

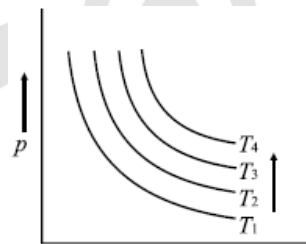
**DETAILS EXPLANATIONS****ME: Paper-2 (Paper-1) [Full Syllabus]****[PART : A]**

1. Viscosity is that property of a real fluid by virtue of which it offers resistance to shear force.
2. When fluid particles flow on a curvilinear path along with the flow with out any external torque or force then it is known as free vortex flow.  
If fluid flow along a curvilinear path along with the flow due to any external torque or force then it is known as forced vortex flow.
3. Reynolds number is the ratio of inertia force to viscous force. The inertia force is proportional to the mass flow and velocity i.e.,  $(\rho u \cdot u)$ . The viscous force is proportional to  $\mu(du/dy)$  or  $\mu(u/D)$ , Dividing

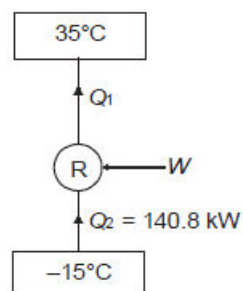
$$\frac{\text{inertia force}}{\text{viscous force}} = \frac{\rho u D}{\mu} = \frac{u D}{\nu}$$

Viscous force tends to keep the layers moving smoothly one over the other. Inertia forces tend to move the particles away from the layer. When viscous force are sufficiently high so that any disturbance is smoothed down, laminar flow prevails in pipes. When velocity increases, inertia forces increase and particles are pushed upwards out of the smoother path. As long as Reynolds number is below 2,300, laminar flow prevails in pipes. The friction factor in flow is also found to be a function of Reynolds number (in laminar flow,  $f = 64/Re$ ).

4. Boyle's law says that if temperature of a gas is held constant then its molar volume is inversely proportional to the pressure. Mathematically it can be related as  $p v = \text{constant}$ . Here  $p$  is the pressure and  $v$  is the molar volume of gas, i.e. volume per mole.

**Boyle's law**

5. (i) First law of thermodynamics does not differentiate between heat and work and assures full convertibility of one into other whereas full conversion of work into heat is possible but the vice-versa is not possible.  
(ii) First law of thermodynamics does not explain the direction of a process. Such as theoretically it shall permit even heat transfer from low temperature body to high temperature body which is not practically feasible. Spontaneity of the process is not taken care of by the first law of thermodynamics.
6. Kelvin-Planck statement of second law of thermodynamics: "It is impossible for a device operating in a cycle to produce net work while exchanging heat with bodies at single fixed temperature".
7. Cold storage plant can be considered as a refrigerator operating between given temperature limits.



Capacity of plant = Heat to be extracted = 140.8 kW

$$\text{Carnot COP of plant} = \frac{1}{\left(\frac{308}{258.15}\right)^{-1}} = 5.18$$

$$\text{Actual COP} = \frac{5.18}{4} = 1.295$$

$$\text{Also actual COP} = \frac{Q_2}{W}, \text{ hence } W = 108.73 \text{ kW}$$

Power required = 108.73 kW

8. The portion of low grade energy that can be converted is called 'available energy' or 'exergy' or 'availability'.
9. During combustion, the chemical energy of fuel gets transformed into molecular kinetic or molecular potential energy of products. This energy associated with combustion also called calorific value of fuel is very important to be known for thermodynamic design and calculations of combustion systems. "Bomb calorimeter" is one of the ways to get the heating value of solid and liquid fuels when burnt at constant volume. Different types of bomb calorimeters as given by At water, Davis, Emerson, Mahler, Parr, Peters and Williams are available. Bomb calorimeter as given by Emerson is discussed here. For getting the heating value of gaseous fuel the gas calorimeter is also discussed here.
10. It is a non return valve at the end of delivery pipe from feed water pump and is placed on boiler shell slightly below normal water level.
11. Based on type of fuel used: IC engines may be classified depending upon the type of fuel being used. These can be :
  - (i) Petrol engines (petrol being used as fuel)
  - (ii) Gas engines (gaseous fuel being used)
  - (iii) Diesel engines (diesel being used as fuel)
  - (iv) Multi-fuel engines (more than one fuel being used)
12. **Valves** : Engine has both intake and exhaust type of valves which are operated by valve operating mechanism comprising of cam, camshaft, follower, valve rod, rocker arm, valve spring etc. Valves are generally of spring loaded type and made out of special alloy steels by forging process.  
**Spark plug** : It is the external ignitor used for initiating combustion process. Spark plug is activated by electrical energy fed by electrical system with engine. It delivers spark with suitable energy to initiate combustion at appropriate time for suitable duration.
13. Refrigeration effect is the amount of heat extracted by refrigerator from the refrigerated space. The higher capacity of refrigerator means higher shall be the refrigeration effect. This refrigeration effect is defined by the unit of refrigeration called 'Ton' of refrigeration. 'Ton' as unit of refrigeration has been defined based on formation of ice as described ahead.  
 "One 'Ton' of refrigeration can be defined by the amount of heat being removed from one ton of water at 0°C to form one ton of ice at 0°C within 24 hours." Thus, a Ton of refrigeration shall quantify the latent heat required to be removed for solidification of water at 0°C.
14. Relative humidity: Relative humidity gives an account of moisture content in an actual mixture as compared to the mixture in saturated state at same temperature and pressure. It can be given by the ratio of actual mass of water vapour in given volume to the mass of water vapour if the air is saturated at the same temperature and pressure.

