Thermal Engineering

Solution of Prelim Paper

Q.1 (a) Attempt any SIX of the following : [12]

Q.1 (a) (i) State first law of thermodynamics. [2]

Ans.: (1) First law for cyclic process [1 mark]

It states that whenever a system under goes a cyclic change, the algebraic sum of work transfer is proportional to algebraic sum of heat transfer.

$$\oint dw = J\oint dQ$$

(2) First law for closed cycle for non cyclic process [1 mark]

It states that if system under goes a process during with both heat transfer and work transfer involved, the net energy transferred will be stored within the system.

$$Q - W = \Delta\varphi$$

where Q = A heat transfer

W = work transfer

$\Delta\varphi$ = change in internal energy.

Q.1 (a) (ii) Define thermodynamics work. Write its SI unit. [2]

Ans.: Thermodynamic work [1 mark]

Work is said to done by a system, it a sole effect on things external to the system can be reduced to the raising of weight.

SI unit : N – m or joule [1 mark]

Q.1 (a) (iii) Write Charles Law as applied to an Ideal gas. [2]

Ans.: Charles Law [2 marks]

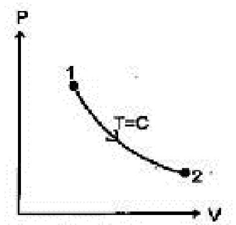
It state that "the volume of given mass of gas varies directly as its absolute temperature when the absolute pressure remains constants.

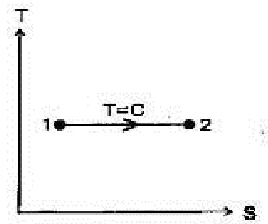
$V \propto T$ P is constant

Q.1 (a) (iv) Represent Isothermal Process for an Ideal Gas on P –V and T – S chart. [2]

Ans.: Isothermal process [2 marks]

Isothermal or constant temperature process (T = C) or n = 1.





Q.1 (a) (v) Define : **[2]**
(1) Degree of superheat (2) Latent Heat for steam

Ans.: (1) Degree of superheat [1 mark]
It is difference between the temperature of Superheated vapour and the saturation temperature correspondingly to given pressure is said to be Degree of Superheat.

(2) Latent heat of steam (LH) [1 mark]
A heat required to vaporized the liquid to vapor at constant temperature without change in temperature is known as Latent heat of steam.

Q.1 (a) (vi) Explain what is bleeding of a steam. **[2]**

Ans.: Bleeding of a seam [2 marks]
The process of draining steam from the turbine at a certain point during its expansion & using these steam for heating the feed water supplied to boiler is known as Bleeding of steam.

Q.1 (a) (vii) Define Mach Number and state the significance of the same. **[2]**

Ans.: Mach Number [1 mark]
Mach number is defined as the Square root of the ratio the inertia of fluid force to elastic force.

$$\text{Mach number} = \sqrt{\frac{\text{inerta force}}{\text{elastic force}}}$$

OR

Mach Number is defined as velocity at a point in a fluid to velocity of sound at that point at given instant of time.

$$M = \frac{V}{C}$$

Where V = velocity of fluid
C = velocity of sound

Significance of Mach Number [1 mark]
It match number is less than one, flow is Subsonic & nozzle is Convergent. If Mach Number is equal to one, flow is sonic, If Mach number is greater than one, flow is Supersonic & nozzle is divergent.

Q.1 (a) (viii) Write the sources of air leakage in steam condenser. **[2]**

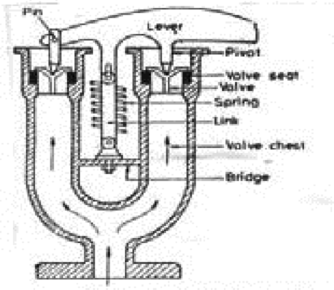
Ans.: Sources of air leakages in condenser : [2 marks]
(i) Feed water to boiler contains some amount of dissolved air in it, this air goes in the condenser with exhaust steam.
(ii) The pressure inside the condenser is less than atmosphere so the out side air leaks through joints, packing and glands in to the condenser.
(iii) In jet condenser, dissolved air with cooling water enters the condensers and it gets separated at Low pressure in the condensers.

Q.1 (b) Attempt any TWO of the following : [8]

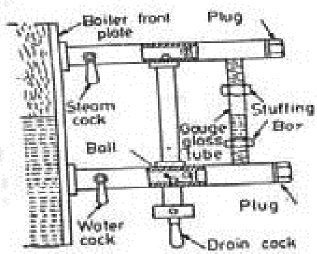
Q.1 (b) (i) List six boiler mountings. Sketch any one boiler mounting and label the same. [4]

Ans.: List of boiler mounting: [List - 3 marks, Diagram - 1 mark]

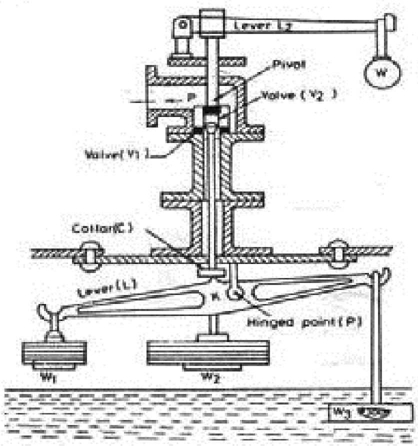
(i) Safety Valves
(ii) Fusible Plug
(iii) Water level indicator
(iv) Combined high steam & Low water safety valve
(v) Pressure Gauge
(vi) Blow off cock
(Any one of the following)



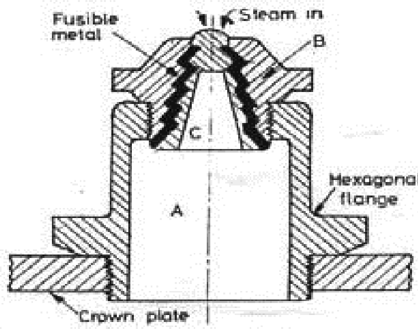
Spring loaded safety valve



Water level indicator



High steam and low water safty valve



Fusible plug

Q.1 (b) (ii) Define Daltons law of partial pressure and give its application. [4]

Ans.: Dalton Law of partial & pressure & equation.

