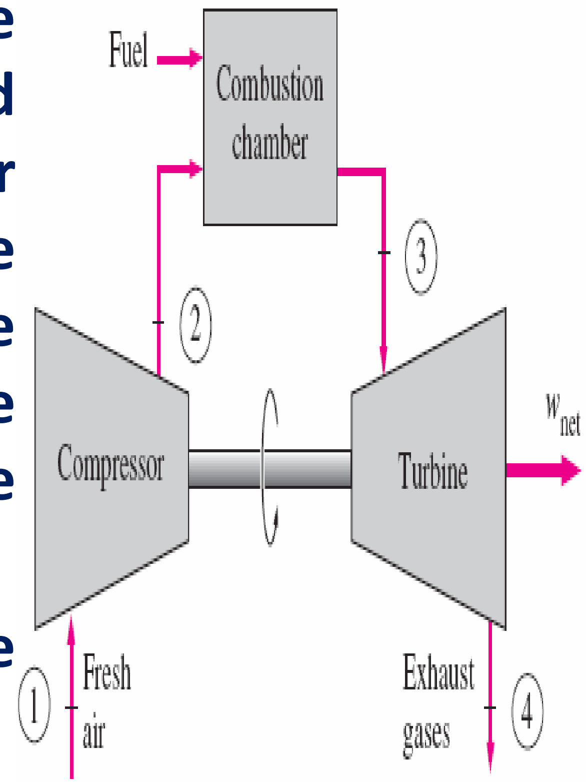


FIGURE 9–29

An open-cycle gas-turbine engine.

Methods of Improvement of Thermal Efficiency of Open Cycle Gas Turbine Plant

1. Regeneration
2. Intercooling
3. Reheating

INTERCOOLING

A compressor utilizes the major percentage of power developed by the gas turbine. The work required by the compressor can be reduced by compressing the air in two stages and incorporation a intercooler between the two.

REHEATING

- The output of gas turbine can be improved by expanding the gasses in two stages with a reheater between the two.
- The H.P. turbine drives the compressor and the LP turbine provides useful power output.

T-S DIAGRAM FOR CLOSED LOOP CYCLE TURBINE

1-2’: Compression

2’-3: C.C (heating)

3’-4’:

Turbine(Expansion)

4’-5:

Reheater(heating) 5-

6’: Turbine(Expansion)

REGENERATION

- The exhaustgasses from the turbine carry a large quantity of heat with them since their temperature is far above the ambient temperature.
- They can be used to heat air coming from the compressor there by reducing the mass of fuel supplied in the combustion chamber.

T-S DIAGRAM FOR OPEN LOOP CYCLE TURBINE

- **2’-3: heat flow into compressed air (heat exchanger)**
- **3-4: heat taken in from combustion fuel.**
- **6:Temp of exhaust gases.**

CLOSED CYCLE GAS TURBINE POWER PLANT AND ITS CHARACTERISTICS

- **The compression and expansion processes remain the same, but the combustion process is replaced by a constant-pressure heat addition process from an external source.**
- **The exhaust process is replaced by a constant- pressure heat rejection process to the ambient air.**

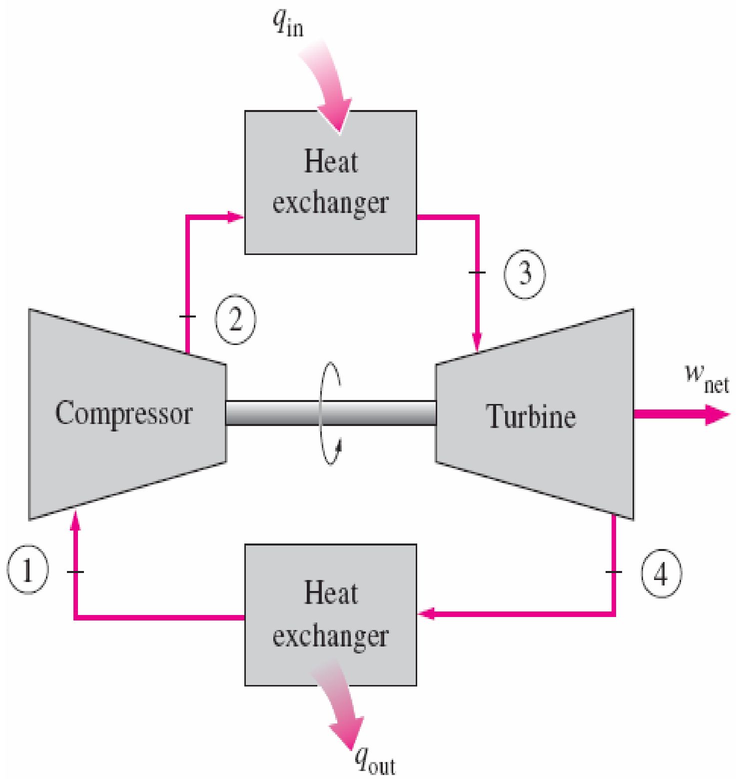


FIGURE 9–30

A closed-cycle gas-turbine engine.

MERITS AND DEMERITS OF CLOSED LOOP CYCLE TURBINE OVER OPEN LOOP CYCLE TURBINE

- Demerits:
- Complexity
- Large amount of cooling water is required.
- Dependent System
- Not economical for moving vehicles as weight
- /kW developed is high.
- Requires the use of very large air heater.

- Merits:
- Higher thermal efficiency
- Reduced size
- No contamination
- Improved heat transmission
- Lesser Fluid friction
- No loss in working medium
- Greater output
- Inexpensive fuel.

COMBINATION OF GASTURBINE CYCLES

- The combination of gas-turbine-steam cycle aims at utilizing the heat of exhaust gases from the gas turbine thus, improve the overall plant efficiency.
- The popular designs are:
- 1. Heating feed water with exhaust gases.
- 2. Employing the gases from a supercharged boiler to expand in the gas turbine.
- 3. Employing the gasses as combustion air in the steam boiler.

COMBINED GAS TURBINE AND DIESEL POWER PLANTS

- The performance of diesel engine can be improved by combining it with exhaust driven gas turbine.

- Three combinations:

1. Turbo charging
2. Gas Generator
3. Compound engine

TURBO CHARGING

- **This method is known as supercharging. The exhaust of the diesel engine is expanded in the gas turbine and the work output of the gas turbine is utilized to run a compressor which supplies the pressurized air to the diesel engine to increase its output.**

STEAM CONDENSERS

DEFINITION

- Condenser is a device in which steam is condensed to water at a pressure less than atmosphere.
- Condensation can be done by removing heat from exhaust steam using circulating cooling water.
- During condensation, the working substance changes its phase from vapour to liquid and rejects latent heat.
- The exhaust pressure in the condenser is maintaned nearly 7 to 8 kpa which corresponds to condensate temperature of nearly 313 kelvin.

Functions of Condenser:

- To reduce the turbine exhaust pressure so as to increase the specific output and hence increase the plant efficiency and decrease the specific steam consumption.
- To condense the exhaust steam from the turbine and reuse it as pure feed water in the boiler. Thus only make up water is required to compensate loss of water
- Enables removal of air and other non condensable gases from steam. Hence improved heat transfer.

ELEMENTS OF CONDENSING PLANT

- Condenser
- Air Extraction Pump
- Condensate Extraction Pump
- Cooling Water Circulating Pump
- Hot Well
- Cooling Tower
- Make up Water Pump
- Boiler Feed Pump

Classification of Condensers:

- According to the type of flow:
  - Parallel flow , Counter flow & Cross flow
- According to the Cooling Action:
  - Jet Condensers:
- Low Level Parallel Flow Jet Condenser
- Low Level Counter Flow Jet Condenser
- High Level Jet Condenser
- Ejector Jet Condenser
  - Surface Condensers:
- Shell and Tube type

1. Down Flow2. Central Flow 3. Inverted Flow

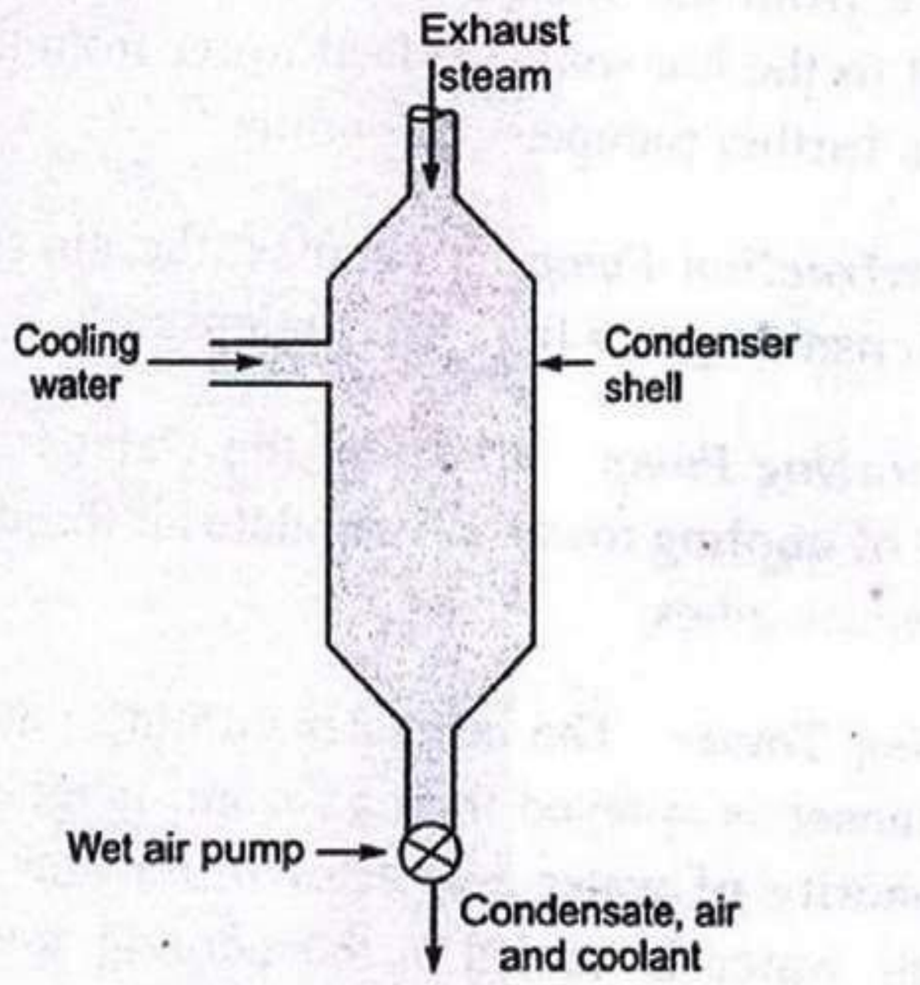
- Evaporative type

JET CONDENSERS

- In jet condensers exhaust steam and cooling water come in direct contact and mix up together. Thus, the final temperature of condensate and cooling water leaving the condenser is same.
- A jet condenser is very simple in design and cheaper.
- It can be used when cooling water is cheaply and easily available.
- Condensate can not be reused in boiler, because it contains impurities like dust, oil, metal particles etc.

