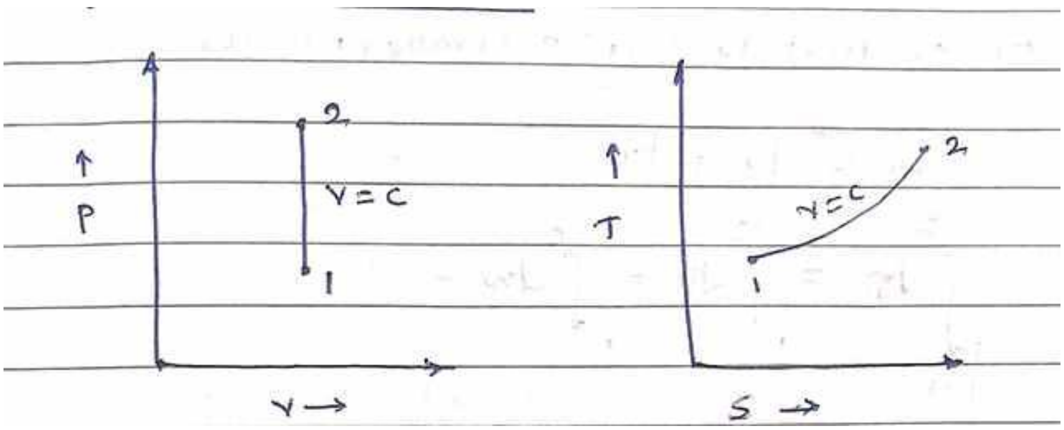
WINTER – 19 EXAMINATION

Subject Name: Thermal Engineering **Model Answer** **Subject Code:** 22337

Important Instructions to examiners:

1) The answers should be examined by key words and not as word-to-word as given in the model answer scheme.
2) The model answer and the answer written by candidate may vary but the examiner may try to assess the understanding level of the candidate.
3) The language errors such as grammatical, spelling errors should not be given more Importance (Not applicable for subject English and Communication Skills.
4) While assessing figures, examiner may give credit for principal components indicated in the figure. The figures drawn by candidate and model answer may vary. The examiner may give credit for any equivalent figure drawn.
5) Credits may be given step wise for numerical problems. In some cases, the assumed constant values may vary and there may be some difference in the candidate's answers and model answer.
6) In case of some questions credit may be given by judgement on part of examiner of relevant answer based on candidate's understanding.
7) For programming language papers, credit may be given to any other program based on equivalent concept.

Q.1.		**Attempt any FIVE of the following:**	**10 Marks**
	a)	**Define-** **(i) Intensive property** **(ii) Extensive property. Give one example of each.**	
	Sol.	**ensive Property:** t is defined as the property which is does not depend upon the mass of the system. **Or** Intensive properties are those whose values are independent of the mass possessed by the system. **Ex.** Pressure, Temperature, Density, Specific volume, specific Enthalpy, etc. **tensive Property:** It is defined as the property which depends upon the mass of the system. **Or** Extensive properties are those whose values are dependent of the mass possessed by the system, such as volume, enthalpy, and entropy. Extensive properties are denoted by uppercase letters, such as volume (V), enthalpy (H) and entropy (S). Per unit mass of extensive properties are called specific properties and denoted by lowercase letters. For example, specific volume v = V/m, specific enthalpy h = H/m and specific entropy s = S/m Ex. Total volume, Area, Enthalpy, Entropy etc.	**01 mark** **01 mark**

