UNIT-2

THERMAL SYSTEMS

Vibha Masti

Feedback/corrections: vibha@pesu.pes.edu

KR Gopalakrishnan - Assignment question

ENGINES

1) Internal Combustion Engines
- gasoline, diesel

2) External Combustion Engines
- steam engine
- gas engine

chemical energy → mechanical energy → electrical energy

IC ENGINES

Based on Method of Ignition
1) Spark-Ignition
2) Compression Ignition

Based on No. of Cylinders
1) Single Cylinder
2) Multi Cylinder

scientist name

Position of Cylinder
1) Horizontal Engine
2) Vertical Engine
3) V Engine
4) Opposed Cylinder
5) Radial

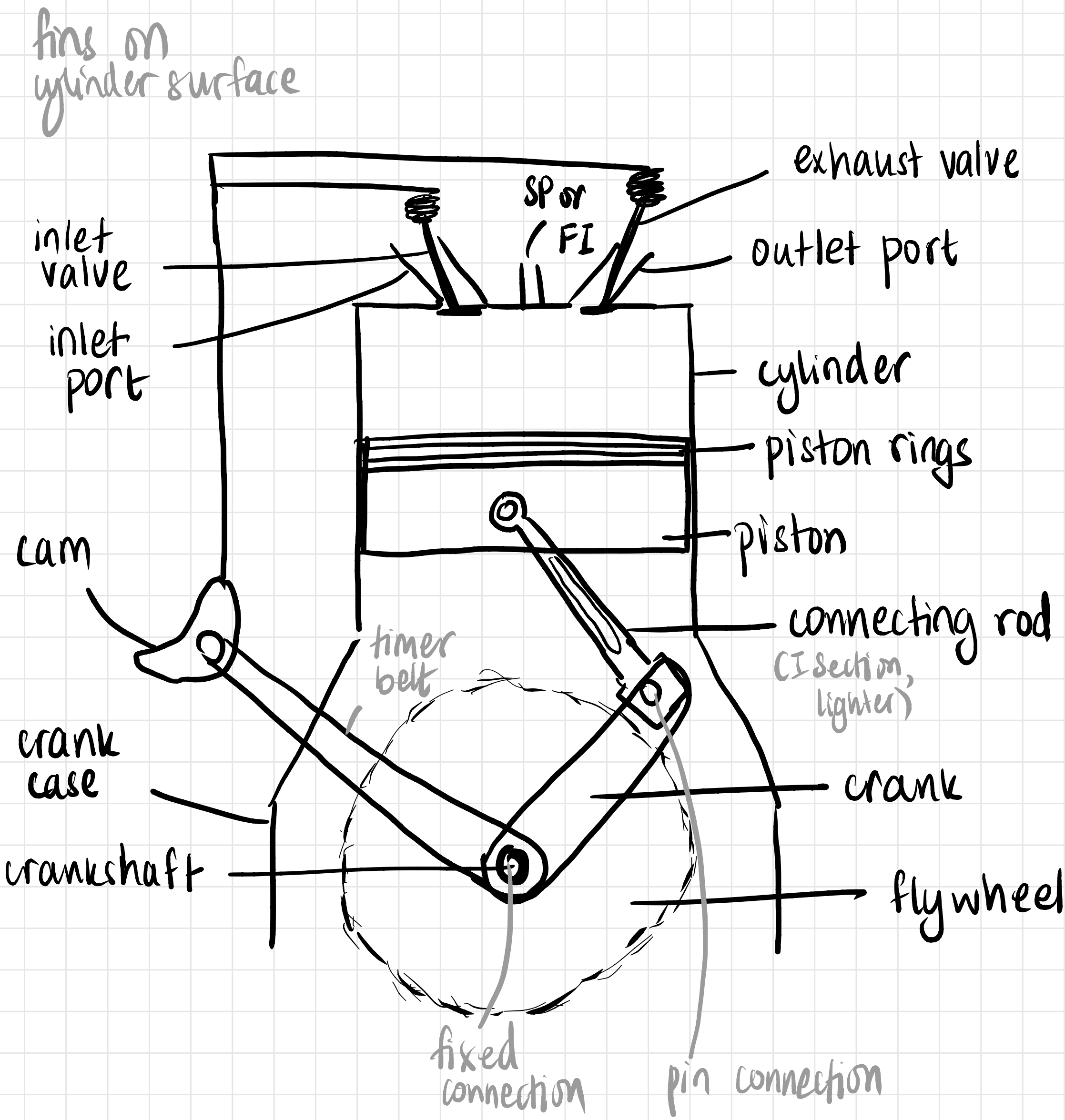
Based on Number of strokes
1) Two stroke
2) Four stroke

Based on Thermodynamic Cycle
1) Otto Cycle
2) Diesel Cycle
3) Dual Combustion Cycle

Based on Cooling Type
1) Air Cooled
2) Oil Cooled

Based on fuel type
1) Petrol Engine
2) Diesel Engine
3) Gas Engine
4) Bi-fuel Engine

FOUR-STROKE ENGINE



Inner diameter of cylinder: bore(?)

Parts of IC Engine

1) Cylinder

- main part of the engine where fuel burns and power is generated
- the inside diameter of the cylinder is called bore
- inside the cylinder, the piston reciprocates and power is generated

2) Piston

- close-fitting hollow cylindrical plunger moving to and fro inside the cylinder
- the power developed by the combustion of the fuel is transmitted by the piston to the crankshaft through the connecting rod.

3) Piston rings

- metallic rings inserted into the circumferential grooves provided at the top end of the piston.
- these rings maintain a gas-tight joint between the piston and the cylinder
- they also help in conducting heat from piston to cylinder

4) Connecting rod

- it is a link that connects the piston and the crank by means of pin joints
- it converts reciprocating motion of piston into rotary motion of crankshaft

5) Crank and Crankshaft

- crank is a lever that is connected to the end of the connecting rod by pin joint with its other end connected rigidly to the shaft

6) Valves

- devices that control the flow of intake and exhaust gases to and from the engine cylinder.
- these valves are operated by means of cam driven by the crankshaft through a timing gear/chime.

7) Flywheel

- heavy wheel mounted on the crankshaft of the engine to maintain uniform rotation of the crankshaft

8) Crank case

- lower part of the engine serving as an enclosure for the crankshaft and also as a sump for lubricating oil.