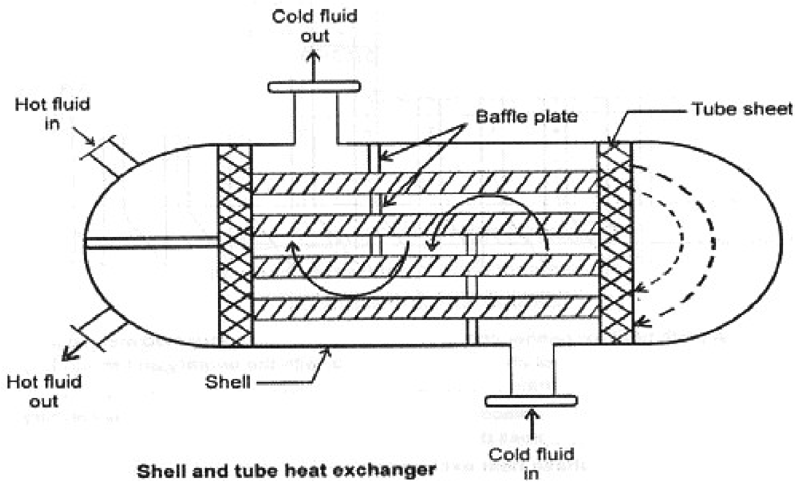
This Law state that- "the total pressure exerted by a mixture of air and water vapor on the walls of its container is the Sum of partial pressure exerted by air separately and that exerted by vapour separately at the common temperature of condenser.

P = Pa + Ps

Where Pa = partial pressure exhausted by air
ps = partial pressure exhausted by vapor
P = total pressure of mixture at temperature
Applications: l) Condenser

Q.1 (b) (iii) Explain working of Shell and Tube type of Heat Exchanger with a neat sketch. **[4]**

Ans.: **Working of Shell and tube type of heat exchanger :** [Sketch - 2 marks]



Shell and tube heat exchanger

[Explanation - 2 marks]

It consist of bundle of round tube placed inside Cylindrical shell with tube axis parallel to that of shell. One fluid is carried through a bundle of tubes enclosed by shell. The other fluid forced through shell and flow over the outside surfaces of tube.

Q.2 Attempt any FOUR of the following : **[16]**

Q.2(a) Write general Steady Flow Energy Equation (SFEE) per unit mass. Apply this equation to a **[4]**
(i) Nozzle (ii) Steam condenser

Ans.: Steady how energy equation per unit mass [2 marks]

$$q + h_1 + gZ_1 + \frac{1}{2}C^2 = w + h_2 + gZ_2 + \frac{1}{2}C_2^{\,2}$$

where
q = heat supplied in KJ or J
h_1 = enthalpy of substance entering in to system
h_2 = enthalpy of substance leaving from system
PE_1 & PE_2 = potential energy
KE_1 & KE_2 = kinetic energy
Z_1 & Z_2 = height from datum
C_1 & C_2 = Velocity
W = work performed

(i) Nozzle [1 mark]

The passage of varying cross sectional area in which heat energy is converted in to kinetic energy.

Applying SFEE

$$q + h_1 + 9Z_1 + \frac{1}{2}C^2 = w + h_2 + 9Z_2 + \frac{1}{2}C_2^2$$

where $q = 0$, $Z_1 = Z_2$

C_1 & C_2 velocity at inlet & outlet

$W = 0$

$$O + h_1 + 0 + \frac{1}{2}C_1^2 = h_2 + \frac{1}{2}C_2^2$$

$$h_1 - h_2 = \frac{1}{2}C_2^2 - C_1^2$$

$$C_2 = \sqrt{2(h_1 - h_2)} + C_1^2$$

OR

If C_1 is less as compare C_2

C_1 = neglected

$C_2 = \sqrt{2(h_1 - h_2)}$

(ii) Steam condenser [1 mark]

It is a device to condenser the exhaust steam.

Heat is lost q is –ve by applying SFEE.

$$q + h_1 + gZ_1 + \frac{1}{2}c_1^2 = w + h_2 + gZ + \frac{1}{2}C_2^2$$

$$-q + h_1 + 0 + 0 = 0 + h_2 + 0 + 0$$

$$q = h_1 - h_2$$

Q.2(b) 0.340 m^3 of gas at 8 bar and 130°C is expanded adiabatically until its pressure is 5 bar. It is then compressed isothermally to its original volume. Calculate **[4]**

(i) Final temperature (ii) Final pressure

of gas. Take $C_p = 0.950$ kJ/kg K

$C_v = 0.710$ kJ/kg K

Ans.: Given data :