LOW LEVEL PARALLEL FLOW JET CONDENSER:

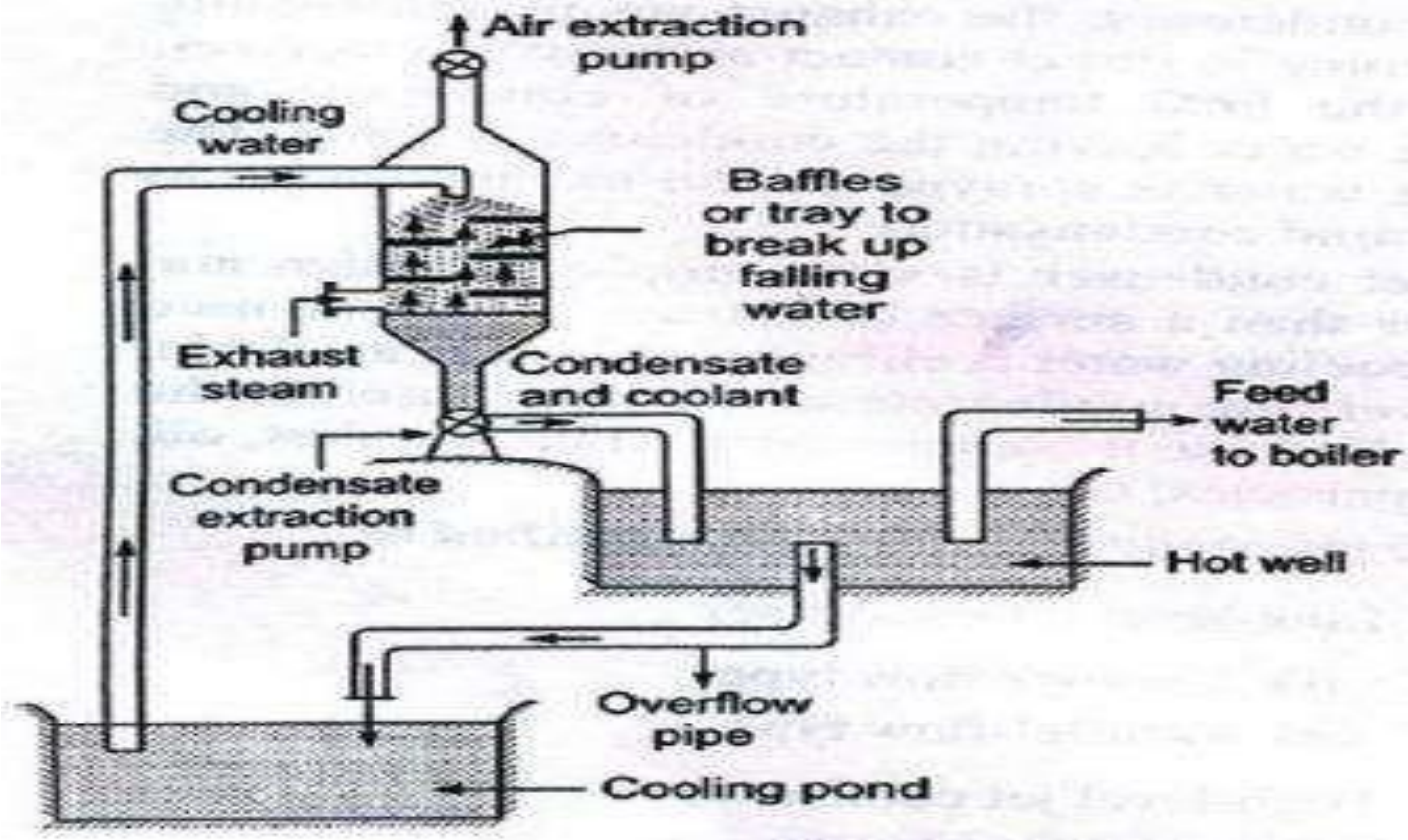
- **Wet air pump is used to extract the mixture of condensate, air & coolant.**
- **Vacuum created is up to 6 kpa.**



Low-level parallel-flow jet condenser

Low Level Counter Flow Jet Condenser:

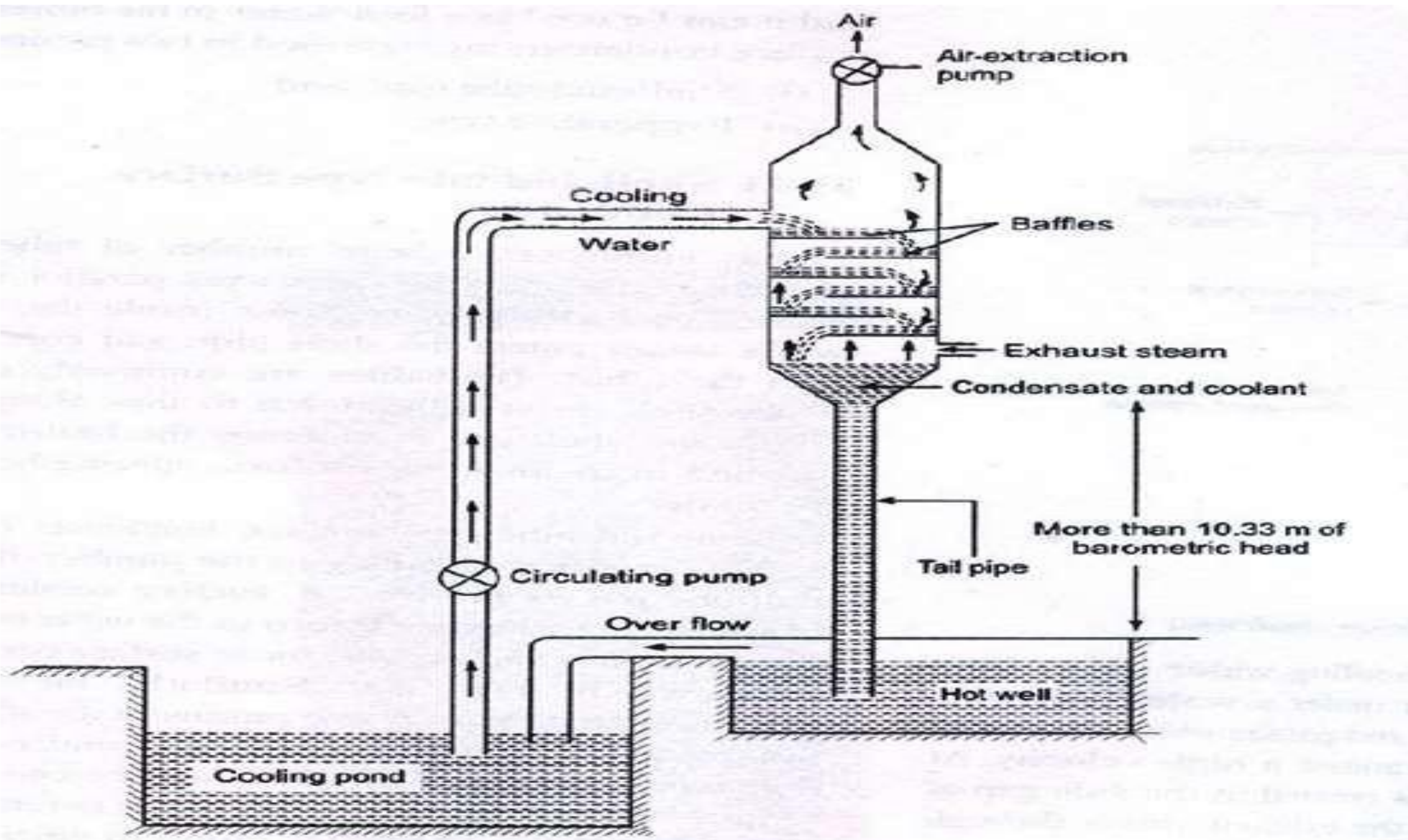
A pump for water supply is required if it is to be lifted more than 5.5 m in height.



Low-level counter-flow jet condenser

High Level Jet Condenser:

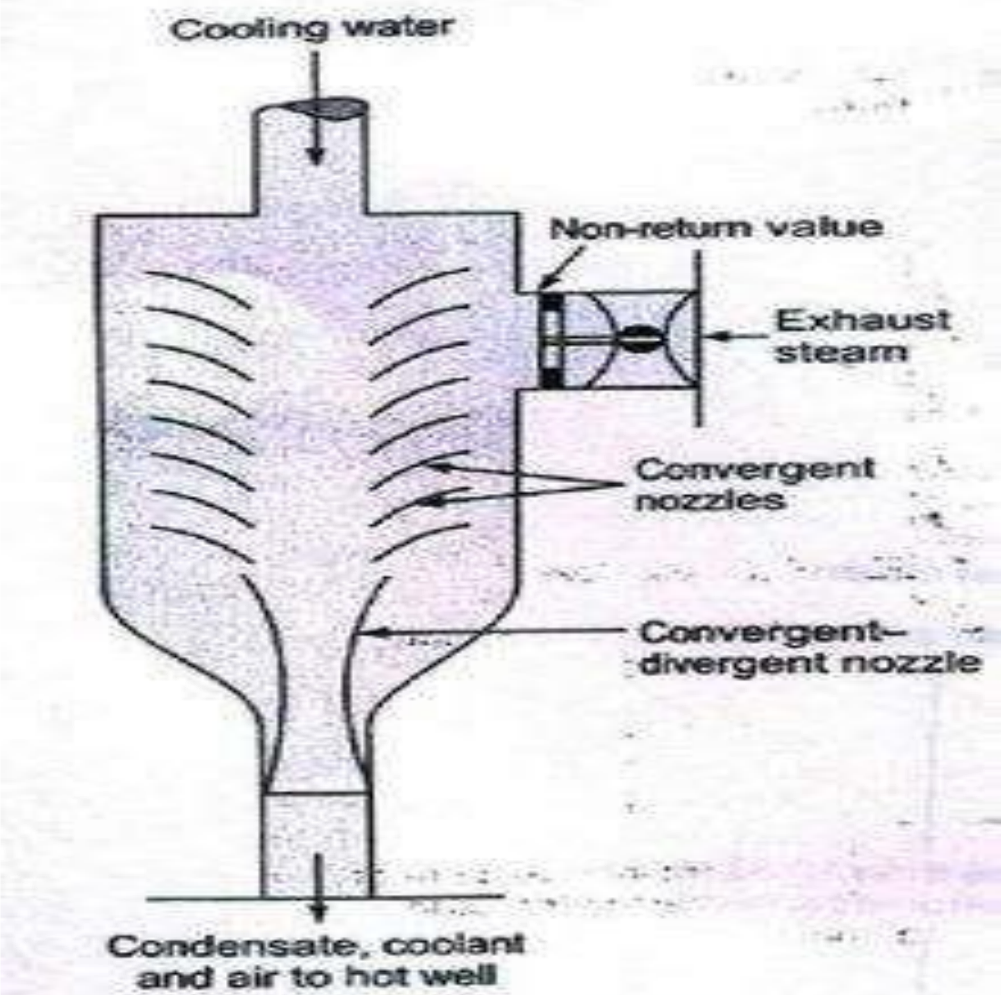
Condenser shell is installed at height greater than that of atmospheric pressure in water column m .