9) Bore

- inner diameter of engine cylinder

10) Stroke

- linear distance measured parallel to the axis of the cylinder between extreme upper and lower positions of the piston

11) Top Dead Centre (TDC)

- extreme position of the piston at the top of the cylinder
- volume is minimum
- for horizontal cylinder, IDC

12) Bottom Dead Centre (BDC)

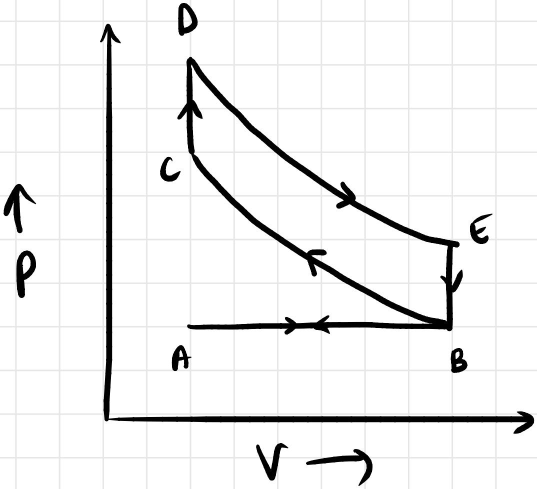
- extreme position of piston at bottom
- volume maximum
- for horizontal cylinder, ODC

13) Compression Ratio

- BDC volume : TDC volume
- volume in cc of engines

Four Stroke Petrol Engine

The four strokes are suction, compression, power and exhaust.



1) Suction stroke

- Here, piston moves from TDC to BDC
- There is a vacuum created inside the cylinder
- Inlet valve open
- Air-fuel mixture (charge) is sucked inside the cylinder through inlet port
- Petrol engine follows otto cycle
- In PV diagram, line AB shows suction stroke

2) Compression stroke

- Piston from BDC to TDC (crank end to cover end)
- Initiation of first & second strokes are by the cranking action during first cycle at the time of starting.
- Petrol-air mixture (charge) contained in the cylinder is compressed

* The ratio of compression in petrol engine ranges from 1:7 to 1:11

- In PV diagram, curve BC shows adiabatic compression (reversible)

- Near the end of the second stroke, the charge is ignited by electric spark using spark plug which is
- This type of engine is called SI engine
- Line CD in PV diagram represents this process
- Both valves closed

3) Working stroke / Power stroke

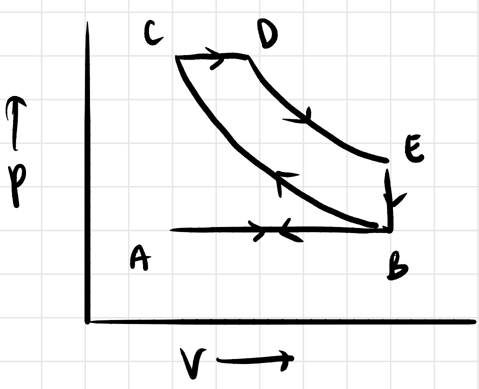
- Piston from TDC to BDC
- Both valves closed
- Crankshaft revolves next half revolution
- High pressure burnt gases forces the piston to perform this stroke.
- Linear motion of piston causes the piston to produce mechanical work or power during this stroke
- Line DE in PV diagram represents this
- Near the end of this stroke, exhaust valve is open, which will release the burnt gases to the atmosphere.
- This will suddenly bring down the cylinder pressure to the atmospheric pressure
- Line EB in PV diagram

4) Exhaust stroke

- During this stroke, exhaust is opened and inlet is closed
- Piston moves from crank end to cover end
- Crankshaft revolves by next half revolution
- The energy required to perform this stroke is supplied by the flywheel from the energy absorbed from the previous stroke

In Diesel engine

- only air enters cylinder in inlet stroke
- fuel injector instead of SP
- C-Ratio ~1:22
- spraying measured amount of fuel to filtered air



- the energy required during this stroke is provided by cranking movement only during initiation
- as this stroke is performed, the air in the cylinder will be compressed.
- the ratio of compression ranges from 1:20 to 1:22
- at the end of this stroke, a metered quantity of diesel oil is sprayed into the cylinder through the fuel injector
- the high temperature of the air ignites the diesel oil as soon as it is sprayed.
- this is called as Otto-ignition or self ignition.

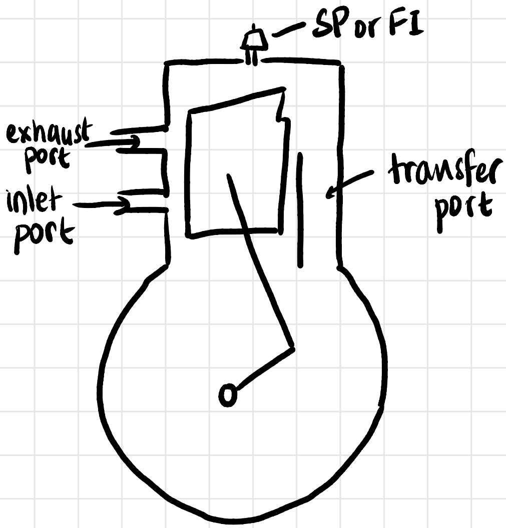
Petrol vs Diesel Engine

Book
KR gopalakrishna

Sl. no	Details	Petrol	Diesel
1	Initial cost	less	more

11.01.2020

TWO-STROKE ENGINE



• scavenging : fuel consumption more

- One cycle : 2 strokes (one revolution)
- ports at cylinder walls ; no valves

Suction + Compression - first stroke

Power + Exhaust

Scavenging

Exhaust gases are removed from cylinder with the help of fresh charges

Deflector

To prevent loss of incoming charge and helps, for exhausting hot gases

Ports

1. Inlet
2. Transfer
3. Exhaust

2 vs 4

4 stroke	2 stroke
heavier flywheel	lighter flywheel
less power	more power for same size
heavy engine	lighter engine
less cooling and lubricating	greater cooling and lubrication
complicated valves & mechanism (cam + timer belt)	simple ports
2 rev per cycle	1 rev per cycle

Specific Fuel Consumption (SFC)

- amount of fuel consumed by an engine to produce unit power
- kg/kJ or kg/MJ or kg/kW-hr

Power

1) Indicated Power

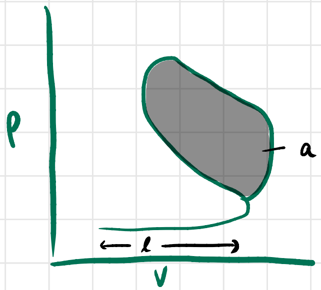
- power produced inside the cylinder and calculated by finding the actual mean effective pressure
- mean effective pressure

$$P_m = \frac{(s*a)}{l}$$

where s = spring value of spring used in the indicator

l = base width of the indicator diagram

a = area of the actual indicator diagram



work done by piston per cycle = (mean force acting) x (piston displacement)