$V_1 = 0.340\ m^3$, $P_1 = 8$ bar,

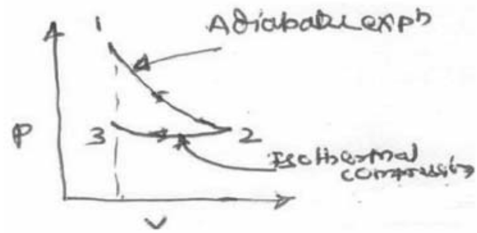
$C_P = 0.950$ kj/kg

$T_1 = 130° + 273 = 403$ k,

$C_V = 0.710$ kj/kg

$P_2 = 5$ bar

Isothermal process $v_3 = v_1 = 0.340\ m^3$



For adiabatic expansion (1-2)

$$\gamma = \frac{C_P}{C_V} = \frac{0.950}{0.710} = 1.338$$

for process 1-2

$$P_1 v_1^{\gamma} = P_2 v_2^{\gamma}$$

$$\frac{P_1}{P_2} = \left(\frac{v_2}{v_1}\right)\gamma \quad = \left(\frac{P_1}{P_2}\right)\frac{1}{\gamma} = \frac{v_2}{v_1}$$

$$\left(\frac{8}{5}\right)^{1/338} \times 0.340 = v_2$$

$$v_2 = (1.6)^{0.7} \times 0.340$$
$$= 1.3895 \times 0.340$$
$$v_2 = 0.472 \text{ m}^3$$ [2 marks]

process 1-2 (Isothermal process)

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

$$T_2 = 403\left(\frac{5}{8}\right)\frac{1.338 - 1}{1.338}$$
$$= 403(0.625)^{0.2526}$$
$$T_2 = 358.\text{K} = T_3 = \text{Isothermal process}$$

For process 2-3 Isothermal process

$$P_2V_2 = P_3V_3$$

$$P_3 = \frac{P_2V_2}{V_3} = \frac{5 \times 0.472}{0.340}$$

$$P_3 = 6.94 \text{ bar}$$ [2 marks]

Q.2(c) Give classification of steam boilers on the basis of **[4]**
(i) according to use **(ii) location of furnace**
(iii) axis of shell **(iv) fuel used**

Ans.: Classification of steam boilers on basis of : [4 marks]

(i) According to use
 (a) Stationary (b) portable (c) Marine (d) Loco motive

(ii) Location of furnace
 (a) Externally fired (b) Internally fired

(iii) Axis of shell
 (a) Vertical (b) Horizontal

(iv) Fuel used
 (a) Coal (b) Oil

Q.2(d) Differentiate between impulse steam turbine and reaction type steam turbine (minimum six points) **[4]**

Ans.: [4 marks]

Sr. No.	**Impulse turbine**	**Reaction Turbine**
(i)	Complete expansion of steam take place in the nozzle	Expansion of steam take place partly in fixed blade & partly in moving blades.
(ii)	This pressure remain constant when the steam passes over rotors blade	This drop take place in moving as well as fixed blade.
(iii)	It friction is neglected the relative velocity of steam passing over rotor blade remains constant	Its friction is neglected the relative velocity & steam passing over rotor blade increase because of expansion in rotor blades.
(iv)	Area of flow of rotor blade remains constant	The area of flow of rotor blades changes like that of nozzles along the blades passage
(v)	At Low load the efficiency is low.	As low load the efficiency is high
(vi)	Less numbers of states required	Moreno of blades are required.
(vii)	Occupies less space per unit power.	Occupies more space per unit power.
(viii)	Suitable for Small power.	Suitable for medium & high power.

Q.2 (e) Describe throttle governing of steam turbines. **[4]**

Ans.: Throttle governing of steam turbine [Sketch & Explanation - 2 marks each]

In throttle governing the pressure of steam is reduced before reaching the turbine at part loads, the flow of steam entering in to the turbine is restricted by a balanced throttle valve which is controlled by the centrifugal governor. The governor may be arranged to actuate the throttle valve directly. This throttle valve is actuated by the relay piston sliding in the cylinder, as floating or differential lever is attached at one end of governor sleeves and other end to throttle valve spindle & at governor sleeves and other end to throttle valve spindle and at intermediate points to a pilot or piston valve which consist of two small piston valve covering the port without any lap.

Operation

Let us assume that turbine is running at a load less than full load, the throttle valve will be Opened so such extent that the steam flow is just sufficient to maintain constant speed under given load condition.

Load on this turbine is reduced rotation quickly there is now an excess of energy being supplied to the turbine and the surplus will accurate the rotor, the turbine and governor speed will rise and this cause a lift of governor sleeves & supplying steam to turbine.

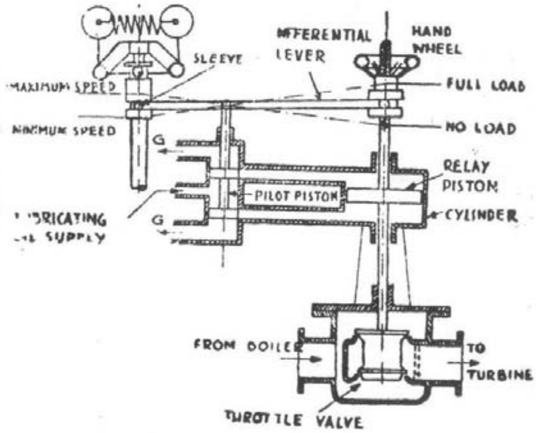


Fig.: Diagrammatic arrangment of throttle governing with oil relay

Q.2 (f) Define : **[4]**

(i) Zeroth law of thermodynamics.

(ii) Law of conservation of energy.

Ans.: (i) Zeroth law of thermodynamics [2 marks]

If two bodies A and B are individually in thermal equilibrium with a third body C, then the two bodies A and B will also be in thermal equilibrium with each other.

Explanation

Since body A is in thermal equilibrium with body C, therefore, they are at equality of temperature T each. Similarly, the body B being in thermal equilibrium with body C, the temperature of body B will also be T.

It follows that body A and B are both at temperature T, hence they are also in thermal equilibrium.