High-level jet condenser

EJECTOR CONDENSER:

- **Momentum of flowing water is used to remove the mixture of condensate & coolant from condenser without the use of any extraction pump.**



Ejector condenser

Advantages & Disadvantages of Jet Condensers:

Advantages:

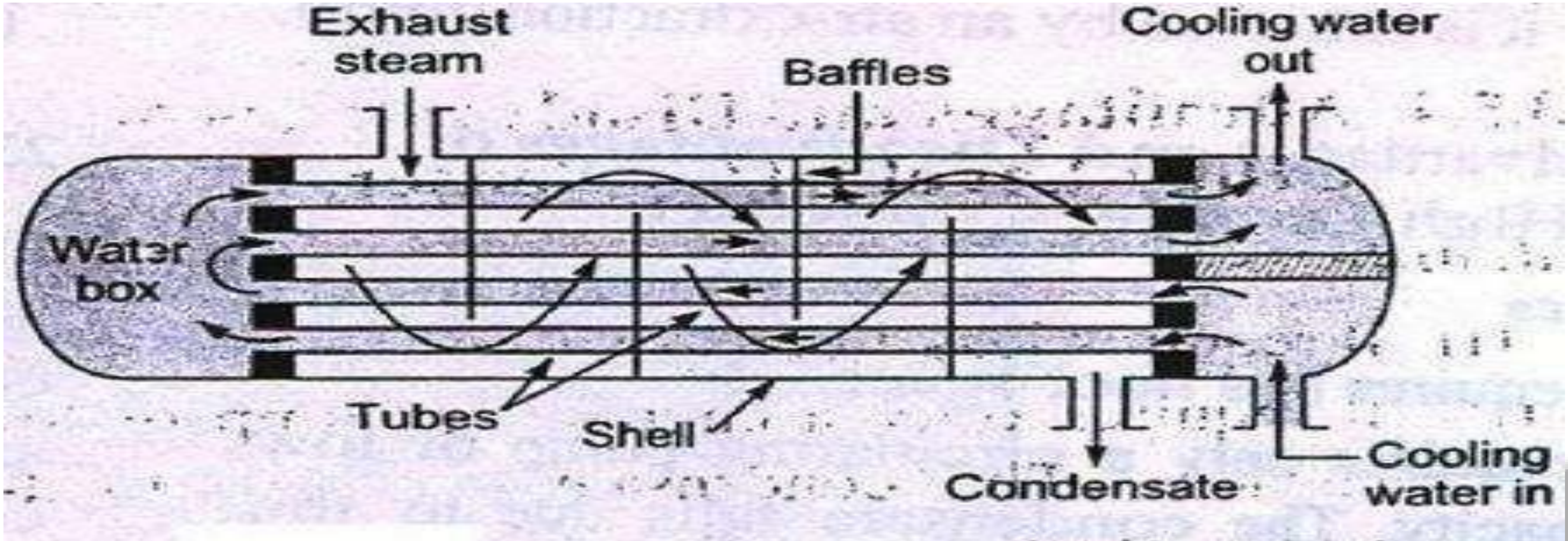
- Simple in design & cheaper.
- Less floor area is required.

Disadvantages:

- Condensate is not pure hence can not be reused.
- Low vacuum efficiency.

SURFACE CONDENSERS:

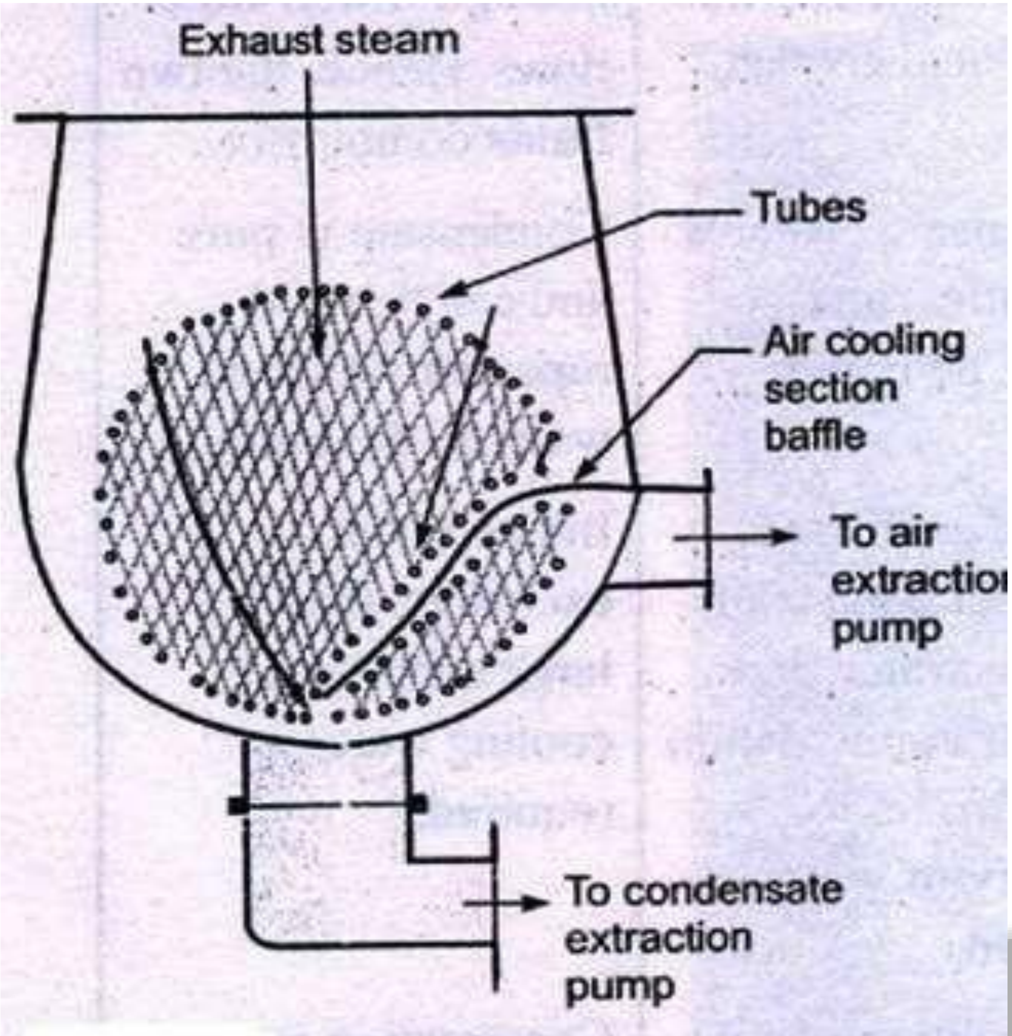
- **In surface condenser, the exhaust steam and cooling water do not come in physical contact, rather they are separated by heat transfer wall. Hence condensate remains pure & can be reused.**



Shell and tube type condenser

DOWN FLOW SURFACE CONDENSER:

- Exhaust steam enters the top of condenser shell & flows downward over water tubes.
- Water tubes are double passed. The cold water flows in lower side first & then in upper side in the reverse direction, which enables the maximum heat transfer.



Down-flow surface condenser

INVERTED FLOW CONDENSER:

- The steam enters the bottom of the shell and air extraction pump connected at the top.
- Steam flows upward first and subsequently, returns to the bottom of the condenser.
- The condensate extraction pump is connected at the bottom of the shell to extract the condensate.

Advantages & Disadvantages of Surface Condensers:

- **Advantages:**
  - High vacuum efficiency.
  - Pure condensate.
  - Low quality cooling water can be used.
  - It allows the expansion of steam through a higher pressure ratio.
- **Disadvantages:**
  - Large amount of water is required.
  - Construction is complicated.
  - Costly maintenance and skilled workers.
  - Large floor area.

- **Lowering the condenser pressure will increase the area enclosed by the cycle on a T-s diagram which indicates that the net work will increase. Thus, the thermal efficiency of the cycle will be increased**
- **Lowering the back pressure causes an inc**
  content of steam leaving the turbine.
- **Increase in moisture content of steam in l**
  there is decrease in efficiency &

erosion of blade may be a very serious probl

work required will be high.

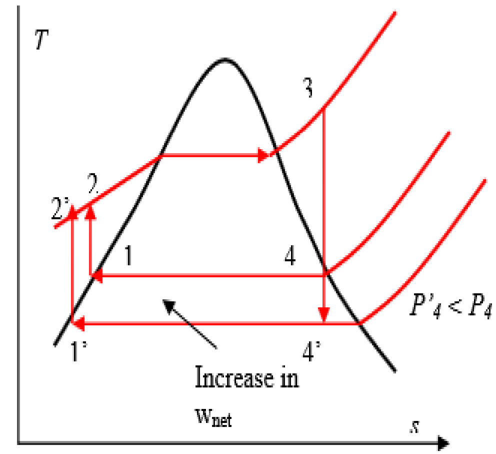


Fig. 4: Effect of lowering the condenser pressure on ideal Rankine cy

VACUUM CREATION IN CONDENSER:

- **When the steam condenses in a closed vessel, the vapour phase of working substance changes to liquid phase, and thus its specific volume reduces to more than one thousand times.**
- **Due to change in specific volume, the absolute pressure in the condenser falls below atmospheric pressure and a high vacuum is created.**
- **This minimum pressure that can be attained depends on the temperature of condensate and air present in the condenser.**

The absolute pressure = Atmospheric pressure – Vacuum Gauge in the condenser Pressure

SOURCES OF AIR IN THE CONDENSER:

- The ambient air leaks to the condenser chamber at the joints & glands which are internally under pressure lower than that of ambient.
- Another source of air is the dissolved air with feed water. The dissolved air in feed water enters into boiler and it travels with steam into condenser.