$= P_m \times A \times L \qquad (Nm^{-2}\, m^2\, m = J)$

work done by piston per minute = (work done by piston per cycle) x (no. of cycles per min)

$= P_m \times A \times L \times n$

Let N = rev. per min

For four-stroke engines,

$$2 \text{ rev} \longrightarrow 1 \text{ cycle} \Rightarrow 1 \text{ rev} \rightarrow \tfrac{1}{2} \text{ cycle}$$

$$\text{no. of cycles per min} = \text{rev. per min} \times \frac{\text{cycles}}{\text{rev}}$$

$$n = \frac{N}{2}$$

For two-stroke engines,

$$1 \text{ cycle} \longrightarrow 1 \text{ rev}$$

$$\text{no. of cycles per min} = \left(\text{rev per min}\right) \times \left(\frac{\text{cycles}}{\text{rev}}\right)$$

$$n = N$$

For four-stroke engines

$$IP = \frac{P_m L A N}{60 \times 2} \quad (W)$$

$$P_m = \frac{S \times a}{l}$$

For two-stroke engines,

$$IP = \frac{P_m L A N}{60} \quad (W)$$

$$1 \text{ bar} = 10^5 \, Nm^{-2}$$

13.01.20

2) Brake Power

Amount of power available at the crankshaft after frictional losses, which is equal to

$$BP = \frac{2\pi N \tau}{60}$$

where N = rpm (speed of crankshaft)

τ = torque developed at the crankshaft

$$\tau = W \times R$$

W = weight applied

R = radius of crankshaft

Since the weight applied is in terms of kg

$$\tau = 9.81\, WR \ \text{Nm}$$
$$= \frac{9.81\, WR}{1000} \ \text{kNm}$$

3) Frictional Power

$$FP = IP - BP$$

Efficiency of the Engine

1) Mechanical Efficiency

$$\eta_{mech} = \frac{BP}{IP} \times 100\%$$

2) Thermal Efficiency

$$\frac{\text{power output}}{\text{heat energy supplied by fuel per unit time}}$$

(i) Indicated Thermal Efficiency

$$\eta_{Ith} = \frac{IP}{CV \times \dot{m}} \times 100\%$$

CV: calorific value
$\dot{m}$: mass flow rate

(ii) Brake Thermal Efficiency

Q1. A four stroke IC engine running at 450 rpm has bore diameter 100mm and stroke length 120mm. The indicator diagram details are:

area of diagram = 4 cm²

length of diagram = 6.5 cm

spring value of spring used = 10 bar cm⁻¹

Calculate IP of engine

$$P_m = \frac{S \times a}{l} = \frac{(10\ \text{bar cm}^{-1})(4\ \text{cm}^2)}{(6.5\ \text{cm})}$$

$$= 6.15\ \text{bar}$$

$$IP = \frac{P_m L A N}{2 \times 60} = \frac{(6.15\ \text{bar})(120\ \text{mm})\left(\frac{\pi \times 100^2}{4}\ \text{mm}^2\right)(450)}{2 \times 60}$$

$$= \frac{6.15 \times 10^5 \times 0.12 \times \pi \times 0.1 \times 450 \times 0.1}{2 \times 60 \times 4}$$

$$IP = 2.17\ \text{kW}$$

Q2. Find the indicated power of 4 stroke petrol engine. The average piston speed is 70 m per min. The mean effective pressure is 5.5 bar and the diameter of the piston is 150mm.

piston speed = $2L \times N$ = distance per revolution × rpm
= distance per minute

$$IP = \frac{P_m L A N}{60 \times 2}$$

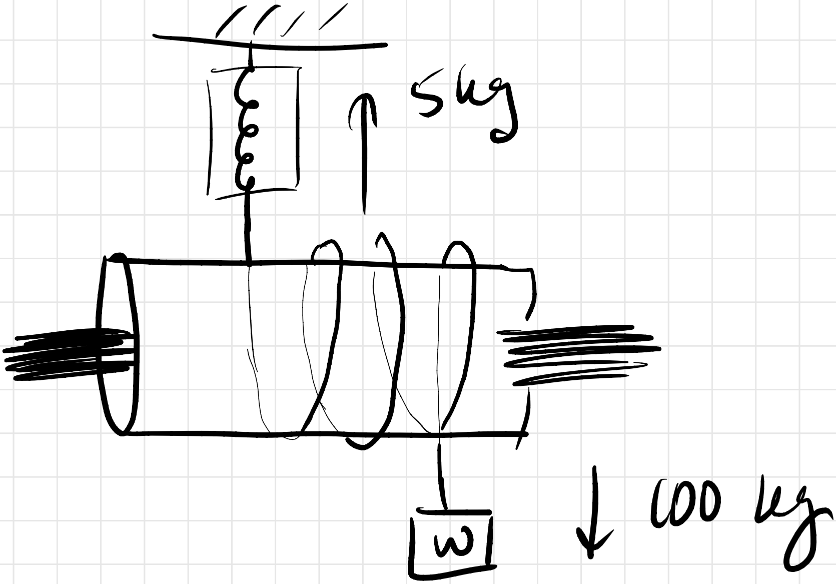
$$= \frac{5.5 \times 10^5 \times 70 \times}{2 \times 60 \times 2} \frac{\pi (0.15)^2}{4} = 2.83 \text{ kW}$$

Q3. The following readings were taken on a four-stroke IC engine:

1) diameter of brake drum = 1.5 m
2) diameter of the rope = 10 mm
3) load suspended on the brake drum = 100kg
4) spring balance reading = 5kg
5) Crankshaft speed = 200 rpm

Determine brake power.

$$BP = \frac{2\pi N \tau}{60}, \quad \tau = W \times R \times 9.81$$



effective radius $R = \frac{1.5m + (10mm)}{2} = \frac{1.51}{2} = 0.755$

$W = 100 - 5 = 95\,kg$

$\tau = 95 \times 9.81 \times 0.755 = 703.62\,Nm$

$BP = \frac{2\pi \times 200 \times 703.62}{60} = 14.736\,kW$

Q4. A 4 stroke single cylinder IC engine of 250 mm diameter and 400 mm stroke length runs at a piston speed of 8 ms^{-1}. If the engine develops 50 kW of IP, find its P_m and the crankshaft speed.

$D = 250mm$
$L = 400mm$
piston speed $= 8 ms^{-1}$

in one rev,
$2L$
$\therefore 2L \times N = \text{piston speed} \times 60$

stroke length $= 0.4 m$

piston speed $= 8 \times 60 = (0.4)(N \times 2)$

$$N = \frac{8 \times 60}{0.8} = 600$$

$$LN = \frac{8 \times 60}{2} = 240 \Rightarrow \frac{LN}{60} = 4$$

$$IP = \frac{P_m A}{2} \times 4 = 2 P_m \times \frac{\pi \times (0.25)^2}{4}$$

$$P_m = 509 \ kNm^{-2} = 5.09 \ bar$$

REFRIGERATION

Method of reducing temp of system to below that of the surroundings and maintaining it at the lower temperature by continuously abstracting the heat from it.