Mathematically, relative humidity ( $\phi$ ) can be given as :

$$\phi = \frac{\text{(Actual mass of water vapour in given volume of mixture)}}{\text{(Maximum mass of water vapour in same volume of mixture being saturated at same temperature and pressure)}}$$

15. Since the purpose of insulation is to reduce the heat loss, it is always better to provide insulating material of lower conductivity on lower radius, because then heat will find lower multiple of area for heat conduction and thermal conductivity. There is also a limitation on the thickness of insulation beyond which there will be less effective insulation. In such cases, the material of insulation adds conductance for heat transfer.

16. **Biot Number** : Biot number<sup>3</sup> is defined as

$$Bi = \frac{h l_c}{k}$$

Where,  $l_c(V/A)$  is called critical length of the body. This lumped heat analysis (also known as Lumped heat capacity approach) is valid only for  $Bi < 0.1$ .

17. Nusselt number (Nu) is defined as ratio of heat convected through the fluid and heat conducted through the fluid :

$$\begin{aligned} Nu &= \frac{hA\Delta T}{kA\Delta T/x} \\ &= \frac{hx}{k} \end{aligned}$$

The Nusselt number is a dimensionless version of the temperature gradient at the surface between the fluid and the solid, and it thus provides a measure of the convection occurring from the surface. Therefore, in most of the empirical relations, the Nusselt number forms the basis of analyzing the convective heat transfer. Nusselt number always increases with increase in Reynolds number in case of forced convection and with an increase in the Grashof number in case of free convection.

18. Intensity of radiation (I) is defined as the heat flux (energy per unit time) incident per unit projected area of the surface with unit solid angle :

$$I = \frac{\text{Heat flux}}{\text{Projected area} \times \text{Solid angle}}$$

19. Absorptivity of a surface ( $\alpha$ ) is not a surface property, but depends upon the intensity of radiation of the incident radiation. Hence, the absorptivity of a surface at a given temperature is measured when the surface is in thermal equilibrium with the black body at the same temperature.

20. Given, that

$$\begin{aligned} k_1 &= 1.2 \text{ W/mK} \\ k_2 &= 0.15 \text{ W/mK} \\ x_1 &= 0.25 \text{ m} \end{aligned}$$

Using Fourier's equation :

$$Q = \frac{kA\Delta t}{x}$$

For constant  $\dot{Q}$  and  $k$  :

$$x_2 = \frac{k_2}{k_1} x_1$$

Therefore,

$$x_1 = 3.12 \text{ cm}$$

**[PART : B]**

21. The equation that can be used is, (n is used to denote rpm)

$$P = \left[ \frac{\mu \pi^3 n^2 L R^3}{450 h} \right]$$

The solution can be obtained from basics also. Adopting the second method,

$$\tau = \mu \left( \frac{du}{dy} \right) = \mu \left( \frac{u}{y} \right)$$

$$\mu = 19 \text{ cP} = 0.019 \text{ Ns/m}^2$$

$$y = 0.5 \text{ mm} = 0.0005 \text{ m}$$

Let the rpm be n

$$u = \frac{\pi D n}{60} = \pi \times 0.145 \times \frac{n}{16} = 7.592 \times 10^{-3} \times n$$

$$\tau = 0.019 \left( 7.592 \times 10^{-3} \times \frac{n}{0.0005} \right) = 0.2885 \times n \text{ N/m}^2$$

$$A = 2 \times \pi DL = 0.182 \text{ m}^2$$

$$\text{Force } F = A \times \tau = 0.2885 \times n \times 0.182$$

$$= 0.0525 \times n \times 0.182$$

$$= 0.0525 \times n$$

$$\text{Torque} = \text{Force} \times \text{radius}$$

$$T = 0.0525 \times n \times \frac{0.145}{2} = 3.806 \times 10^{-3} \times n \text{ Nm}$$

Power,

$$P = 2\pi n \frac{T}{60} = 15 = 2 \times \pi \times n \times 3.806 \times 10^{-3} \times \frac{n}{60}$$

Solving, speed,

$$n = 194 \text{ rpm (Check using the equation)}$$

$$15 = [0.019 \times \pi^3 \times n^2 (2 \times 0.20) \times 0.0725^3 / (450 \times 0.0005)]$$

Solving speed,

$$n = 194 \text{ rpm.}$$

22. Using bernouli equation in the following form

$$\frac{P}{\gamma} + z + \frac{V^2}{2g} = \text{Constant,}$$

Taking the datum as section 1, the pressure  $P_2$  can be calculated.

$$V_1 = 0.8 \times \frac{4}{\pi} \times 0.6^2 = 2.83 \text{ m/s}$$

$$V_2 = 0.8 \times \frac{4}{\pi} \times 0.3^2 = 11.32 \text{ m/s}$$

$$P_1 = 10 \times 10^5 \text{ N/m}^2$$

$$\gamma = \text{sp. gravity} \times 9810 .$$

$$\text{Substituting} \quad \frac{10 \times 10^5}{9810 \times 1.3} + 0 + \frac{2.83^2}{2 \times 9.81} = \frac{P_2}{9810 \times 1.3} + 1 + \frac{11.32^2}{2 \times 9.81}$$

Solving,

$$P_2 = 9.092 \text{ bar } (9.092 \times 10^5 \text{ N/m}^2)$$

As  $\frac{P}{\gamma}$  is involved directly on both sides, gauge pressure or absolute pressure can be used without error. However, it is desirable to use absolute pressure to avoid negative pressure values (or use of the term vacuum pressure).

**23. Geometric Similarity :**

Some of the PI terms involve the ratio of length parameters. All the similar linear dimension of the model and prototype should have the same ratio. This is called geometric similarity. The ratio is generally denoted by the scale or scale factor. One tenth scale model means that the similar linear dimensions of the model is 1/10 th of that of the prototype. For complete similarity all the linear dimensions of the model should bear the same ratio to those of the prototype. There are some situations where it is difficult to obtain such similarity. Roughness is one such case. In cases like ship, harbour or dams distorted models only are possible.