EFFECTS OF AIR LEAKAGE:

- The presence of air lowers vacuum in the condenser. Thus back pressure of the plant increases, and consequently, the work output decreases.
- Air has very poor thermal conductivity. Hence, the rate of heat transfer from vapour to cooling medium is reduced.
- The presence of air in the condenser corrodes to the metal surfaces.

Therefore, the life of condenser is reduced.

UNIT V
THERMAL ENGINEERING

PRINCIPLE OF JET PROPULSION:-

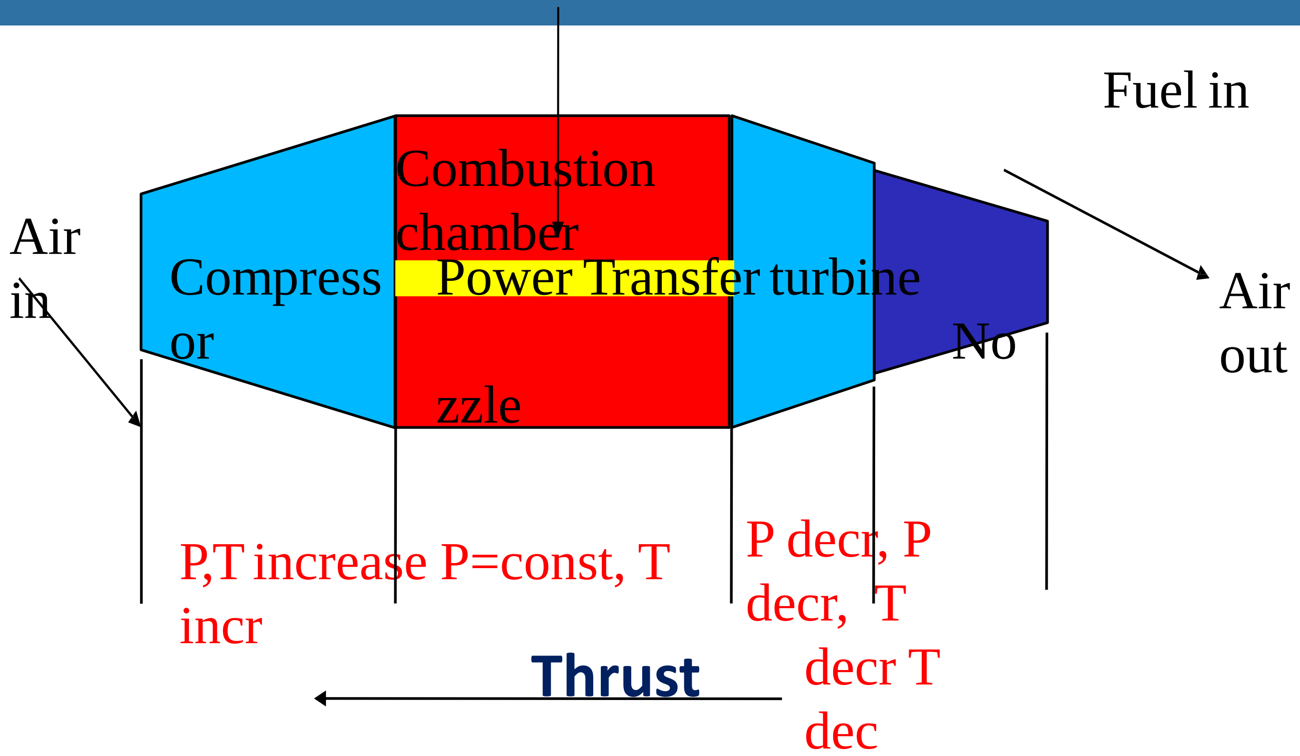
Jet is produced by combustion of fuel. The mixture of burnt fuel and compressed air exerts the thrust to the jet engine.

PRINCIPLE OF JET PROPULSION:-

The mixture is then expanded into the turbine, which is coupled with the compressor. The work produced by the turbine is used to run the compressor.

Then the fuel air mixture is allowed to expand into the nozzle at very high speed. The equivalent and opposite thrust force can be obtained.

PRINCIPLE OF JET PROPULSION:-



Turbojet engine

MAIN PARTS OF THE TURBOJET ENGINE:-

Compressor

Combustion Chamber

Turbine

Nozzle

COMPRESSOR:-

- A compressor is a mechanical device, which increases the pressure of a gas by decreasing its volume.
- Dynamic type, multistage axial compressor is used mainly in the turbojet engine. Centrifugal type compressor, axial centrifugal compressor may also be used.

Multistage axial compressor:-

- **An axial compressor is typically made up of many alternating rows of rotating and stationary blades called rotors and stators.**
- **Compressors with many blade rows are termed**
- **multistage compressors.**

COMBUSTION CHAMBER :-

- Also known as combustor, Flame holder.
- This is a chamber where fuel is continuously burned in the compressed air. Pressure remains almost constant.
- Can type combustion chamber is mainly used in jet engines.

CAN TYPE COMBUSTION CHAMBER

A large no. of single burners are arranged in parallel circumferentially around the engine axis.

Burners are linked up by interconnectors, that enable the flame to spread into the neighboring combustion chamber, thus igniting the fuel air mixture there.

TURBINE:-

- Primary task of turbine in the jet engine is mainly
- to run the compressor.
- Axial type turbines is mainly used in the jet engine. Axial flow type turbine can be single stage or multi stage. Similar to the compressor it has stationary nozzle guide vanes followed by a set of rotating blades.

ANALOGIES:-

Rocket

Aerodynamics

Air craft propulsion

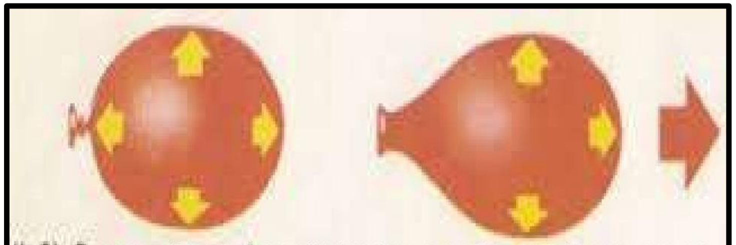
Ship propulsion

High speed vehicles

Newton’s law

WORKING PRINCIPLE

- Jet engine is nothing but a Gas turbine.
- It works under the principle of Newton's third law
- It states that "For every acting force there is an equal and
force".
- Gas turbine operates like toy balloo



(Left) Pressure is equal in all directions in an inflated tied balloon. (Right) When untied the pressure on one side is unbalanced and can move the balloon.

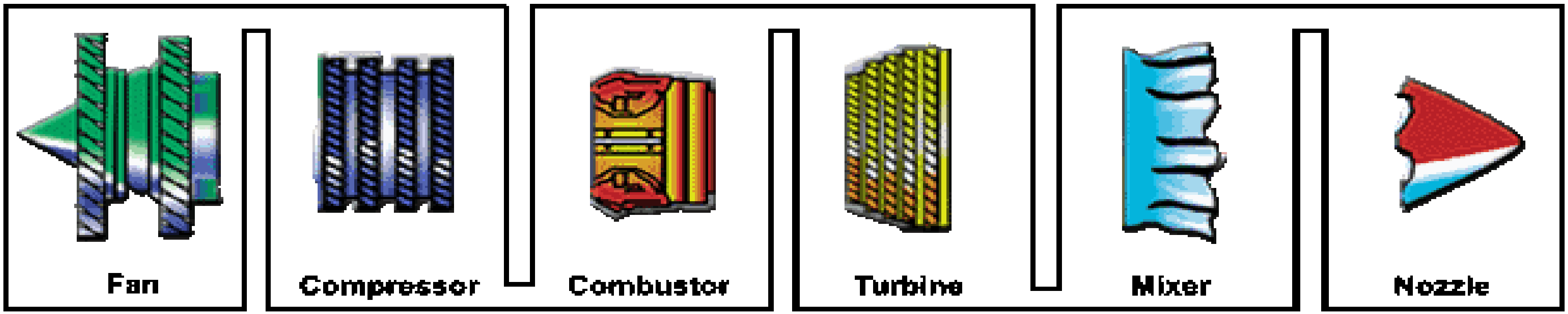
- Operating principle based on Newton's laws of motion.

Propulsive Efficiency $\eta_p = \dfrac{2V_{inlet}}{V_{inlet} + V_{exit}}$

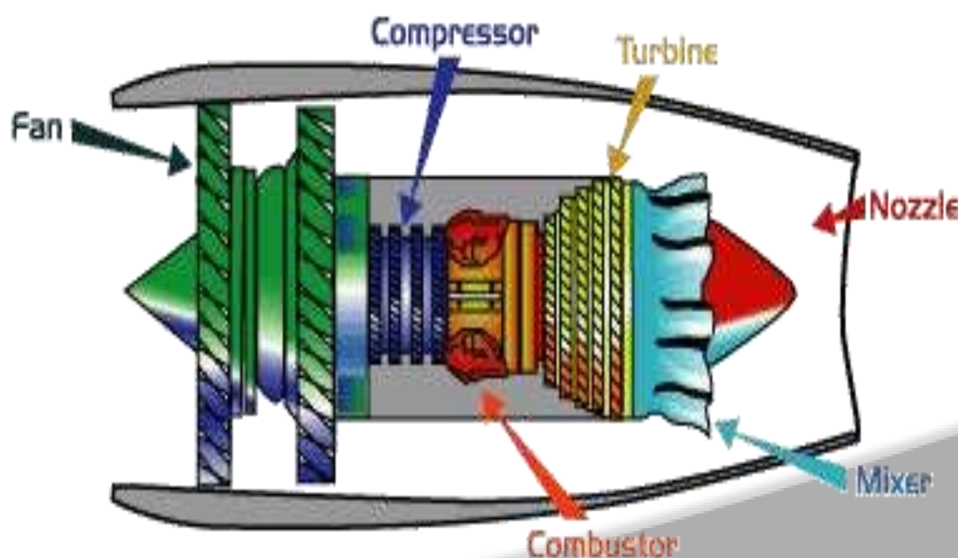
- Propulsion means to push forward or drive an object forward.

