THERMAL ENGINEERING II — important...

UNIT - 1

Q.1 General process of Thermal Engineering,

- Constant volume process
- Constant pressure process
- Isothermal process
- Adiabatic process
- Polytropic process.

Q.2 Explain terms,

- Turbine
- Gas Turbine, its working and type.

Q.3. Explain and clearify terms in "Braton cycle".

Q.4. Write down comparisions between,

a. 'Gas Turbine' and 'IC engine'

b. 'Gas Turbine' and 'Steam Turbine'

Q.5. Explain Jet and its propulsion.

Q.6. Determine Rocket and advantages with its propulsion

UNIT - 2

Q.1 Explain these terms,

- Saturated Liquid
- Saturated Vapour
- Saturation Temperature
- Saturated liquid line
- Saturated vapour line
- Vapour done.
- Critical point
- Dry fraction.
- Superheated vapour
- Degree of superheat.

Q2. Explain Steam Table. [

Q3. Explain in deep Calorimeter.

UNIT-3

Qn. 1 Write about boiler, its function and also classify it into different terms.

Qn. 2 Write down cochran boiler and working with diagram.

Qn. 3 Write down Babcock and Wilcox Boiler with diagram and explain working.

Qn. 4 Write about boiler mounting and accessories.

Qn 5. Explain,

- Equivalent evaporation
- Boiler Horse Power
- Boiler Efficiency.
- Benson Boiler
- Lamont Boiler
- Draught.

UNIT-4

Q. 1 Write about Nozzle, its type and uses of nozzle.

Q. 2 Derive the equation of Dishcharge through nozzle.

Q. 3 Write the effect of friction and super saturated flow on nozzle.

Q. 4 Write about Steam Injector.

UNIT-5

Q. 1 Write about Steam turbine, with classification.

Q. 2 Write the function and working of steam turbine and derive, (i) Workdone, (ii) blade efficiency (iii) Nozzle efficiency.

Q. 3 Write short Notes on, (i) Velocity compounding (ii) Pressure compounding & (iii) P-V compounding.

THERMAL Engineering II.

Basic of Thermal Engg.

Work -

$$\delta W = PA\,ds$$

$$\delta W = P\,dV$$

$$\int \delta W = \int P\,dV$$

$$\boxed{W = \int P\,dV}$$

Close system
Reversible, Quasi-static Process

- If system volume expand work is said to positive and work is said to be done by system.
- If system volume contracts work is said to be negative and work is said to be done on system.

Non flow Work - (Control Mass)

1. Isochoric or Isometric Process or constant volume process;

$$V = C$$

$$dV = 0$$

$$\boxed{W = \int P\,dV = 0}$$

2. Isobaric process or constant pressure process

$$P = C \quad , \quad dp = 0$$

$$W = \int_{V_1}^{V_2} P\,dV$$

$$W = P[V]_{V_1}^{V_2}$$

$$\boxed{W = P(V_2 - V_1)}$$

3. Isothermal process;

$$T = c \,.\quad dT = 0$$

$$PV = c \quad , \quad P_1V_1 = P_2V_2$$

$$P = \frac{c}{V}$$

$$W = \int_{V_1}^{V_2} P\,dv = \int_{V_1}^{V_2} \frac{c}{V}\,dv$$

$$= c\,[\log V]_{V_1}^{V_2}$$

$$= c\,[\log V_2 - \log V_1]$$

$$= P_1V_1 \log\frac{V_2}{V_1} = P_2V_2 \log\frac{P_1}{P_2}$$

$$\Rightarrow \boxed{W = RT_1 \log\frac{P_1}{P_2} = RT_2\,\frac{P_1}{P_2}}$$

4. Adiabatic Process;

$$Q = 0 \quad , \quad S = C$$

It is so fast process that heat transfer is not posible because for heat transfer to take place finite amount of time is required which is not avaible in adiabatic process.

$$PV^{\gamma} = c$$

$$P = c/V^{\gamma}$$

$$W = \int_{V_1}^{V_2} P\,dv = \int_{V_1}^{V_2} \frac{c}{V^{\gamma}}\,dv$$

$$= c\left[\frac{V^{-\gamma+1}}{-\gamma+1}\right]_{V_1}^{V_2}$$

$$= c\left[\frac{V_2^{-\gamma+1} - V_1^{-\gamma+1}}{-\gamma+1}\right] \quad , \quad \boxed{W = \frac{P_1V_1 - P_2V_2}{\gamma - 1}}$$

5. Polytropic Process

$$PV^n = C$$

$$P = \frac{C}{V^n}$$

$$\boxed{W = \frac{P_1V_1 - P_2V_2}{n-1}}$$

Ideal Gas Equation In Various Process

$$PV = mRT$$

$$\frac{PV}{T} = mR$$

$$\frac{PV}{T} = C$$

$$\therefore \frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

1. For constant volume

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

2. For constant Pressure

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

3. For constant temperature

$$P_1V_1 = P_2V_2$$

4. For Adiabatic Process

$$PV^\gamma = C$$

for Ideal gas

$$V \propto \frac{T}{P}$$

$$P\left(\frac{T}{P}\right)^{\gamma} = C$$

$$\Rightarrow \frac{T^{\gamma}}{P^{\gamma-1}} = C$$

$$\Rightarrow \frac{T_1^{\gamma}}{P_1^{\gamma-1}} = \frac{T_2^{\gamma}}{P_2^{\gamma-1}}$$

$$\Rightarrow \left(\frac{T_2}{T_1}\right)^{\gamma} = \left(\frac{P_2}{P_1}\right)^{\gamma-1}$$

$$\Rightarrow \therefore \boxed{\frac{T_2}{T_1} = \left[\frac{P_2}{P_1}\right]^{\frac{\gamma-1}{\gamma}}}$$

$$TV^{\gamma-1} = C,$$

$$\Rightarrow T_1 V_1^{\gamma-1} = T_2 V_2^{\gamma-1}$$

$$\Rightarrow \therefore \boxed{\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{\gamma-1}}$$

$$PV^{\gamma} = C$$

$$\Rightarrow \therefore \boxed{P_1 V_1^{\gamma} = P_2 V_2^{\gamma}}$$

PV diagram for Various process;

$$PV^{n} = C$$

Value of n	Type of process
$n = 0$	Isobaric Process
$n = 1$	Isothermal Process
$n = n$	Polytropic Process
$n = \gamma$	Adiabatic Process
$n = \infty$	Isochoric Process.

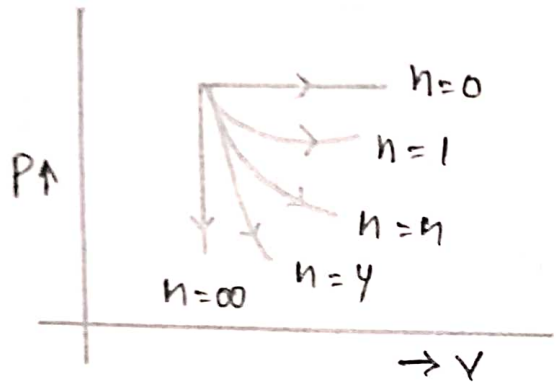
$$PV^n = c$$

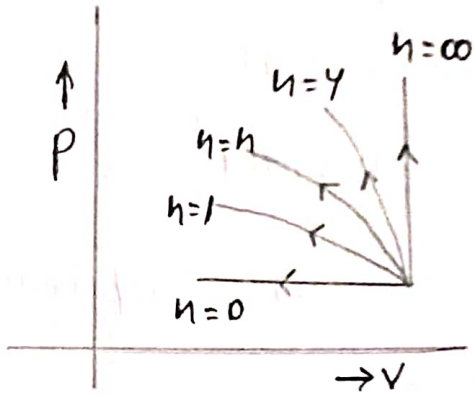
$$(PV^n)^{1/n} = c^{1/n}$$

$$P^{1/n} V = c^{1/n}$$

$$\because n = \infty$$

$$\therefore \boxed{V = c}$$





Heat:

from the first law of thermodynamics,

$$\delta Q = du + \delta W$$

Heat — Internal Energy — Work

For constant Volume Process;

$$V = c$$

$$dv = 0$$

$$\delta W = 0$$

$$\delta Q = du$$

$$du = m c_v dT$$

$$\therefore \boxed{Q = m c_v dT}$$

For constant pressure process,

$$P = c$$

$$\delta Q = du + \delta W$$

$$\delta Q = du + Pdv$$

$$\delta Q = d(u + Pv)$$

$$\delta Q = dH$$

$$dH = m c_p dT$$

$$\therefore \boxed{Q = m c_p dT}$$

For constant temperature process,

$$T = c$$

$$dT = 0$$

$$\delta Q = du + \delta W$$

$$\delta Q = m c_v dT + \delta W$$

$$\boxed{\delta Q = 0 + \delta W}$$

$$\therefore \boxed{\delta Q = \delta W}$$

For adiabatic process,

$$\boxed{\delta Q = 0}$$

Adiabatic expansion process,

$$dW = +Ve$$

$$dT = -Ve$$

$$T_y - T_i < 0$$

$$\boxed{T_i > T_y}$$

For Adiabatic compression process;

$dW = -ve$

$dT = +ve$

$T_y - T_i > 0$

$T_y > T_i$

For Isolated system,

$dQ = 0$

$dW = 0$

$\because dU = 0$

$U_2 - U_1 = 0$

$U_2 = U_1$

$U = \text{constant}$

- For Isolated system internal energy remains constant.

UNIT - 1. GAS Turbine

Turbines :

- A turbine is a rotary mechanical device that extract energy from a fluid flow and converts it into useful Work.
- Turbine receives its power from a wheel that is turned by the pressure of fluid.
- The work produced by turbine can be used for generating electrical power when combined with a generator.
- A turbine is a turbomachine.

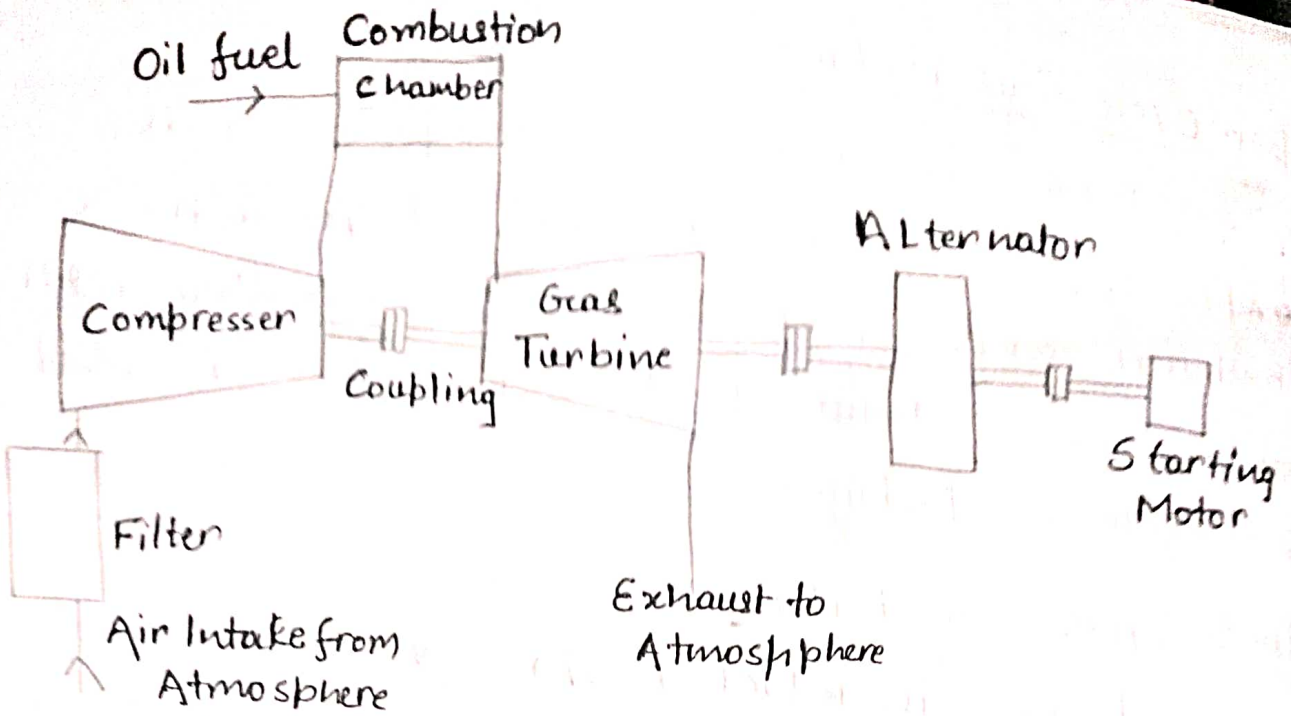
Gas Turbine

A turbine is driven by the pressure of burning mixture of compressed air and fuel, like gas and called Gas Turbine.

- Gas turbine works on Brayton cycle.
- Components of gas turbine

The components of gas turbine are;

1. Compressor
2. Combusten
3. Turbine
4. Regenerator
5. Alternator
6. Starting Motor.



Working of Gas Turbine;

- A rotary compressor sucks air from atmosphere and compress it.
- The pressurized air is introduced into combustion chamber where heat is added to air and its temperature is raised.
- The addition of heat to air or any other working medium is accomplished by injection of ~~fluid~~ fuel under high pressure in the cumbuster or by employing and air heater.
- The high temperature gas is then directed into gas turbine.
- The high velocity jet produced by expaintion in the turbine nozzle impinge on the turbine moving blade and the kinetic energy is transferred into mechanical work.

Types of Gas Turbine

1 Open cycle Gas TURBINE
2 CLOSE Cycle Gas Turbine.

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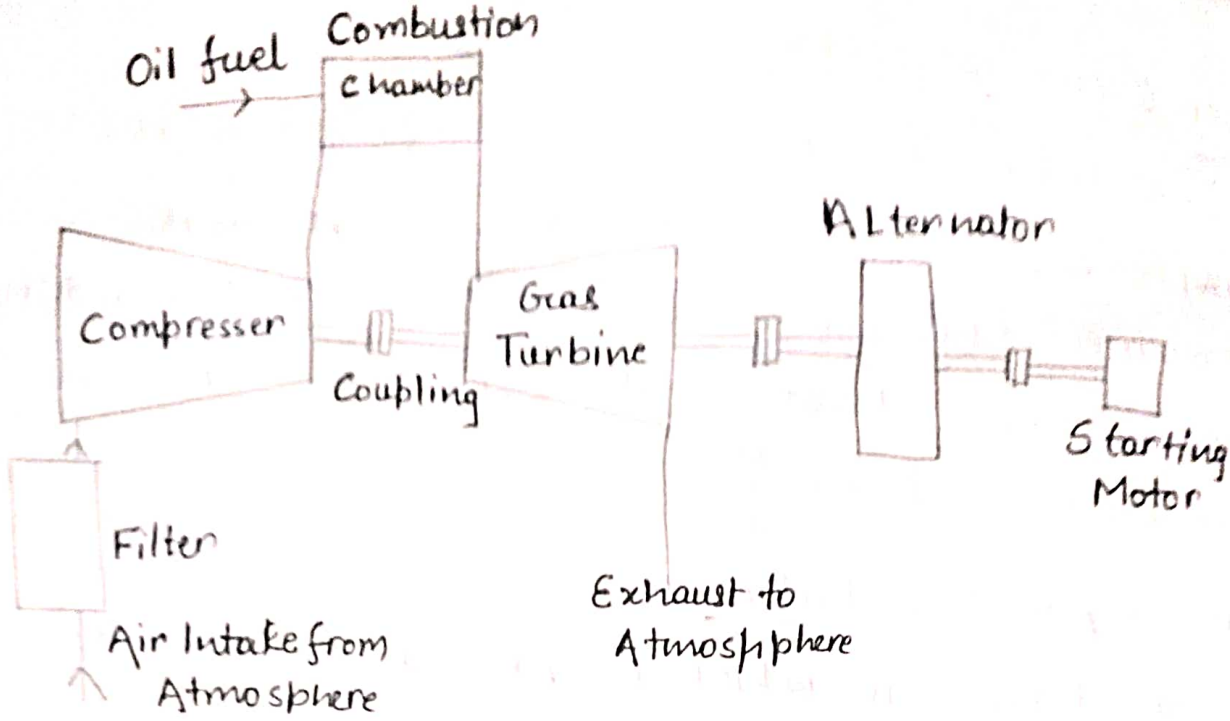

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Types of Gas Turbine

1 Open cycle Gas TurBINE
2 CLOSE Cycle Gas Turbine.

Open Cycle Gas Turbine

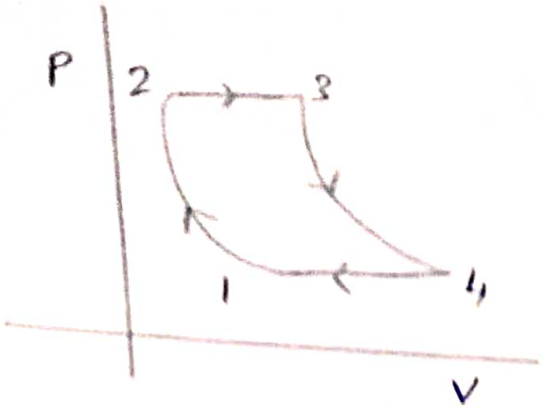
A gas turbine in which air is compressed in the compressor, fuel is injected and burn in the combustor and hot product are expandend in the turbine and exhaust to the atmosphere is called open cycle gas turbine.

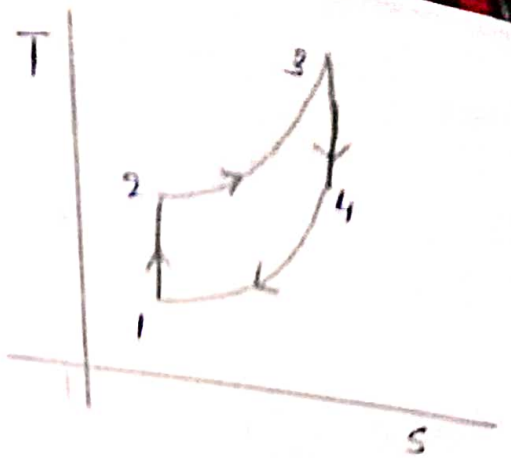
Close Cycle Gas Turbine

A gas turbine in which compressed working fluid which may be air, hydrogen or carbon-dioxide is delivered to a heater where fluid then expanded in the gas turbine and the exhaust from the turbine is cool again and feed to the compressor thus closing the cycle is called close cycle gas turbine

Brayton Cycle

- Brayton cycle is also known by Joule cycle.
- Brayton cycle is theoretical cycle on which constant pressure gas turbine runs.
- The process of compression, combustion and expansion take place in different component in gas turbine
- The schematic arrangment of different component of gas turbine and p-v & T-s diagram for ideal Brayton cycle is next page;





Process 1-2 : Isentropic compression air in rotary compressor which raise the temperature of air from P_1, T_1 to P_2, T_2.