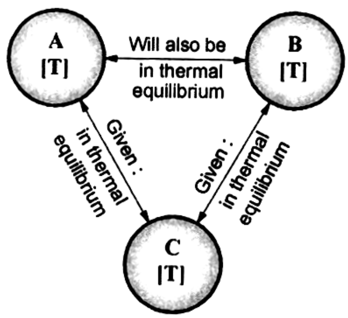


Fig. : Representation-zeroth law of thermodynamics

The science of measurement of temperature is called thermometry. It is based on the concept of zeroth law of thermodynamics. It can be explained as follows :

- The body 'C' can be uses as thermometer to measure the temperature of the bodies.
- Alternately, if body 'C' is used to measure the temperature of body A and B it will only show the equality of temperature, or in other words the thermometer 'C' indicates its own temperature which is being in thermal equilibrium with bodies A and B.
- However, the problem remains to relate the temperature which might be read on different thermometers on the other measuring devices.

(ii) Law of conservation of energy [2 marks]

The law of conservation of energy states "Energy can neither be created nor destroyed but it can only be converted from one form to another".

First Law of Thermodynamics (Joule's Experiment)

This law of thermodynamics is a particular statement of the general principles of law of conservation of energy as applied to heat transfer and work. Initially the statement of conservation of energy was quantitatively analyzed for thermodynamics systems by Joule during the period 1840 to 1849 which has led to the statement of 1st law of thermodynamics.

Arrangement similar to Joule's experiment is shown in figure 1.

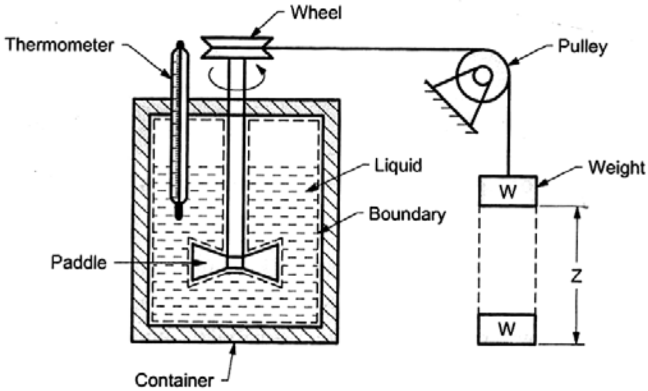


Fig. 1 : Joule's Experiment

It consists of a paddle wheel arrangement with the liquid filled in an insulated container.

The work is supplied across the boundary of the system by a falling weight of mass m (W = mg). The system is formed by the liquid in the container as a closed system. The work input to the system equals to m.g.z. As a result of work transfer the temperature of liquid rises which is measured by, a thermometer from initial atmospheric temperature t_1, to final temperature t_2. The system has undergone a process (l-A-2) as shown in figure 1. Next the system was kept in contact with the water bath. While in contact, the heat is transferred from liquid to water bath till the system returns to its original state of pressure and temperature. The heat transfer process is shown by process (2-B-1) in figure 2.

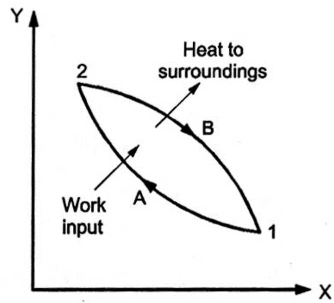


Fig. 2 : Representation of processes of Joule's Experiment on (X-Y) co-ordinates

Thus the closed system has completed a cycle.

Similar experiments were conducted by Joule in which the modes of work transfer to different systems were different e.g in another experiment he measured the electric work input to a heating coil and then its heat energy was transferred to water bath so that the system returned to its original state.

With the help of such experiments, Joule concluded that in every case the work input W was always proportional to heat transfer Q from the system at the end of conclusion of a cycle.

Using the sign $\oint$ for cyclic integral, the results of the experiment can be put mathematically as follows :

$$\oint d'W \propto \oint d'Q$$

or, $\oint d'W = J\oint d'Q$ … (1)

Where, J is constant and called mechanical equivalent of heat.

In M.K.S. System, J = 4.187 kJ/k cal

However, in S.I. system J = 1 J/Nm, Since work W and heat Q are both measured in J or Nm. Therefore, Equation 1 can be rewrittens as :

$$\oint d'W = \oint d'Q \qquad \text{… (2)}$$

The relationship expressed by the equation 2 has been found to be true in all cases investigated involving the cyclic processes. It's generalization has led to formulations of first law of thermodynamics as applied to closed system undergoing a cycle.

Therefore, statement of First Law of Thermodynamics in various forms can be stated as follows:

(i) When closed system executes a cyclic process the algebraic sum of work transfers is proportional to the algebraic sum of the heat transfers i.e. $(\sum W)$ cycle = $(\sum Q)$ cycle.

(ii) Heat and work are mutually convertible, since the energy can neither be created nor destroyed, therefore, the total energy conversion associated with an energy conversion remains constant during a cycle.

(iii) If a closed system goes through a cycle, the algebraic sum of total energy transfers to it as heat and work is zero Mathematically,

$$\oint (d'Q - d'W) = 0$$

Q.3 Attempt any FOUR of the following : [16]

Q.3(a) Explain : [4]

(i) Point function (ii) Path function

(iii) State (iv) Process

Ans.: **(i) Point Function** [1 mark]

Thermodynamic properties which have got definite value (single value) for given state, they are called as point functions. They are independent of path and depend on only initial and final states e.g. pressure, volume, temperature.

(ii) Path Function [1 mark]

Thermodynamic quantities, which are dependent on path followed between two end states of process are called as path functions, e.g. Work, heat.