Fig.3. Newton's 3rd law of motion [1]

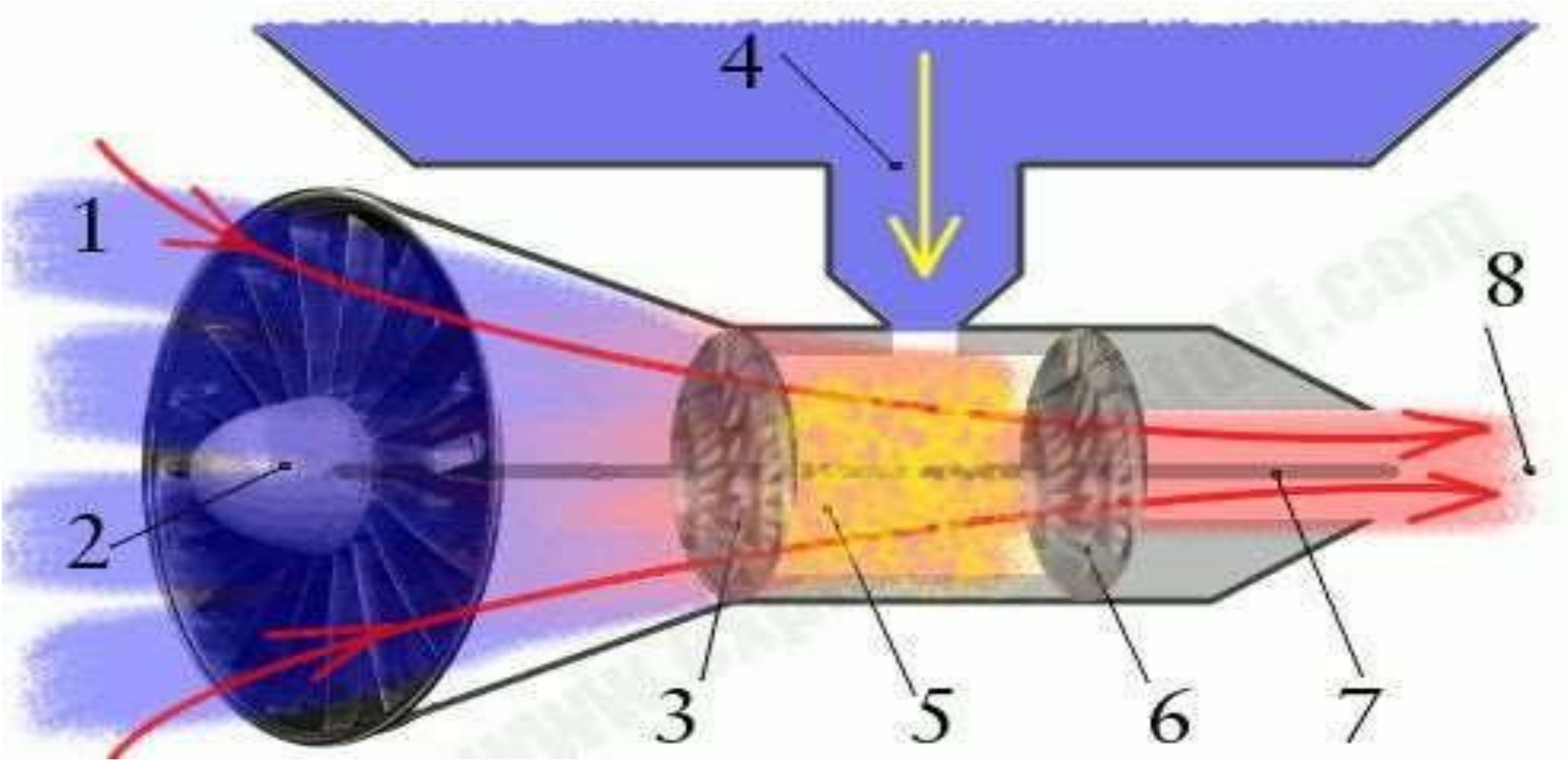
Parts of jet engine



- FAN
- COMPRESSOR
- COMBUSTOR
- TURBINE
- MIXER
- NOZZLE

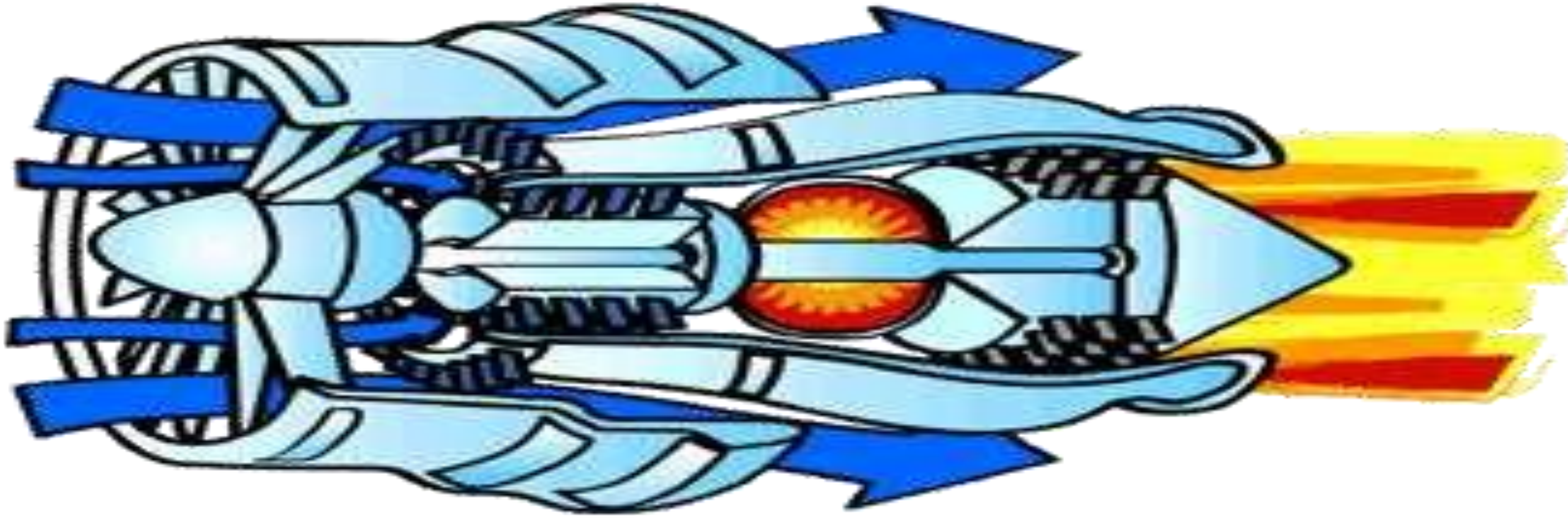


HOW A JET ENGINE WORKS ?



“Strictlyspeaking, energy is not “consumed”, but rather is converted into different forms.”

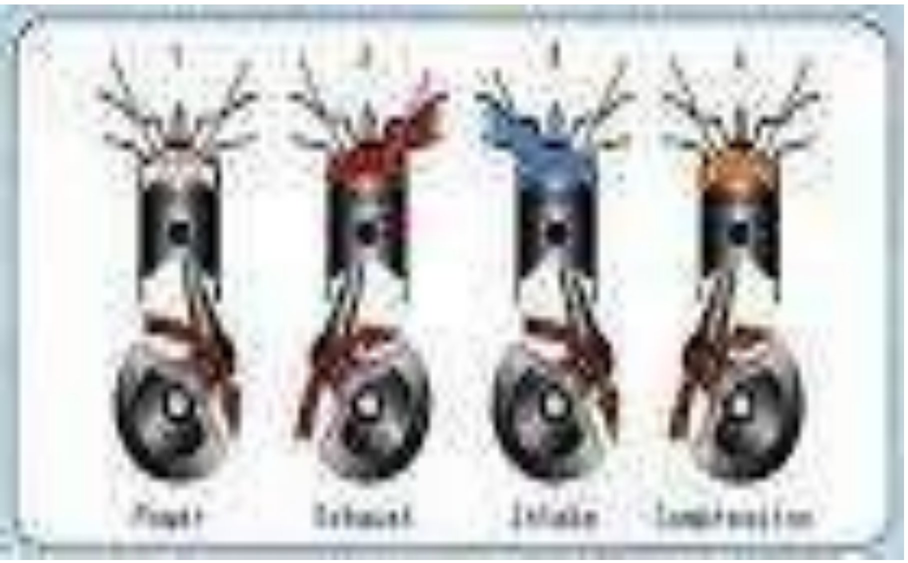
HOW AIR FLOWS THROUGH THE ENGINE ?



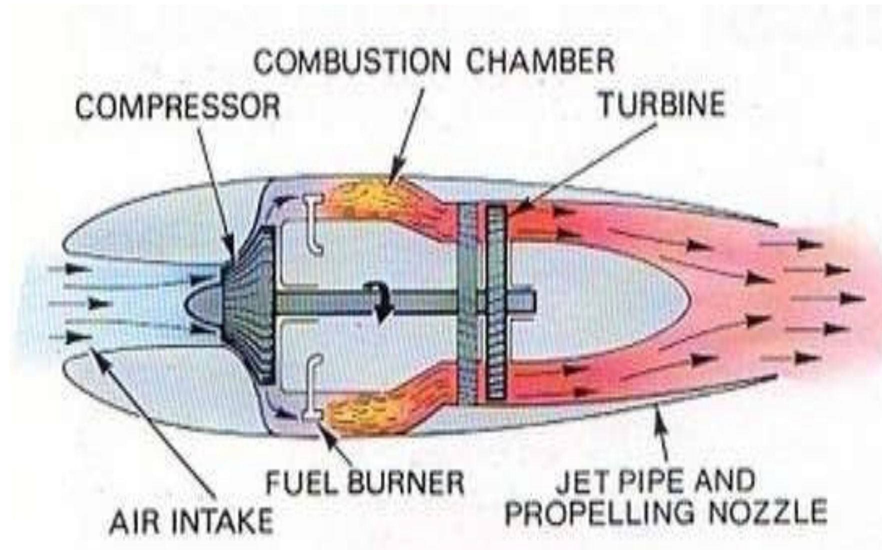
The image above shows how the air flows through the engine. The air goes through the core of the engine as well as around the core. This causes some of the air to be very hot and some to be cooler. The cooler air then mixes with the hot air at the engine exit area.