Second Law of Thermodynamics

Claussius: heat cannot flow from body at lower temp to higher temp unless assisted by some external means.

working fluid: vapour → liquid during rejection
liquid → vapour during absorption

Heat continuously removed from system at lower temp and rejected to surroundings at higher temp

Refrigerant: medium through which heat is abstracted from lower temp.

Refrigerating systems

two types

1) vapour compression refrigerator
2) vapour absorption refrigeration

1) VCR

convection faster than radiation

absorbs more latent heat

evaporator

phase change; refrigerating effect

drop in pressure; lower saturation pressure

mix of two phases (some might be vapour)

vapour, low pressure

using thermostat

compressor

increase pressure

expansion valve

high pressure, condensed liquid

high T, P vapour

condensor

leaves latent heat to env due to higher T, P

There are 4 parts in VCR

1) Compressor

It is used to compress and circulate the low temp, low pressure working fluid into high temp, high pressure vapour.

They are power-absorbing mechanical devices and need input power

2) Evaporator

Cooling coils arranged in form of u-tube

Reduce the temp of refrigerator cabinet

The low temp, 2 phase mixture of refrigerant passing through the evaporator coils absorbs heat from the cabinet and changes into vapour phase

This effect of cooling is aka refrigerating effect

3) Condensor

Series of coils in form of u-tubes

High P, T refrigerant from compressor enters condensor

Where the refrigerant rejects its heat to the surrounding atmosphere

The latent heat of the refrigerant is given to the surroundings, which results in change of phase of ref.

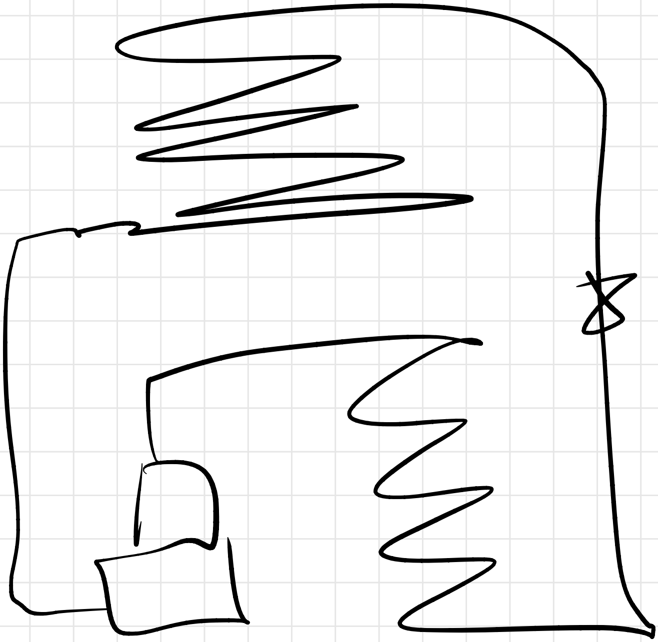
4) Expansion valve

High pressure & temp liquid refrigerant expands in expansion valve to low pressure & temp two-phase mixture

Temp of refrigerant drops due to partial evaporation

- note: propeller blades in ships (motor boats)
- cavitation

Refrigerator



Refrigeration Effect

Rate at which heat is absorbed in a cycle from the interior space to be cooled is called refrigeration

Capacity of ref. system is expressed in ton of refrigeration

Ton of refrigeration

Quantity of heat absorbed in order to produce one ton of ice in 24 hr when in initial temp of water is 0°C

$$1 \text{ ton of ref} = 210 \text{ kJ/min} = 3.5 \text{ kW}$$

COP

coefficient of performance

ratio of heat absorbed in a system to the work supplied

Q = heat absorbed/removed (kW)
W = work supplied (kW)

$$COP = \frac{Q}{W}$$

Q5. Find the indicated power of a 4 stroke petrol engine of swept volume 6L running at 1000 rpm. The mean effective pressure is 600 kNm^{-2}

$$IP = \frac{P_m L A N}{2 \times 60} = \frac{(\cancel{600}^{10})(\cancel{10^3})(6 \times \cancel{10^{-3}})(1000)}{\cancel{2} \times \cancel{60}}$$

$$IP = 30\ kW$$

MISFIRES

Q6. A 6 cylinder 4 stroke IC engine develops 50kW of IP at $P_m = 7$ bar. The bore and stroke of cylinder are 70mm and 100mm respectively. If the engine speed is 3700 rpm, the find the average misfires per minute.

(single cylinder)

$$IP = \frac{P_m L A N}{60 \times 2}$$

$$\frac{50}{6} \times 10^3 = \frac{7 \times 10^5 \times 100 \times 10^{-3}}{60 \times 2} \times \frac{\pi (70 \times 10^{-3})^2}{4} \times N$$

$$N = 3712\ rpm$$

$$\text{no. of cycles} = \frac{N}{2} = 1856$$

Actually, $N = 3700$ rpm $\Rightarrow n = 1850$

$\therefore$ no. of misfires $= 6$

Q7. A four-stroke petrol engine of 100 mm bore and 150 mm stroke consumes 1kg of fuel per hour. $P_m = 7$ bar, indicated thermal efficiency $= 30\%$. Calorific value of fuel $= 40 \times 10^3$ kJ kg^{-1}. Find the crankshaft speed.

$D = 0.1$ m
$L = 0.15$ m
$m_0 = 1$ kg h^{-1}
$P_m = 7$ bar
$\eta = 30\%$
C.V. $= 4 \times 10^4$ kJ kg^{-1}

energy from fuel per hour $= 4 \times 10^4$ kJ h^{-1}

energy delivered (indicated power) $= 12 \times 10^3$ kJ h^{-1}

$$IP = \frac{10^3 \times 12 \times 10^3}{3600} = \frac{P_m L A N}{60 \times 2}$$

$$10^3 \times 400 = \frac{7\times10^5 \times 0.15 \times \pi \times 0.01 \times N}{4}$$

$$N = 485$$

Q8. The following data refers to a single cylinder four-stroke petrol engine.