(iii) State [1 mark]

It may be identified by observable quantities such as volume, pressure, temp, etc. All such quantities are thermodynamic properties. Minimum two properties are required to define state of a system. Each property has a single value at each state, i.e. all properties are state or point functions.

(iv) Process [1 mark]

When a system changes its state from one equilibrium state to another equilibrium state, then the path of successive states, through which, the system has passed, is known as thermodynamic process.

Q.3(b) Write equation for [4]

(i) change in internal energy (ii) work done

for a reversible adiabatic process.

Ans.: For reversible Adiabatic process, Write equations

(i) Change in internal energy [2 marks]

$dU = mCv\,(T_2 - T_1)$ … with usual notations

(ii) Work done [2 marks]

$$W = mR\,\frac{(T_2 - T_1)}{y - 1}$$

$$= \frac{(P_1\ V_1 - P_2V_2)}{y - 1}$$ … with usual notations

Q.3(c) Explain the principle used in forced draught and induced draught in a boiler. Also, state advantages of artificial draught over natural draught. [4]

Ans.: **Principle used for forced draught :** [2 marks]

Draught is a difference of pressure which causes a flow of gas in order to maintain continuous flow of fresh air into combustion chamber. Natural draught is dependent on climatic conditions and become less when outside air temp, is high. So artificial draught is created using fan or steam jet.

In forced draught system, a fan or blower is installed near or at the base of boiler grate. The fan delivers air to the furnace under pressure varying from 2.5 cm to about 7.5 cm of water. This is positive draught system because pressure of air throughout the system is above atmospheric pressure.

In induced draught system, the fan is placed near or at the base of chimney. The pressure over the fuel bed is reduced to a level below the atmospheric pressure by fan. By creating partial vacuum in the furnace, the products of combustion are drawn from the main flue and they go up to the chimney.

Advantages of artificial draught : [2 marks]

(i) High draught requirement can be met (300 mm of water).
(ii) Draught is independent of climatic conditions.
(iii) No chance of air leakage into furnace as pressure inside furnace is above atmospheric pressure.
(iv) Easy control of combustion and evaporation.
(v) Reduced fuel consumption.

Q.3(d) Explain the necessity of compounding of steam turbines. Also, state various types of compounding in steam turbines. **[4]**

Ans.: Necessity of compounding of steam turbines: [3 marks]

Generally, in steam power plants, the steam temp and pressure are very high, in order to maintain high thermal efficiency. If in turbine, entire pressure drop from boiler pressure to condenser pressure is carried out in single stage, the velocity of steam entering the turbine becomes very high. This results in very high rotational speed of turbine, which is not useful/ desirable from practical point of view. This may even result in failure of blades due to centrifugal stresses.

To overcome this difficulty, multiple system of rotors is keyed to a common shaft in series and steam pressure or jet velocity is absorbed in stages as it flows over rotor blades. This is known as compounding.

Methods of compounding: [1 mark]

(i) Pressure compounding.
(ii) Velocity compounding.
(iii) Pressure - Velocity compounding.

Q.3(e) Explain the function of cooling tower in steam power plant. List various types of cooling towers. **[4]**

Ans.: Function of cooling tower in steam power plant : [2 marks]

A majority of large power plants are built adjacent to rivers where cooling water is available in large quantities, but for many plants, source of water is local water supply, in such cases, the same water is circulated over and over again. It must be cooled before it re-enters the condenser tubes. The water is cooled by means of cooling towers.

Thus cooling tower is an artificial device used to cool the hot cooling water coming out of condenser. These are classified as : [2 marks]

(1) According to type of draught
   (i) Natural draught cooling water
   (ii) Forced draught cooling water
   (iii) lnduced draught cooling water

(2) According to material used

(i) Concrete cooling water
(ii) Timber cooling water
(iii) Steel duct type cooling water

Q.3(f) (i) Define thermal conductivity. State its unit. [4]
(ii) State Fouriers law of heat conduction.

Ans.: (i) Thermal conductivity
K = (Q/A)* dX/dT [2 marks]

It is defined as amount of energy conducted through a body of unit area and unit thickness in unit time when the difference in temperature between the faces carrying the heat flow is 1°C thermal conductivity depends on molecular structure, specific gravity etc.

K = (Q/A) * dX/dT
= $(J/s)/m^2$ * m/k
= watts/mk

(ii) Fourier's law of heat conduction : [2 marks]
For a homogeneous material the rate of heat transfer per unit area in any direction is linearly proportional to temperature gradient in that direction.

Q/A = dT/dx
Q/A = –K*dT/dx
Q = – KA*dT/dx

Q.4 Attempt any FOUR of the following : [16]

Q.4 (a) Define point function and path function with two examples of each. [4]

Ans.: **Point function:** The properties of the system whose change depends on only initial and final state of the system and not on the path followed by the system then such properties are called point function [1 mark]
Ex : pressure, volume, temperature etc. [1 mark]

Path function: The quantities of a system which are depend on path followed by the system and not depend on point or state of the system are called path function. [1 mark]
Ex: Heat, work etc. [1 mark]

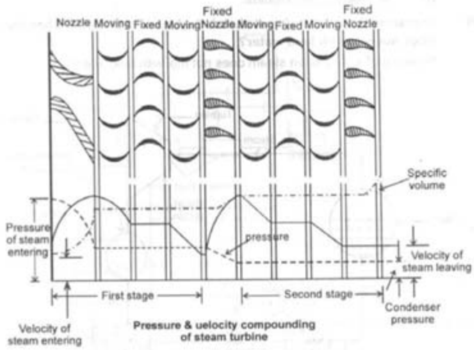
Q.4 (b) What is boiler draught? State its necessity. [4]