PISTON ENGINE VS JET ENGINE

Unsteady flow



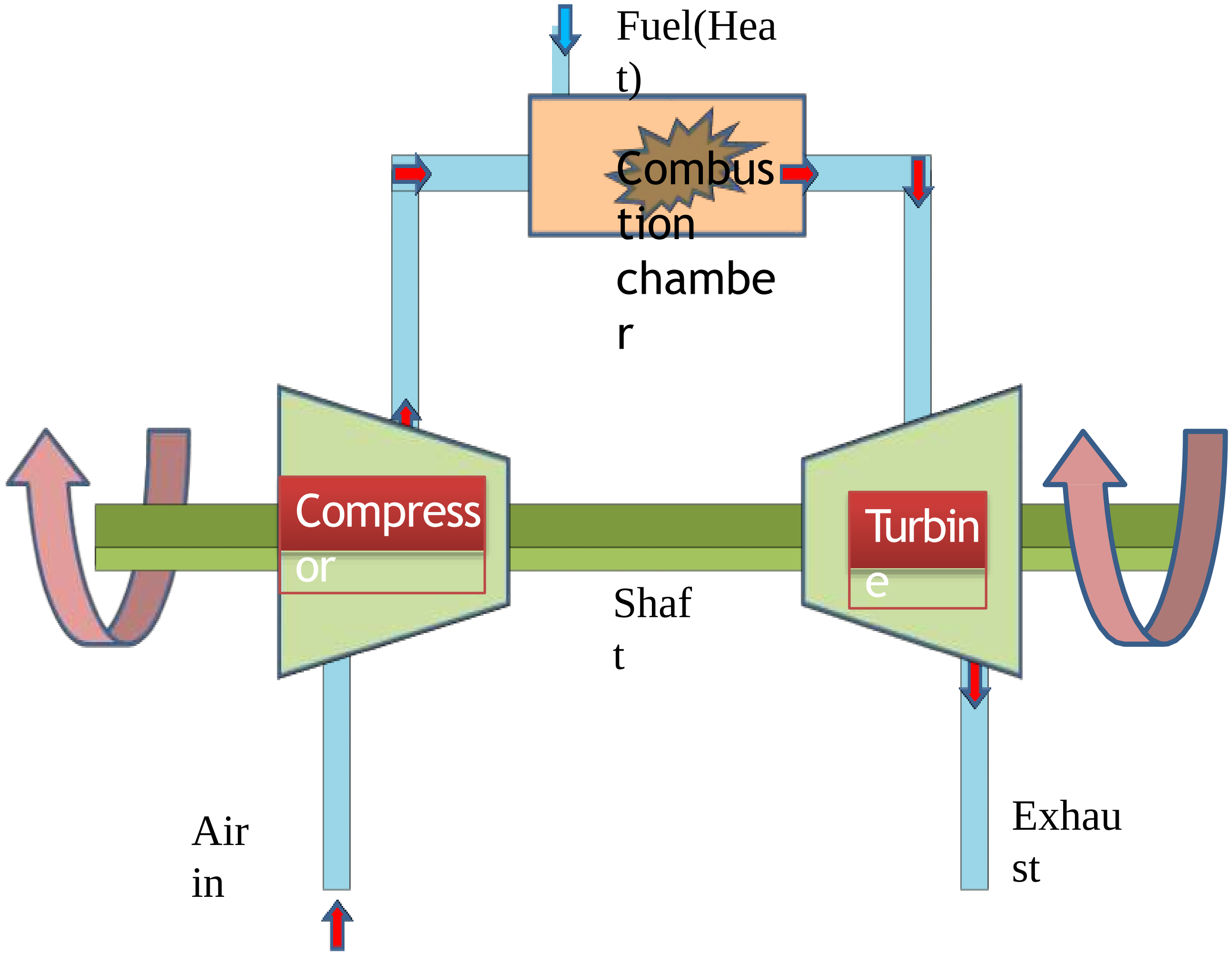
Steady flow



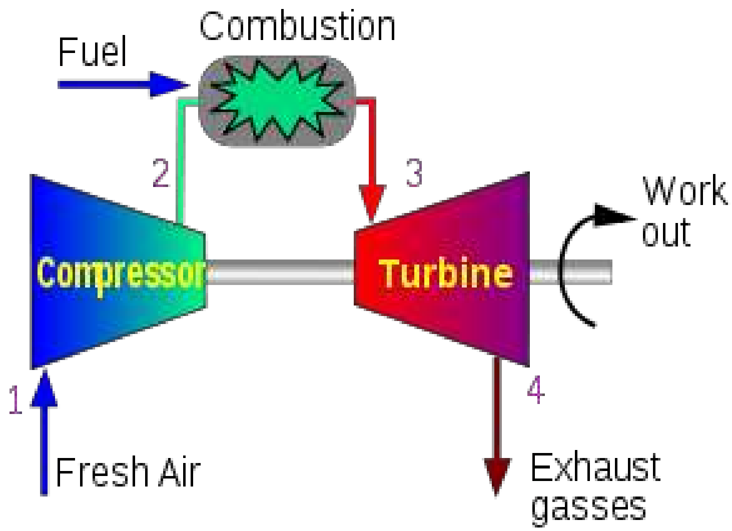
- **RATE OF MASS AND ENERGY FLOW IS NOT CONSTANT.**

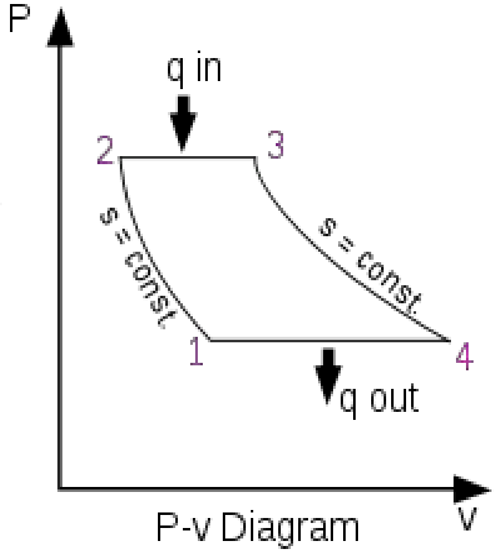
- **RATE OF FLOW OF MASS AND ENERGY IS CONSTANT.**

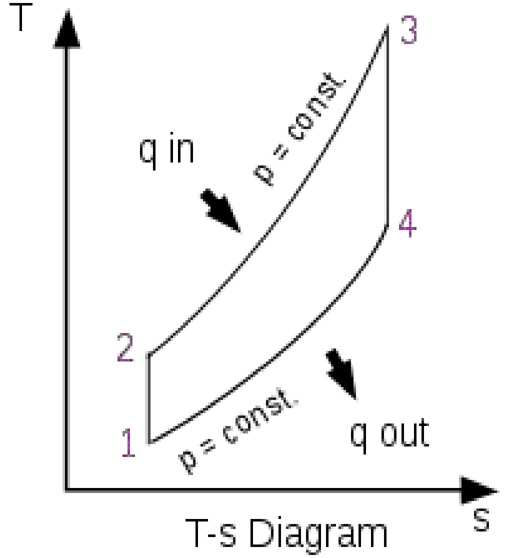
GAS TURBINE PLANT LAYOUT



SIMPLISTIC GAS TURBINES WORKING PRINCIPLES







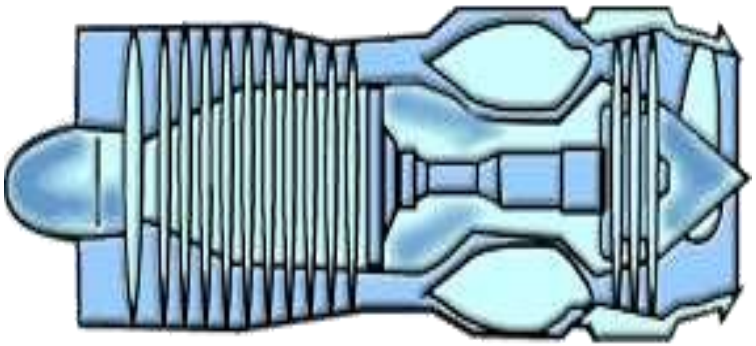
1-2 Isentropic compression (in a compressor); h_2-h_1 = $mC_p(T_2\text{-}T_1)$

2-3 Constant pressure heat addition (in a combustor); h_3-h_2 = $mC_p(T_3\text{-}T_2)$

3-4 Isentropic expansion (in a turbine); h_3-h_4 = $mC_p(T_3\text{-}T_4)$

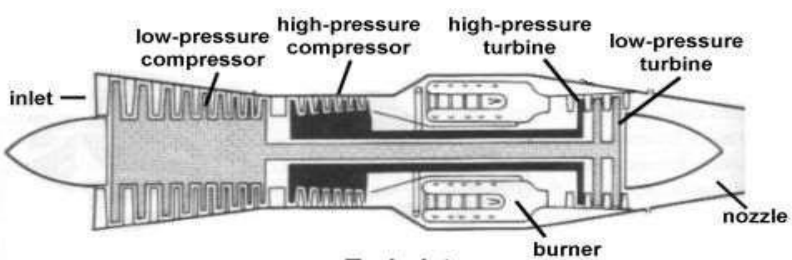
4-1 Constant pressure heat rejection

Turbojet

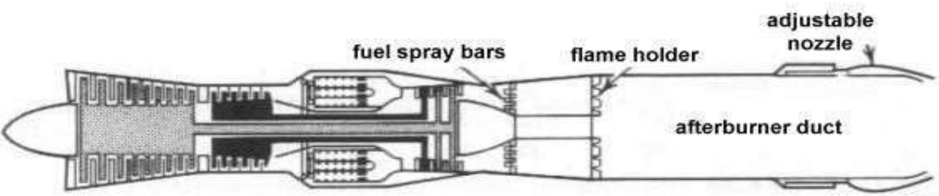


- The turbojet engine is a reaction engine.