Cylinder diameter = 20 cm = 0.2 m
Stroke = 40 cm = 0.4 m
Engine speed = 400 rpm
Indicated mean effective pressure = 7 bar
Fuel consumption = 10 L $hour^{-1}$
Calorific value = 45000 kJ kg^{-1}
Specific gravity of fuel = 0.8

Find the indicated thermal efficiency

$$\text{fuel consumption} = 10\times\cancel{10^{-3}}\times0.8\times\cancel{10^{3}} \text{ kg hour}^{-1}$$

$$= 8 \text{ kg hour}^{-1}$$

$$IP = \frac{P_m LAN}{60\times2} = \frac{7\times10^5\times0.4\times\pi\times0.04}{4\times60\times2}\times400$$

$$= 29.32 \text{ kJ s}^{-1}$$

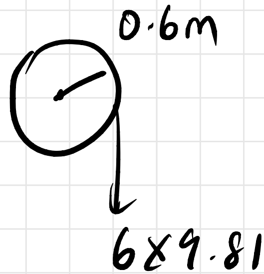
$$\text{fuel consumption} = \frac{\overset{2}{\cancel{8}}}{\underset{4}{\cancel{3600}}}\times \overset{50}{\cancel{45000}} \text{ kJ s}^{-1}$$

$= 100 \ kJs^{-1}$

$\eta = 29.32\%$

Q9. Single cylinder 4-stroke engine runs at 1000 rpm and has a bore of 115 mm and stroke of 140 mm. The brake load is 6 kg at 600 mm radius. Mechanical efficiency is 80%. Calculate BP and P_m

$$BP = \frac{2\pi N \tau}{60}$$



$$= \frac{2\pi \times 10\cancel{00} \times \overset{0.6}{\cancel{3.6}} \times 9.81}{\cancel{60}}$$

$BP = 3.698 \ kW$

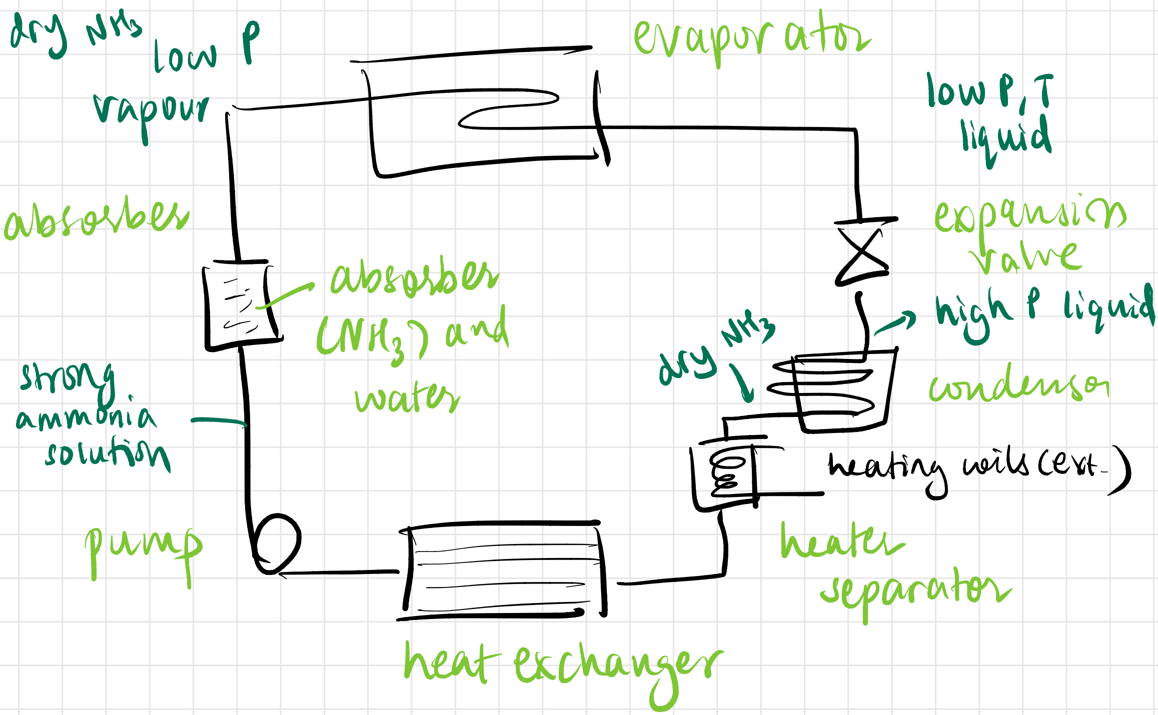
$$\eta = \frac{BP}{IP} = 0.8 = \frac{3.698}{IP} \Rightarrow IP = 4.623 \ kW$$

$$\frac{P_m LAN}{2 \times 60} = 4622$$

$P_m = 3.81$ bar

2) Vapour Absorption System (VAS)

- NH_3 is flammable and toxic
- combination of absorber and refrigerant
- COP lower
- absorber absorbs refrigerant solution and gives up vapour refrigerant when heated.
- NH_3 is refrigerant, not freon 12



The main parts of this system include NH_3 as refrigerant and H_2O as absorbant.

It includes evaporator, absorber, circulation pump, heat exchanger, heater-separator, condensor, and expansion valve as the main parts of the system

Not used domestically

Properties of Refrigerants

1. Low boiling point (for easy evaporation)
2. low freezing point (should not freeze)
3. Very high latent heat (to accomplish refrigeration with min. amount of refrigerant)
4. Pressure higher than atm (slightly)
5. Specific volume low (high density)
   reduce size of compressor
   volume / mass (per kg)
6. low specific heat in liquid, high in vapour
   decrease superheating
   increase sub cooling
7. low viscosity for pumping pressure
8. Non-toxic
9. Non-flammable
10. Non-corrosive
11. Non-reactive

- Sulphur dioxide (SO_2) as refrigerant
- Forms H_2SO_4

12. COP high
13. Non-reactive with lubricating oil

Commonly used Refrigerants

1) Ammonia

- VAS
- high latent heat, low specific volume
- toxic, flammable, irritating
- not used domestically
- cold storage, ice-making plants

2) Carbon Dioxide (CO_2)

- low efficiency
- dry ice
- non-toxic, non-flammable, non-corrosive

3) Sulphur Dioxide (SO_2)

- household
- low refrigeration effect, high specific volume, increases compressor size
- with H_2O, forms sulphurous and sulphuric acids, corrosive to metals

4) Methyl Chloride

- small scale
- flammable, toxic

5) Freon-12 and Freon-22

- harmful to O_3 layer
- colourless, non-toxic, non-flammable, non-explosive
- dichlorodifluoromethane (CF_2Cl_2)
- non-corrosive, odourless
- domestic VCR and AC

Steam & Properties of Steam

Steam Formation & Properties

A pure substance retains its chemical comp. eventhough it undergoes a change in phase during thermodynamic process

Water can be considered as one of the pure substances. Here, the diff. states of existence and associated properties of steam required in its thermodynamic analysis are studied.