	b)	**Represent Isochoric Process on P-V and T-S chart.**	
	Sol.	 **Figure: P-V and T-S representation of Isochoric process**	**01 mark each**
	c)	**A sample of 35 Kg of dry steam contains 0.7 Kg of water is in suspension, find its dryness fraction.**	
	Sol.	Mass of dry steam=35 kg Mass water suspension=0.7 kg Weight of wet steam=35+0.7=35.7 kg So, Dryness fraction X=Actual mass of dry steam/ weight of wet steam = 35 / (35+0.7) =0.098039	**01 mark** **Formula** **01 mark**
	d)	**Suggest the different methods to control the speed of rotation of steam turbine constant at all varying loads.**	
	Sol.	Following are the different methods to control the speed of rotation of steam turbine constant at all varying loads; a) Throttle governing b) Nozzle control governing c) By pass governing d) Combine throttle and nozzle control governing e) Combine throttle and by pass governing	**½ mark each**
	e)	**Explain the functions of steam nozzle.**	
	Sol.	The **steam nozzle** is a passage of varying cross section by means of which the thermal energy of **steam** is converted into kinetic energy. When **steam** f lows through a **nozzles** expansion process take place.(Only function is expected and not in detail working)	**2 marks**
	f)	**Write the elements of forced draught cooling tower.**	
	Sol.	Following are the elements of forced draught cooling tower; a) Forced draught fan b) Eliminator c) Spray header d) Spray nozzle	**½ mark each**

e) Circulating pump

g) Define-

(i) Thermal conductivity

(ii) Thermal resistance

Sol. **Thermal conductivity** of material is define as ,"the amount of energy conduct through a body of unit area and unit thickness in unit time when the difference in temperature between the face causing heat flow is unit temperature difference." **01 mark**

$$\therefore Q = -K.A.\frac{dt}{dx} \therefore Q = -K.A.\frac{dt}{dx}$$

$$\therefore\therefore \quad K = \frac{Q}{A.}\frac{dt}{dx}K = \frac{Q}{A.}\frac{dt}{dx}$$

K=Thermal conductivity.

01 mark

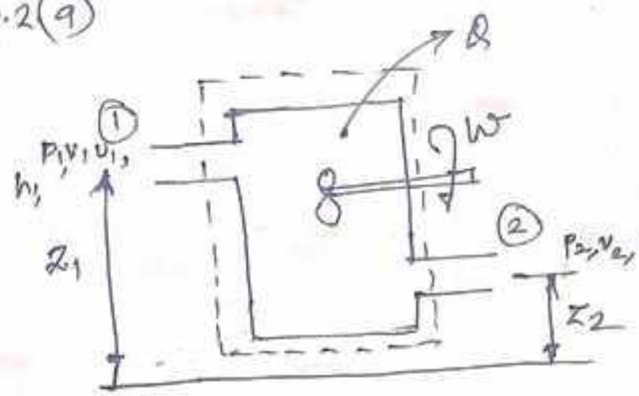
Thermal resistance is a property of a heat and measured by a temperature difference of a substance resist heat flow.

Q.2. Attempt any THREE of the following: **12 Marks**

a) Explain the concept of flow work associated with flow processes.

Sol. A **control volume** may involve one or more forms of **work** at the same time. ... **Work** is needed to push the fluid into or out of the boundaries of a **control volume** if mass **flow** is involved. This **work** is called the **flow work** (**flow** energy). **Flow work** is necessary for maintaining a continuous **flow** through a **control volume**. **02 marks**

Q.2(a)



eq^n for flow process.

$$E_1 + Q = E_2 + W$$

$$[KE_1 + PE_1 + U_1] + Q = [KE_2 + PE_2 + U_2] + W$$

$$Q - W = \frac{V_2^2 - V_1^2}{2} + (Z_2 - Z_1)g + (h_2 - h_1)$$

02 marks

b) Two leg of gas contained in cylinder at a pressure of 7 bar and temperature 27°C expands four times its original volume at constant pressure. Calculate-

(i) Work done by gas

(ii) Heat added

Sol.

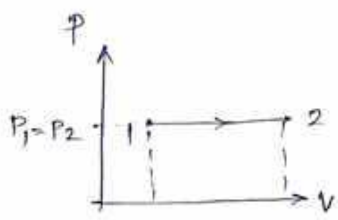
Note:

1) **Printing mistake: instead of mass(Kg), leg is printed**
2) **Values of C_P, R are not mentioned.**

(If student assume a data and solve the numerical with correct procedure then give appropriate marks)