Ans.: **Boiler Draught:** Force necessary to draw is called as draught. This force may be due to small pressure difference the steam or current of gas or air which causes the flow to take place. In boiler support combustion by means of draught. So draught is a small pressure difference which causes flov gases. The draught may be classified as below. [2 marks]

Necessity: Draught is necessary to continuously remove the products of combustion [2 marks]

Q.4 (c) Explain working of impulse steam turbine by using pressure velocity variation diagram. **[4]**

Ans.: **Impulse steam turbine:** it works on the principal of impulse. It consists of nozzle or set of nozzles, a rotor moujnted on shaft, one set of moving blades attached to rotor. [Sketch & Explanation - 2 marks each]



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Pressure velocity compounding of impulse turbine: the total pressure drop of the steam from boiler to condenser pressure is divided into a number of stages as done in pressure compounding and the velocity obtained in each stage is also absorbed in several stages. The velocity, pressure and specific volume variation of steam along the axos of the turbine are shown in figure. The blade height in the second stage must be greater than the first stage as

Q.4 (d) Determine the rate of heat flow through the boiler wall made of 3 cm thick steel and covered with an insulating material of 0.5 cm thick. The temperature of wall inside boiler is 300°C and temperature of outer surface is 50°C. **[4]**
Assume K for steel = 60 W/mK
K for insulation = 0.12 W/mK

Ans.: Thickness of wall = b_1 = 3cm = 3×10^{-2} m [4 marks]

Thickness of insulation = b_2 = 0.5 cm
= 0.5×10^{-2} cm

Inside temp = 300° C
Outside temp = 50° C
K_1 = 60 w/mk
K_2 = 0.12 w/mk
Rate of heat flow;

$$\frac{q}{A} = \frac{(T_1 - T_2)}{\left(\frac{b_1}{K_1} + \frac{b_2}{K_2}\right)}$$

$$= \frac{300 - 50}{\frac{3 \times 10^{-2}}{60} + \frac{0.5 \times 10^{2}}{0.12}}$$

= 5929.79 W/m^2

Q.4 (e) The vacuum in a surface condenser is 705 mm of Hg and the barometer reading is 760 mm of Hg. The outlet and inlet temperature of cooling water to condenser is 37.5°C and 30°C respectively. Determine condenser efficiency. **[4]**

Ans.: $tw_1 = 30°C$, $tw_2 = 37.3°C$ [4 marks]

Absolute pressure in the condenser

= 760 − 705 = 53 mm of Hg

= 56 × 0.001333 = 0.073 bar

From steam table corresponding to 0.073 bar

$t_3 = 40°C$

condenser efficiency

$$= \frac{\text{Rise the temp. of cooling water}}{\begin{array}{c}\text{(temp corresponds to vaccum in condenser}\\ -\text{inlet temp. of cooling water)}\end{array}}$$

$$= \frac{(tw_s - tw_1)}{(t_s - t_{w1})} = \frac{37.5 - 30}{40 - 30} = \frac{7.5}{10}$$

= 0.75 or 75%

Q.4 (f) Determine the state of steam if : **[4]**

(i) Pressure is 10 bar and specific volume is 0.185 m^3/kg.

(ii) Pressure is 12 bar and temperature is 200°C.

Ans.: (i) $P_1 = 10$ bar [2 marks]

$\nu_s = 0.185\ m^3/kg$

From steam tables, at P_1,

$\nu_t = 0.0011274$

$\nu_g = 0.19429$

Hence the steam is in wet condition

(ii) $P_1 = 12$ bar [2 marks]

$T_1 = 200°C$

From steam tables at P_1

$Ts\mu p = 187.96°C$

Hence the steam is in superheated condition.

Q.5 Attempt any TWO of the following : **[16]**

Q.5 (a) Explain the application of second law of thermodynamics to heat engine. **[8]**

Ans.: **(i) Kelvin-Plank Statement of second law of thermodynamics:** [2 marks]

"It Is impossible to construct a heat engine to work in a cyclic process whose sole effect is to convert all the heat supplied to into an equivalent amount of work

OR

It is impossible to construct 100 % heat engine

(ii) Clausius statement of second law of Thermodynamics [2 marks]

It states that it is impossible to construct a device working in a cyclic process whose sole effect is the transfer of energy in the form of heat from a body at a lower temperature (sink) to a body at a higher temperature (source).

OR

It is impossible for energy in the form of heat to flow a body at a lower temperature to a body at a higher temperature without the aid of external work.

Application of Second Law of Thermodynamics to Heat Engine:

Kelvin-Planck Statement of Second Law of Thermodynamics

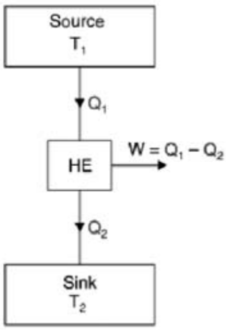
"It is impossible to construct an engine, which while operating in a cycle produces no other effect except to extract heat from a single reservoir and do equivalent amount of work".

There are three important applications of Statement of Second Law of Thermodynamics namely:

(a) Heat Engine

(b) Heat Pump and

(c) Refrigerator



Heat engine is shown in the figure below' having source of temperature (T_1) and Sink at temperature (T_2). The amount of heat taken from source is Q_1. Out of this amount of eat work done by the engine is W and remaining part of heat rejected to the sink.

As per the statement of Statement of Second Law of Thermodynamics, it is observed that heat engine operates between the two reservoirs in a cyclic manner. It also extracts the heat from source only (single reservoir) and does the equivalent amount of work as shown.