- Substantial increases in thrust can be obtained by employing an afterburner

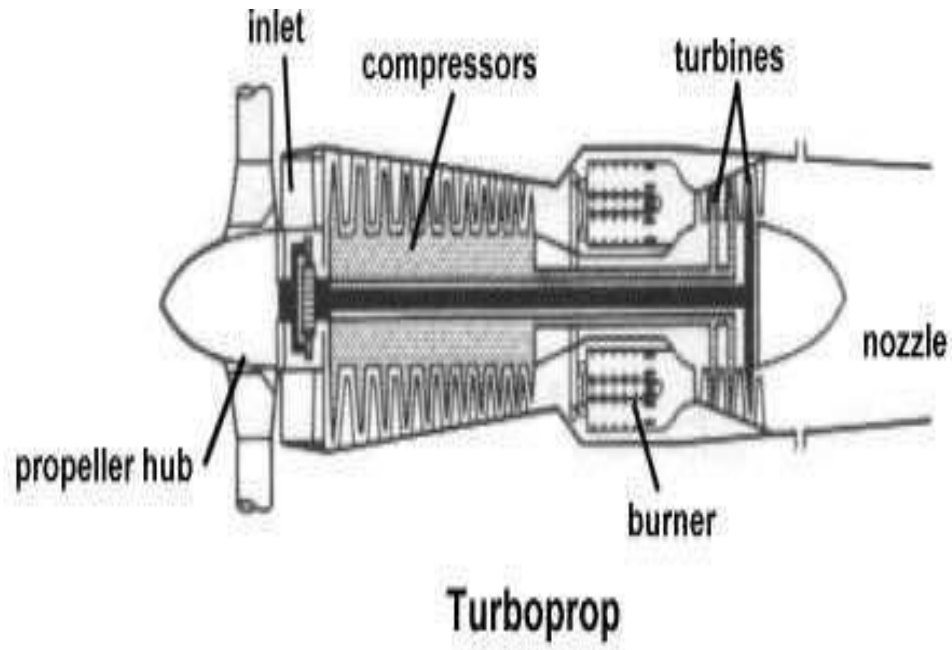


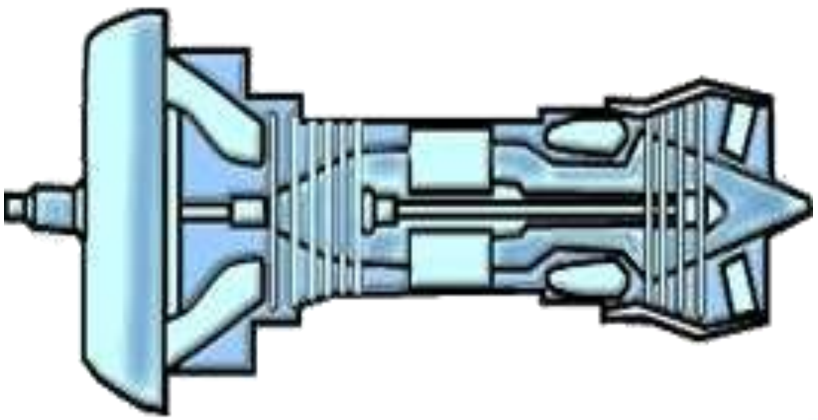
Turbojet



Turbojet with Afterburner

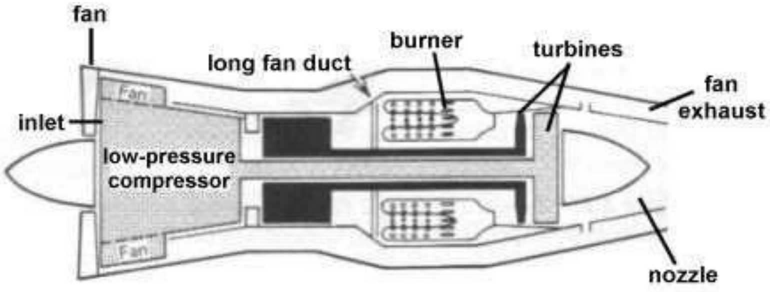
TURBOPROP



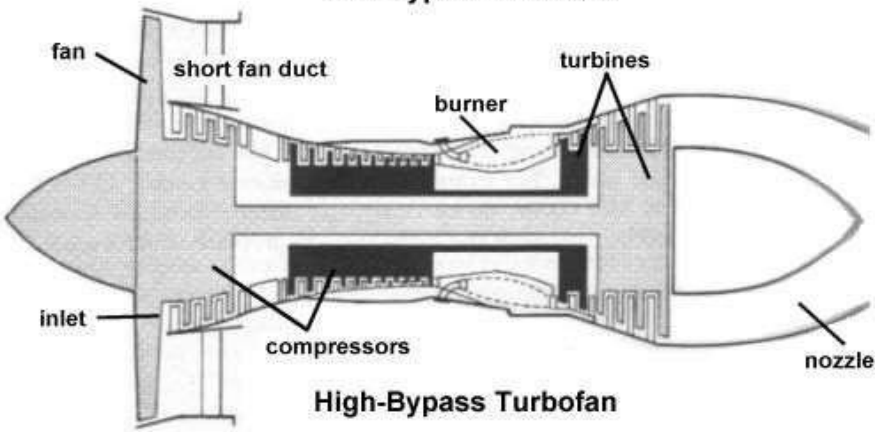


- A turboprop engine is a jet engine attached to a propeller.
- Modern turboprop engines are equipped with propellers that have a smaller diameter but a large number of blades for efficient operation at much higher flight speeds.

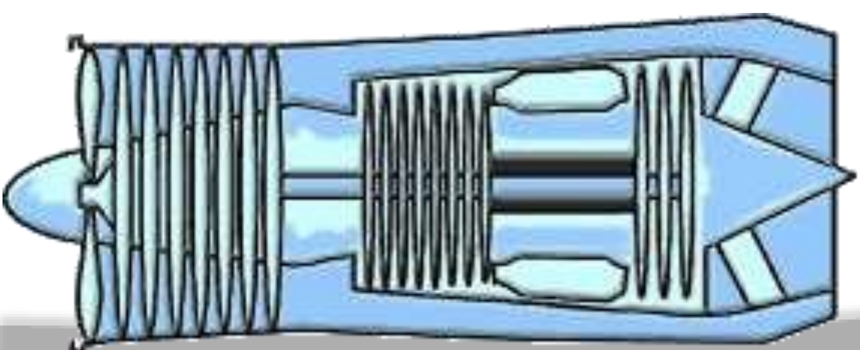
TURBOFAN



Low-Bypass Turbofan



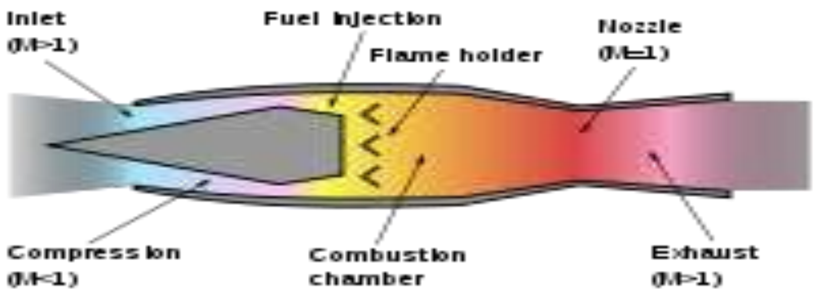
High-Bypass Turbofan

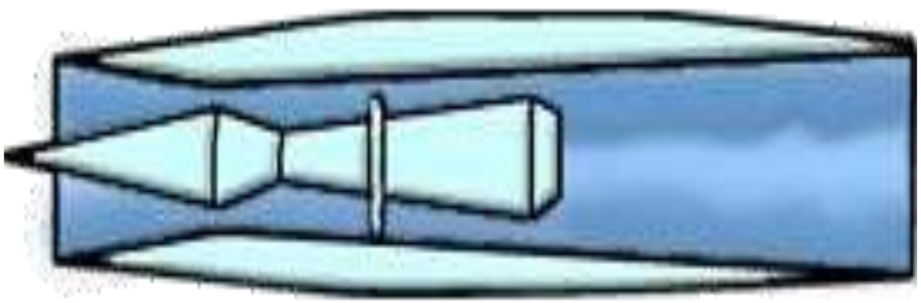


- The objective of this sort of bypass system is to increase thrust without increasing fuel consumption.

- It achieves this by increasing the total air-mass flow and reducing the velocity within the same total energy supply.

RAMJET





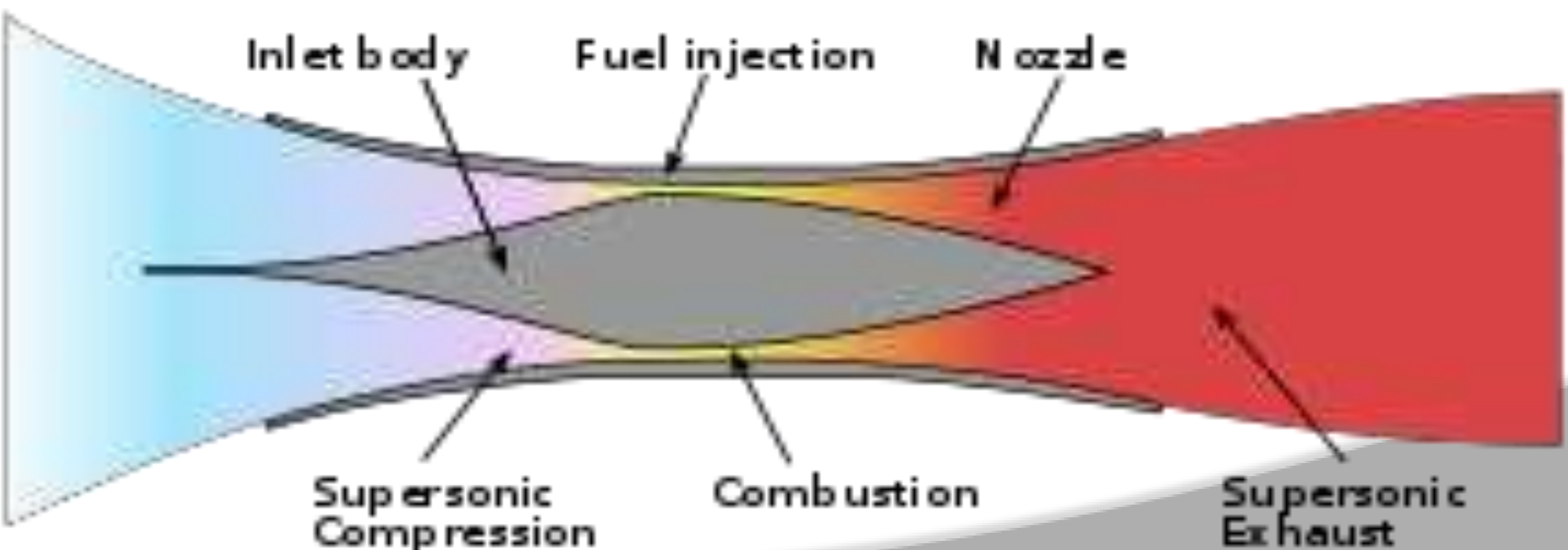
- ➢It has no moving parts.
- ➢Combustion occurs at subsonic speed of airflow.
- ➢Guided-missile systems, in defense sector used this type of jet.