Important Properties of Steam

1. Pressure
2. Temperature
3. Specific volume
4. Enthalpy
5. Internal energy
6. Entropy

Steam Formation

- Water is heated to higher temp to form steam where there is increase in pressure which intern transforms from boiler to engine of turbine at constant pressure, so here we study properties of steam at constant pressure.
- A steam generation experiment is conducted by heating water from 0°C at a particular pressure.
- Since the steam is generated at constant pressure, the amount of heat energy supplied to convert water into steam will be equal to enthalpy.

Enthalpy of steam

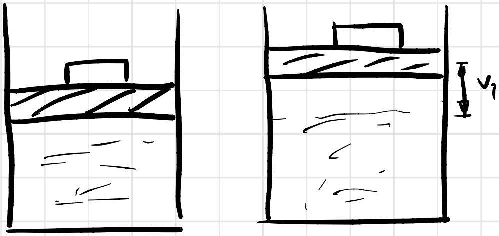
$$dQ = du + pdV$$
$$= du + d(pV) - Vdp$$

$$dQ = d(u + pV) - Vdp$$

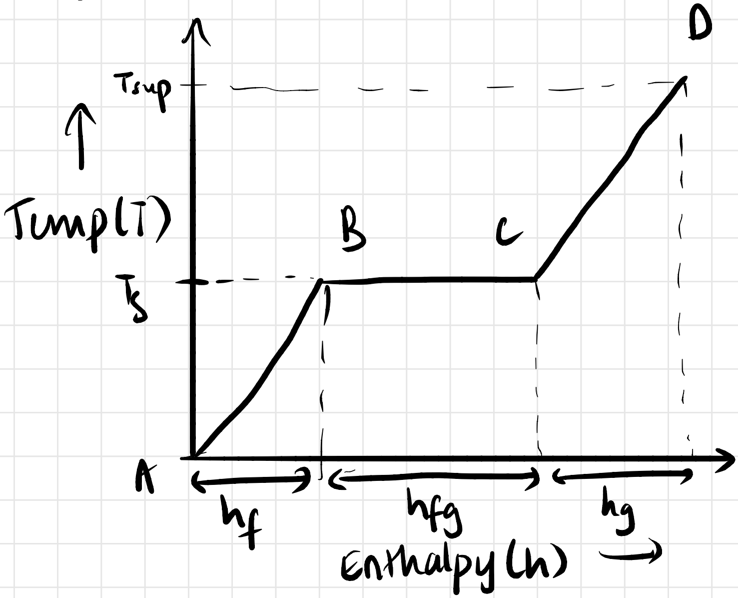
Pressure constant ($dp = 0$)

$$dQ = d(u + pV)$$

$$dQ = dH$$



1kg water at 0°C



- At point A in the graph, 1 kg of water is at 0°C and at constant pressure acting on it.
- As the temp. of heat input increases, H_2O reaches its saturation temp. at point B
- T_s = temp. at which H_2O begins to boil at given pressure (saturation temperature).
- h_f = the amount of heat req. to raise temp. of 1 kg of water from 0°C to saturated temp. T_s °C at given constant pressure (sensible heat). It is also called heat of liquid or enthalpy of liquid
- Further supply of heat initiates evaporation of water while temperature remains at T_s where additional heat changes only the phase from liquid to vapour.
- h_{fg} = the amount of heat required to evaporate 1 kg of water at T_s into 1 kg of dry steam at T_s and at given constant pressure is called Latent Heat of Vaporisation
- Further addition of heat can lead to superheating.
- h_g = amount of heat req. to increase temp. of dry steam from T_s to any desired higher temp at a given constant pressure is called amount of superheat.
- The difference between the superheated temperature and T_s is called degree of superheat.

Different States of Steam

1) Wet steam

- Here, in the process of heating, both entrained water molecules and steam coexist to form a two-phase mixture called wet steam. (B to C)

- Dryness varies from B to C. Wet steam can be of different qualities, i.e. different proportion of water molecules and dry steam. Therefore, it is necessary to state the quality of wet steam, which is specified by dryness fraction (x) which indicates the amount of dry steam present in a given quantity of wet steam

$$x = \frac{\text{mass of dry steam}}{\text{mass of wet steam}} = \frac{m_g}{m_f + m_g}$$

2) Dry saturated steam

- Saturated steam at T_s corresponding to a given pressure and having no water molecules entrained in it is defined as dry saturated steam or dry steam

3) Superheated steam

- Steam that is heated beyond its dry saturated state to temp. higher than T_s at given constant pressure.

Enthalpy of wet steam

$$h = h_f + x h_{fg}$$

Enthalpy of Dry saturated steam

$$h_g = h_f + h_{fg}$$

Enthalpy of superheated steam

$$h_{sup} = h_g + C_{ps}(T_{sup} - T_s)$$

$h_f + h_{fg}$

specific heat

* reading steam tables

Steam Tables

1) Temperature-based
2) Pressure-based

Specific Volume

- inverse of density
- volume occupied by unit mass of a substance
- expressed in $m^3\,kg^{-1}$

Specific volume of saturated water

- volume occupied by 1kg of water at saturation temperature at a given pressure
- denoted by V_f

Specific volume of dry saturated steam

- volume occupied by 1kg of DSS at a given pressure denoted by V_g

Specific volume of wet steam

- when steam is wet, its specific volume = sum of volume occupied by dry steam in 1kg of wet steam and the volume occupied by entrailed water molecules in the same kg of wet steam.

- If x = dryness fraction of the steam and mass of water molecules is $= 1-x$

can neglect

$$V = xV_g + (1-x)V_f$$

$$V = xV_g$$

specific volume of superheated steam

- it is defined as volume occupied by 1kg of superheated steam at a given pressure and superheated temperature
- this T_{sup} behaves like a perfect gas ∴ its sp. vol. is determined using Charles' Law

$$\frac{V_g}{T_s} = \frac{V_{sup}}{T_{sup}}$$

$$V_{sup} = \frac{V_g}{T_s} \times T_{sup}$$

External work of evaporisation

blue colour book pg 37?

A fraction of latent heat of vaporisation which does external work.

Internal latent heat

Energy required to change the phase is called true latent heat/internal latent heat which is obtained by subtracting the external work of vaporisation from latent heat of vaporisation.