Process 2-3 : The air at condition 2 passes through heat exchanger where heat is externally supplied at constant pressure. Thus raise the temperature from T_2 to T_3.

Process 3-4 : Isentropic expantion of high temperature and high pressure air in the turbine during which work is done by system.

Process 4-1 : The air is at state point 4 is passed through a heat exchanger and heat is rejected at constant pressure. This cools the air to initial condition and the cycle is completed.

For unit mass of air,

Heat supplied ; $Q_1 = C_p(T_3 - T_2)$

Heat rejected, $Q_2 = C_p(T_4 - T_1)$

Work done , $C_p(T_3 - T_2) - C_p(T_4 - T_1)$.

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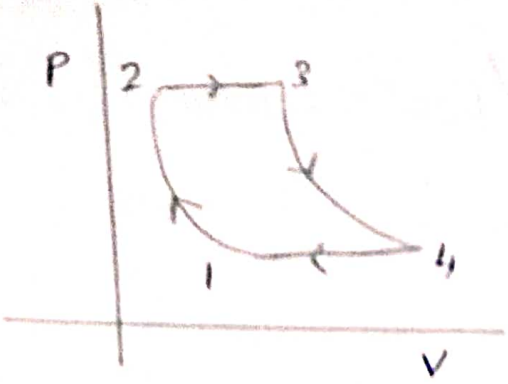

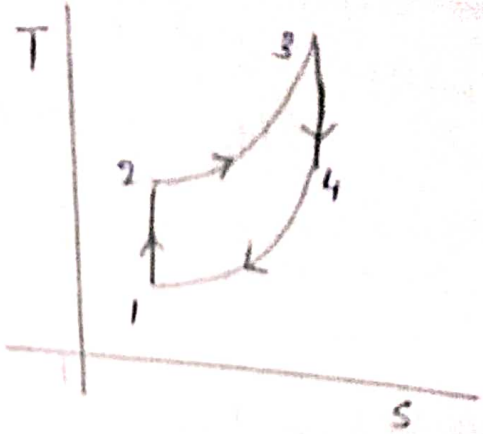

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Heat rejected, $Q_2 = C_p(T_4 - T_1)$

Work done , $C_p(T_3 - T_2) - C_p(T_4 - T_1)$.

$\therefore$ Thermal efficiency,

$$\eta_{th} = \text{Workdone} / \text{Heat supplied}$$

$$= \frac{C_p(T_3 - T_2) - C_p(T_4 - T_1)}{C_p(T_3 - T_2)}$$

$$\eta_{th} = 1 - \frac{T_4 - T_1}{T_3 - T_2}.$$

Let pressure ratio, $r_p = \frac{P_2}{P_1} = \frac{P_3}{P_4}$.

In process 1-2,

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = (r_p)^{\frac{\gamma-1}{\gamma}}$$

In process 3-4

$$\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}} = (r_p)^{\gamma-1/\gamma}$$

$$\frac{T_2}{T_3} = \frac{T_3}{T_4}$$

$$\eta_{th} = 1 - \frac{T_1\left(\frac{T_4}{T_1} - 1\right)}{T_2\left(\frac{T_3}{T_2} - 1\right)}$$

$$\eta_{th} = 1 - \frac{T_1}{T_2}$$

$$\boxed{\eta_{th} = 1 - \left(\frac{P_1}{P_2}\right)^{\frac{\gamma-1}{\gamma}} = 1 - \frac{1}{(r_p)^{\gamma-1/\gamma}}}$$

Note; $\because$ $\eta = 1 - \frac{1}{(r_p)^{\gamma-1/\gamma}}$

$\because$ $\boxed{r_p \uparrow \rightarrow \eta \uparrow}$ $\left[(r_p)^{\frac{\gamma-1}{\gamma}} \uparrow \quad \frac{1}{(r_p)^{\gamma-1/\gamma}} \downarrow \quad 1 - \frac{1}{(r_p)^{\gamma-1/\gamma}} \uparrow \quad \eta \uparrow \right]$

Work Ratio;

Work ratio for gas turbine system define as the ratio of net or usful Work to turbine expansion Work.

$$\text{Work Ratio} = \frac{\text{Net Work}}{\text{Turbine Work}}$$

$$\text{Net Work} = \text{Turbine Work} - \text{Compress Work}$$

$$= C_p(T_3 - T_4) - C_p(T_2 - T_1)$$

$$= C_p T_3\left(1 - \frac{T_4}{T_3}\right) - C_p T_2\left(1 - \frac{T_1}{T_2}\right)$$

$$= C_p T_3\left(1 - \frac{1}{(r_p)^{\frac{\gamma-1}{\gamma}}}\right) - C_p T_2\left(1 - \frac{1}{(r_p)^{\frac{\gamma-1}{\gamma}}}\right)$$

$$\therefore \boxed{\text{Work done} = 1 - \frac{T_1}{T_3}(r_p)^{\gamma-1/\gamma}}$$

Net Work Output;

$$= \text{Turbine Work} - \text{Compressor Work}$$

$$\text{Turbine Work} = W_T = C_p(T_3 - T_4)$$

$$\text{Compressor Work} = W_c = C_p(T_2 - T_1).$$

Qn. A brayton cycle operates with air entering the compressor at 1 bar at 25°C. The pressure ratio across the compressor is 3 to 1 and maximum temperature in the cycle is 650°. Determine the compressor Work, turbine Work, thermal efficiency and Work ratio of the cycle. [TE-II LIVE-8]

Qn. In a oil-gas turbine installation. It is taken as pressure of 1 bar and 27°C and compressed to a pressure of 4 bar. The oil with a calorific value of 42000 kJ/kg is brunt in the combustion chamber to raise the temperature of air to 550°. If the air flows at the rate of 1.2 kg/s.

find. (i) Net power for installation.

(ii) Air fuel ratio.

Take $C_p = 1.005$ kJ/kg

[TE Live - 09]

Isentropic Compression and expation efficiency:

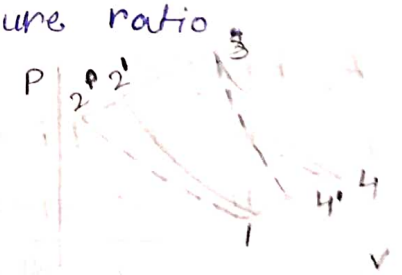
In actual practice, it is not possible to achive either isentropic compression or isentropic expantion.

These processes tends to become irreversible due to losses causes by internal friction.

In actual cycle the temperature at the end of compression and at the end of expantion are higher than in an ideal case for the same pressure ratio.

Efficiency of compresion process

$$H_c = \frac{T_2' - T_1}{T_2 - T_1}$$



Efficiency of expation process

$$H_e = \frac{T_3 - T_4}{T_2 - T_4'}$$

Qn. Air enters the compresser of a gas turbine plant oberating on Brayton Cycle at 1 bar and 300K. The pressure ratio is 5 and maximum cycle cycle temperature is limited to 1075 K. If the compressor and turbine efficiency are 80 % & 85 %, respectively. Calculate

a) Net work output

b) Cycle efficiency

c) Work Ratio.

[TE Lecture - 10]

Comparision Between "Gas turbine" and "IC engine".

1. The efficiency of Gas turbine is quite high as compared to IC engine because IC engine has large number of sliding Parts.
2. The exhaust from gas turbine is less polluting than IC exhaust because gas turbine used excess of air
3. The work develop by gas turbine per kg of air is more as compared to IC engine because gasses in gas turbine expands upto atmoshpheric pressure.
4. Because of low specific weight, gas turbine are used in Aircraft.
5. It is used difficult to start gas turbine than IC engine.
6. Thermal efficiency of simple gas turbine is less than IC engine.

Comparision Between "Gas Turbine" and "Steam Turbine".

1. The capital and running cost of gas turbine is less than steam turbine.
2. For same output gas turbine require less space than steam turbine.
3. Gas turbine can be install any where but steam turbine is install where water is available.
4. Start of gas turbine is more easily than steam turbine.

Jet propulsion

Jet: A highly velocity thin current of water gas comming out of a small hole is called jet.

Propulsion: The force which moves something forward is called propulsion.

Jet propulsion:

The thrust produced by passing a jet of fluid in the direction opposite to the motion of the object is called jet propulsion.

Principle of jet propulsion;

- The principal of jet propulsion involves imparting momentum to the mass of fluid in such a manner that the reaction of imparted momentum produced a propulsive force.
- The momentum to a mass of fluid may be acheved by expanding the gas, which is at high temperature and pressure through a nozzle.
- For jet propulsion the open cycle gas turbine is most suitable.
- Jet propulsion follow Newton's third law.

Classification of Jet propulsion systems;

1. Air Breathing Engines:

The engine in which oxygen necessary for combustion of fuel is taken from atmosphere is called air breathing engines.

2. Non Breathing Engines;

The engine which contain fuel and oxidizer which is necessary for cumbustion in the unit itself is called non breathing engines (Rocket).

Type of Air Breathing Engine;

1. Turbojet
2. Turboprop
3. Ramjet
4. Pluse Jet

Turbo jet :

The basic components of turbojet propulsion are;

a. Diffuser
b. Compressor
c. Combuster
d. Gas turbine
e. Nozzle

Diffuser;

- Diffuser is fitted at the entrance of turbojet and ambient air enters it at a velocity equal to speed of air craft.
- In diffusing system section, the entering air down and part of kinetic energy is converted into pressure. This type of air compression is called ram compressure.

Rotary Compressor;

The air after ram compression, get further compressed to pressure 3.2 to 4 bar in compressor.

Combuster;

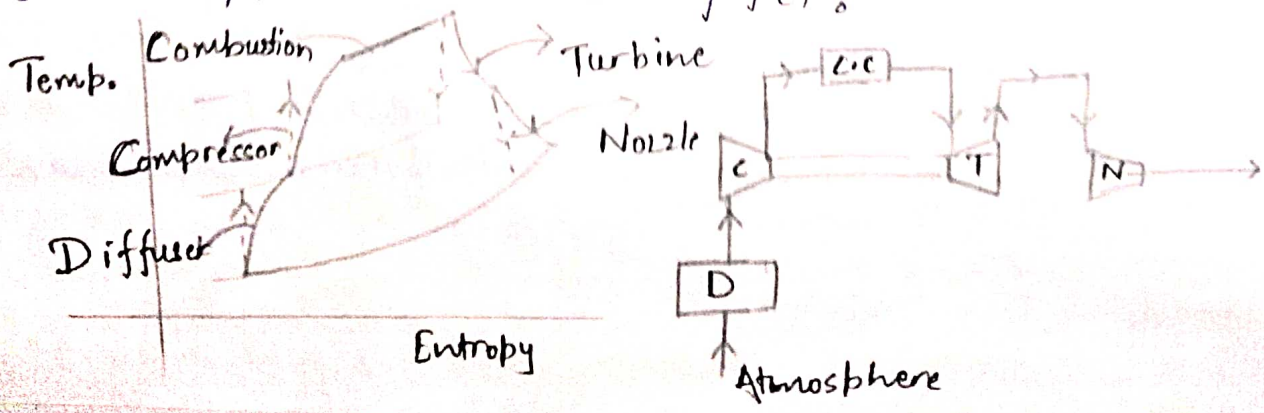
- The pressurised air from compressor is passed into the Combustion chember where fuel is injected.
- During combustion, the pressure remains constant.

Gas Turbine;

- The hot combustion product then enter the gas turbine where they are expand partially, undergo limited expantion.
- The turbine is design as the power output from it is Just sufficient to derive the compressor and auxilary equipment like fuel and lubricating pump.

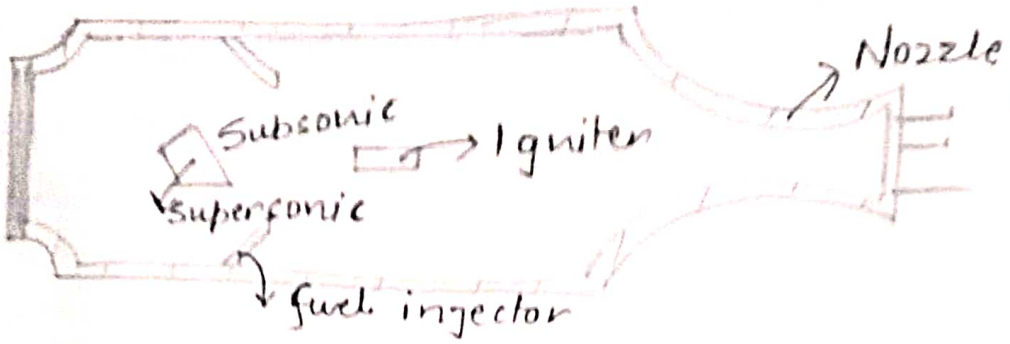
Nozzle;

- The exhaust gases from gas turbine which is at high pressure than atmospheric are expand in a nozzle and very high velocity Jet is produced.
- The exit velocity is much higher than that at the entry.
- Due to increase in velocity, there is change in momentum which provides thrust that propels the aircraft in a direction opposite to the exiting jet.



Ramjet:

- The ramjet is an aero-thermodynamic duct having continuous firing
- The basic components of Ramjet are;
  a. Diffuser
  b. Combustion chamber
  c. Exit Nozzle
- The system does not need the compressor and turbine units as the entire compression process is achieved through ram compression.
- The atmospheric air enters in the ramjet with supersonic speed and they gets slowdown to sonic speed in the supersonic diffuser.
- A shocked wave is formed accompanied by an increase in pressure. further increase in pressure occurs pressure in the subsonic diffuser.
- The pressure increase cause the temperature of air to rise above the ignition temperature.
- The unit has fuel injectors which inject the fuel in the combustion chamber.
- The air-fuel mixture is ignited by means of spark plug and temperature of the order of 2000k are attained due to heat released by combustion.
- The hot gases are at a pressure which is higher than that at the after end of diffuser, the hot gases are constrained to move forwards the nozzle and undergo expansion.
- The pressure energy is converted into kinetic energy and high velocity gases leaving nozzle provide forward thrust to the unit.

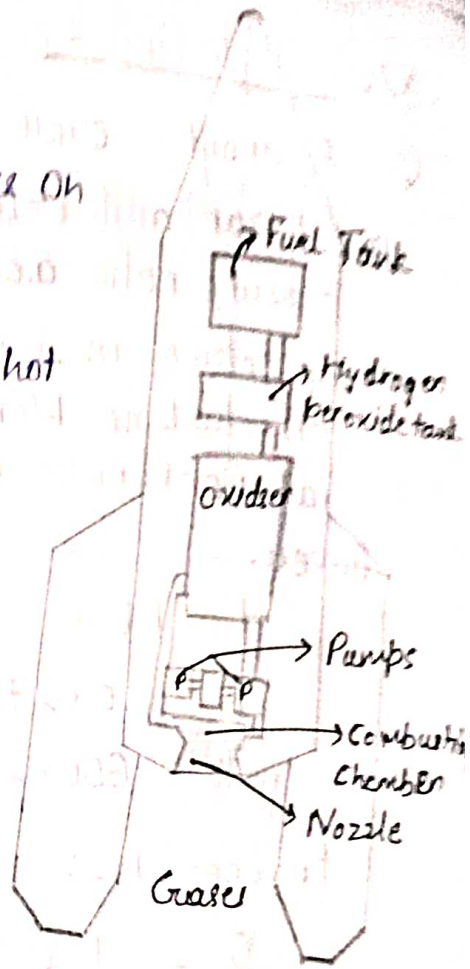


Rocket Engine:

- In rocket propulsion system the entire mass of the fuel and oxidizing agent is carried by rocket body itself.
- It operate better in vaccum, since no parts of the thrust developed will be wasted in overcoming the friction.
- The basic components of rocket engine are;
  a. fuel tank, b. oxidiser tank, c. two pumps, d. steam turbine, e. combustion chamber.
- The fuel contain alchohal and oxider tank contain liquid tank.
- The fuel and oxidiser are supplied by the pump to combustion chamber where fuel is ignited by electrial means.
- The pump is driven by steam turbine.
- Steam is produced by mixing a very concentrated hydrogen peroxide and potasium permagnet.
- The product of combustion are discharge from the compuston chember through the nozzle and rocket move in opposite side.
- This type of rocket may be used in missiles but in modified form.

Principle of rocket propulsion;

- The principle of rocket propulsion works on Newton third law of motion.
- The engine of the rocket released hot burning fuel in downward direction.
- As a result the gases apply equal and opposite force on the rocket in the upward direction.
- Due to this reaction rocket take off from earth.



Rocket

Application of Rocket propulsion;

1. It is used in long range artillary.
2. It is used in lethal weapon.
3. It is used is space ship.
4. It is used for satelite.
5. It is used for research purpose.

Numerical Unit 1

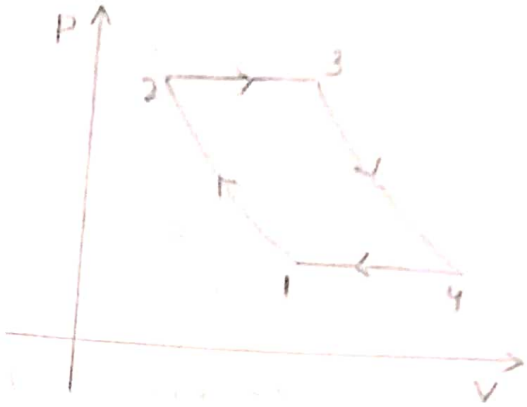
Qn. A brayton cycle operate with air entering the compre at 1 bar and entering the compressor and 25°C. The pressure ratio across the compressor is 3 to 1 and maximu temperature in the cycle is 650°C. Determine the compres work, turbine Work, thermal efficiency, thermal efficiency and work ratio of cycle.

Given.