**Dynamic Similarity :**

Similitude requires that  $\pi$  terms like Reynolds number, Froude number, Weber number etc. be equal for the model and prototype. These numbers are ratios of inertia, viscous gravity and surface tension forces. This condition implies that the ratio of forces on fluid elements at corresponding points (homologous) in the model and prototype should be the same. This requirement is called dynamic similarity. This is a basic requirement in model design. If model and prototype are dynamically similar then the performance of the prototype can be predicted from the measurements on the model.

**24. Hydraulic Efficiency :**

It is defined as the ratio of the power produced by the turbine runner and the power supplied by the water at the turbine inlet.

$$\eta_H = \frac{\text{Power produced by the runner}}{\rho Q g H}$$

Where, Q is the volume flow rate and H is the net or effective head. Power produced by the runner is calculated by the Euler turbine equation  $P = Q\rho[u_1V_{u1} - u_2V_{u2}]$ . This reflects the runner design effectiveness.

**Mechanical Efficiency :**

The power produced by the runner is always greater than the power available at the turbine shaft. This is due to mechanical losses at the bearings, indage losses and other frictional losses.

$$\eta_m = \frac{\text{Power available at the turbine shaft}}{\text{Power produced by the runner}}$$

**Overall Efficiency :**

This is the ratio of power output at the shaft and power input by the water at the turbine inlet.

$$\eta_o = \frac{\text{Power available at the turbine shaft}}{\rho Q g H}$$

- 25.** Performance of engineering systems are generally measured using efficiency as defined by first law of thermodynamics. Efficiency as defined by first law uses energy for its' quantification. Second law efficiency or effectiveness or exergetic efficiency is an analogous parameter defined using availability. Energy balance for a system with steady state yields, Energy in = Energy output + Energy loss Availability equation shall yield, Availability in = (Availability output + Availability loss + Availability destruction due to irreversibility)

Mathematically, (by first law) Efficiency

$$\eta = \frac{\text{Energy out in product (= Output)}}{\text{Energy in}}$$

$$\eta = \frac{\text{Energy input} - \text{Energy loss}}{\text{Energy input}}$$

$$\eta = 1 - \frac{\text{Energy loss}}{\text{Energy input}}$$

(by Second law) Efficiency

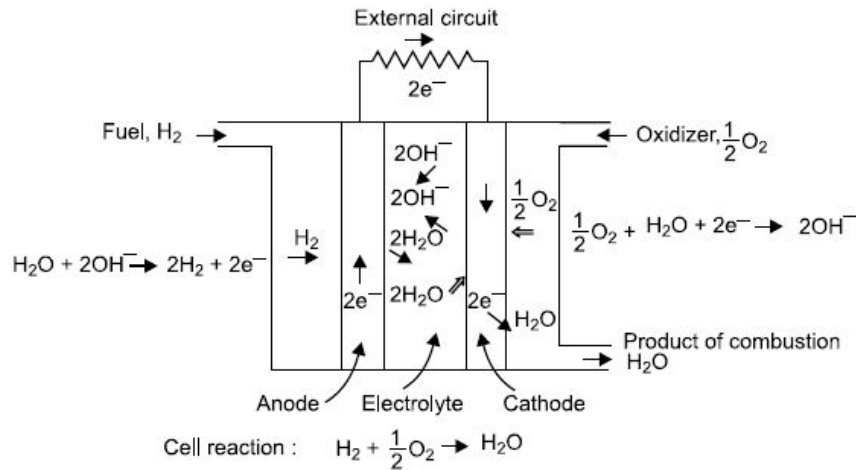
$$\varepsilon = \frac{\text{Availability output}}{\text{Availability in}}$$

$$\varepsilon = 1 - \left[ \frac{\text{Availability loss} + \text{Availability destruction due to irreversibility}}{\text{Availability in}} \right]$$

Effectiveness can also be given as the ratio of thermal efficiency to the maximum possible thermal efficiency (reversible processes) under same conditions.

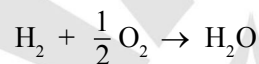
- 26.
- Working fluid should be cheap and easily available.
  - Working fluid should be non-toxic, non-corrosive and chemically stable.
  - Fluid must have higher saturation temperature at moderate pressures as it shall yield high efficiency because most of heat will be added at high temperature. Thus, mean temperature of heat addition shall be high even at moderate pressure.
  - Working fluid should have smaller specific heat so that sensible heat supplied is negligible and Rankine cycle approaches to Carnot cycle. In case of fluid having small specific heat hatched portion shown in figure will be absent or minimum.
  - Saturated vapour line should be steep enough so that state after expansion has high dryness fraction.
  - Working fluid density should be high so that the size of plant becomes smaller.
  - Working fluid should have its' critical temperature within metallurgical limits.
  - It should show significant decrease in volume upon condensation.
  - Working fluid should have its' freezing point much below atmospheric pressure so that there is no chance of freezing in condenser.
27. Fuel cell refers to a device having fuel and oxidizer in it which undergoes controlled chemical reaction to produce combustion products and provide electric current directly. In fuel cells the fuel and oxidizer react in stages on two separate electrodes i.e. anode (positive electrode) and cathode (negative electrode). Two electrodes are separated by electrolyte in between. The chemical reaction is carried out to produce electric power without moving parts or the use of intermediate heat transfers as in power cycles. Thus fuel cell does not work on any cycle. Fuel cells based on hydrogen-oxygen fuel cells have been used to provide power to the spacecrafts. Fuel cells based on natural gas are also under process of development. Fuel cells are also being developed to power automobiles. Let us look at hydrogen-oxygen fuel cell in detail.