In a full cycle of a heat engine, three things happen:

(1) Heat is added. This is at a relatively high temperature, so the heat can be called Q_1.

(2) Some of the energy from that input heat is used to perform work (W).

(3) The rest of the heat is removed at a relatively cold temperature (Q_2).

An efficiency of the heat engine can be calculated as:

Efficiency Workdone (W) / Input Heat (Q_1)

Kelvin–Plank statement is directly related with heat engines. As the heat engine takes some amount of heat from high temperature source and coverts partly into workdone. Remaining part of heat is rejected to the low temperature sink. It is also clear that heat engine cannot work with one heat reservoir and there is always a rejection of heat.

From the above discussion it is clear that Heat Engine is an important application of Second Law of Thermodynamics.

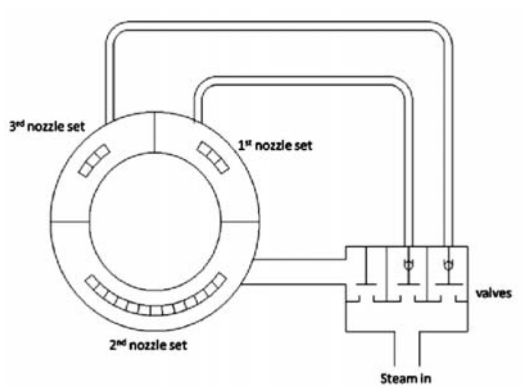
Q.5 (b) What is governing of steam turbine? Explain with neat sketch nozzle control governing. **[8]**

Ans.: Governing : [3 marks]

Steam turbine governing is the procedure of controlling the flow rate of steam to a steam turbine so as to maintain its speed of rotation as constant. The variation in load during the operation of a steam turbine can have a significant impact on its performance. In a practical situation the load frequently varies from the designed or economic load and thus there is always exists a considerable deviation from the desired performance of the turbine. The primary objective in the steam turbine operation is to maintain a constant speed of rotation irrespective of the varying load. This can be achieved by means of governing in a steam turbine.

Nozzle control governing: [3 marks]

In nozzle governing the flow rate of steam is regulated by opening and shutting of sets of nozzles rather than regulating its pressure. In this method groups of two, three or more nozzles form a set and each set is controlled by a separate valve. The actuation of individual valve closes the corresponding set of nozzle thereby controlling the flow rate. In actual turbine, nozzle governing is applied only to the first state whereas the subsequent stages remain unaffected. Since no regulation to the pressure is applied, the advantage of this method lies in the exploitation of gull boiler pressure and temperature. Figure shows the mechanism of nozzle governing applied to steam turbines. As shown in the figure the three sets of nozzles are controlled by means of three separate valves.



[2 marks]

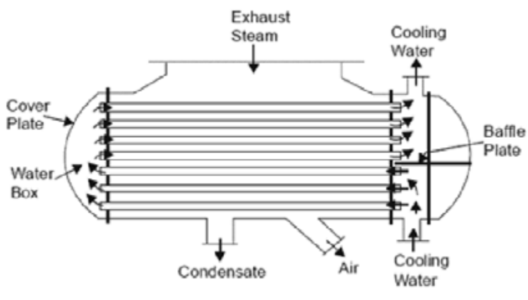
Q.5 (c) 1 kg of air at a pressure of 14 bar occupies 0.6 m^3 and from this condition it expands to 1.4 bar according to law $PV^{1.25}$ = C. Find : **[8]**
(i) Change in internal energy (ii) Work done by air
Assume C_p = 1.005 KJ/kg K and C_v = 0.718 KJ/kg K

Ans.: Given data: Initial pressure = P_1 = 14 Bar = 14×10^5 N/m^2 [4 marks]
Final pressure = P_2 = 1.4 Bar = 1.4×10^5 N/m^2. Initial volume = V_1 = 0.6 m^3
C_p = 1.005 kJ/kgK. C_v = 0.718 kJ/kgK & process is $PV^{1.25}$ = C Air mass m = 1 kg
$R = C_p - C_v$ = 0.287 kJ/kgK
For Polytropic process, we have
$[V_1/V_2]^n = [P_2/P_1]$ or $[V_1/V_2] = [P_2/P_1]^{1/n}$
$[0.6/V_2] = [1.4/14]^{1/1.25}$
$[0.6/V_2] = [0.1]^{0.8}$
$V_2 = 0.158\ m^3$
Also from following two general gas equations for initial & final conditions
[4 marks]
$T_1 = P_1 V_1/m R = 1400 \times 0.6/0.287 = 2926$ K
$T_2 = P_2 V_2/m R = 140 \times 0.158/0.287 = 77$ K
Now change in internal energy
dU= $m C_v[T_2 - T_1] = 1 \times 0.718$ [2926.8 – 77] – 2045
Workdone = $1400 \times 0.6 - 140 \times 0.58/ 1.25 - 1$ = 327152 kJ

Q.6 Attempt any TWO of the following : **[16]**

Q.6(a) Explain construction and working of surface condenser with neat sketch. **[8]**

Ans.: Surface condenser [3 marks]
A surface condenser is a commonly used term for a water-cooled shell and tube heat exchanger installed on the exhaust steam from a steam turbine in thermal power stations. These condensers are heat exchangers which convert steam from its gaseous to its liquid state at a pressure below atmospheric pressure. Surface condensers are also used in applications and industries other than the condensing of steam turbine exhaust in power plants. One such surface condenser is shown below:



[2 marks]

Shell: The shell is the condenser's outermost body and contains the heat exchanger tubes. The shell is fabricated from carbon steel plates and is stiffened as needed to provide rigidity for the shell. Vacuum system: For water-cooled surface condensers, the shell's internal vacuum is most commonly supplied by and maintained by an external steam jet ejector system. Such an ejector system uses steam as the motive fluid to remove any non-condensible gases that may be present in the surface condenser.