$P_1 = 1$ bar

$T_1 = 25 + 273 = 298\,k$

$T_3 = 650 + 273 = 923\,k$



Process 1-2;

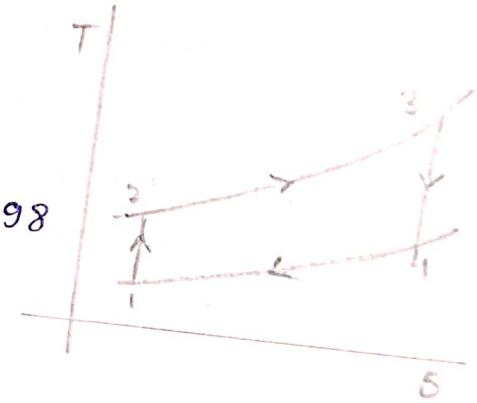
$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\gamma-1/\gamma}$$

$$\Rightarrow \frac{T_2}{T_1} = (3)^{\frac{0.4-1}{0.4}}$$

$$\Rightarrow \frac{T_2}{T_1} = 3^{\frac{0.4}{1.4}}$$

$$\Rightarrow T_2 = 3^{0.2857} \times T_1 = 1.368 \times 298$$

$$\Rightarrow T_2 = 407.877\,k$$



Process, 3-4,

$$\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}}$$

$$\Rightarrow \frac{T_3}{T_4} = 3^{0.2857}$$

$$\Rightarrow T_4 = \frac{T_3}{3^{0.2857}} = \frac{923}{1.368} = 678.36\,k.$$

Heat added to air

$$Q_1 = C_p (T_3 - T_1) = 1.005(923 - 407.87)$$

$$Q_1 = 517.70\ kJ/kg$$

Heat rejected from air,

$$Q_2 = C_p(T_4 - T_1) = 1.005(678.36 - 298)$$

$$Q_2 = 382.29 \text{ kJ/kg}.$$

Cycle efficiency;

$$\eta_{cycle} = \frac{\text{Work}}{\text{Heat supplied}} = \frac{Q_1 - Q_2}{Q_1}$$

$$= \frac{517.70 - 382.29}{517.70}$$

$$= \frac{135.44}{517.7} = 0.2616$$

$$\therefore \eta_{cycle} = 26.16\%$$

Compressor Work,

$$W_c = C_p(T_2 - T_1)$$

$$= 1.005(407.87 - 298)$$

$$= 110.41 \text{ kJ/kg}$$

Turbine work,

$$W_T = C_p(T_3 - T_4)$$

$$= 1.005(923 - 678.36)$$

$$= 245.86 \text{ kJ/kg}$$

Net work output;

$$W_n = W_t - W_c$$

$$= 245.86 - 110.41$$

$$= 135.45 \text{ kJ/kg}.$$

Thermal efficiency,

$$\eta_{th} = \frac{\text{Net work output}}{\text{Heat supplied}} = \frac{135.45}{517.70} = 0.2616$$

$$\therefore \eta_{th} = 26.16\%$$

Work Ratio;

$$WR = \frac{\text{Net work output}}{\text{Turbine Work}} = \frac{135.45}{245.86} = 0.5509$$

$$\therefore \text{Work Ratio} = 0.5509.$$

Qn. Air enters the compressor of a gas turbine plant operating on Braton cycle at 1 bar and 300k. The pressure ratio is 5 and Maximum cycle temperature is limited to 1075 k. If the compressor and turbine efficiency are 80% and 85% respectively. Calculate, a. Net work output
b. Cycle efficiency
c. Work Ratio.

Given,

$P_1 = 1$ bar

$T_1 = 300$ k

$r_p = 5$

$T_3 = 1075$ k

$\eta_c = 0.8$, $\eta_T = 0.85$,

Process, 1-2 :

$$\frac{T_2'}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$

$$T_2' = 5^{0.2857} \times T_1 = 475.13 \text{ k}.$$

$$\because \eta_c = \frac{T_2' - T_1}{T_2 - T_1}$$

$$0.8 = \frac{475.13 - 300}{T_2 - 300}$$

$$T_2 = 218.91 + 300 = 518.91 \text{ k}$$

Process, 3-4:

$$\frac{T_3}{T_4'} = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}}$$

$$T_4' = \frac{T_3}{(5)^{0.2857}} = \frac{1075}{1.583} = 679.09 \text{ k}$$

$$\eta_T = \frac{T_3 - T_4}{T_3 - T_4'}$$

$$\Rightarrow 0.85 = \frac{1075 - T_4}{1075 - 679.09} \Rightarrow T_4 = -0.85(395.91) + 1075$$

$$T_4 = 738.476 \text{ K}$$

Compressor Work;

$$W_c = C_p(T_2 - T_1)$$
$$= 1.005\,(518.91 - 300)$$
$$= 220.004 \text{ kJ/kg.}$$

Turbine Work,

$$W_T = C_p(T_3 - T_4)$$
$$= 1.005(1075 - 738.476)$$
$$= 338.206 \text{ kJ/kg.}$$

Net work output,

$$W_N = W_T - W_c$$
$$= 338.206 - 220.004$$
$$= 118.2026 \text{ kJ/kg}$$

Work Ratio;

$$WR = \frac{\text{Net Work Output}}{W_T}$$
$$= \frac{118.2026}{338.206}$$
$$= 0.349$$

∴ Work Ratio = 0.349.

Plant Efficiency/Thermal Efficiency

$$\eta_{\text{Plant/Thermal}} = \frac{\text{Net Work Output}}{C_p(T_3 - T_2)}$$
$$= \frac{118.2026}{1.005(1075 - 518.91)} = \frac{118.2026}{558.87} = 0.2115.$$

$$\therefore \eta_{\text{Plant}} = 21.15\%$$

Qu. In an oil gas turbine installation, it is taken at pressure of 1 bar and 27°c and compressed to a pressure of 4 bar. The oil with a calorific value of 42000 kJ/kg is burnt in the combustion chember to raise the temperature of air to 550°. If the air flows at the rate of 1.2 kg/s. Find (i) Net Power for installation. (ii) Air fuel ratio.

Given,

$P_1 = 1$ bar , $P_2 = 4$ bar

$C = 42000$ KJ/kg

$T_1 = 27°C = 300$ K

$T_3 = 550°C = 823$ K

$M = 1.2$ kg/s $C_p = 1.005$ kJ/kgK

Process 1-2 :

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$

$$T_2 = 4^{0.2857} \times T_1$$

$$= 1.485 \times 300$$

$$T_2 = 445.789 \text{ K}$$

Process 3-4 :

$$\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}}$$

$$T_4 = \frac{T_3}{1.485} = \frac{823}{1.485}$$

$$T_4 = 553.848 \text{ K}$$

Compressor work,

$$W_c = mC_p(T_2 - T_1)$$

$$= 1.2 \times 1.005(445.78 - 300)$$

$$= 183.71 \text{ kJ/kg}$$

Turbine Work

$$W_T = mC_p(T_3 - T_4)$$

$$= 1.2 \times 1.05 (823 - 553.848)$$

$$= 339.13 \text{ kJ/kg}.$$

Net power of installation

$$W_N = W_T - T_c$$

$$= 339.13 - 183.71$$

$$= 155.42 \text{ kJ/kg}$$

Heat supplied by oil,

$$Q_1 = mC_p(T_3 - T_2)$$

$$= 1.2 \times 1.05 (823 - 445.789)$$

$$= 475.66 \text{ kJ/s}$$

Mass of fuel burn per second,

$$= \frac{\text{Heat supplied}}{\text{Calorific Value}}$$

$$= \frac{475.66}{42000}$$

$$= 0.011 \text{ kg}$$

$\therefore$ Air fuel ratio $= \frac{1.2}{0.011}$

$\therefore$ Air fuel ratio $= 109.09$

UNIT - 2

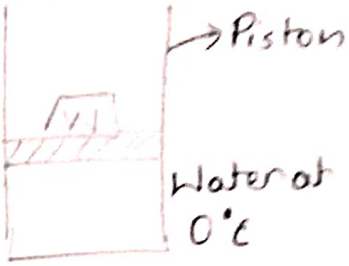
Properties of Steam ;

Vapour : The gaseous state of any substances is called vapour.

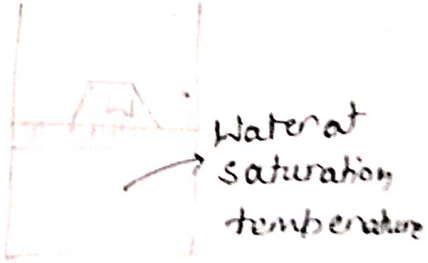
Steam : The gaseous state of water is called steam.

- Steam is always vapour but Vapour is not always steam.

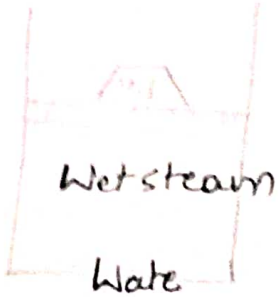
Steam formation at constant pressure ;



- Consider a cylinder piston arrangement in which piston can move upward-downward.
- In cylinder consider 1 kg of water at 0°C under piston.
- Above the piston, there is load W is kept to ensure heating at constant pressure.
- If we supply heat to water, there will be raised in temperature and this raised will continued till boiling point is reaches.
- As we know know temperature at which water start boiling depends upon the pressure therefore for each pressure there is a different boiling point.
- The temperature at which water start boiling is called Saturation point.



- During heating to boiling point, there will be slight increase in volume due to which piston move upward.
- If supply of heat to water is continued. The rise of temp. after the boiling point is reached but piston start moving upward which indicate increase volume which is only possible if steam formation occure

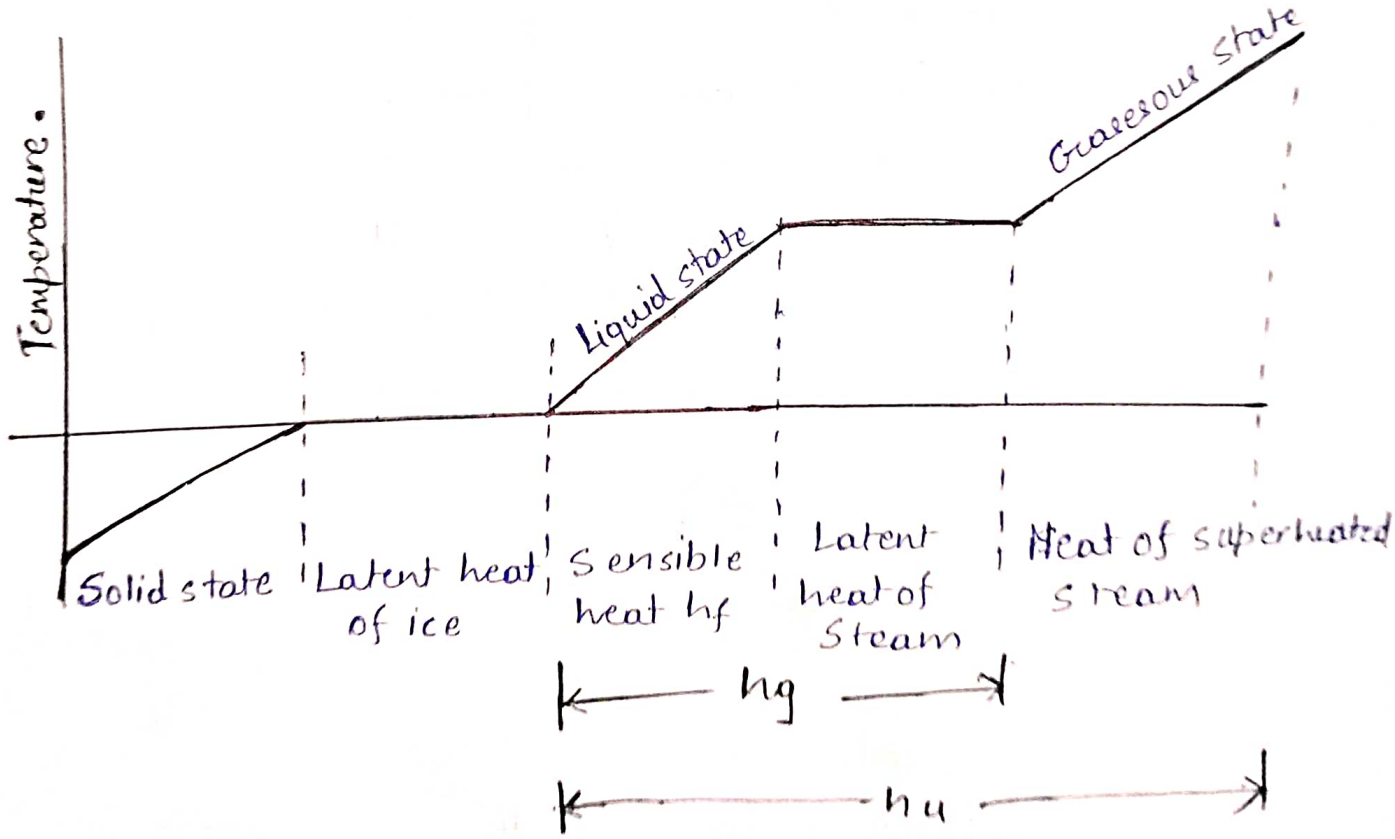


- So long as the steam is in contact with water, it is called wet steam.

- If again heat supplied is continuous the all water particle associated with steam are evaporated, the steam so obtained is called dry and saturated steam.

- Again if supply of heat to the dry and saturated steam is continued at constant pressure, there will be increase in temperature & volume of steam. The steam obtained is called super heated steam & it behave like perfect gas.

Graphical Representation of formation of steam;



Basic Terms:

Saturated liquid;

- The liquid is about to vaporised is called saturated liquid.
- In other words, the liquid which is about to convert into vapour is called saturated liquid.
- At atmospheric pressure the liquid at 100°c is called saturated liquid.

Saturated Vapour;

- The vapour which is about to condence into liquid is called saturated Vapour.
- At atmospheric pressure the vapor is at 100°c is called saturated vapour.

Saturation temperature;

- The temperature at which about to boiling at fixed pressure is called saturation temperature.
- In other words, the temperature at which pure substance changes its phase is called saturation temperature.

Saturated liquid line;

The line passing through all saturated liquid at different pressure is called saturated liquid line.

Saturated vapour line;

The line passing through all saturated vapour at different pressure is called saturated vapour line.

Vapour Dome;

The saturated liquid line and saturated vapour line inclined towards each other and form like dome structure is called vapour or saturated dome.

Critical point;

The point where liquid is directly and fully converted in vapour (dry) without going phase of evaporation is called critical point.

Wet Region;

The region between vapour dome between saturated liquid line and saturated vapour line is called Wet region.

- In all wet region, liquid & vapour both exist.

Dry fraction (x):

The ratio of mass of dry saturated vapour to the total mass of the mixture is called dryness fraction (x).

- It is denoted by 'x'.

$$x = \frac{\text{mass of dry saturated vapour}}{\text{mass of mixture}} = \frac{m_g}{m + m_g}$$

- If $x = 0.6$ then it represent 60% of mass dry saturated & 40% m_g.

Sensible Heat;

The quality of heat required to raise the temperature of 1 kg of water from 0°c to the boiling point or saturation temperature at given pressure is called sensible heat.

- It is denoted by h_f.
- It is also called total heat of water/enthalpy of Water.

- As pressure increases sensible heat will also increase.

Latent Heat of vaporisation (h_{fg});

- The quanity of heat required to converted 1kg of water at saturation temperature for given pressure into dry and saturated steam at the temp. and pressure is called latent heat of vaporisation
- If pressure ↑ → h_{fg} ↓
- At critical point, $h_{fg} = 0$.

Total heat of wet steam;

- The quantity of heat required to convert 1kg of water at ~~saturation~~ 0°c into wet steam at constant pressure is called total heat of wet steam.
- It is denoted by "h_{wet}".
- $h_{wet} = h_f + x h_{fg}$

$$\boxed{h_{wet} = h_f + x(h_g - h_f)}$$

Total heat of dry saturated steam;

The quantity of heat required to convert 1 kg water at 0°c into dry saturated steam at constant pressure is called total heat of dry saturated steam.

- It is denoted by 'h_g'.
- $h_s = h_f + x(h_g - h_f)$

for dry saturated steam, $x = 1$,

$h_s = h_f + (h_g - h_f)$

$$\boxed{h_s = h_g}$$

Total heat of superheated steam;

It represent the quantity of heat required to convert 1 kg of water at 0°c into superheated steam at constant pressure.

- It is denoted by 'hsup'.
- $h_{sup} = h_f + h_{fg} + C_{ps}(t_{sup} - t_s)$

$$\Rightarrow \boxed{h_{sup} = h_g + C_{ps}(t_{sup} - t_s)}$$

Wet steam;

- The mixture of saturated liquid and dry vapour during the phase change is called wet steam.
- Wet steam is charaterised by it dryness fraction.

Superheated Vapour;

The vapour whose temperature is greater than the saturation temperature crossponding to the pressure of the vapour called superheated vapour.

Degree of superheat;

The amount by which the temperature of a superheat vapour exceeds the saturation temperature is called degree of superheat.

- Degree of superheat = $(T_{sup} - T_s)$.

Wetness Steam fraction;

The ratio of mass of water vapour or moisture in ~~suber-pention~~ suspention with the total mass of steam which contain it, is called wetness steam fraction

- It is denoted by 'y'.

$$\boxed{y = \frac{m_f}{m_f + m_g}}$$

$$y = 1 - \frac{m_g}{m_f + m_g}$$

$$\boxed{y = 1 - x}$$

Steam Table;

- For any fluid, working as working fluid, the six basic T.D. property are required;

→ Pressure, Temperature, volume, Enthalpy, internal energy, and entropy.

- The value of these properties are determined theoratically or experimently and tabulated in form of tables which are known as steam table

- Steam table gives the value of specific volume entropy and enthalpy for saturated liquid and dry saturated vapour labulated against pressure or crosponding saturation temperature.

Qn. Calculate the dryness fraction of steam which has 1.25 kg of water in suspension with 40 kg of steam. [TE-II Live-2017]

Qn. Determine the state of steam i.e. wheather it is wet, dry or superheated in following cases;

1) Steam has a pressure of 10 bar and specific volume 0.175 m^3/kg.

2) Steam has a pressure of 15 bar and temperature of 220°C.

3) Steam has pressure of 20 bar and if 2700 kJ/kg of heat is required to generate the steam from water at 0°C.

Qn. A spherical shell of 30 cm in radius contains saturated steam and water at 300°c. Calculate the mass of each if their volumes are equal

Qn. A closed container hold 1kg of water at 158°c temperature with following composition by volume 1/3 liquid & 2/3 vapour. Determine the pressure, quality, volume and entropy of mixture.

Qn. A vessel of 0.05 m³ capacity contains a mixture of Saturated steam and water at a temperature of 300°c. The mass of liquid water is 10 kg. Determine pressure, mass enthalpy, specific volume, internal energy and entropy of contents present in vessel.

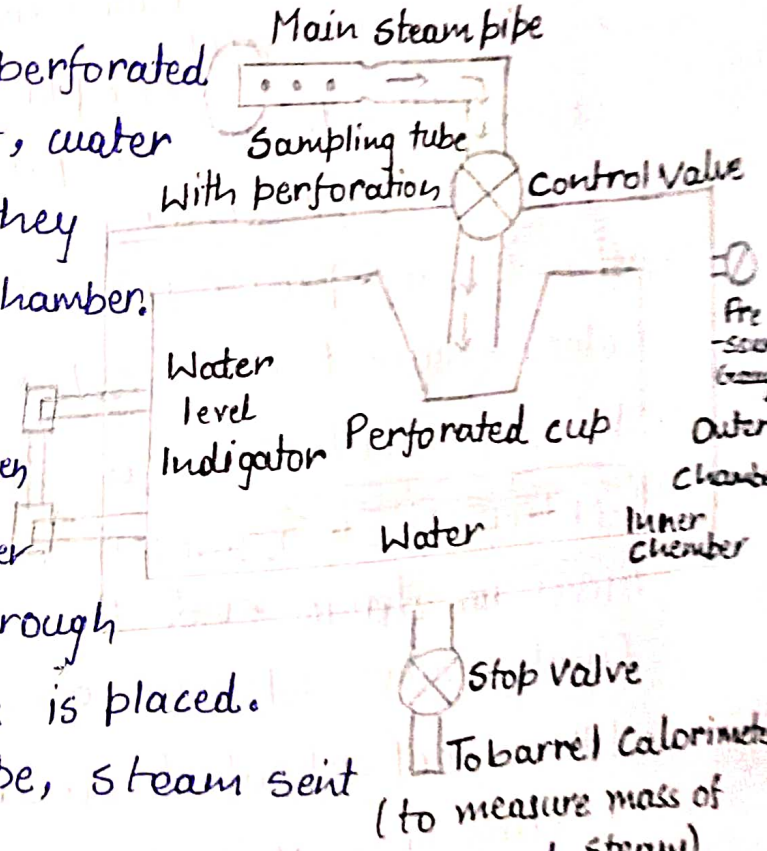
Qn. Steam at 1000 kPa and 300°c enter an engine and expand to 20 kPa. If the exhaust steam has dryness fraction of 0.9 make calculation for the drop in enthalpy and change in entropy.