Figure shows the schematic of hydrogen-oxygen fuel cell. Here  $H_2$  supplied diffuses through the porous anode and reacts on anode surface with  $OH^-$  ions resulting into  $H_2O$  and free electrons, the reaction for it is given in figure.



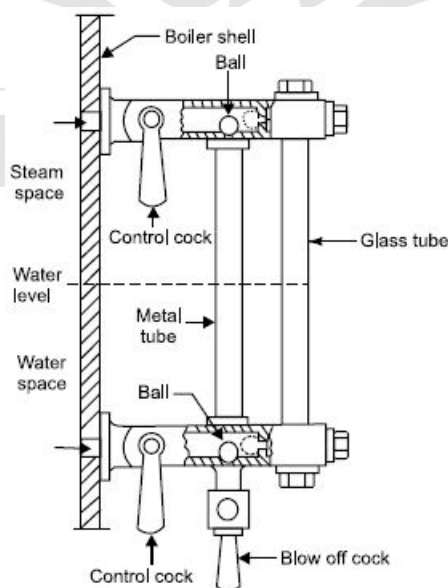
**Figure : Hydrogen-Oxygen fuel Cell**

Free electrons liberated enter the circuit while water goes into electrolyte. Oxygen supplied combines with water in electrolyte and electrons coming from electric circuit to produce  $OH^-$  ions and  $H_2O$  as per chemical reaction given in figure.  $OH^-$  ions are transported through the electrolyte. Overall fuel cell has chemical reaction as



Thus in hydrogen-oxygen fuel cell electricity and water are produced.

28. It is used for knowing the level of water in boiler as water level inside boiler should not go below a certain limit. General arrangement is shown in Fig. with the different parts in it. It has two tubes one is front glass tube while other is metal tube. Water level is seen through glass tube which is made strong enough to withstand high steam pressure and temperature. Two control cocks are provided for regulating steam and water passage from boiler to glass tube. For blow off purpose a blowing cock is also provided as shown. In case of breakage of glass tube the possibility of accident is prevented by providing two balls. As glass tube breaks the rush of water and steam carries the two balls with it and closes the openings for glass tube, thus water and steam flowing out can be prevented. Number of other types of water level indicators are also available



**Figure : Water Level Indicator**

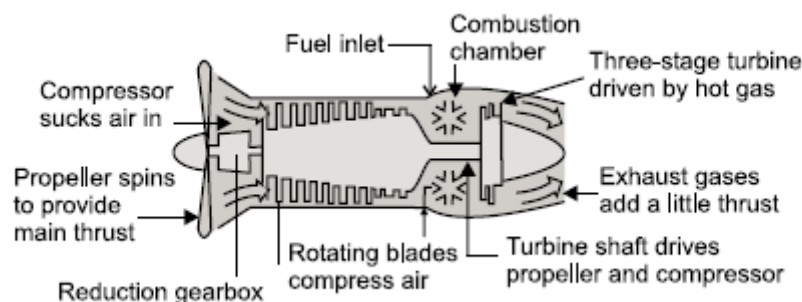
29. Differences between throttle governing and nozzle control governing are as given :

|       | <i>Throttle governing</i>  |       | <i>Nozzle control governing</i>   |
|-------|--|-------|---|
| (i)   | This governing is realized by throttling of steam at inlet to turbine so there occur severe throttling losses. | (i)   | This governing is realized by nozzle control so the degree of throttling losses in valves are negligible. |
| (ii)  | It has smaller losses due to partial admission of steam.   | (ii)  | It has large partial admission losses.  |
| (iii) | This governing is generally employed in both impulse turbines and reaction turbines.                           | (iii) | This governing is employed in impulse turbine and reaction turbines having initial impulse stages.        |

30. Comparison between the centrifugal compressor and axial flow compressor is given as under :

|       | <i>Centrifugal Compressor</i>  |       | <i>Axial flow compressor</i>  |
|-------|--|-------|---|
| (i)   | Centrifugal compressors generally have stage pressure ratio of around 5 and have radial flow inside with, axial entry of fluid. Maximum pressure up to 400 bar can be achieved by multistaging, although multistaging is slightly difficult. | (i)   | Axial flow compressors generally have stage pressure around 1.5 and have axial inlet and axial exit with flow inside compressor being parallel to the compressor axis. Maximum pressure up to 10 bar is possible to be achieved through multistaging which is very convenient in axial compressors. |
| (ii)  | Centrifugal compressors have good part load efficiency and wide operating range between singing and choking limits.  | (ii)  | Axial flow compressors have poor part load efficiency and narrow operating range between surging and choking limits.  |
| (iii) | Centrifugal compressors have small starting torque requirement.  | (iii) | Axial flow compressors have large stalling torque requirement.  |
| (iv)  | Due to large frontal area these are well suited for land applications  | (iv)  | Due to small frontal area axial flow compressors are well suited for aviation applications.   |
| (v)   | These have simple construction and are comparatively cheap   | (v)   | These have complex construction and are costly.   |
| (vi)  | These have poor isentropic efficiency ( $\approx 70\%$ ). Power required per kg of air flow rate is more.  | (vi)  | These have better isentropic efficiency ( $\approx 85$ to $90\%$ ). Power required per kg of air flow rate is less in axial flow compressors.   |

31. Turboprop (Turbo-propeller) engine, also called turboshaft engine or propjet engine differs slightly from turbofan engine. It uses thrust to turn a propeller. It consists of a compressor for compressing the inlet air, combustion chamber and turbine followed by exit nozzle. A part of turbine output is used to drive the compressor and remaining for driving propeller. Thus some stages of turbine give shaft work for driving compressor and some stages produce shaft work for driving propeller as shown in figure.