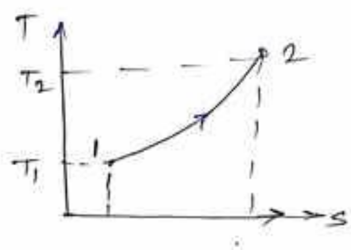
Q. 2.
(b) given data: mass of gas m = 2 kg. @ 7 bar & 27°C — **01 mark**

expands to $V_1 = V_2 \times 4$ | at constant pressure



Applying gas eq° at constant pr

$P_1 V_1 = R T_1$
$P_2 V_2 = R T_2$ | $P_1 = P_2$



$\frac{V_1}{V_2} = \frac{T_1}{T_2}$ | but $V_2 = 4V_1$

$\frac{4V_1}{4V_1} = \frac{T_1}{T_2}$ ∴ $T_1 = 27 + 273$, $T_1 = 300\ K$ — **01 mark**

$T_2 = 4 T_1$
$= 4 \times 300$
$T_2 = 1200\ K$

∴ Work done $W = mR(T_2 - T_1)$ — $kg \cdot \frac{kJ}{kg \cdot K} K$
$= 2 \times 0.287 (1200 - 300)$ — **01 mark**

$W = 516.6\ kJ.$

ΔH Heat added $\Delta H = m \cdot C_p \Delta T$ — **01mark**
$= 2 \times 1 (1200 - 300)$ ∴ $C_p = 1 \frac{kJ}{kgK}$
$\Delta H = 1800\ kJ.$

c) **In a constant pressure vapour process, the initial condition of steam is wet and final condition is superheated. Represent the process on P-V, T-S, and H-S chart.**

Sol.