Steam Caloremeter

- The cylindrical vessel made of copper sheet which is used to measure the dryness fraction of steam is called steam calorimeter.
- The dryness fraction of steam can be measured by using following calorimeters;
  - Seperating calorimeter
  - Throttling Calorimeter
  - Seperating and throttling calorimeter.
- A calorimeter function by measuring condensation of known mass of steam.

Seperating Calorimeter

- Seperating calorimeter is used to measure dryness fraction of wet steam.
- The steam is supplied to calorimeter from main steam pipe through a sampling tube where it strike to perforated cup.
- The perforated cup has minute hole.
- As wet steam reaches to perforated cup. due inertia of droplet, water particle are seperated & they are collected in inner chamber.
- The steam due to light density, it will move between outer and inner ~~dia~~ chamber And then steam passes through the pipe where stop valve is placed.
- After passing through pipe, steam sent to barrel calorimeter where steam condence and mass of steam calculated.
- Through water level indicated we can find mass of water.
- Finally as we found mass of water and mass of steam then we able to calculated dryness fraction of wet steam.

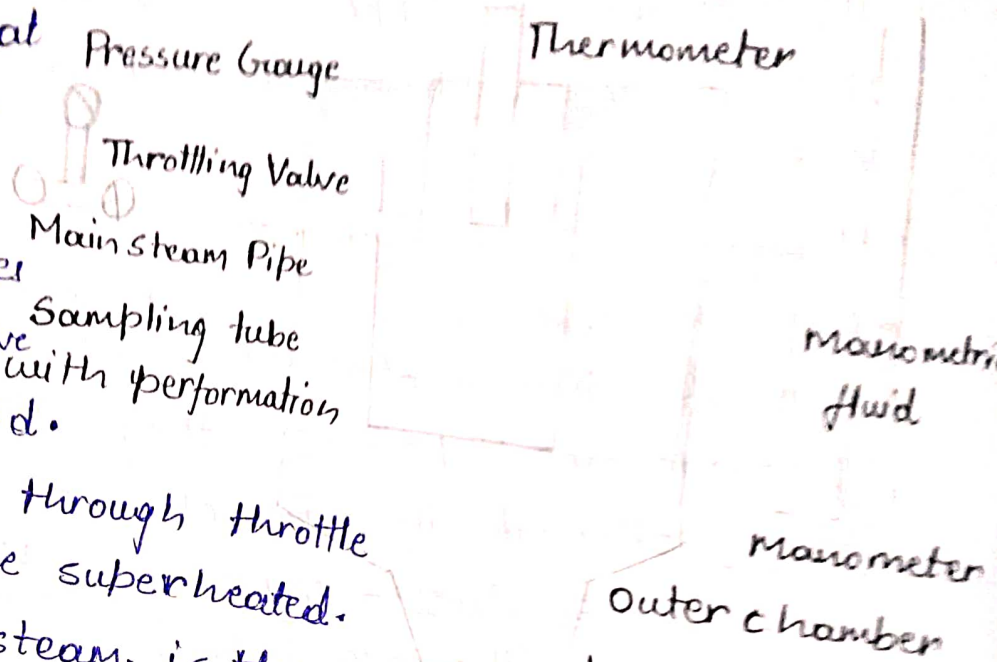


Throttling Calorimeter

- The dryness fraction of wet steam can be calculated by using throttling calorimeter.
- It is used to measure dryness fraction of very dry steam.
- The sample of steam at pressure P_1 is taken from main pipe.
- Then steam is passes through throttle valve where it is throttled.
- After steam passes through throttle valve, steam become superheated.
- The superheated steam is then enter to centre portion of charimeter and moves down and then moves ~~to~~ down and then moves in innerchamber and finally moves up and goes to outer chamber.
- When superheated steam moves in outer chamber, Steam goes into manometer and pressure of steam can be measure.
- After throttling, A temperature of steam is measure by therometer.
- Principle of throttling calorimeter:

Enthalpy of steam before throttling = Enthalpy of steam after throttling

$$\boxed{h_{f_1} + x_1 h_{fg_1} = h_{g_2} + C_{ps}(t_{sup} - t_{sat})}$$



Seperating & Throttling Calorimeter :

A combination of seperating & throttling calorimeter are used to remove the drawback of separating calorimeter (ie water particles from wet steam are not fully seperated) and the drawback of Throttling Calorimeter (i.e. not suitable for very wet steam).

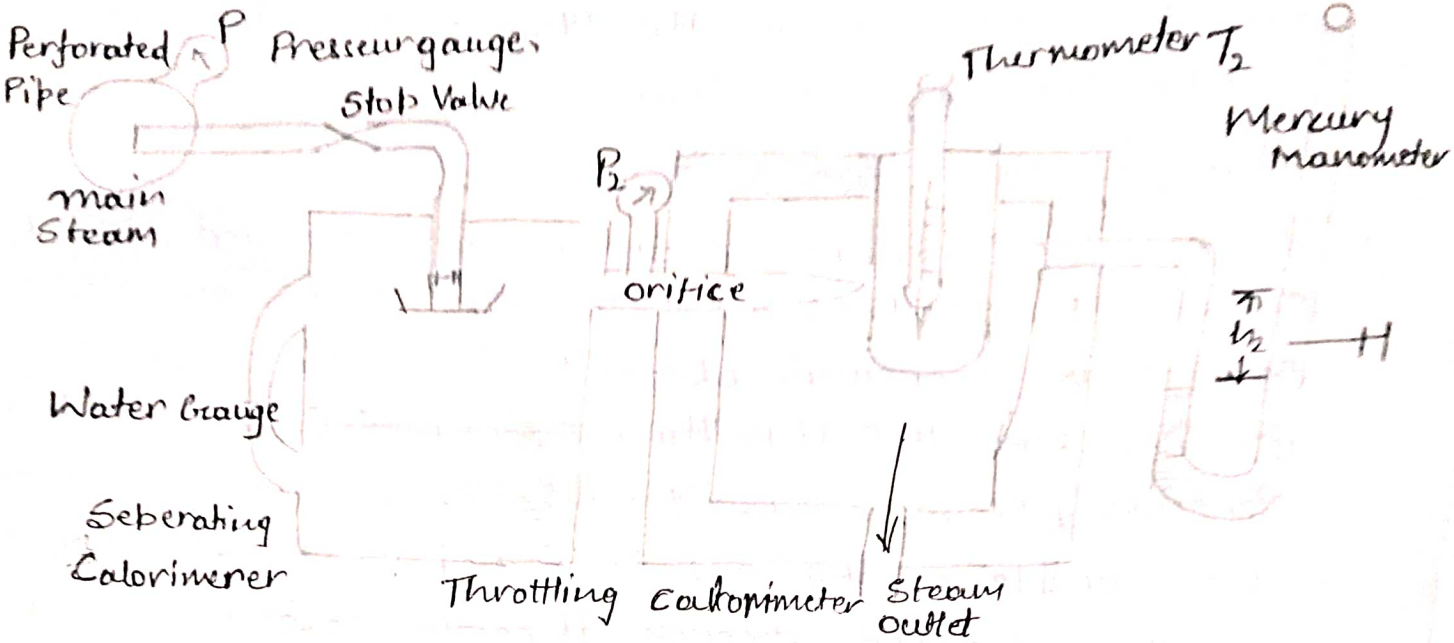
Working :

- The moisture from wet steam is first removed in seperating calorimeter, so that dryness fraction of wet steam sample is increased above 0.95 before steam sample is entering into throttling calorimeter. During this process pressure and temperature remains constant.
- The sample coming out from separating calorimeter is then passed through throttling calorimeter where it expands to superheated steam.

Procedure :

- A sample of wet steam from main steam pipe is first enters the separating calorimeter through a sampling tube.
- While passes through separating calorimeter, most of the moisture from wet steam is seperated out and collected in the inner chamber of the seperating calorimeter where it is measure with scale.
- Now, comparitively dry steam having dryness fraction above 0.15 from separating calorimeter is passed into throttling calorimete through throttling valve where it expands to superheated steam.

- The superheated steam after passing through throttling Calorimeter is then exhaust from calorimeter into a condenser, provided at the bottom of the throttling calorimeter, where it is finally condensed & measured.



Qn. Calculate the dryness fraction of steam which has 1.25 kg of water in suspension with 40kg of steam.

Given, mass of steam, $m_s = 40kg$

mass of water, $m_w = 1.25 kg$

Dryness fraction, x

$$x = \frac{m_s}{m_s + m_w}$$

$$= \frac{40}{40+1.25}$$

$$= 0.9696$$

$\therefore$ Dryness fraction, $x = 0.97$.

Qn. Determine the state of steam, i.e. whether it is wet, dry or superhead in following cases,

i) Steam has a pressure of 10 bar and specic volume 0.175 m

ii) Steam has a pressure of 15 bar and temperature of 220°C.

iii) Steam has a pressure of 20 bar and if 2700 kJ/kg of heat is required to generate the steam from water at 0°C.

(i) At, $p = 10 bar$

$v_g = 0.194 \ m^3/kg$

$v_g > 0.175$

$\therefore$ Steam is wet.

(ii) At, $p = 12$ bar

$T_s = 198.3°C$

$T_s < 220°$

$\therefore$ Steam is superheated.

(iii) At, $p = 20$ bar

$h_g = 2797.2 \ kJ/kg$

$h_g > 2700 \ kJ/kg$

$\therefore$ Steam is wet.

Qn. A spherical shell of 30 cm in radius contains saturated steam and water at 300°c. Calculate the mass of each if shear volumes are equals.

Radius of shell, $r = 30\,cm = 0.3\,m$

Volume of shell, $V = \frac{4}{3}\pi r^3$

$= \frac{4}{3}\pi (0.3)^3$

$= 0.1130\ m^3$.

Volume of vapour = Volume of water

$$V_g = V_f = \frac{0.1130}{2} = 0.0565\ m^3$$

from steam table,

At, $t = 300°C$

$V_f = 0.001404\ m^3/kg$

$V_g = 0.0216\ m^3/kg$

$\therefore$ mass of vapour $= \frac{0.0565}{0.0216} = 2.616\ kg$

mass of water $= \frac{0.0565}{0.001404} = 40.242\ kg$

Qn. A container (closed) hold 1 kg of water at 153.3°c temperature with following composition by volume 1/3 liquid and 2/3 vapour.

Determine the pressure, quality, volume and enthalpy of mixture.

Given, $t = 153.3°C$

$$\frac{V_f}{V_g} = \frac{1/3}{2/3} = \frac{1}{2}$$

According to question, there is mixture of water and its vapour. Therefore pressure should be same as the saturation pressure.

At, $t = 153.3°C$, pressure $p = 5.2$ bar.

$$\frac{V_f}{V_g} = \frac{1}{2}$$

$$\frac{m_f \times 0.001094}{m_g \times 0.361} = \frac{1}{2}$$

$$\frac{m_f}{m_g} = 165$$

∴ Dryness fraction,

$$x = \frac{m_g}{m_f + m_g} = \frac{m_f/165}{m_f + m_f/165}$$

$$x = 0.00602.$$

For wet steam, specific volume,

$$v = (1-x)v_f + x\,v_g$$

$$= (1-0.00602)\,0.001094 + 0.00602 \times 0.361$$

$$= 3.2606 \times 10^{-3}\ m^3/kg.$$

Specific enthalpy,

$$h = (1-x)\,h_f + x\,h_g$$

$$= h_f + x(h_g - h_f)$$

$$= 646.7 + 0.00602\,(2103.8)$$

$$h = 659.36\ kJ/kg.$$

Qn. A vessel of $0.05\ m^3$ capacity contains a mixture of saturated steam and water at a temperature of 300°C; The mass of liquid water being 10 kg. Determine pressure, mass, enthalpy, specific volume, internal energy and entropy of contents present in vessel.

Volume of vessel, $V = 0.05\ m^3$

Steam is wet,

$t = 300°C$,

pressure, $p = 86$ bar

Total volume = Vol^m of water + Vol^m of steam

$$V = V_f + V_g$$
$$= m_f v_f + m_g v_g$$

$$0.05 = 10 \times 0.001404 + m_g \times 0.0216$$

$$m_g = 1.6648\ kg.$$

$\therefore$ Total mass, $m = m_f + m_g$

$$= 10 + 1.6648$$

$$m = 11.6648\ kg$$

Dryness fraction,

$$x = \frac{m_g}{m_f + m_g} = \frac{1.6648}{10 + 1.6648}$$

$$= 0.1427.$$

Specific volume of steam, $v = \frac{V}{m} = \frac{0.05}{11.6648} = 0.004286\ m^3/kg.$

Enthalpy of steam,

$$H = m(h_f + x\ h_{fg})$$
$$= 11.6648(1345.4 + 0.1427 \times 1045.5)$$
$$= 180335$$

Qn. A vessel of 0.05 m^3 capacity contains a mixture of saturated steam and water at temperature of 300°C, The mass of liquid water being 10 kg. Determine pressure mass, enthalpy, specific volume, internal energy and entropy of contents present in vessel.

~~Volume of vessel, $v = 0.05\ m^3$~~

~~Steam is wet,~~

~~$t = 300°C$~~

Qn. Steam at 1000 kPa at 300°C enters an engine and expands to 20 kPa. If the exhaust steam has a dryness fraction of 0.9 make calculation for the drop in enthalpy and changes in enthalpy.

At entry of engine,

$p = 1000\ kPa = 10\ bar$,

$t = 300°C$

At $p = 10\ bar$,

$t_{sat} = 179.9°C$

∴ Steam enter to engine at super heat state,

At $p = 10\ bar$

$h_f = 3051.2\ kJ/kg$

$S_f = 7.123\ kJ/kgK$

At $p = 20\ kPa = 0.2\ bar$

$h_f = 251.5\ kJ/kg$

$h_{fg} = 2358.4\ kJ/kg$

$S_f = 0.8321\ kJ/kgK$,

$S_{fg} = 7.0773\ kJ/kgK$

$h_2 = h_f + x h_{fg}$

$= 251.5 + 0.9 \times 2358.4$

$= 2374.06\ kJ/kg$

$S_2 = S_f + x S_{fg}$

$= 0.8321 + 0.9 \times 7.0773$

$= 7.2017\ kJ/kgK$.

Change in enthalpy $= h_2 - h_1$

$= 2374.06 - 3051.2$

$= -677.14$ kJ/kg

Drop in enthalpy $= 877.14$ kJ/kg.

Chang in entropy $= S_2 - S_1$

$= 7.2017 - 7.129$

$= 0.0787$ kg/kgK.

UNIT - 3

Boiler:

- The equipments used for producing steam is called boiler.
- Boiler is also known by steam generater.
- In other words boiler may be define as a closed vessel in which steam is produced from water by combustion of fuel.
- The steam produced by boiler is used in
  - a. Steam Turbine
  - b. Steam Engine
  - c. For heating the building in cold season.

Function of Boiler:

- The water is contained in boiler called shell and thermal energy realeased during combustion of fuel.
- The fuel may be solid, liquid or gas.
- The thermal energy released from combustion of fuel is transferred to water and this convert water into steam at desired temperature and pressure.

Classification of Boiler;

1. Relative position of Hot gasses and water;

a. Fire Tube Boiler:

The boiler in which hot gasses pass through the tube and water surrouds the tubes is called fire tube boiler.

Example; Cochran, Locomotive etc.

b. Water Tube Boiler:

The boiler in which water passes through the tube and hot gasses surrounds the tube is called water tube boiler.

Example; Babcock and Wilcox, Stirling, etc.

2. Method of Firing;

a. Initially fixed Boiler / Internally fixed boiler:

The boiler in which ~~combustion~~ furnace region (space in which combustion of fuel take place) is provided inside the boiler is called internally fixed boiler.

Example ; Cochran , Lancashire boiler.

b. Externally Fixed Boiler:

The boiler in which furnace region is provided outside the boiler shell is called externally fixed boiler.

Example ; Stirling, Babcock and Wilcox boiler.

3. Relative to axis of boiler;

a. Horizontal Boiler;

The boiler whose axis is horizontal is called horizontal boiler.

Example; Lancashire, Locomotive, Babcock & Wilcox.

b. Vertical Boiler;

The boiler whose axis is vertical is called vertical boiler. Example ; Cochran Boiler.

c. Inclined Boiler;

The boiler whose axis is inclined is called inclined boiler.

4. Method of circulation of water:

a. Force Circulation:

In a boiler, the circulation of water is done by forced pump, then such type of boiler is force circulation type boiler.

Example, Lamont, Benson boiler.

b. Natural Circulation:

In a boiler, circulation of water is take place due to natural convection current produce by application of heat, then such type of boiler is natural circulation type boiler.

Example; Lancashire, Babcock & Wilcox Boiler,

5. Pressure of Steam;

a. High Pressure Boiler:

The boiler which produce steam above the pressure of 80 bar is called high pressure high pressure boiler.

b. Low Pressure Boiler:

The boiler which produce steam below the pressure of 80 bar is called low pressure boiler.

Example; Cochran, Lancashire, Locomotive etc.

6. No of tubes in boiler;

a. Single Tube Boiler:

A boiler which has only one fire tube or water tube ~~boiler~~ is called single tube boiler.

Example; Cornish, vertical boiler.

b. Multitube Boiler:

A boiler which having two or more than two fire tube or water tube is called multitube boiler.

Example; Lancashire, Locomotive, Willcock & Babcocks boiler.

7. Nature of service to be performed;

a. Stationary boiler. The boiler which is stationary and cannot move from one place to other is called Stationary boiler.

b. Portable Boiler;

The boiler which can more from one place to another is called portable boiler.

Those boiler are made on wheel.

It is also known by mobile boiler.