It can also be understood as if the gases expand through main turbine which drives compressor and also expands through power turbine which drive propeller through suitable reduction gear box. Turboprop engines are used in small passenger planes, cargo planes etc.

32. The resistance to heat transfer without shield is  $R_1$ , therefore,

$$\frac{\dot{Q} \text{ with } n \text{ shields}}{\dot{Q} \text{ without shields}} = \frac{1}{n+1}$$

$$\frac{1-0.80}{1} = \frac{1}{n+1}$$

$$n + 1 = \frac{1}{0.2}$$

$$n = 5 - 1 = 4$$

[PART : C]

33. Blades or vanes may be fixed at the periphery of the wheel in which case the radius at which fluid enters will be the same as at fluid exit. There are cases where the blades are fixed at the sides of a disc such that the radius at which the fluid enters the vane will be different from the radius at which it exits. The former type is known axial blading and the later is known as radial blading. In the former case the blade velocity will be constant and in the latter case the blade velocity will vary with radius. Thus the force on the blade will vary with the radius and the previous method cannot be used to find the fluid force on the blade. In this case the moment of momentum theorem is used to determine the torque on the wheel. The theorem states that torque on the wheel equals the rate of change of moment of momentum of the fluid as it flows over the blades. Thus it is necessary to determine the moment of momentum at the inlet and outlet to determine the torque. Torque can be produced only by the velocity component along the periphery.

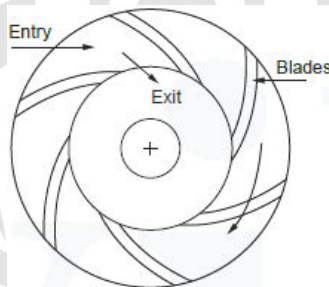


Figure : Radial Blading

The components of the velocity in tangential direction are  $V_{u1}$  and  $V_{u2}$  equal to  $V_1 \cos \alpha_1$  and  $V_2 \cos \alpha_2$ .

Momentum at entry =  $\dot{m} V_1 \cos \alpha_1$ . Moment of momentum of entry =  $\dot{m} V_1 \cos \alpha_1 \times r_1$

Similarity moment of momentum at exit =  $\dot{m} V_2 \cos \alpha_2 \times r_2$

$$T = \dot{m}(r_1 V_1 \cos \alpha_1 - r_2 V_2 \cos \alpha_2)$$

$$\text{Power} = \omega T \cdot \omega = \frac{2\pi N}{60}$$

34. It is a horizontal fire tube boiler. General arrangement in the boiler is shown in figure Boiler is mounted on a brickwork setting with front end of shell sloping about 1 : 250 for emptying the shell. It has a circular shell connected to end plates supported by gusset plates. Two fire tubes run throughout the length of the boiler. Fire tubes are of diameter less than half the diameter of shell and diameter of fire tubes is reduced as shown to have access to lower side of boiler. Fire bridge is provided to prevent fuel from falling over the end of furnace. Fire bridge also helps in producing a better mixture of air and gases for perfect combustion by partly enveloping the combustion space. Hot gases start from grate area, enter into fire tubes and come out at back of boiler from where these gases flow towards the front of boiler through bottom flue. Upon reaching the front these hot gases flow through the side flues and enter the main

outlet. Outlet passage may also be used commonly by more than one boilers. About 85% of actual heat transferred is transferred through surface of fire tubes while 15% is transferred through bottom and side flues Plan, elevation and side views of Lancashire boiler shown in figure explain the furnace, different firetubes, bottom flues, side flues etc. Dampers are provided at the end of side flues for regulating the pressure difference (draught) for exit of burnt gases. Other mountings and accessories are shown in the elevation of Lancashire boiler.

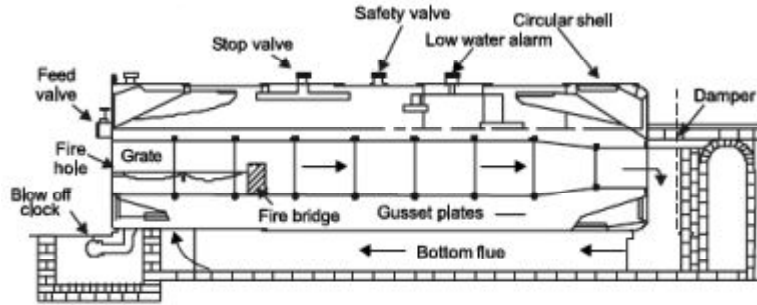


Figure : Front view of Lancashire boiler

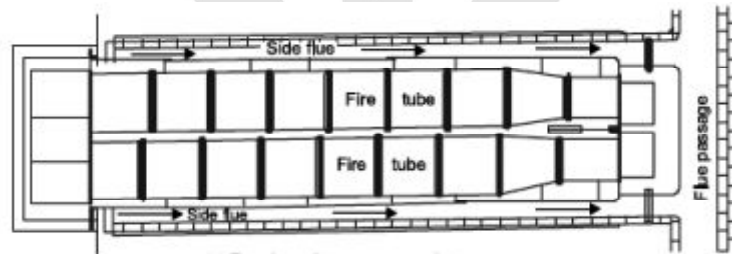


Figure : Top view of Lancashire boiler

Working pressure in these boilers are in the range of 0.7 MPa to 2 MPa and efficiency of the boiler is about 65% – 70%. Size of these boiler depends upon size of shell which may be 2 m to 3 m in diameter and 6m to 10m in length.