Internal Energy of steam

It is defined as the difference between enthalpy of steam and external work of vaporisation

Q: Find the enthalpy of 1kg of steam at 12 bar when
a) steam is dry saturated
b) steam is 22% wet
c) superheated at 250°c
Use steam tables. Assume that sp. heat of superheated steam is 2.25 kJ/kg K

A: $T_s = 188\,°C$, $h_f = 798.4$, $h_{fg} = 1984.3$, $h_g = 2782.7$

(a) $h_g = h_f + h_{fg}$

$= 2782.7$

(b) $x = 0.78$

$h = h_f + x h_{fg} = 798.4 + 0.78 \times 1984.3$

$= 2346.154$

(c) $h = h_g + (250-188) \times 2.25$

$= 2782.7 + 62 \times 2.25$

$= 2922.2$

Q: Steam of 10 bar, dryness 0.98 receives 140 kJ/kg heat at the same pressure. What is the final state of steam?
$C_{sup} = 2.25$ kJ/kgK

A: $T_s = 179.9°C$, $h_f = 762.6$, $h_{fg} = 2013.6$, $h_g = 2776.2$

- to become superheated, first must lose wetness

- heat req. for that = $0.02 \times 2013.6 = 40.272$
- at this point, temp = $T_s = 179.9$

- heat left = 99.728
- inc. in temp = $\frac{99.728}{2.25} = 44.32°$

- $\therefore$ final temp = $224.22°C$ (superheated steam)
  = 497.2 K

Q: Enthalpy of 1kg of steam at 70 bar is 2680 kJ. What is the condition of steam?

$h_g = 2773.5$ kJ/kg
$h_{fg} = 1506.0$
$h_f = 1267.4$ kJ/kg

$\therefore$ it is wet steam

$$x = \frac{(2680 - 1267.4)}{1506} = 0.937$$

Steam Turbines

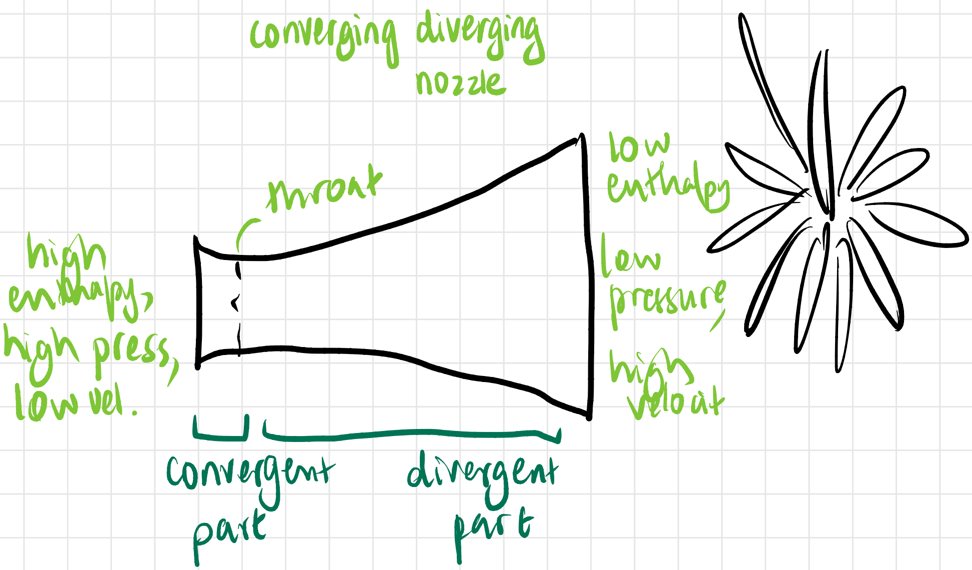
- prime mover (self-moving device that converts available natural sources of energy to mech. energy)
- heat ⟶ mechanical

1) Impulse turbine (De Laval)

- use impulse action of steam to impinge on surface of blades and transfer KE to ME.
- high speed rotation of blades (rotor) ⟶ electrical

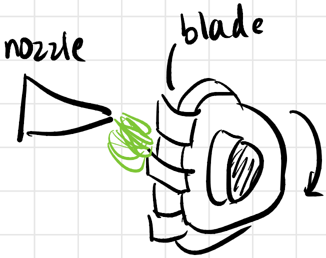
2) Reaction turbine (Parson's)

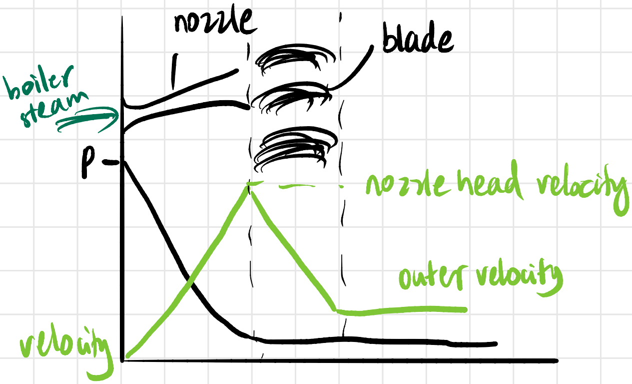
- no nozzle
- high pressure



De Laval Turbine (Impulse)

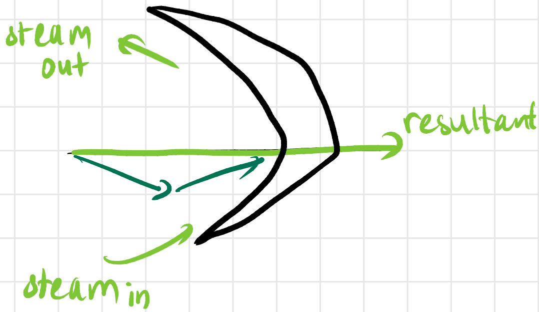
- steam expanded in nozzle
- high $\vec{v}$ steam from nozzle glides over blades
- particle of steam – change in momentum – force
- causes blades to rotate



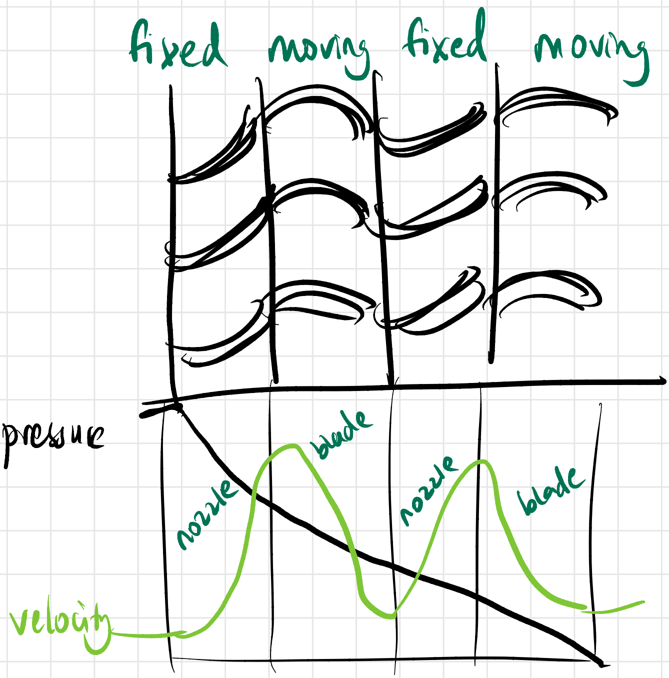


Parson's Turbine (Reaction)

- steam does not expand in nozzle
- directly on blade
- blades designed in such a way that the steam flowing between blades subjected to nozzle effect.