Tube and Tube sheets: [3 marks]
At each end of the shell, a sheet of sufficient thickness usually made of stainless steel is provided, with holes for the tubes to be inserted and rolled. The inlet end of each tube is also bell-mouthed for streamlined entry of water. Generally the tubes are made of stainless steel, copper alloys such as brass or bronze, nickel, or titanium depending on several selection criteria.

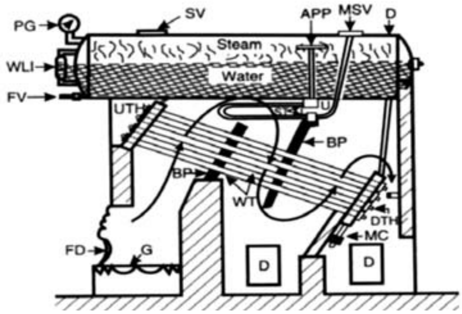
Waterboxes: The tube sheet at each end with tube ends rolled, for each end of the condenser is closed by a fabricated box cover known as a waterbox.

Q.6 (b) Explain the construction and working of Babcock and Wilcox boiler with neat labelled sketch. [8]

Ans.: Babcock and Wilcox Boiler [3 marks]
This type of boiler consists of following parts:
Water tubes: Water tubes are placed between the drum and furnace in an inclined position (at an angle of 10 to 15 degree) to promote water circulation. These tubes are connected to the uptake-header and the down-comer as shown. Uptake-header and down-comer (or down-take-header).The drum is connected at one end to the uptake-header by short tubes and at the other end to the down-comer by long tubes. Grate: Coal is fed to the grate through the fire door. Furnace: Furnace is kept below the uptake-header. Baffles: The fire-brick baffles, two in number, are provided to deflect the hot flue gases. Superheater: The boiler is fitted with a superheater tube which is placed just under the dram and above the water tubes Mud box: Mud box is provided at the bottom end of the down comer. The mud or sediments in the water are collected in the mud box and it is blownoff time to time by means of a blow-off cock. Inspection doors: Inspection doors are provided for cleaning and inspection of the boiler.

Working of Babcock and Wilcox Boiler: [3 marks]
Coal is fed to the grate through the fire door and is burnt. Flow of flue gases:
The hot flue gases rise upward and pass across the left-side portion of the water tubes. The baffles deflect the flue gases and hence the flue gases travel in the zig-zag manner (i.e., the hot gases are deflected by the baffles to move in the upward direction, then downward and again in the upward direction) over the water tubes and along the superheater. The flue gases finally escape to atmosphere through chimney.

Water circulation: That portion of water tubes which is just above the furnace is heated comparatively at a higher temperature than the rest of it. Water, its density being decreased, rises into the drum through the uptake-header. Here the steam and water are separated in the drum. Steam being lighter is collected in the upper part of the drum. The water from the drum comes down through the down-comer into the water tubes. A continuous circulation of water from the drum to the water tubes and water tubes to the drum is thus maintained. The circulation of water is maintained by convective currents and is known as “natural circulation”. A damper is fitted as shown to regulate the flue gas outlet and hence the draught.



[2 marks]

Q.6 (c) A steam pipe of 16 cm inside diameter and 17 cm outside diameter (K = 58 W/mk) is covered with first layer of insulating material of 3 cm thick (K = 0.17 W/mk) and second layer of insulating material 5 cm thick (K = 0.093 W/mk). The temperature of steam passing through the pipe is 300°C and atmosphere is 30°C. **[8]**

Take $h_i = 30\ W/m^2K$

$h_o = 5.8\ W/m^2K$

Find the heat lost per metre length of pipe.

Ans.: Give data [2 marks]

Inner radius of pipe = r_1 = 8 cm = 0.08 m

Outer radius of pipe = r_2 = 8.5 cm = 0.085 m

Radius r_3 = 0.085 + 0.03 = 0.115 m

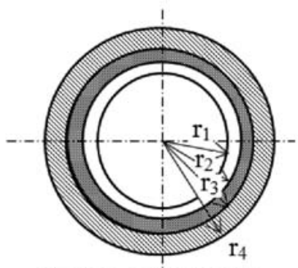
Radius r_4 = 0.115 + 0.05 = 0.165 m

K_1 = 58 W/mK for steam pipe

K_2 = 0.17 W/mK for first layer of 3 cm

K_3 = 0.093 W/mK for second layer of 5 cm

hi = 30 W/m^2K and ho = 5.8 W/m^2K



Steam pipe covered with two insulating layers

[3 marks]

Inside Temperature = T_1 = 300°C and outside Temperature = T_2 = 30°C

The rate of heat loss (Q) per meter length from of pipe to outside is given by the equation. [3 marks]

$$Q = \frac{2\pi L(T_1 - T_2)}{\left[\frac{1}{h_i r_1} + \frac{\ln(r_2/r_1)}{K_1} + \frac{\ln(r_3/r_2)}{K_2} + \frac{\ln(r_4/r_3)}{K_3} + \frac{1}{h_0 r_4}\right]}$$

Now $2\pi L(T_1 - T_2) = 1696.46$

$1/h_i r_1 = 0.417$

$1/h_0 r_4 = 1.045$

In $(r_2/r_1)/K_1 = 0.0010$

In $(r_3/r_2)/K_2 = 1.7776$

In $(r_4/r_3)/K_3 = 3.8817$

so, Q = 238.19 kW per m length of pipe.

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