35. At inlet section (1),

$$h_1 = 3478.5 \text{ kJ/kg}$$

$$s_1 = 7.7022 \text{ kJ/kg-K}$$

Due to isentropic expansion,

$$s_1 = s_2$$

At exit section (2),

$$s_2 = 7.7022 \text{ kJ/kg-K}$$

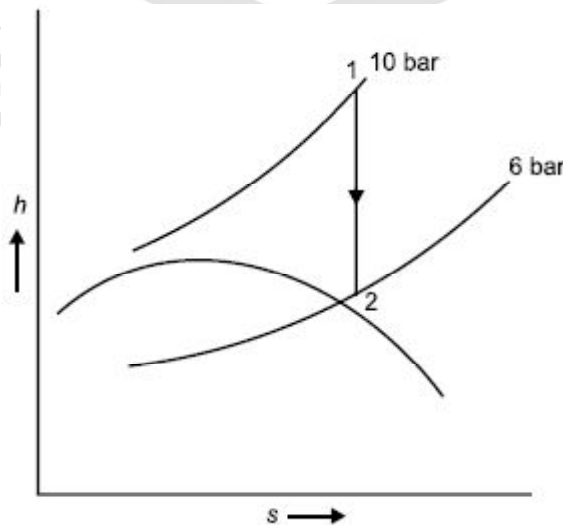


Figure : Flow through nozzle on h-s diagram

Enthalpy at rate (2) can be directly looked from mollier diagram by drawing vertical line from state (1) till it intersects 6 bar line. Else from steam table it can be obtained as under, looking at steam table for 6 bar it indicates that the state (2) shall be superheated state because  $s_2 > s_g$  at 6 bar.

Degree of superheat can be determined by interpolation.

Entropy 7.7622 kJ/ks-K,  $s_2$  lies between temperature of 400°C ( $s_{400^\circ\text{C}, 6 \text{ bar}} = 7.7079$  kJ/kg.K) and 500°C ( $s_{500^\circ\text{C}, 6 \text{ bar}} = 8.0021$  kJ/kg.K)

$$7.7622 = 7.7079 + \frac{(8.0021 - 7.7079)}{(500 - 400)} \times (T_2 - 400)$$

Hence enthalpy at (2),

$$h_2 = h_{418.45^\circ\text{C}, 6 \text{ bar}}$$

$$h_2 = h_{400^\circ\text{C}, 6 \text{ bar}} + \frac{(h_{500^\circ\text{C}, 6 \text{ bar}} - h_{400^\circ\text{C}, 6 \text{ bar}})}{(500 - 400)} (418.45 - 400)$$

$$h_2 = 3270.3 + \frac{(3482.8 - 3270.3)}{100} \times 18.45 = 3309.51 \text{ kJ/kg.K}$$

Neglecting inlet velocity,

$$C_1 \approx 0, \text{ assuming no heat loss,}$$

$$C_2 = \sqrt{2(h_1 - h_2)} = 851.36 \text{ m/s}$$

$$\text{Mass flow rate} = \frac{A_2 \times C_2}{v_2}$$

Specific volume at exit (2)

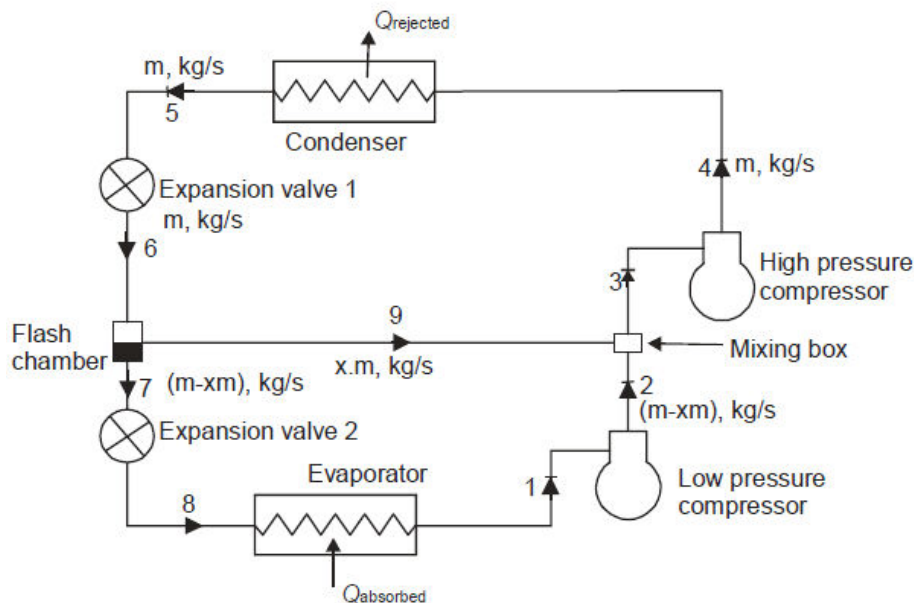
$$v_2 = v_{400^\circ\text{C}, 6 \text{ bar}} + \frac{(v_{500^\circ\text{C}, 6 \text{ bar}} - v_{400^\circ\text{C}, 6 \text{ bar}})}{(500 - 400)} \times (418.45 - 400) = 0.5137 + \left(\frac{0.5920 - 0.5137}{100}\right) \times 18.45$$

$$v_2 = 0.5281 \text{ kJ/kg.K}$$

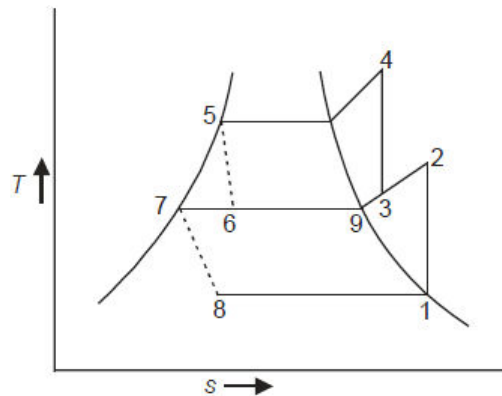
$$\text{Mass flow rate} = \frac{20 \times 10^{-4} \times 851.36}{0.5281} = 2.2017$$

$$\text{Mass flow rate} = 2.202 \text{ kg/s}$$

36. Intercooled compression using flash chamber is shown in figure. Here compression for total compression ratio occurs in two stages i.e. LP compressor and HP compressor



(a) Two stage intercooled vapour compression cycle with flash chamber



(b) *T-s representation of two stage intercooled vapour compression cycle*

1 – 2, 3 – 4 Reversible adiabatic compression.