- alternate moving & fixed blades (rows)



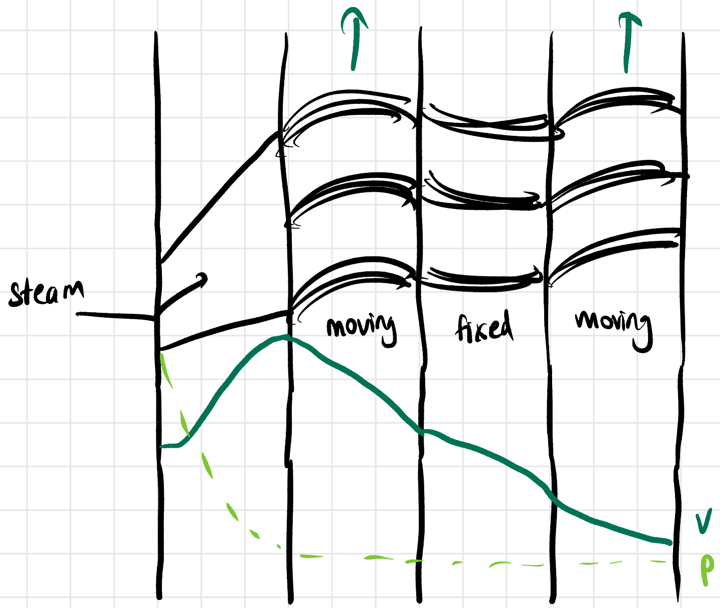
Comparision

Impulse	Reaction
• expansion from high P to low P in nozzle	• continuously expands in both fixed & moving blades
• high steam & rotor speed	• rotor & steam speed less
• less space / power	• more space / power
• suitable for small power generation	• suitable for med. / high power
• high speed; compounding req to reduce speed	• compounding not req.

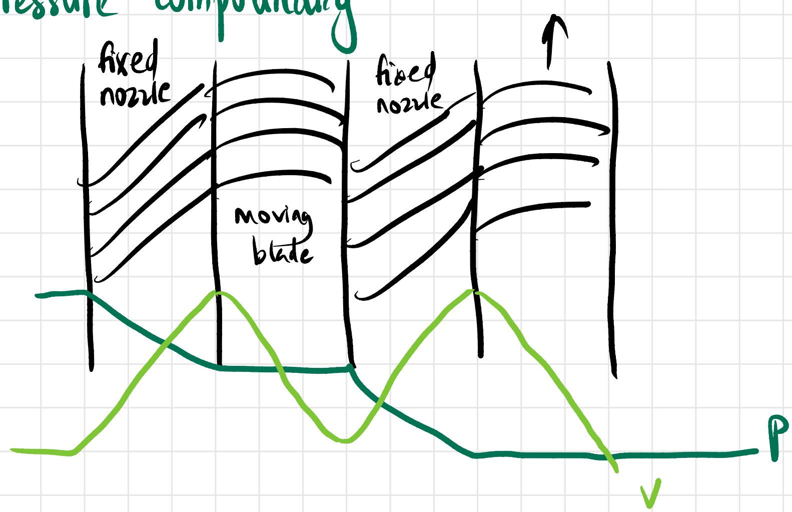
Compounding Steam Turbines

- rotors too fast due to high $\vec{v}$ of steam
- technical difficulties
- expansion in several stages
- utilisation of high pressure energy of steam by expanding it in successive stages —— compounding
- methods
  1) Velocity compounding
  2) Pressure compounding
  3) Pressure - velocity compounding
  4) Compounding of rxn turbine

Velocity compounding



Pressure Compounding



Q: 6 kg of wet steam contains 0.56kg of water particles in it. What is the dryness fraction of it?

$$d.f = \frac{6-0.56}{6} = \frac{68}{75} = 0.907$$

Q: 1 kg of superheated steam at 1.5 MPa contains 3000 kJ of of heat energy. Find the superheated temperature. If 500 kJ of heat energy is removed at the same pressure, what is the condition of the steam if $C_{psup} = 2.25$ kJ/kg K?

1.5×10^6 Pa = 15 bar

$T_s = 198.3°C$
$h_f = 844.7$
$h_{fg} = 1945.2$
$h_g = 2789.9$

$$h_{sup} = h_g + (T_{sup} - T_s) C$$

$$3000 = 2789.9 + (T_{sup} - 198.3)(2.25)$$

$$T_{sup} = 291.68°C$$

if 500 J removed

2500 → wet steam

$$\text{dryness factor} = x = \frac{2500 - 844.7}{1945.2} = 0.85$$

Q: 2kg of dry saturated steam at 1MPa is produced from water at 40°C. Determine the quantity of heat supplied. Consider specific heat of water = 4.18 kJ/kg.

$T_s = 179.9°C$, $h_f = 762.6$, $h_{fg} = 2013.6$, $h_g = 2776.2$

heat supplied $= ((4.18)(T_s - 40) + h_{fg}) \times 2$

$= 2598.4 \times 2$

$= 5196.7$ kJ

Q: 5kg of wet steam of dryness 0.8 passes from a boiler to a superheater with constant pressure of 1 MPa. In the superheater its temperature increases to 350°C. Determine the amount of heat supplied in the superheater. The specific heat of sup. steam = 2.25 kJ/kgK

$T_s = 179.9°C$ $h_{fg} = 2013.6$

heat to become dry steam $= ((0.2) \times (h_{fg}) + (350 - 179.9)(2.25)) \times 5$

$= 5(785.445) = 3927.225$ kJ

Hybrid Vehicles

- more than one means of propulsion
- combination of petrol/diesel with electric motor

Parallel Hybrid cars

- both run simultaneously, or one can be used as primary source with other source for assisting in starting, uphill

Series Hybrid

- IC engine and generator to generate but not drive car
- energy stored in battery or sent directly to electric motor
- high capacity battery very expensive

Plug-in Hybrids

- Can be plugged in to charge
- ICE used as backup

Electric Vehicles