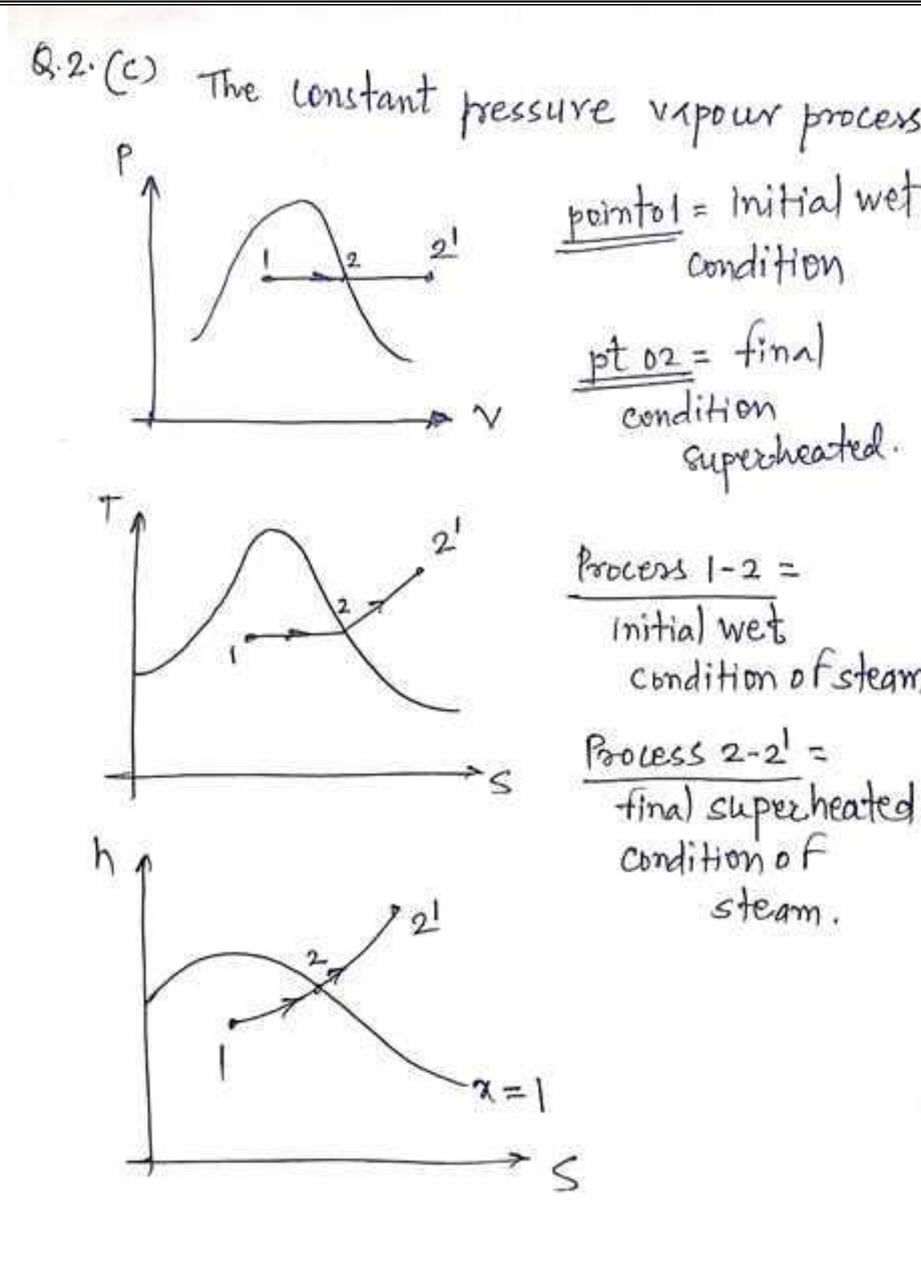


Figure: P-V, T-S, and H-S chart

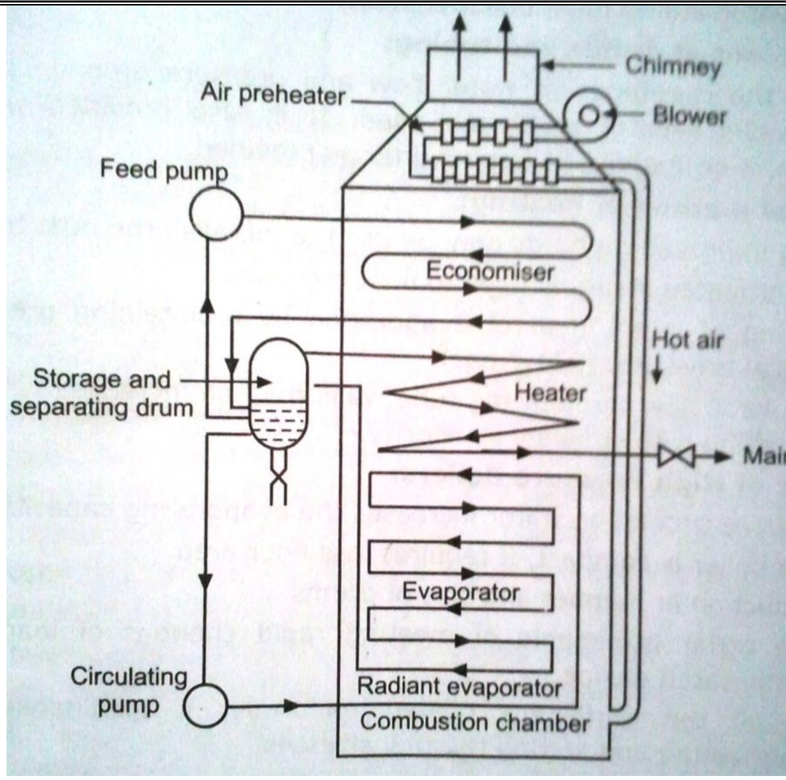
03 marks

For charts

01 mark for labels

d) **Explain the working of Lamont boiler with neat sketch.**

Sol.



02 marks

Figure: Lamont boiler

1. This is a modern high pressure, water tube boiler working on a forced circulation.
2. The circulation is maintained by a centrifugal pump, driven by a steam turbine, using steam from the boiler.
3. Feed water is supplied to economiser from hot well which is passed to separating and storing drum.
4. Water from separating and storing drum, flows by gravity to circulating pump.
5. Circulating pump circulates the water to set of tubes known as convective evaporator and then radiant evaporator.
6. By the time, water leaves the radiant evaporator, it converts into steam.
7. This steam is passed through storage and separator drum.
8. From separator and storage drum steam is fed to super heater to superheat.
9. The superheated steam is passed to main stream to supply for required application.