5 – 6, 7 – 8 Irreversible throttling process

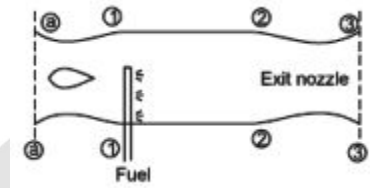
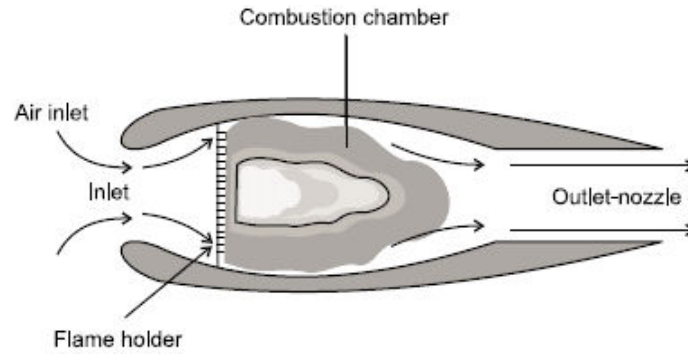
6 – 7, 6 – 9 In flash chamber

4 – 5 Isobaric condensaton

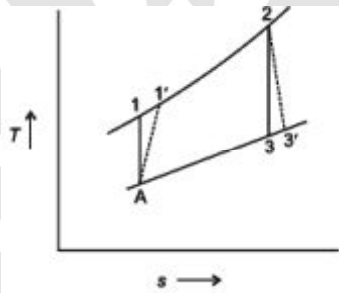
9 – 3 – 2 Mixing of refrigerant from LP compressor with cool vapour from flash chamber.

Refrigerant is partly compressed in LP stage from 1 to 2. Compressed refrigerant leaving compressor is cooled by mixing it with the cool vapour leaving flash chamber at state 9 and finally yielding low pressure refrigerant at low temperature, state 3 (Temperature at 3 < Temperature at 2). This reduced temperature of refrigerant from 2 to 3 results in smaller compressor work requirement. Subsequently, refrigerant is compressed in high pressure compressor upto state 4. High pressure refrigerant is passed through condenser where it gets condensed into saturated liquid form of refrigerant and passed through expansion valve (expansion valve 1) from state 5 to state 6. Expansion is carried out till the refrigerant's pressure gets reduced to interstage pressure and sent to flash chamber. Liquid vapour mixture entering flash chamber is separated such that liquid fraction of refrigerant passes into next expansion valve (expansion valve 2) at state 7 and the gaseous (vapour) fraction of refrigerant leaves flash chamber at state 9 for intercooling refrigerant in mixing box between state 2 and 3. Fraction of liquid refrigerant entering expansion valve is expanded from state 7 to 8. As a result of expansion the refrigerant's pressure gets reduced and low pressure liquid refrigerant is passed through evaporator from state 8 to 1 and its phase transformation occurs from liquid to vapour. Inside evaporator this phase transformation from liquid to vapour (gas) occurs by absorbing latent heat of vaporization from the refrigerated space thereby showing cooling affect.

37. Ramjet engine is the simplest of jet engines having no moving parts. Ramjet is a typically shaped duct open at both ends with air being compressed merely due to forward motion of engine. Fuel is subsequently added for combustion and thus high pressure, high temperature gases exit from exhaust nozzle. High pressure air is continuously available as engines keeps on moving forward. These ramjets are extensively used for propulsion in number of high speed aircrafts Ramjet is also called Athodyd Lorin tube based on the name of its inventor Rene Lorin, a French engineer. First ramjet engine was developed in 1913 and it had steady flow through inlet diffuser, combustion chamber and outlet nozzle. These can not operate under stationary condition as sole compression of air occurs due to ram compression. Ram pressure ratio is relatively small initially as forward speed is slow but increases as the speed increases. Ramjet is boosted up to substantially high speed using turbojet or rocket engine for getting desired thrust by ramjet. Ramjet are boosted up to speed of 300 km/hr. The efficiency of ramjet largely depends upon the design of diffuser section.



(i) Schematic of ram jet



(ii) T-s representation of ram jet

**Advantages of ramjet engine are:**

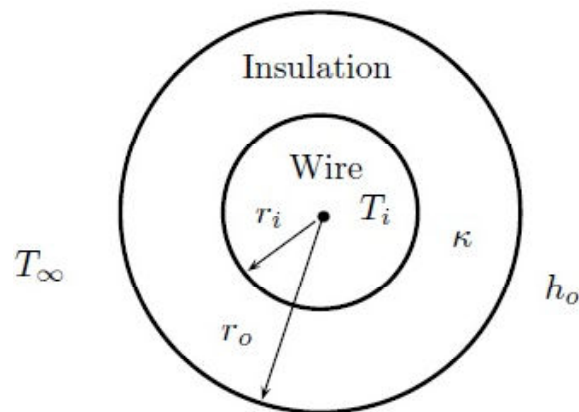
- It has no moving parts and hence ramjet are better balanced.
- It yields greater thrust per unit mass as compared to any other propulsion engine at supersonic speed.
- It is much simpler in construction and light in weight.
- It yields much greater thrust per unit frontal area at supersonic speeds. Best performance can be had at 1700 km/hr to 2200 km/hr speed range.
- Variety of fuels can be used in ramjet.
- These are ideal propulsion device for aircraft missiles.