- Comparision between Fire & Water tube boiler;

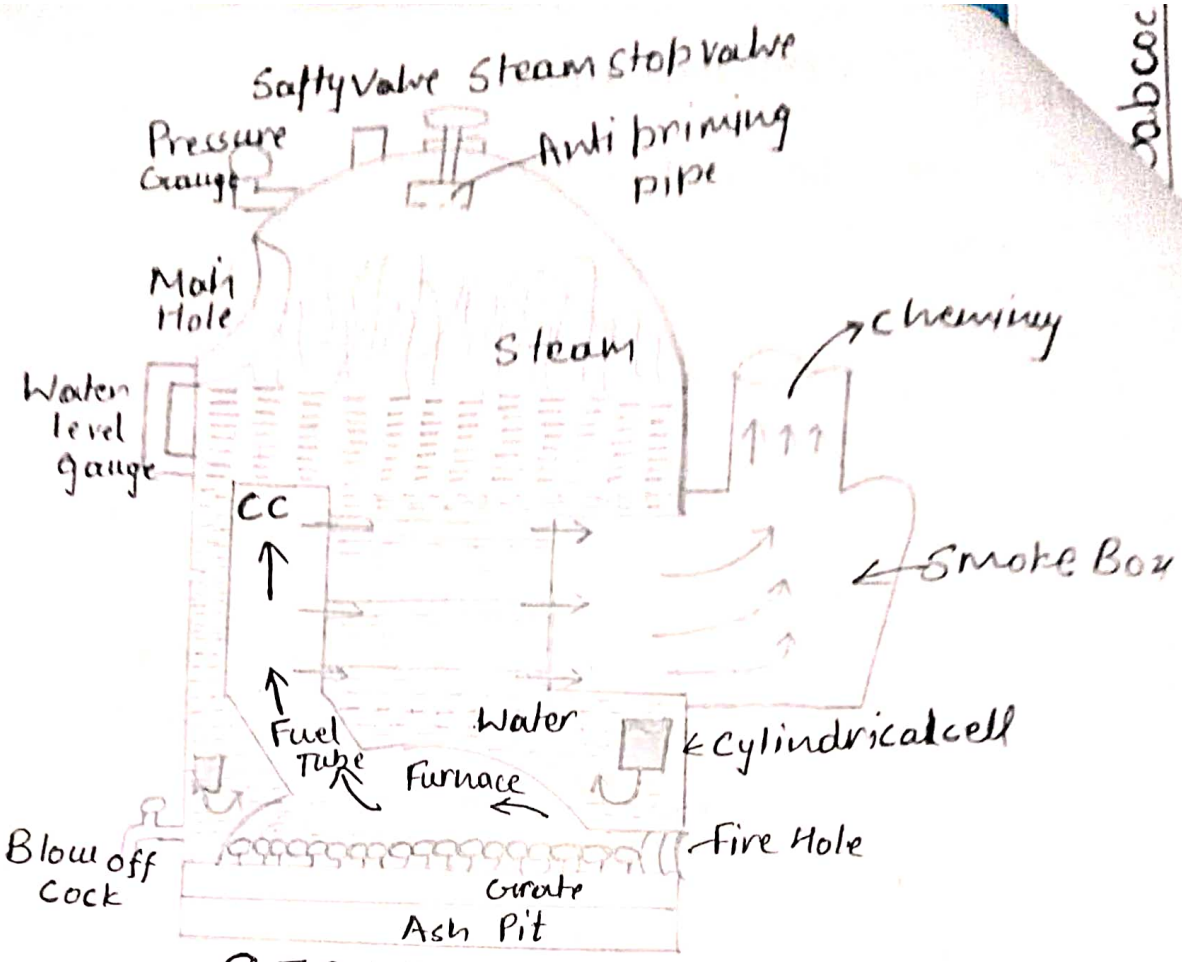
1. In fired tube boiler, fire is inside the tube and water is outside the tube whereas, in water tube boiler, Water is inside the tube and fire is outside the tube.
2. Fire tube boiler are internally fixed boiler whereas water tube boiler is externally fixed.
3. Rate of steam production in fire tube boiler is less than water tube boiler.
4. Operating pressure of fire tube boiler is limited to 16 bar whereas in water tube operating pressure is limited to 100 bar.
5. Fire tube boiler is cheaper than water tube boiler.

Cochran Boiler

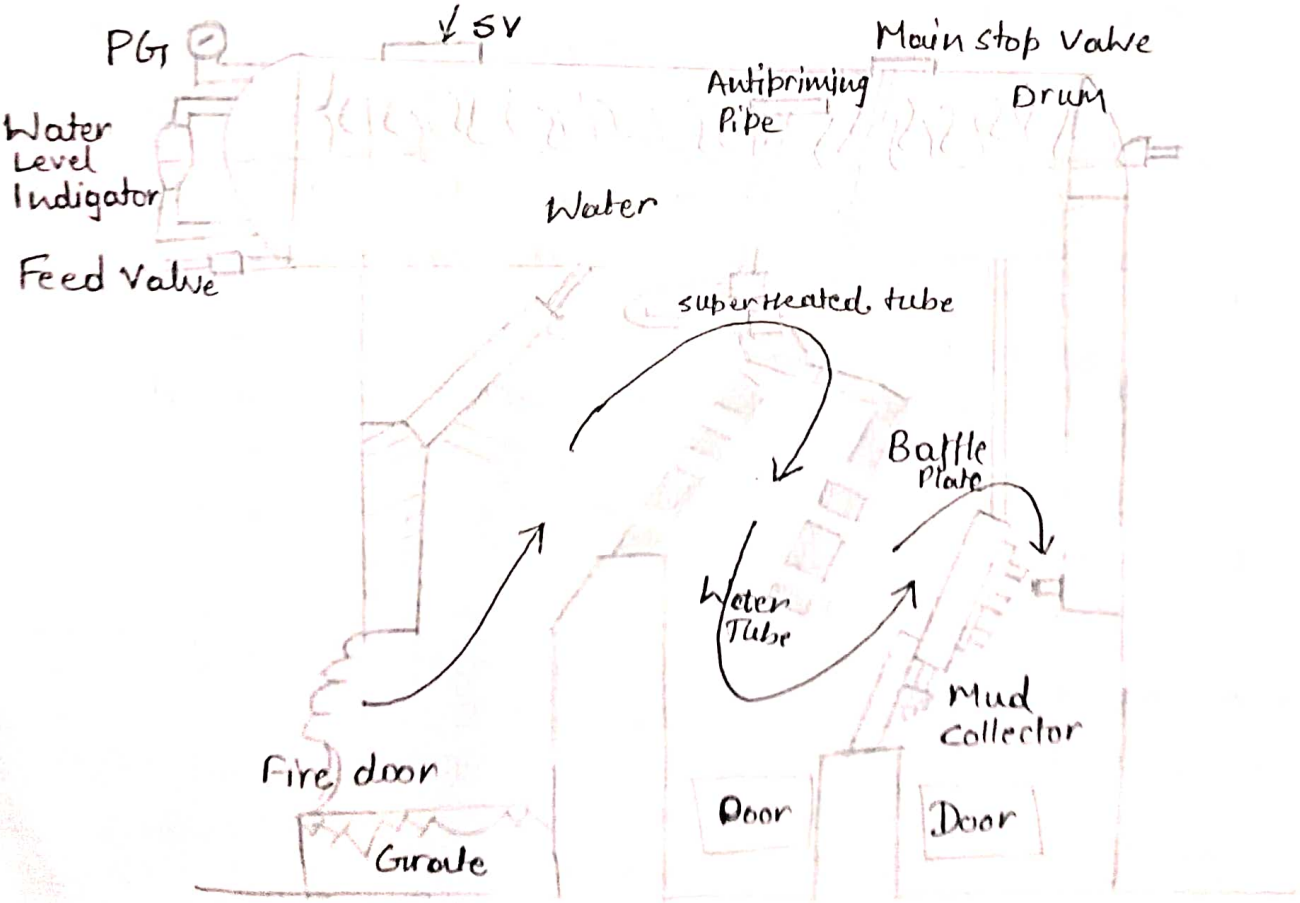
- Cochran boiler is vertical, internally fixed, muti-tubular boiler having number of horizontal fire tube.
- Height of cochran boiler is 5.8 m and work between 6.5 bar to 15 bar.
- Cochran boiler produce 3500 kg to 4000 kg of steam per hour and efficiency of this boiler is 70 - 75%.

Working of Cochran Boiler:

- Cochran boiler is vertical, internally fired, multitubular boiler consist of cylindrical shell with a dome shaped top where space is provided for steam.
- The shell is made of steel plate.
- The fuel is brunt on grate in the furnace provided at the bottom-most part of boiler.
- The grate consist of iron bar which are arrange with spacing between them. The spacing allow the air to pass onto the fuel for combustion.
- The firebox is hemispherical so that the unbrunt fuel, if any, is deflected back to grate and complete combustion can achieved.
- An ashpit is attached below the furnace for collecting after regular interval.
- The fuel on burning produce hot fuel gases and these hot gases produces of combustion from fire box enter through small fuel pipe into the combustion chamber, which is lined with fire bricks.
- After striking against fire bricks, hot gases is directed to pass through no. of horizontal tube, which is surrounded by water.
- The hot gas gives heat to water and water is converted into steam.
- After giving heat, hot gases escape to atmosphere through make box & chimney.



COCHRAN BOILER



BOBCOCK & Willcox BOILER

Babcock & Wilcox Boiler;

- Babcock & wilcox boiler is horizontal, externally fired, water tube boiler having no. of inclined water tube.
- Length of this boiler is 6m to 9m and work at maximum pressure of 40 bar.
- It can produce 40000 kg of steam per hours and has efficiency of 60-80%.

Working of Babcock & Wilcox Boiler:

- It consist of welded steel high pressure drum mounted at top.
- The end of drum is connected with uptake and downtake header.
- The header are joined to each other by large number of tubes which are kept inclined at an angle of 15° to the horizontal tubes are straight.
- The furnace is arrange below the Uptake header and combustion of fuel take place and ash is drop in ashpit.
- At the bottom of downtake header mud box is provided across the water tubes to acts as deflectors to flue gases and to provide them with gas pass.
- To get superheated steam, superheater tube is provided which are arrange above the water tube.
- Feed valve is provided on the drum to fill water to drum.
- The boiler drum shell is filled with water through feed valve and constant water level is maintained upto about 2/3rd part in the shell.
- The water through drum flow through inclined tube via downtake header and then goes back into the shell in form of water and steam via uptake header.

- The steam get collected in the steam space of the
- The steam then enter the antipriming pipe and flows in the superheated tube where it further heated.
- Finally taken out through the main stop valve and supplied to the engine when needed.

Boiler Mounting :

- The mechanical device which are fitted on boiler to operate the boiler smoothly and safely is called boiler mounting.
- Boiler mounting are part of boiler which are mounted on the boiler own's body.
- Boiler mounting protect the boiler from damage to itself due to high pressure, low water, irregular water pressure.

Example of Boiler Mounting;

1. Pressure Gauge
2. Water Level Indicator
3. Fusible plug
4. Blow Down cock
5. Stop Valve
6. Safety Valve
   a. Dead Weight
   b. Spring loaded type
   c. High pressure & Low pressure safety valve.

Pressure Gauge :

Function; Each boiler has a pressure guage which records the pressure at which steam is being generated in the boiler.

• Location;

The pressure gauge is usually mounted at the front top of boiler shell or drum so that it is easily visible to attendant to record pressure reading.

Pressure recorded by pressure gauge is the difference of pressure between steam and atmosphere.

Water Level Indicator;

- Function; The function of water level indicator is to indicate exact level of water in a boiler.
- Location; Water level indicator is fitted in the front of boiler from where it is easily indicator is connected with steam space and bottom with water space.

It is also known by "water gauge".

Fusible Plug :

- Function; The function of a fusible plug is to protect the boiler against the damage due to overheating for low water level.

As we know that when the water on heating transforms into steam, the level of water in the boiler falls down. If water is not fill again and steam generation continues then the part which have been uncovered by water may get overheat and get melted to safe card against this we use furible plug.

- Location; The furible plug is inserted at the box crown or over the combustion chamber at the lowest permissible water level.

Blow Down cock:

- Function;

The blow down cock serves to drain out the water from the boiler for any one of following reason;

a. To discharge mud, scale and other impurities which ie H/p down at the bottom of boiler.

b. To empty boiler for internal cleaning and inspection.

c. To lower the water level rapidly if the level of water in boiler become high.

- Location; Blow down cock is mounted at the lowest portion of the boiler.

Stop Valve;

- Function; The function of stop valve is to shut off or regulate the flow of steam from boiler to steam pipe or from steam pipe to engine.
- Location: The stop valve is mounted on the highest part of steam space of boiler and is connected to steam pipe which carry steam to engine.

Safety Valve:

Function; The function of safety valve is to permit the steam in the boiler to escape to atmosphere when pressure in the steam exceeds a certained specified limit. Thus safety valve prevent the building up excessive pressure in boiler.

Location; The safety valve is located above the steam space in the boiler.

Working Principle;

The safety valve operate on the principle that a valve is pressed against its seat through some agency such as strut, screw or spring by external weight or force.

When the steam force due to boiler pressure acting under the valve exceeds the external force, the valve gets lifted off its sheat and some of the steam rushes out till normal pressure is restored again.

Commonly used safety valve:

1. Dead weight safety valve
2. Spring loaded safety valve
3. High steam Low water safety Valve

Dead Weight safety valve:

- The dead weight safety valve consist of a valve 'V' which is made-up of gun metal to prevent rusting.
- This valve rest on the gun metal sheet 'S' and fix to the top of a vertical steam pipe 'P'.
- The pipe has a flange 'F' at the bottom for fixed at the top of the boiler shell.
- The weight carrier 'c' is suspended from top of the boiler.
- It carries cast iron rings (Weight W).
- The total weight must be sufficient to keep the valve on its seat against normal working pressure.
- When steam pressure in a boiler exceeds the normal working pressure, it lift the valve with its weight.
- The excess steam therefore escape through the pipe to the atmosphere until the pressure reaches its normal value.

Spring loaded Safety Valve :

- A spring loaded safety valve is a type of pressure relief valve designed to automatically release excess pressure from a close system to prevent failure.
- It is used in stram boiler, pressure vesseled etc.
- The basic principle behind a spring loaded safety valve is relatively simple.
- The valve is equipped with a spring that exerts a force to keep it lightly closed.
- As pressure build up within a system, it acts against the force of spring.
- Once the pressure reached to predetermined set point, it over come the spring force, causing the valve to open and discharge the excess pressure.

Boiler Accessary:

The mechanical devices which is install to increase the efficiency of steam boiler and help in proper working of boiler unit are called boiler accessaries.

- Boiler accessary are not important part of boiler but without boiler accessries, boiler efficiency becom less.
- Some important boiler accessories;
  - a. Feed Pump.
  - b. Economiser
  - c. Super Heater
  - d. Air-pre Heater.

Feed Pump :

- The pressure inside a boiler is high and so feed water has to be raised in pressure before its entry.
- Feed pump is a device which raised the pressure of water and force it into the boiler.
- The commonly employed pumping devices are a. centrifugal pump. b. Reciprocating pump.

Economiser :

- The economiser is a device which serves to recover some of the heat being carried by exhaust fuel gases.
- The heat thus recovered is uttilized in raising the temperature of feed water being supplied to the boiler.
- If feed water at raised temperature is supplied to the boiler, it needs heat for its conversion into steam and thus there is saving in the consumption of fuel.
- Advantages of economiser are
  a. Improve Thermal Efficiency
  b. Reduction in the losses of heat with fuel gases.

Super Heater:

- The steam generated by a simple boiler is generally wet or at most dry saturated.
- Steam super Heater is a surface heat exchanger in which wet steam is first dried at the same temp. and pressure and than raised to the temperature above the saturation temperature at constant pressure.

- Heat of fuel gases is utilized in superheating steam.
- Super heater is placed in path of flue gases.

Air PreHeater;

- Air heater or air preheater are waste heat recovery device in which air on its way to the furnace is raised in temperature by utilizing the heat of exhaust gases.
- Air preheater is classified into two category;

a. Recuperative Air Heater:

In this air heater, heat transfer is through metal wall. The fuel gas pases through one side and air pass through other side.

b. Regenerative Air Heater:

In this air heater, the flue gases and the air are made made to pass alternatively through same path. Initially when hot gases passes through a certain medium called matrix receive heat from the gas and store itself. Next when air is made to transverse the path, the matrix transfer the heat stored in it to the air and air become hot.

Explanation of Terms :

Equivalent Evaporation: The evaporation which would be obtained if the feed water were supplied at 100°c converted into dry saturated steam at 100°c at standard atmospheric pressure of 1 bar is called equivalent evaporation.

Let, m_a = Mass of water actually evaporated into steam per kg of coal brunt at boiler working pressure.

h_s = Specific enthalpy of steam at working pressure.

h_w = Specific enthapy of feed water.

∴ Heat absorbed by water at the boiler working pressure = $m_a(h_s - h_w)$ — (I)

Let,

m_e = Equivalent Evaporation

Heat absorption under condition = $m_e L_o$ — (II)

Where, L_o = Enthalpy of evaporator (Latent heat) of steam at 1 bar and 100°c and equal to 2256 kJ/kg.

Equating (I) & (II)

$$m_e L_o = m_a(h_s - h_w)$$

$$\boxed{m_e = \frac{m_a(h_s - h_w)}{L_o}} \quad \text{kg/kg of coal brunt}$$

Where the factor $\frac{h_s - h_w}{L_o}$ is called factor of evaporation which is greather than unity.

Boiler Horse Power:

It is the term used for the performance unit equivalent to evaporation of 15.653 kg of water in one hour from and at 100°c.

$$\text{Boiler Horse power} = \frac{\text{Equivalent evaporator per hour at } 100^\circ c}{15.653}$$

Boiler Efficiency:

The ratio of heat energy utilzed by feed water in converting it into steam in boiler to the heat energy produce by complete combustion of fuel during same time is called boiler efficiency. It is denoted by η_{boiler}.

$$\eta_{boiler} = \frac{\text{Energy absorbed by feed water } [m_a(h_s - h_w)]}{\text{Energy produce by fuel } [m_f \times \text{Calorific value of fuel.}]}$$

Qn. A boiler generate 45×10^3 kg/hr of wet steam at 10 bar & 0.95 dryness fraction. The boiler recieve water at 40°c and cool burn in the furnace at the rate of 5×10^3 kg/hr. Calculate the equivalent evaporation of boiler per kg of cool brunt.

Qn. A boiler generates steam at 10 bar and 200°c from feed water. 37°c. The cool used in furnace has a calorific value of 33695 kJ/kg and 10 kg of steam generated per kg of cool brunt. Find.

a. Equivalent evaporation from at 100°c.

b. Generation factor.

c. Boiler HP if 250 kg of cool is fixed per hours.

A boiler evaporation 5kg of water per kg coal brunt on the fire in the combustion chamber. The temperature of feed water is 30°c and the steam is raised at 10 bar. Calculate the equivalent from and at 100°c per kg of coal as well as factor of evaporation is steam produce is
a) 0.95 dry b) Superheated to 250°c.

Given,

$m_a = 5 kg/kg$ of coal,

At 30°c feed water

$h_f = h_w = 125.77 kJ/kg$

At 10 bar

$h_g = 762.79 kJ/kg$

$h_{fg} = 2015.3 kJ/kg$

$T_{sat} = 179.91°c$

a.) for 0.95 dry

Enthalpy of steam, h_s

$h_s = h_g + x h_{fg}$

$= 762.79 + 0.95 \times 2015.3$

$= 2677.32 kJ/kg$

Equilibrium evaporation, m_e

$$m_e = \frac{m_a (h_s - h_f)}{2257}$$

$$= \frac{5(2677.32 - 125.77)}{2257}$$

$= 5.65$ kg/kg of coal.