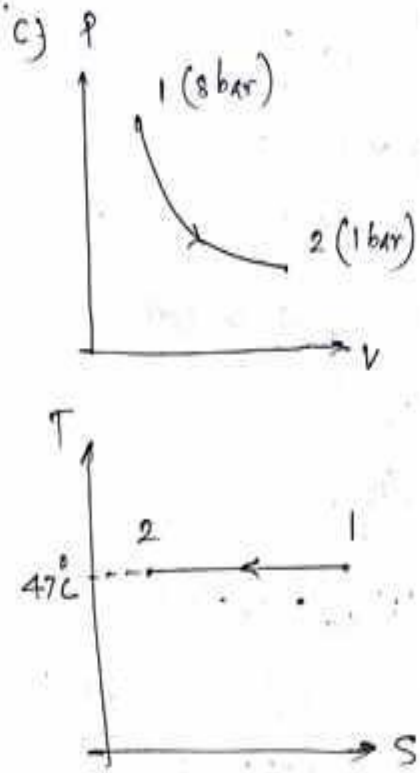
02 marks

Lamont boilers generates 45 to 50 tones steam per hour at 130 bar with 500^0 C.

Q.3.	Attempt any <u>THREE</u> of the following:	12 Marks
a)	**Write the criteria for selection of nozzle for given situation.**	
Sol.	**Following are the situation for selection criteria of nozzle.** **Situation first:** It is used when the back pressure is equal or more than the critical pressure ratio. It is also used for non – compressible fluids. Convergent nozzle: Cross sectional area is decreases continuously from entrance to exit. **Situation second:** When back pressure is less than critical pressure divergent nozzle is used. Divergent nozzle: Cross sectional area is increases continuously from entrance to exit. **Situation third:** When back pressure is less than critical pressure convergent divergent nozzle is used. Convergent and Divergent nozzle: Cross sectional area of nozzle first continuously decreases and then increases from entrance to exit.	**02 marks** **02 marks**
b)	**Explain the need of compounding. Suggest the method of compounding for reaction steam turbine with justification.**	
Sol.	**Need of compounding:** ✔ The compounding of steam turbine means the methods to reduce the speed of rotor shaft. ✔ To increase the thermal efficiency in power plants, high pressure and high temp. steam is used. ✔ If the entire pressure drop (from boiler pressure to condenser pressure)is carried out one stage only. ✔ Then the velocity of steam entering into the turbine will be extremely high. ✔ This will make the rotor to run at a very high speed, which is not useful from practical point of view. ✔ Hence it becomes necessary to reduce the rotor speed of turbine by gearing or no. of stages. **Following are the methods of compounding:** i. Velocity compounding ii. Pressure compounding iii. Pressure-Velocity compounding	**02 marks** **02 marks**
c)	**A nitrogen gas is expanded from 8 bar to 1 bar at 47°C according to law PV = C. Plot the process on P- V and T-S diagram and state the formulas to be used to find out work done, Amount of heat supplied and change in entropy.**	

Sol.

Q.3. c)



01 marks for figure

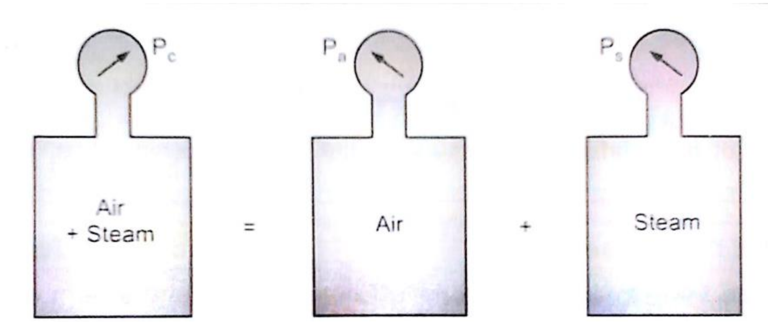
Work done (dw) = $R \cdot T \log_e (P_1/P_2)$