**Disadvantages of ramjet engine are :**

- Forward motion is very much necessary to realize ram compression.
- Ram pressure ratio increases gradually.
- Ramjets are unable to work at low flight speeds.

Ram compression results in decrease in velocity and increase of pressure of air passing through this diffuser section. At the end of diffuser section a pressure barrier is created and after this point fuel is injected through nozzles and ignited using spark plug. Combustion results in expansion of gases which is restrained due to pressure barrier on one side and so move out through exit nozzle with high velocity.

38. Consider a cylindrical element of radius  $r_p$ , length  $l$  over which an insulation of thermal conductivity  $k$  is laid upto outer radius  $r_o$ . Temperature of the element is  $T_p$ , the outside temperature is  $T_\infty$  and  $h_o$  is convection coefficient on the outer surface



**Figure : Critical thickness**

The heat transfer involves two elements of resistance in series :

(i) The convective heat transfer resistance at outer layer :

$$R_1 = \frac{1}{(2\pi r_o l)h_o}$$

(ii) The conductive resistance [equation] in the insulation :

$$R_2 = \frac{\ln\left(\frac{r_o}{r_i}\right)}{2\pi k l}$$

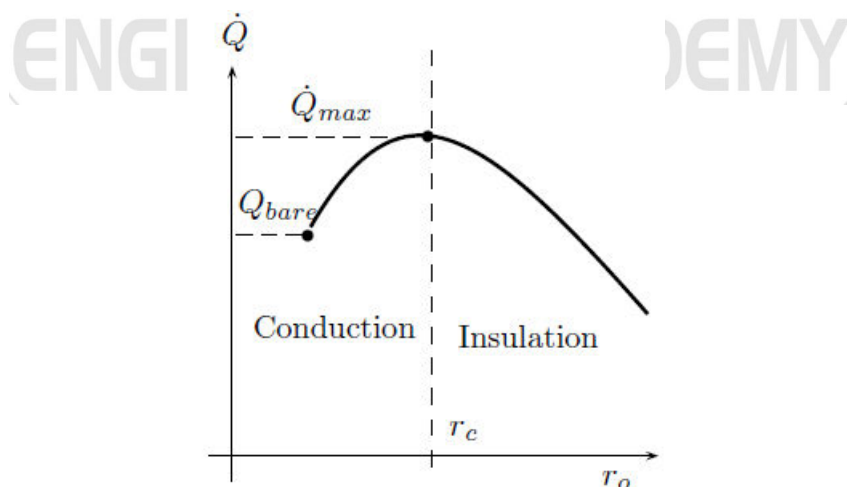
The effective thermal resistance is given by

$$R_e = R_1 + R_2 = \frac{1}{(2\pi r_o l)h_o} + \frac{\ln\left(\frac{r_o}{r_i}\right)}{2\pi k l}$$

This resistance  $R_e$  acts over the temperature potential of  $(T_i - T_\infty)$ . Therefore, the rate of heat transfer is written as the rate of heat transfer through conduction and convection :

$$\dot{Q} = \frac{(T_i - T_\infty)}{\frac{1}{(2\pi r_o l)h_o} + \frac{\ln(r_o/r_i)}{2\pi k l}}$$

The variation profile of  $\dot{Q}$  with  $r_o$  is seen in figure.



**Figure : Critical radius of insulation**

Rate of heat transfer reaches its maximum value where

$$\frac{d\dot{Q}}{dr_o} = 0$$

$$r_o = \frac{k}{h_o}$$

This value of outer radius  $r_o$  is known as the critical radius of insulation for cylinders. It depends on the thermal conductivity of insulation ( $k$ ) and the external convection heat transfer coefficient ( $h_o$ ). For perfect conduction, radius of the insulation layer should be within  $r_c$ ; while for perfect insulation, the layer should be more than  $r_c$ . The radius of electrical wires is generally smaller than the critical radius. This permits use of plastic electrical insulation to actually enhance the heat transfer from electrical wire.

39. Given that,

$$R = \frac{0.06}{2} = 0.03 \text{ m}$$

$$T_0 = 1030^\circ\text{C}$$

$$T_\infty = 30^\circ\text{C}$$

$$h = 20 \text{ W/m}^2\text{K}$$

$$k = 40 \text{ W/mK}$$

$$\rho = 7800 \text{ kg/m}^3$$

$$c = 600 \text{ J/kg-K}$$

$$T = 430^\circ\text{C}$$

For spherical objects of radius  $R$

$$\frac{V}{A} = \frac{4\pi R^3 / 3}{4\pi R^2} = \frac{R}{3}$$

The time required for the body to be cooled from  $T_0$  to  $T$  temperature in transient state is given by

$$\frac{T - T_\infty}{T_0 - T_\infty} = \exp\left(-\frac{3ht}{\rho R c}\right)$$

$$\ln\left(\frac{T - T_\infty}{T_0 - T_\infty}\right) = -\frac{3ht}{\rho R c}$$

Therefore,

$$t = \ln\left(\frac{T - T_\infty}{T_0 - T_\infty}\right) \times \frac{\rho R c}{3h}$$

$$= -\ln\left(\frac{430 - 30}{1030 - 30}\right) \times \frac{7800 \times 0.03 \times 600}{3 \times 20} = 2144.12$$

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