Factor of evaporation,

$$= \frac{h_s - h_f}{2257} = \frac{2677.32 - 125.77}{2257} = 1.13$$

b.) For super heated to 250°C

Enthalpy of steam h_s

$$h_s = h_f + h_{fg} + C_{ps}(T_{sup} - T_{sat})$$

$$= 762.79 + 2015.3 + 2.1(250 - 179.9)$$

$$= 2925.28 \text{ kJ/kg}$$

Equilibrium evaporation,

$$m_e = \frac{m_a(h_s - h_f)}{2257}$$

$$= \frac{5(2925.28 - 125.77)}{2257}$$

$$= 6.2 \text{ kg/kg of coal.}$$

Factor of evaporation $= \frac{h_s - h_w}{2257}$

$$= \frac{2925.28 - 125.77}{2257}$$

$$= 1.24.$$

Qn. A boiler generate 45×10^3 kg/hr of wet steam at 10 bar and 0.95 dryness fraction. The boiler receive water at 40°c and coal brunt in the furnace at the rate of boiler per kg of coal brunt.

Given, Mass of steam generated per kg of coal brunt,

$$m = \frac{\text{mass of steam generated / hr}}{\text{mass of coal brunt / hr}}$$

$$m_a = \frac{45 \times 10^3}{5 \times 10^3}$$

$$= 9 \text{ kg/kg of fuel or coal brunt.}$$

At 10 bar,

$h_f = 762.6$ kJ/kg

$h_{fg} = 2013.6$ kJ/kg

At $t = 40°c$ feed water, temperature,

$h_f = 167.6$ kJ/kg

Enthalpy of steam,

$$h_s = h_f + x h_{fg}$$
$$= 762.6 + 0.95 \times 2013.6$$
$$= 2675.52 \text{ kJ/kg}$$

Equilibrium evaporation, $e = \frac{m_a (h_s - h_w)}{2252}$

$$= \frac{9 (2675.52 - 167.6)}{2252}$$

$$= 10 \text{ kg/kg of coal}$$

Qn. A boiler generates steam at 10 bar and 200°C from feed water 37°C, the coal used in furnace has a calorific value of 33695 kJ/kg and 10 kg of steam generated per kg of coal brunt. Find,

a. Equivalent evaporation from and at 100°C.

b. generation factor.

c. Boiler horse power if 250 kg of cal is fixed per hour.

Given, At 37°C feed water,

$$h_f = h_w = 154.9 \text{ kJ/kg}$$

At 10 bar pressure,

$$h_f = 762.79 \text{ kg/kg}$$
$$h_{fg} = 2015.3 \text{ kJ/kg}$$
$$T_{sat} = 179.91°C$$

Enthalpy of steam, h_s,

$$h_s = h_f = h_{fg} + C_{ps}(T_{sup} - T_{sat})$$
$$= 762.79 + 2015.3 + 2.1(200 - 179.91)$$
$$h_s = 2820.3 \text{ kJ/kg}.$$

Mass of steam generated,

$M_a = 10$ kg/kg of coal.

i) Equivalent evaporation,

$$M_e = \frac{m_a (h_s - h_w)}{2257}$$

$$= \frac{10(2820.3 - 154.9)}{2257}$$

$M_e = 11.81$ kg/kg of coal

(ii) Generation factor

$$= \frac{h_s - h_f}{2257}$$

$$= \frac{2820.3 - 154.9}{2257} = 1.181$$

iii) Boiler horse power,

$$= \frac{\text{equivalent evaporation per hour}}{15.653}$$

$$= \frac{11.81 \times 250}{15.653}$$

$$= 188.62$$

Rankine Cycle

- Rankine cycle is the fundamental operating cycle of all power plant where operating fluid continuously evaporate and condense.
- Rankine cycle is ideal cycle for comparing the steam plant.
- It is modify form of Carnot cycle.
- Principle of rankine cycle; It works on the principle of heat engine which converts chemical energy of fuel in thermal energy for generation of steam.

Component of Rankine Cycle;

There are main four parts or components of rankine cycle;

(i) Steam boiler

(ii) Steam Turbine

(iii) Steam condenser

(iv) Feed pump.

Steam Boiler - In boiler heat is transfered to the feed water from an external source to generate the steam.

Steam Turbine - In turbine, high pressure and high temp. steam expands to produce mechanical work, then this expanded steam is passed to condenser.

Steam condenser - It is an heat exchanger, in which the steam condensers into water by rejecting heat to cooling water which is continuously circulated. The water is pump to boiler help of feed pump.

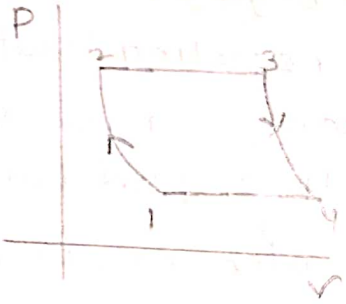
Feed Pump - It is recirculate the water from condensor to boiler. work required to run the feed pump is relatively small in comparison with work produce by turbine.

- Process of Rankine cycle:

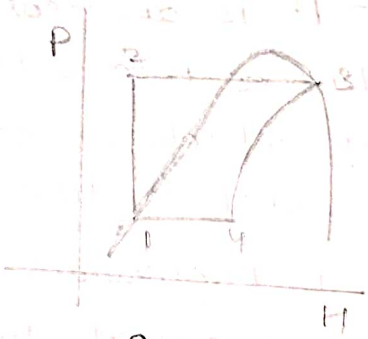
1. Isentropic pump
2. Constant pressure heat addition
3. Isentropic turbine
4. Constant pressure heat rejection.

Working of Rankine cycle;

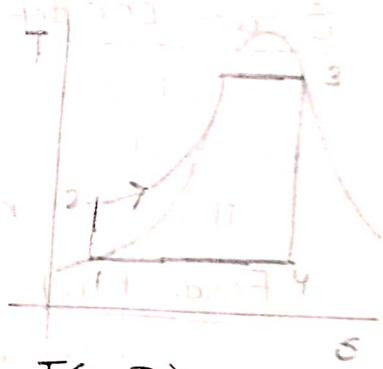
- This process start with feed pump. Feed Pump supplies the water in necessary amount to steam boiler.
- In this device, heat is supplied for the generation of steam supplied water.
- When the steam is generated, it transferred to steam turbine and turbine start to rotate and give the work.
- After this, the steam is transferred to steam condenser, wher heat is rejected and steam is converted into hot water and it is converted into cool water which is supply to the pump.
- And the cycle repeat.



PV-Diagram



PH-Diagram



TS-Diagram

Energy Analysis;

- $h_1 = h_f$ (low Pressure)
- workdone by pump, $W_p = h_2 - h_1$

  $= v_f (P_{high} - P_{low})$

  Where,

  v_f = Specific volume of saturated liquid at low pressure.
- Heat addition in boiler, $Q_{in} = h_3 - h_2$
- Heat rejected from condensor, $Q_{out} = h_4 - h_1$
- Work done by turbine, $W_t = h_3 - h_4$ and $s_3 - s_4$

- $W_{net} = W_T - W_P$
- $Q_{net} = Q_{in} - Q_{out}$
- Thermal efficiency, $\eta_{th} = \frac{W_{net}}{Q_{net}}$.

Benson Boiler :-

- Benson boiler is high pressure, drumless, super critical water tube boiler with force circulation.
- It works on the principle that pressure of water is increased to the supercritical pressure (above critical pressure of 225 bar).
- When pressure of water is increased to super critical level, the latent heat of water become zero and due to this, it directly change into steam without boiling.

Working of Benson Boiler :-

- In Benson boiler, the feed pump increase the pressure of supercritical pressure and then entre to economiser.
- From economiser, the water passes to the radial heater. Here water receive the heat through radiation and patially get converted into steam.
- After that mixture of steam and water enters into convective evaporation where it is completly converted into steam and may superheated to same degree. Finally it is passed through the superheater to obtained the desired steam
- This superheated steam is used by turbine or engine to produce electrically.

Lamont Boiler:

- Lamont boiler is a high pressure, forced circulation water tube boiler with internally fire furnace.
- It work on the principle of forced circulation of water with the help of centrifugal pump.
- Its working totally depends upon the pump.
- The centrifugal pump circulates the mixture of steam and water through the small diameter tubes of the boiler.

Working ~~principle~~ of Lamant Boiler:

- In Lamant boiler, the feed, pump circulates the water in the economiser of the boiler.
- The economiser heats the water to some degree.
- From economiser water enter into steam seperating drum.
- From steam seperating drum the mixture of water and steam is forced circulated through the radient evaporator by an external centrifugal pump.
- Radiat evaporator heats the water and changes it into steam.
- From radiant evaporator, the water-steam mixture passes through convective evaporator.
- Here the temperature of the fluid increase and most of water get converted into saturated steam.
- After that saturated steam entre into steam separator drum and steam seperate from water.
- Steam get collected at upper portion of drum.
- From steam seperator drum, steam passes through the superheater.

Draught :

- The small pressure difference that cause a continuous flow of fresh air into combustion chamber / furnace is called draught.
- The function of the draught in case of boiler, is to force air to the fire and to carry away the gaseous product of combustion.
- In boiler furnace, proper combustion take place only when sufficient quantity of air is supplied to burning fuel, so drough is necessary.

Classification of draught :

A. Natural Draught

- The natural drough is produced by the use of chimney therefore it is also called chimmey draught.
- This chimney is vertical tubular structure made of either reinforcement concrete or steel.
- The chimney carries the fuel gases to such height before discharging that it causes no harm to surrounding atmoshphere.
- The natural draught is caused by the difference in temperature between a column of hot gases inside the chimney and similar column of normal atmospheric air outside the chem

B. Artifical Draught

- The use of chimney for producing draught of order of 250 - 300 mm of water coloumn needed for bigger power plant is not economical.
- To produce sufficient high draught, some mechanical system has to adopted.
- The draught produced by fan or steam jet is called artificial draught.

Types of Artificial Draught

a. Force Draught

- The draught produced by fan is called forced draught.
- A fan or blower is installed near or at the base of boiler grate deliver air to the furnace under pressure.
- The pressure help in circulation of flue gases through component of boiler and then through chimney to boiler.

b. Induced Draught

Steam Nozzle

UNIT-4

Nozzle:

A nozzle is a duct of varying cross-sectional area used for increasing the velocity of a steadly flowing steam of fluid.

- The fluid enters the nozzle with high pressure and relatively small velocity.
- During the flow process, its pressures fall and velocity increases continously from the entrance to exit of nozzle.

Steam Nozzle:

- The passage or duct of varying cross-section, through which heat energy of steam is converted into kinetic energy is called steam nozzle.
- The major function of the nozzle is to produce steam jet with high velocity to derive steam turbine.

Uses of Nozzle:

- In steam and gas turbine, the high speed steam of fluid is directed on curve blade and kinetic energy is converted into mechanical energy.
- In jet propulsion unit, and rocket motor, thrust produced by jet produces necessary propulsion effect.
- Nozzle is used for injecting feed water into boiler.

Type of Nozzels:

1. Convergent Nozzle:

When the cross-section of nozzle decreases continously from inlet to exit, it is called convergent Nozzle.

- At inlet of a convergent nozzle, velocity of steam is always less than sonic velocity hence it is also known by subsonic nozzle.
- At smaller section, at exit velocity become sonic velocity.

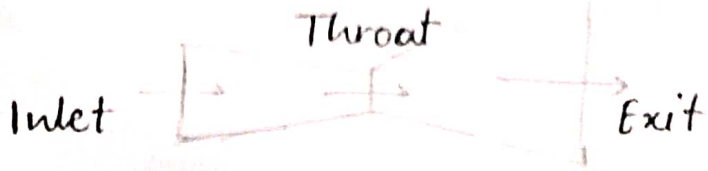
2. Divergent Nozzle:

When cross-section of nozzle increases continously from inlet to exit, is called divergent nozzle.

3. Convergent-Divergent Nozzle:

When the cross-section of nozzle first decreases from inlet to throat and then increases from throat to exit, it is called convergent-divergent nozzle.

- In actual Practice, the pressure of steam at inlet of convergent portion is very high and velocity is negligible.
- Therefore, the velocity increases in the conversing portion so that velocity become sonic at throat and further expansion of steam take place in the diverging portion, so that velocity become super sonic in diverging portion.



Steam Flow Through Nozzle:

- The steam flow through is assume to be adiabatic flow.
- The flow is adiabatic means during expansion of steam in nozzle, neither heat supplied nor rejected.
- But work is performed by increasing in kinetic energy.
- As steam passes through nozzle, steam losses pressure and heat.
- Therefore workdone is equal to adiabatic heat drop.

Velocity of steam:

Let,

h_1 = Enthalpy of steam at entering the nozzle,

h_2 = Enthalpy of steam at section consider,

h_d = heat drop during expansion of steam,

$h_d = (h_1 - h_2)$

V = Velocity of steam at section consider

Consider 1kg steam flow through frictionless adiabatic nozzle, Work Done = Adiabatic heat drop

Gain in kinetic energy = Adiabatic Heat drop

$$\frac{V^2}{2} = h_d$$

$$\boxed{V = \sqrt{2h_d}}$$

Note: In actual pratice, there is loss due to friction in nozzle and loss varies 10 to 15%.

This mean heat drop minimized,

Actual drop of heat, Kh_d

Coefficient of friction.

$$V = \sqrt{2 \times 1000 \times Kh_d}, \quad \boxed{V = 44.72\sqrt{Kh_d}}$$

Qn. Dry saturated steam enters a steam nozzle at a pressure of 15 bar and discharge at a pressure of 2 bar. If the dryness fraction of discharge steam is 0.96. what will be velocity of steam?

Qn. Dry saturated steam enters a frictionless adiabatic nozzle with negligible velocity at a temperature of 300°c. It is expand to a pressure of 5000 kPa. The mass flow rate is 1 kg/s. Calculate the exit velocity of steam.

<u>Discharge Through Nozzle:</u>

p_1 = initial pressure of steam

v_1 = Initial volume of 1 kg steam at p_1.

p_2 = Steam pressure at throat

v_2 = Volume of 1 kg steam at p_2.

A = cross-sectional area of nozzle.

V = Volume of steam.

The steam flowing through nozzle follows;

pv^n = Constant

$n = 1.135$ - Saturated steam

$n = 1.3$ - Superheated steam

Workdone per kg of steam during cycle (Rankine Area)

$$= \frac{n}{n-1}(p_1V_1 - p_2V_2)$$

Gain, in K.E. = Adiabatic Heat drop = Workdone during Rankine cycle

$$\frac{V^2}{2} = \frac{n}{n-1}(p_1V_1 - p_2V_2)$$

$$\Rightarrow \frac{n}{n-1}(p_1V_1)\left(1 - \frac{p_2V_2}{p_1V_1}\right) = \frac{v^2}{2} \quad -(1)$$

Also, $p_1 v_1^n = p_2 v_2^n$

$$\frac{v_2}{v_1} = \left(\frac{p_1}{p_2}\right)^{1/n}$$

$$v_2 = v_1 \left(\frac{p_1}{p_2}\right)^{1/n} \quad -(11)$$

$$\because \frac{v_2^2}{2} = \frac{n}{n-1} p_1 v_1 \left(1 - \frac{p_2}{p_1} \cdot \frac{p_1^{1/n}}{p_2}\right)$$

$$\frac{v^2}{2} = \frac{n}{n-1} p_1 v_1 \left[1 - \frac{p_2}{p_1}\left(1 - \frac{1}{n}\right)\right]$$

$$\Rightarrow \frac{v^2}{2} = \frac{n}{n-1} p_1 v_1 \left[1 - \frac{p_2}{p_1}\left(\frac{n-1}{n}\right)\right]$$

$$\Rightarrow v = \sqrt{\frac{2n}{n-1} p_1 v_1 \left[1 - \frac{p_2}{p_1}\left(\frac{n-1}{n}\right)\right]} \quad -(3)$$

Let, m = mass of steam discharge

$$m = \frac{AV}{v^2}$$

$$m = \frac{AV}{v'\left(\frac{p_1}{p_2}\right)^{1/n}} \quad -(4)$$

$$m = \frac{A}{v'\left(\frac{p_1}{p_2}\right)^{1/n}} \sqrt{\frac{2n}{n-1} \times p_1 v_1 \left[1 - \frac{p_2}{p_1}\right]^{\frac{n-1}{n}}}$$

$$\boxed{m = \frac{A}{v'} \sqrt{2\left(\frac{n}{n-1}\right) p_1 v_1 \left[\left(\frac{p_2}{p_1}\right)^{2/n} - \left(\frac{p_2}{p_1}\right)^{\frac{n+1}{n}}\right]}}$$

For max^m discharge,

$$\frac{dm}{d(p_2/p_1)} = 0$$

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$$\frac{v^2}{2} = \frac{n}{n-1} p_1 v_1 \left[1 - \frac{p_2}{p_1}\left(1 - \frac{1}{n}\right)\right]$$

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$$\boxed{m = \frac{A}{v'} \sqrt{2\left(\frac{n}{n-1}\right) p_1 v_1 \left[\left(\frac{p_2}{p_1}\right)^{2/n} - \left(\frac{p_2}{p_1}\right)^{\frac{n+1}{n}}\right]}}$$

For max^m discharge,

$$\frac{dm}{d(p_2/p_1)} = 0$$

$$\Rightarrow \frac{d}{d\left(\frac{p_2}{p_1}\right)}\left[\frac{p_2}{p_1}^{2/n} - \left(\frac{p_2}{p_1}\right)^{\frac{n+1}{2}}\right] = 0$$

$$\Rightarrow \frac{2}{n}\left[\frac{p_2}{p_1}\right]^{2/n-1} - \frac{n+1}{2}\left[\frac{p_2}{p_1}\right]^{\frac{n+1}{n}-1} = 0$$

$$\Rightarrow \frac{2}{n}\left[\frac{p_2}{p_1}\right]^{2/n-1} = \frac{n+1}{2}\left[\frac{p_2}{p_1}\right]^{1/n}$$

$$\Rightarrow \left[\frac{p_2}{p_1}\right]^{2-n} = \left(\frac{n+1}{2}\right)^{n} \frac{p_2}{p_1}$$

$$\Rightarrow \boxed{\frac{p_2}{p_1} = \left(\frac{2}{n+1}\right)^{n/n-1}}$$

$\frac{p_2}{p_1}$ = Critical pressure ratio,

For saturated steam,

$$\frac{p_2}{p_1} = 0.58$$

For superheated steam,

$$\frac{p_2}{p_1} = 0.546.$$

Maximum discharge,

$$M_{max} = \frac{A}{V_1}\sqrt{\frac{2n}{n-1} P_1 V_1 \left[\left\{\left(\frac{2}{n+1}\right)^{n/n-1}\right\}^{2/n} - \left\{\left(\frac{2}{n+1}\right)^{\frac{n}{n-1}}\right\}^{\frac{n+1}{n}}\right]}$$

$$\therefore \boxed{M_{max} = A\sqrt{n\left(\frac{P_1}{V_1}\right)\left(\frac{2}{n+1}\right)^{\frac{n+1}{n-1}}}}$$

Note:

- Velocity of steam, $v = \sqrt{2 \times 1000\, h_d}$ m/s
- Discharge through nozzle,

$$m = \frac{A}{v_1}\sqrt{2\left(\frac{n}{n-1}\right)p_1 V_1\left[\left(\frac{p_2}{p_1}\right)^{2/n} - \left(\frac{p_2}{p_1}\right)^{\frac{n+1}{n}}\right]}$$

- Maximum discharge through nozzle,

a. Critical pressure ratio, $\frac{p_1}{p_2} = \left(\frac{2}{n+1}\right)^{\frac{n}{n-1}}$

b. $V_{max} = \sqrt{2\left(\frac{n}{n+1}\right)p_1 V_1}$

c. $M_{max} = A\sqrt{n\left(\frac{p_1}{V_1}\right)\left(\frac{2}{n+1}\right)^{\frac{n+1}{n-1}}}$.