Heat supplied (Q) = $P_1 V_1 \log_e (P_1/P_2)$

Entropy (s) = $m R \log (V_2/V_1)$

01 marks each formula

	d)	**Determine the amount of heat supplied to 2kg of water at 25°C to convert it into steam at 5 bar and 0.9 dry.**	
Sol.		**Note: Value of C_p of water is not given assuming it standard value.** Q.3.d. given data mass of water $m_w = 2$ kg. $T_{water} = 25°C$ dryness fraction $x = 0.9$ Heat in water $= m \cdot C_p \cdot \Delta T$ $= 2 \times 4.187 \times 25$ $= 209.35$ kJ. —— (1) From steam table h_f & h_{fg} at 5 bar, $h_f = 640.1$ kJ/kg $h_{fg} = 2107.4$ kJ/kg. Enthalpy of steam $(H)_{steam} = h_f + x\,h_{fg}$ per kg. $= 640.1 + 0.9(2107.4)$ $= 2536.76$ kJ/kg. for 2 kg steam $= 2 \times 2536.76$ $= 5073.52$ kJ. ∴ Amount of heat needed to convert water into steam at (.9) dry. $= 5073.53 - 209.35$ $= 4864.17$ kJ (Note: Cp of water is not given in the problem.)	01 marks 01 marks 02 marks

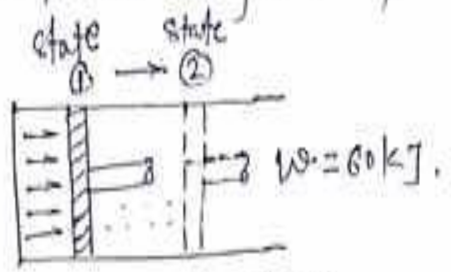
Q.4.		**Attempt any <u>THREE</u> of the following:**	**12 Marks**
	a)	**Explain Dalton's law of partial pressure. How it is applicable to condenser?**	
Sol.		It states that' "The pressure exerted by mixture of air and steam is equal to sum of partial pressures, which each constitute would exert, if it occupies the same volume".  Figure: Dalton's law of partial pressure In condenser total pressure is the sum of partial pressure of steam and air. Mathematically, $$P_c = P_a + P_s$$ Where; P_c = Pressure in condenser containing mixture of air and steam P_a = Partial pressure of air P_s = Partial pressure of steam	**02 marks** **02 marks**
	b)	**A system is composed of a gas contained in a cylinder fitted with a piston. The gas expands from the state 1 for which internal energy U 1 = 75 KJ to state 2 for which U2 = -25 KJ. During the expansion the gas does 60 KJ of work on the surrounding. Determine the heat transferred to or from the system during the process.**	

Sol.

Q 4. b)

02 marks

Expansion of gas in cylinder



$U_1 = 75\text{kJ}$ $U_2 = -25\text{kJ}$

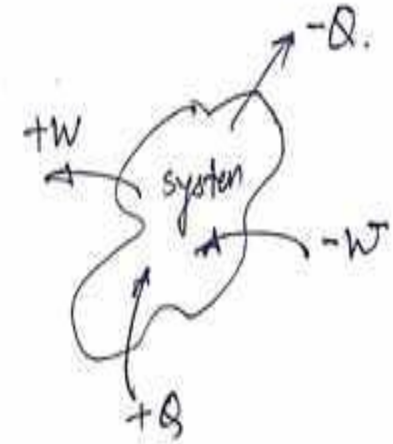
Applying first Law of thermodynamics

$$U_1 + Q = U_2 + W$$

$$75 + Q = (-25) + 60$$

$$Q = -25 + 60 - 75$$

$$\underline{Q = -40\text{ kJ}}$$



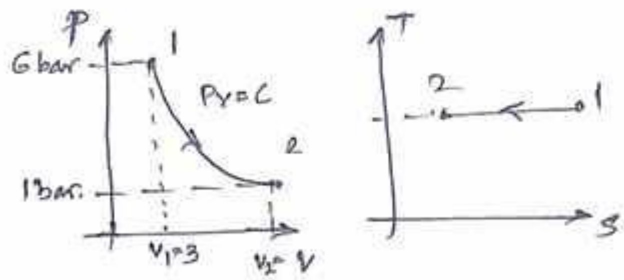
02 marks

'-' sign indicates that heat is transferred from the system.

	c)	3 m^3 of gas of 30°C and 6 bar pressure is expanded isothermally to 1 bar. Find work done, change in internal energy and heat transferred during the process.	