Mach 0.8 to Mach 5, efficient at high speed (> Mach 2.0)

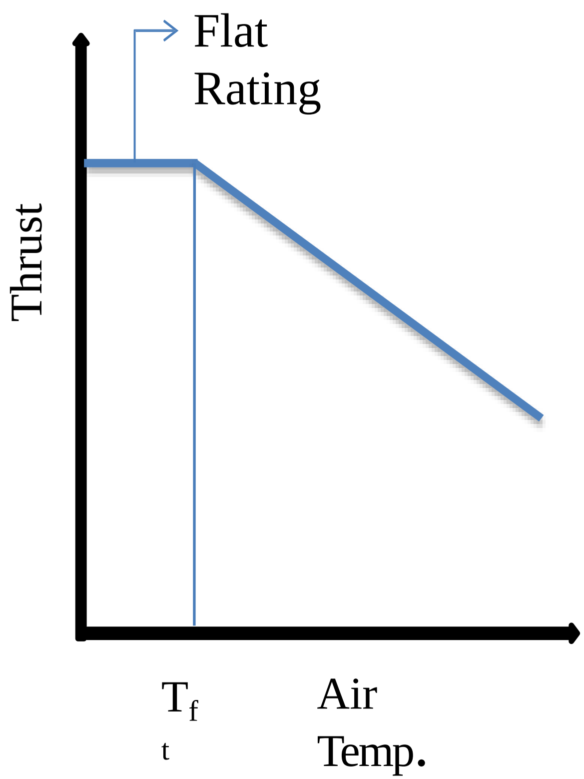
SCRAMJET

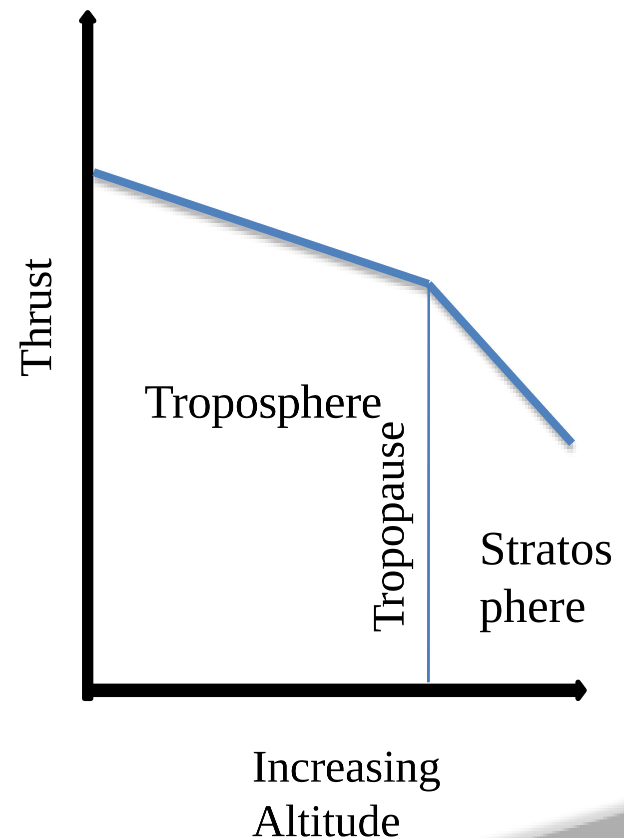
➢ **Scramjet (Supersonic Combustion Ramjet)**

- **A variant of Ramjet Air-breathing jet engine where combustion occurs in supersonic airflow.**
- **Few mechanical parts, can operate at very high Mach numbers**
- **(Mach 8 to 15) with good efficiencies.**



FACTOR AFFECTING THRUST





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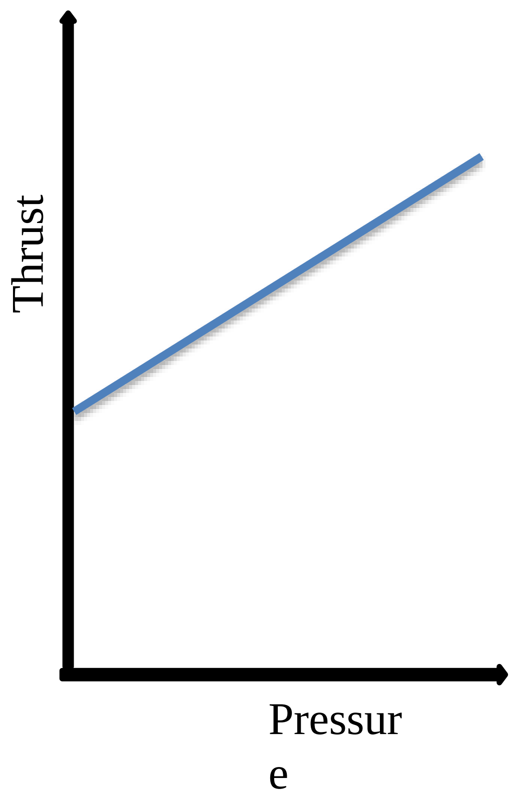
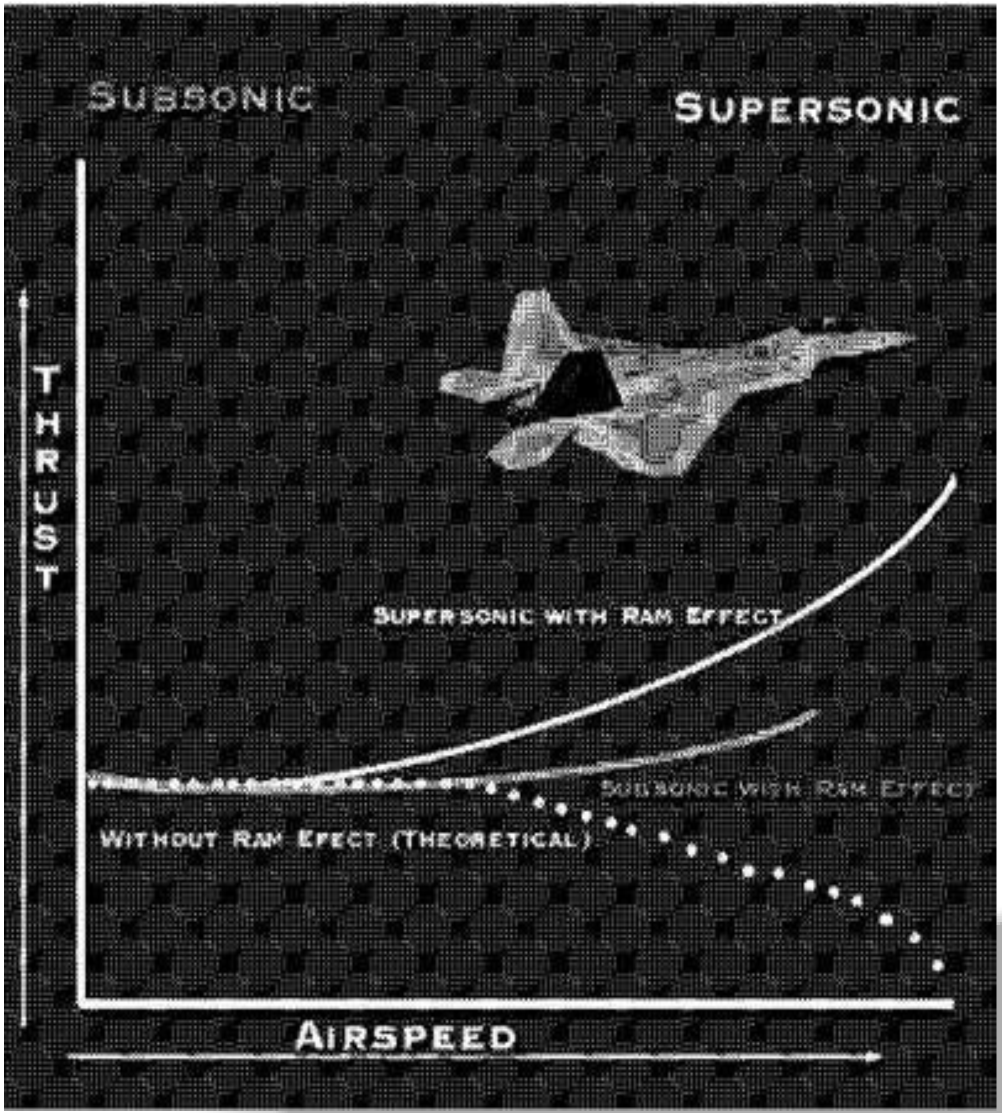

Thrust
Pressur
e


SUBSONIC
SUPERSONIC
THRUST
SUPERSONIC WITH RAM EFFECT
SUBSONIC WITH RAM EFFECT
WITHOUT RAM EFECT (THEORETICAL)
AIRSPEED

APPLICATIONS

- **IN AIRCRAFT- Fighter plane, Missiles, Rocket, Airplane.**
- **Jet propulsion, land and sea transport, racing car.**
- **The first use of the jet engine was to power military aircraft.**
- **The General electric company used a “turboprop” jet engine to run an electric generator.**
- **The jet engine is not only used on aircraft but on boats, where water jets are used to propel the boat forward.**
- **Normal type of jet engine is used for domestic purpose i.e. Traveling, carrying goods etc.**

ADVANTAGES

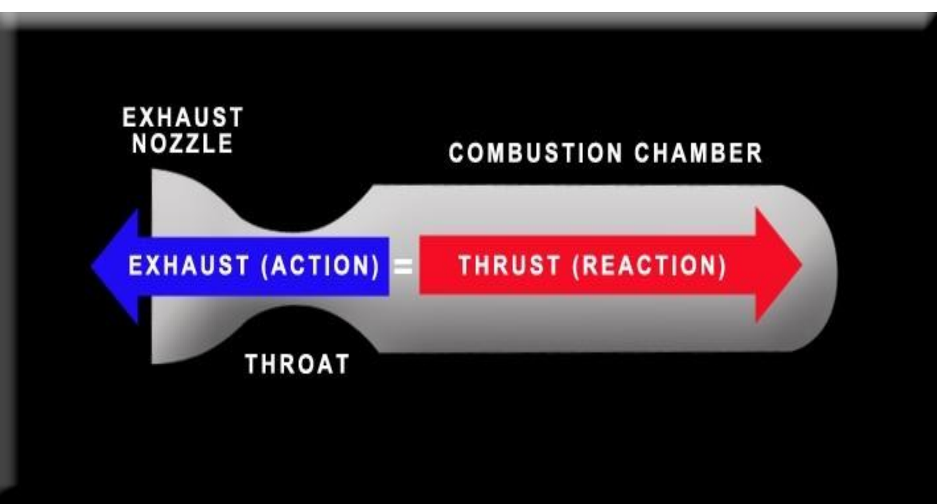
- High power to weight ratio.
- Very high speed therefore saves times.
- Mechanical efficiency of jet engine is compared to IC engine.

DISADVANTAGES

- High fuel consumption.
- It is difficult to design a turbine that will work in high temperature
with high speed.
- Thermal efficiency of Jet engine is low compared to IC engine.

How Rocket Engines Operate

Rocket propulsion is based on Sir Isaa Newton’s three laws of motion. The third law is the heart of rocketry because the action of the rocket engine produces the forward motion of the rocket.



Solid Propellant

- In a solid propellant rocket system the fuel and oxidizer are mixed together from the start.

The rocket case is the combustion chamber and holds the propellants. There are no valves, pumps, or sensors.

Additives, if needed to increase temperature or to control burning, are simply mixed with propellant grains.

LIQUID PROPELLANT ROCKET

- Liquid Propellant Classifications
  - Monopropellants
    - Contains its oxidizer and fuel in one solution.
    - May be a single chemical compound.
    - The compounds are stable at ordinary temperatures and pressures, but break down when heated and pressurized, or when the breaking down process is started by a catalyst.
    - Monopropellant rockets are simple since they need only one propellant tank and associated equipment.

Thank you