Method of finding cross-sectional area of nozzle at throat and exit for maximum discharge;

1. between inlet and throat,

$$\frac{V_1^2}{2} + h_1 = \frac{V_2^2}{2} + h_2$$

$$V_2 = \sqrt{2\left(\frac{V_1^2}{2} + h_1 - h_2\right)}$$

mass flow rate at throat, $\dot{m} = \frac{A_2 V_2}{v_2}$

$$A_2 = \frac{\dot{m}\, v_2}{V_2}$$

2. Between throat and exit.

$$\frac{V_2^2}{2} + h_2 = \frac{V_3^2}{2} + h_3$$

$$V_3 = \sqrt{2\left(\frac{V_2^2}{2} + h_2 - h_3\right)}$$

mass flow rate at exit, $\dot{m} = \frac{A_3 V_3}{v_3}$

$$A_3 = \frac{\dot{m}\, v_3}{V_3}.$$

Effect of friction in nozzle;

1. Due to friction in nozzle, ~~friction~~ enthalpy drops decreases.
2. Due to friction, exit velocity of steam through nozzle decreases.
3. There will be decrease in mass flow rate from nozzle due to friction.
4. In case of convergent-divergent nozzle, length of convergent part is less than divergent part therefore most of friction loss in divergent part.
5. Due to friction in nozzle dryness fraction of steam increases.
6. The degree of superheat increases due to friction in nozzle.

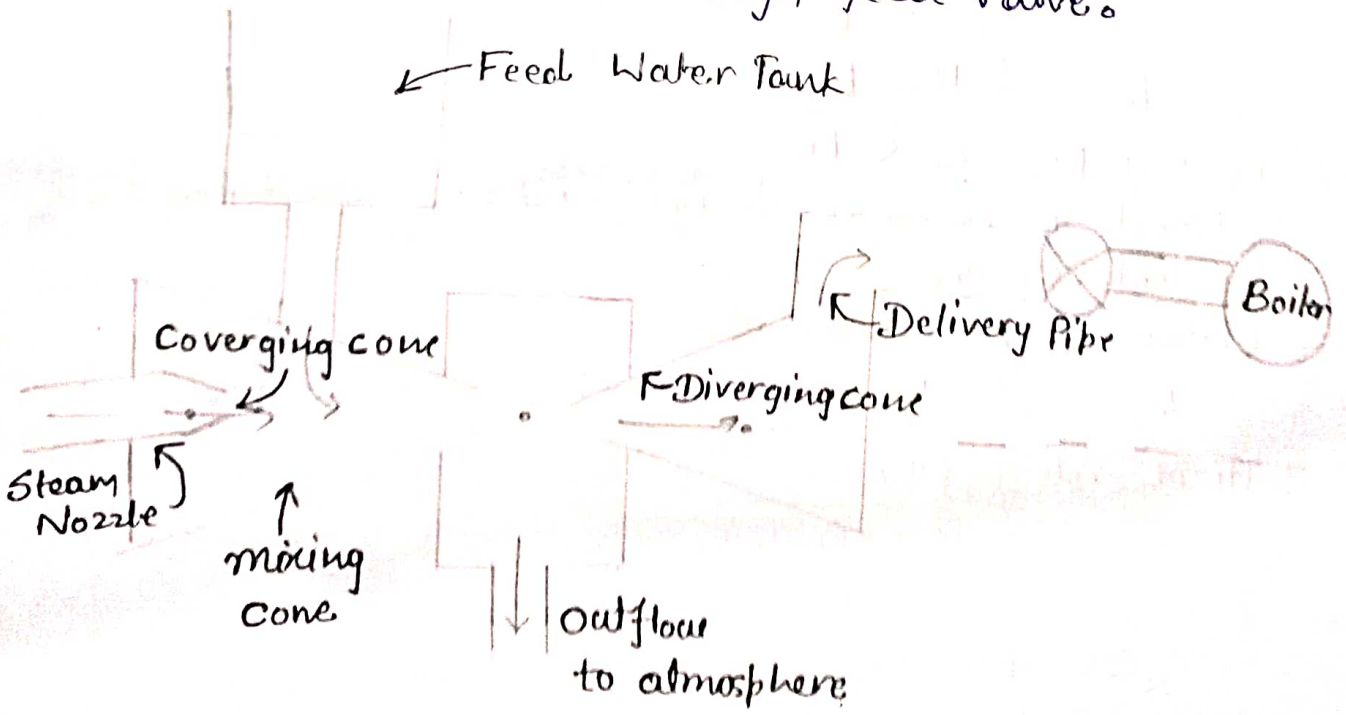
Effect of supersaturated flow in nozzle;

1. The dryness fraction is improved.
2. There is increase in specific volume of steam.
3. Entropy will increase.
4. The heat drop is reduce.
5. Exit volume of steam decreases.
6. Mass of discharge through nozzle increases.

Steam Injector

- Steam injector is employed to force water into the boiler under pressure.
- The steam enter the steam chamber whose outlet is in form of a converging nozzle.

- Steam injector works on the principle of nozzle by which it utilises the kinetic energy of steam jet for increasing the pressure and velocity of quantity of water.
- In the nozzle section, the steam expands with consequent gain in velocity at the expance of pressure.
- The resulting jet mixes with water in the mixing tube.
- The steam condense and vaccume is created in mixing tube.
- Due to vacum, more water is drawn from feed tank into mixing chamber.
- The jet of water then enters into diverging cone where kinetic energy of mixture is converted into pressure.
- The increase of pressure is sufficient to force the water into the boiler through feed valve.



Qn. A nozzle with throat area 200 mm² is used to have isentropic expansion of air at 60 bar pressure and 310 K temperature to back pressure 40 bar. Neglect entrance velocity. Determine the outflow velocity and mass flow rate of air.

Qn. In a propulsion nozzle gases expand 4 bar and 650 K to back pressure 1 bar at rate of 15 kg/s. The coefficient of discharge is 0.98 and assume initial velocity to be negligible. Find throat and exit area. Take $\gamma = 1.3$ and $C_p = 1.1$ kJ/kgK.

Given, $P_1 = 4$ bar, $T_1 = 650$ K, $P_2 = 1$ bar, $m = 15$ kg/s, $C_d = 0.98$
$\eta_n = 95\%$, $\gamma = 1.3$ and $C_p = 1.1$ kJ/kgK.

Critical pressure,

$$p_c = p_1 \left(\frac{2}{\gamma+1}\right)^{\frac{\gamma}{\gamma-1}}$$

$$= 4\left[\frac{2}{2.3}\right]^{\frac{1.3}{0.3}}$$

$$p_c = 2.182 \text{ bar}$$

Since exit pressure < p_c

∴ Nozzle is convergent-divergent and exit velocity reaches to critical velocity,

Critical temp. at throat,

$$T_c = \left(\frac{2}{n+1}\right)T_1 \Rightarrow \frac{2}{2.3} \times 650 = 565.22 \text{ m/s}$$

Critical velocity (throat)

$$V_c = \sqrt{2 \times 1000 \times C_p (T_1 - T_2)}$$

$$= \sqrt{2000 \times 1.1 [650 - 565.22]}$$

$$= \sqrt{186516} = 431.874 \text{ m/s}.$$

Specific gas constant,

$$R = C_p \left(\frac{\gamma-1}{\gamma}\right) = 1.1 \times \frac{0.3}{1.3} = 0.2538 \text{ kJ/kgK}.$$

∵ $P_c V_c = R T_c$

$$v_c = \frac{R T_c}{P_c} = \frac{253.8 \times 565.22}{2.182 \times 10^5} = 0.657 \text{ m}^3/\text{kg}.$$

Mass flow rate,

$$\dot{m} = \frac{15}{C_d} = \frac{15}{0.98} = 15.306 \text{ kg/s}$$

Throat Area,

$$\dot{m} = \frac{A_c V_c}{v_c}$$

$$15.306 = \frac{A_c \times 431.17}{0.657}$$

$$A_c = \frac{15.306 \times 0.657}{431.17} = 0.0233 \text{ m}^2$$

Exit velocity,

$$\frac{T_1}{T_E} = \left(\frac{P_1}{P_2}\right)^{\frac{\gamma-1}{\gamma}}$$

$$\Rightarrow \frac{650}{T_E} = \left(\frac{4}{1}\right)^{\frac{0.3}{1.3}}$$

$$\Rightarrow T_E = \frac{650}{(4)^{0.3/1.3}} = \frac{650}{4^{0.23}} = \frac{650}{1.375} = 472.72 \text{ K},$$

$$\because P_2 v_E = R T_E$$

$$1 \times 10^5 \times v_E = 253.85 \times 472.72$$

$$v_E = \frac{253.85 \times 472.72}{10^5} = 1.199 \text{ m/s}$$

Exit velocity,

$$V_E = \sqrt{2 \times 1000 \times 1.1 (650 - 472.72)}$$

$$= \sqrt{390016}$$

$$= 624.512 \text{ m/s}$$

Exit Area,

$$\dot{m} = \frac{A_c v_e}{V_c}$$

$$15.306 = \frac{A_c \times 624.52}{1.199}$$

$$A_c = \frac{15.306 \times 1.199}{624.52} = 0.0293 \text{ m}^2.$$

Numerical UNIT 4

Qn. A nozzle with throat area 200 mm² is used to have isentropic expansion of air at 60 bar pressure and 310 K temperature to back pressure 40 bar. Neglect entrance velocity, Determine outflow velocity and mass flow rate

$P_1 = 60$ bar, $P_2 = 40$ bar, $T_1 = 310$ K, $A_{throat} = 200\ mm^2$

Critical pressure,

$$P_c = P_1 \left(\frac{2}{\gamma+1}\right)^{\gamma/\gamma-1}$$

$$= 60\left[\frac{2}{2.4}\right]^{\frac{1.4}{0.4}}$$

$$= 31.696 \text{ bar}$$

Since, Exit pressure > P_c

∴ Exit velocity doesnot reach critical velocity and nozzle is only convergent section.

a) Outflow velocity,

$$v_2 = \left[\frac{2\gamma}{\gamma-1} P_1 V_1 \left\{1-\left(\frac{P_2}{P_1}\right)^{\gamma-1/\gamma}\right\}\right]^{1/2}$$

$$P_1 v_1 = mRT_1$$

$$60 \times 10^5 v_1 = 1 \times 287 \times 310$$

$$v_1 = 0.01483 \ m^3/kg.$$

$$v_2 = \sqrt{\frac{2 \times 1.4}{1.4-1} \times 60 \times 10^5 \times 0.01483\left[1-\left(\frac{40}{60}\right)^{\frac{0.4}{1.4}}\right]}$$

$$v_2 = 261.16 \ m/s$$

b). Mass flow rate.

$$\dot{m} = \frac{A_2}{V_1}\sqrt{2\left(\frac{\gamma}{\gamma-1}\right) P_1 V_1 \left[\left(\frac{P_2}{P_1}\right)^{2/\gamma} - \left(\frac{P_2}{P_1}\right)^{\frac{\gamma+1}{\gamma}}\right]}$$

$$= \frac{200 \times 10^{-6}}{0.01483}\sqrt{\frac{2 \times 1.4}{0.4} \times 60 \times 10^5 \times 0.01483 \times \left[\left(\frac{40}{60}\right)^{2/1.4} - \left(\frac{40}{60}\right)^{\frac{2.4}{1.4}}\right]}$$

$$\dot{m} = 2.6 \ kg/s.$$

STEAM TURBINE

UNIT 5

Turbine: A machine which recieved its power from the wheel that is turned by pressure of water, air or gas is called turbine.

Steam Turbine:

The device that extracts thermal energy from the pressurised steam and converts it to mechanical work on a rotating output shaft, is called steam turbine.

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

Classification of Steam turbine;

1. According to the mode of action
   a. Impulse Turbine
   b. Reaction Turbine
2. According to direction of steam flow
   a. Axial flow turbine
   b. Radial flow turbine

Axial flow Steam Turbine

The turbine in which steam flow in a direction parallel to axis of turbine is called axial flow steam turbine

Example: ----

Radial flow Steam Turbine

The turbine in which steam flow in a direction perpendicular to axis of turbine is called radial flow steam turbine.

Impulse Turbine

- In impulse turbine steam coming out through a fixed nozzle at very high velocity strike the blades mounted on the periphery of a roller.
- So energy at inlet of turbine is kinetic energy.
- The moving blades changes the direction of steam flow without change its pressure.
- Example; De-lavel, Curtis and Rateau turbine.

Reaction Turbine

- In reaction turbine steam expands both in fixed and moving blade continously as the steam passes over them.
- The pressure drop occur continously over both moving and fixed blades.
- Energy at inlet of turbine is kinetic energy and pressure energy.
- Examples; Parson's Turbine.

Differece between Impulse turbine and reaction turbine

Impulse Turbine	Reaction Turbine
1. Steam strike on the bucket with kinetic energy.	1. Steam strikes the moving blade with pressure and kinetic energy.
2. The blades of impulse turbine are symetrical.	2. The blade of reaction turbine is not symetrical.
3. It is suitable for low disharge.	3. It is suitable for medium and high disharge

4. During the flow of steam through moving blades, its pressure remains constant.

4. During the flow of steam through moving blade its pressure radius.

Impulse Turine

A turbine in which comple process of expansion of steam take place in stationary nozzle and velocity energy is converted into mechanical work on turbines blade are known as impulse turbine.

Working of Impulse turbine;

- A impulse turbine depends almost wholly for its operation on the impulsive force of high velocity steam jet.
- The high velocity steam jet are obtained by expantion of the steam in stationary nozzle only.
- This high velocity steam jet are obtained by expantion of the steam jet in stationary nozzle only.
- This height velocity steam jet strike the blade of turbine at no drop of pressure.
- Due to strike of steam jet with high velocity rotating motion of shaft velocity rotating motion of shaft take place.

Velocity Diagram of impulse turbine :

Let, V_{be} = linear velocity of moving blade,

V_1 = Absolute velocity of steam entering the moving blade

V_0 = Absolute velocity of moving blade

V_{w1} = Velocity of whirl at entrance of moving blade tangential compound of V_1

V_{w0} = Velocity of whirl at exit of moving blade tangential compound of V_0.

V_{f1} = Velocity of flow at entrance of moving blade axial component of V_1

V_{f0} = Velocity of flow at exit of moving blade axial component of V_0.

V_{r1} = Relative velocity of steam to moving blade at entrance

V_{r2} = Relative velocity of steam to moving blade at exit.

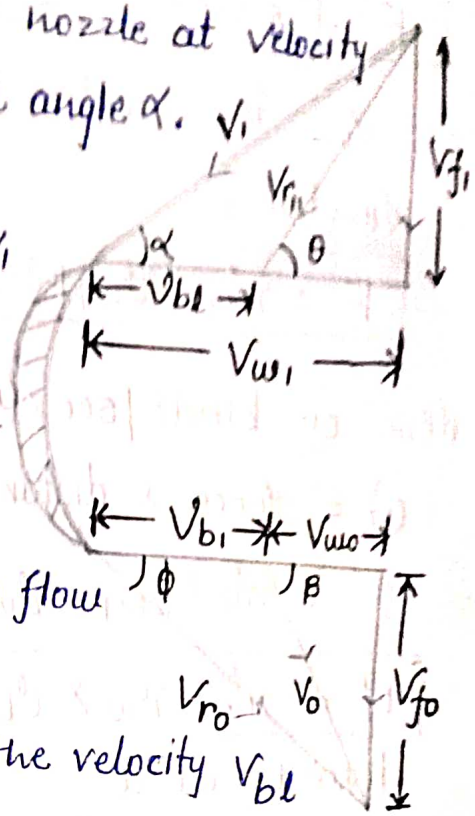
α = Nozzle angle = Angle of tangent of wheel at which steam with velocity V_1 enters.

β = Angle which the discharge steam makes with the tangent of wheel at exit of moving blade.

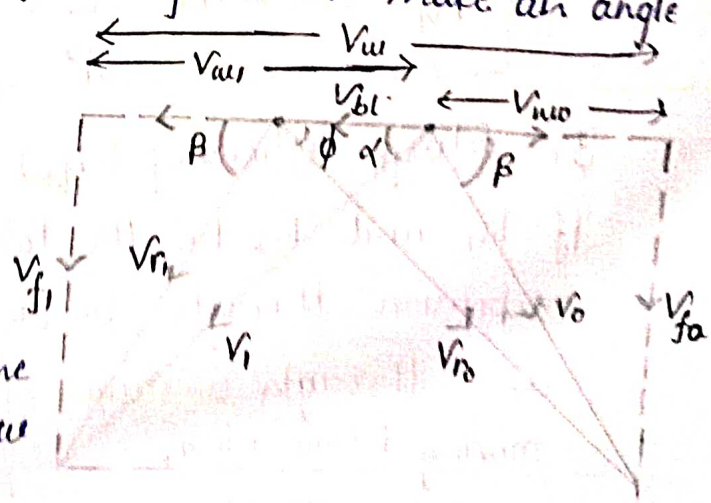
θ = Entrance angle of moving blade

ϕ = Exit angle of moving blade.

- The steam jet comes out from nozzle at velocity of V_1 strike an blade at an angle α.



- The tangential component of V_1 ie V_{w_1} perform work on blade and the axial component of V_1 ie V_{f_1} does not work but couse the steam to flow through turbine.
- As the blade moves with the velocity V_{bl} the entering steam jet has relative velocity V_{r_1} which make an angle θ with wheel tangent.
- The jet steam then move over blade without any shock and discharge at relative velocity V_{ro} at an angle ϕ with tangent of blade.
- If these is no frictional losses then $V_{r_1} = V_{ro}$.
- The absolute velocity V_0 of leaving steam make an angle β to wheel tangent.



1. Work done on blade;

The workdone on the blade may be found out from change of momentum of the steam jet during its flow over the blade.

Force (tangential) on wheel, f

$$f = \text{mass of steam} \times \text{acceleration}$$

$$= \frac{\text{mass of steam}}{50\,c} \times \text{Change in velocity} = M_s(V_{w_1} - V_{wo})$$

$$\boxed{F = \dot{M}_s (V_{w_1} - V_{w_0})}$$

Note ; V_{w_0} is negative as steam discharge in opposite direction.

$$\boxed{F = \dot{m}_s (V_{w_1} + V_{w_0})}$$

workdone on blade/sec ; W,

W = force x distance travel/sec

$= \dot{m}_s (V_{w_1} + V_{w_0}) \times V_{b_1}$

$$\boxed{W = \dot{m}_s \times V_w \times V_{b_1}}$$ watt $[V_w = V_{w_1} + V_{w_0}]$

Power per wheel

2. Blade or diagram efficiency (η_B)

$$\eta_B = \frac{\text{Workdone on the blade}}{\text{Energy supplied to blade}}$$

$$\eta_B = \frac{\dot{m}_s (V_{w_1} + V_{w_0}) V_{b_1}}{\frac{\dot{m}_s V_1^2}{2}}$$

$$\boxed{\eta_B = \frac{2 V_{b_1} (V_{w_1} + V_{w_0})}{V_1^2}}$$

3. Stage efficiency (η_s)

If h_1 and h_2 be the total heat before and after expansion through nozzle, the $(h_1 - h_2)$ is the heat drop through a stage of fixed blade ring and moving blade ring.

$$\eta_s = \frac{\text{Workdone on blade per kg of steam}}{\text{total energy supplied per kg of steam}}$$

$$\boxed{\eta_s = \frac{V_{b_1} (V_{w_1} + V_{w_0})}{(h_1 - h_2)}}$$

4. Nozzle efficiency (η_N):

$$\boxed{\eta_N = \frac{v_1^2}{2(h_1 - h_2)}}$$

Note, $\boxed{\eta_{stage} = \eta_{blade} \times \eta_{Nozzle}}$

5. Axial force on wheel;

The axial thrust on the wheel is due to difference between the velocities of flow at entrance and outlet.

Axial thrusth on wheel, F_{axial};

F_{axial} = mass of steam × axial acceleration.

$$\boxed{f_{axial} = \dot{m}(v_{f_1} - v_{f_0})}$$

6. Energy converted to heat by blade function;

= loss of kinetic energy flow over blade

$= \dot{m}(v_{r_1}^2 - v_{r_0})$

7 Blade velocity coefficient (K);

$v_{r_0} = K v_{r_1}$

$$\boxed{K = \frac{v_{r_0}}{v_{r_1}}}$$

Note: Blade speed, $\boxed{\rho = \frac{v_{b1}}{v_1}}$

For max^m blade efficiency $\boxed{\rho = \frac{\cos\alpha}{2}}$

Maximum blade efficiency, $\boxed{(\eta_{b1})_{max} = \frac{\cos^2\alpha}{2}(1+KZ)}$

Where K = blade vel. coeff.

$Z = \frac{\cos\phi}{\cos\theta}$

Maximum workdone per kg of steam

$\boxed{(W)_{max} = \rho v_1^2}$

Qn. In De Level turbine steam issue from the nozzle with velocity of 1200 m/s. The nozzle angle is 20° the mean velocity is 400 m/s and inlet and outlet angle of blade are equal. The mass of steam following through the turbine per hour is 1000 kg. find,

a. Blade Angle
b. Relative velocity of steam entring the blade
c. Tangential force on blade
d. power develop
e. Blade efficiency

Take blade velocity coefficient, K = 0.8. [TE2 - Last Rec. 38]

Qn. A single stage steam turbine is supplied with steam at 5 bar 200°C at the rate of 50 kg/min. It expands into a condenser at a pressure of 0.2 bar. The blade speed is 400 m/s. The nozzle are inclined at an angle of 20° to plane of wheel and outlet blade angle is 30°. Neglect frictional losses, determine power develop, blade efficiency and stage efficiency.

[TE2 - Last Rec - 38]

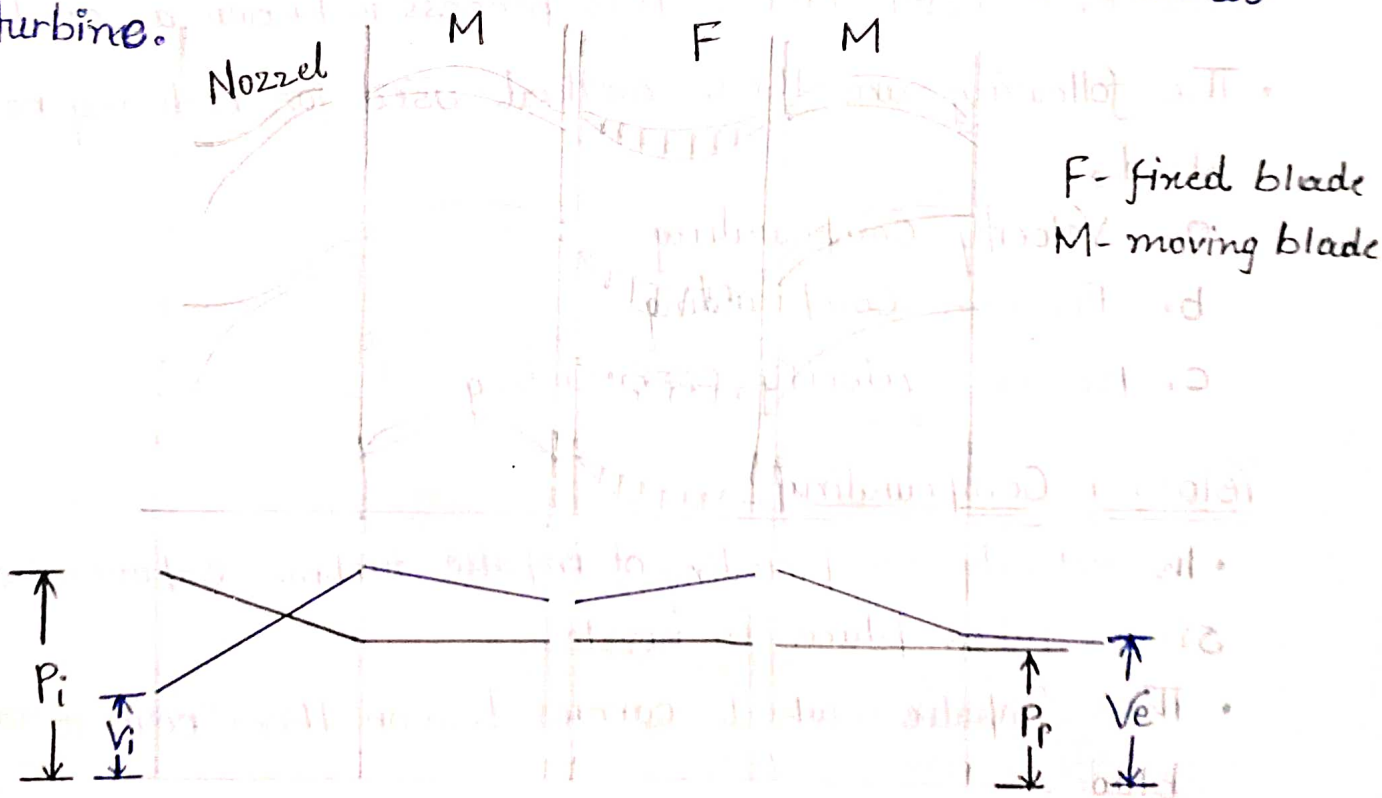
Method of reducing rotor speed or wheel:

- In power plant, high pressure and temperature steam is used in order to increase thermal efficiency.
- If entire pressure drop (from boiler to condenser pressure) is carried out in one stage only, the volume of steam entering the turbine will be very high.
- Due to which turbine rotar will run at very high speed which have no. of disadvantages.
- In order to reduce rotor speed, various method are used.
- All these method consist of a multiple system of rotor in series, keyed to a common shaft and the steam pressure or the jet velocity is observed in stage as it flow over rotor blade. This process is known as compounding.
- The following are three method used for reducing rotor speed,
  a. Velocity compounding
  b. Pressure compounding
  c. Pressure - velocity compounding

Velocity Compounding

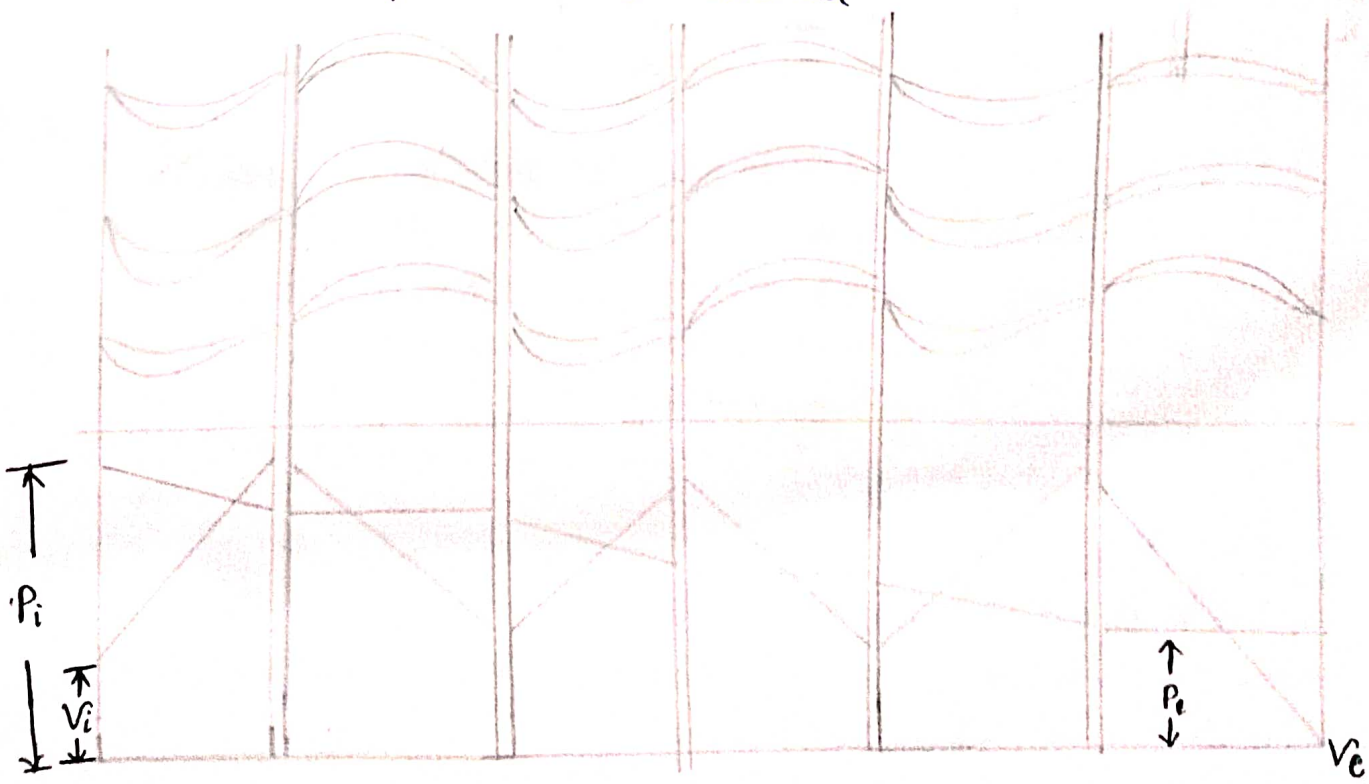
- In velocity compounding of impulse turbine, expansion of steam takes place in nozzle.
- The impulse wheel carries two or three rows of moving blade.
- The steam after expanding through nozzle, enters the first ring of moving blade at high velocity.

- A portion of this high velocity is absorved by this blade ring and remaining passed on to the next ring of fixed blade.
- The fixed blades change the direction of steam and direct it to the second ring of moving blade without changing velocity.
- After passing through this moving blade, a further portion of velocity is absorved.
- The steam is now directed by the second ring of fixed blade to third ring of moving blade.
- In entire process, no pressure drop take place and turbine runs about one-third of speed to De-Laval turbine.



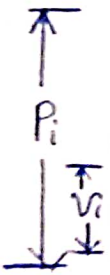
Pressure compounding

- In pressure compounding of impulse turbine, the ring of moving blade, each have a ring of fixed nozzle.
- The total pressure drop, of the steam does not place in the first nozzle ring, but is devided equally among all nozzle ring.
- The steam from boiler is passed through the first nozzle ring, small pressure drop occur with increase in velocity of steam.
- The steam is now directed on the first moving blade ring, where the velocity decreases but pressure remains same and this constitutes first stage.
- The steam from the first moving blade ring enter the second nozzle ring where it pressure further reduced.
- The process is repeated in remaining ring, untill condenser pressure is reached



Pressure velocity compounding

- In pressure velocity compounding, both velocity compounding and pressure compounding methods are used.
- The total pressure drop is divided into two stages.
- In pressure-velocity compounding, bigger pressure drop take place and hence less number of stage are required.



Numerical UNIT 5

In delevel turbine steam issue from the nozzle with velocity of 1200 m/s. The nozzle angle is 20° the mean blade velocity is 400 m/s and inlet and outlet angle of blade are equal. The mass of steam flowing through turbine per hour is 1000 kg.

Find. a. Blade Angle

b. Relative velocity of steam entering on blade

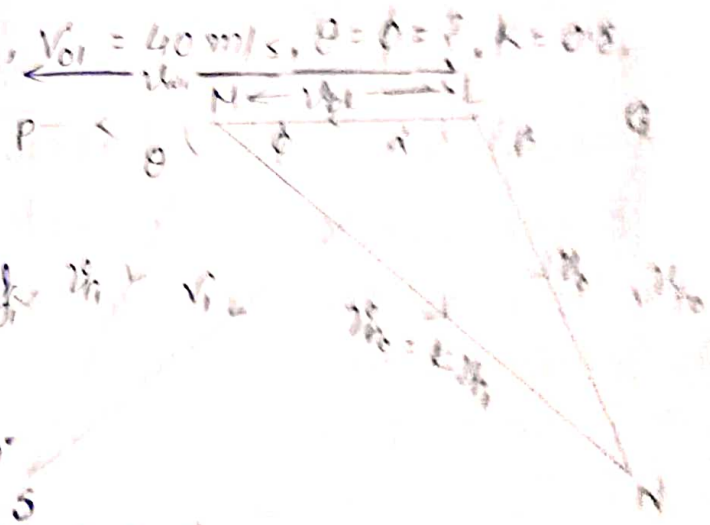
c. Tangential force on blade

d. Power develop

e. Blade efficiency

Given, $V_1 = 1200$ m/s, $\alpha = 20°$, $V_{b1} = 40$ m/s, $\theta = \phi = ?$, $k = 0.8$,

$m_s = 1000$ kg/hr.



Let take suitable scale and draw line LM to represent $V_{b1} = 400$ m/s

At point L makes angle 20° and cut LS to represent, $V_1 = 1200$ m/s.

So in MS and M to meet the perpendicular drawn from S to P. Inlet triangle is completed.

By measurement, $\theta = 30°$, $V_{r1} = MS = 830$

$\theta = \phi = 30°$

$V_{r2} = k V_{r1}$

$= 0.8 \times 830 = 664$ m/s.

At M make angle of 30° and cut MN to represent the 664 m/s

Join LN and produce L to meet the perpendicular drawn from N at θ and outlet triangle.

(i) Blade angle; $\theta = \phi = 30°$

(ii) Relative velocity of steam entering the blade, $V_{r_1} = 830 \, m/s$.

(iii) Tangential force on blade, $F_t = m(V_{w_1} + V_{w_0})$

$$= \frac{1000}{60 \times 60}(1310) = 363.8 N.$$

(iv) Power develop, $P = m_s (V_{w_1} + V_{w_0}) V_{b1}$

$$= \frac{1000}{60 \times 60} \times 1300 \times 400 = 145.5 \times 1000 W.$$

(v) Blade Efficiency,

$$\eta_B = \frac{2 V_{b1} (V_{w_1} - V_{w_0})}{V_1^2} = \frac{2 \times 400 \times 1310}{1200^2} = 0.7287$$

$$\eta_B = 72.87 \%$$

Qn. A single stage steam turbine is supplied with steam at 5 bar, 200°C at the rate of 50 kg/min. It expands into a condensor at a pressure of 0.2 bar. The blade speed is 400 m/s. The nozzle are inclined at an angle of 20° to plane of wheel and outlet blade angle is 30°. Neglect frictional losses, determine power develop, blade efficiency and stage efficiency.

Given, $p_1 = 5$ bar, $p_2 = 0.2$ bar, $m_s = 50$ kg/min

$V_{b1} = 400 \, m/s$, $\alpha = 20°$

At $p_1 = 5$ bar, 200°C.

$h_1 = 2855.4$ kJ/kg, $s_1 = 7.0592$ kJ/kgK.

At $p_2 = 0.2$ bar

$h_{f2} = 251.5$ kJ/kg, $h_{fg_2} = 2358.4$ kJ/kg

$s_{f2} = 0.832$ kJ/kgK, $s_{fg_2} = 7.0773$ kJ/kgK

Steam expand isentropically

$$s_1 = s_2$$

$$7.0592 = 0.8321 + x_2 \times 7.0773$$

$$x_2 = 0.88.$$

Enthalpy at 0.2 bar,

$$h_2 = h_{f2} + x\, h_{fg2}$$

$$= 251.5 + 0.88 \times 2358.4$$

$$h_2 = 2326.9$$

Enthalpy drop $= h_1 - h_2 = 2855.4 - 2326.9$

$$= 528.5 \text{ kJ/kg}$$

Volume of steam entering the blde

$$V_1 = 44.7\sqrt{h_1 - h_2}$$

$$= 1028 \text{ m/s}$$

$$V_{w1} = 1028 \cos 20 = 966 \text{ m/s}$$

$$V_{f1} = 1028 \sin 20 = 351.6 \text{ m/s}$$

$$\tan\theta = \frac{V_{f1}}{V_1 \cos 20^\circ - V_{b1}}$$

$$\tan\theta = \frac{351.6}{1028 \cos 20^\circ - 400}$$

$$\therefore \theta = 31.85$$

$$V_{r1} \sin 31.85 = V_{f1} = 351.6$$

$$V_{r1} = 666 \text{ m/s}$$

$$V_{wo} = V_{ro} \cos 30^\circ - V_{b1}$$

$$= 666 \cos 30^\circ - 400$$

$$V_{wo} = 177 \text{ m/s}$$

Power develop,

$$P = \dot{m} s (V_{w_1} + V_{w_2}) V_{b1}$$

$$= \frac{50}{60} (966 + 177) \times 400$$

$$= 381 \times 1000 \text{ W}$$

Blade efficiency,

$$\eta_{b1} = \frac{2 V_{b1} (V_{w_1} + V_{w_0})}{V_1^2}$$

$$= \frac{2 \times 400 (966 + 177)}{(1028)^2}$$

$$\eta_{b1} = 0.865 = 86.5\%$$