Sol.

Q.4. c)



01 mark

Given Data:

$P_1 = 6$ bar, $P_2 = 1$ bar,

$V_1 = 3\ m^3$

$T_1 = T_2 = 30^\circ C + 273 = 303\ K$

As process is isothermal. PV = Constant

01 mark

$\therefore P_1V_1 = P_2V_2$

$V_2 = \frac{P_1V_1}{P_2}$

$= \frac{6 \times 3}{1}$

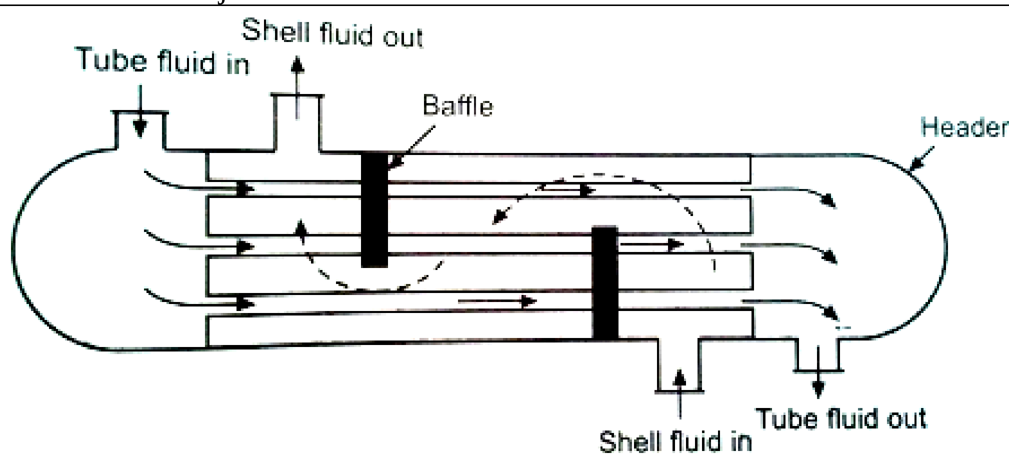
01 mark

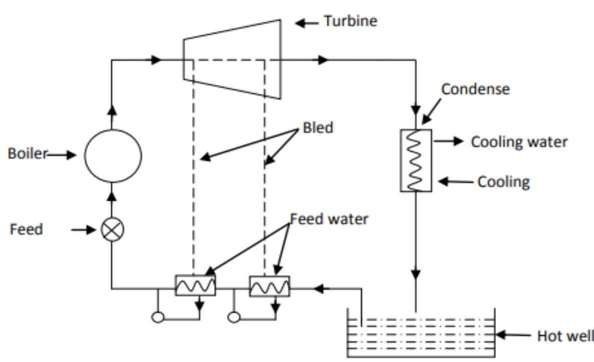
$V_2 = 18\ m^3$

$\therefore$ work done $(dw) = P_1V_1 \log_e(P_1/P_2)$

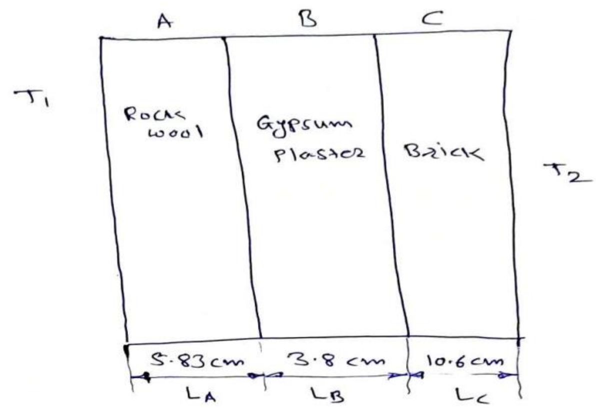
$= 6 \times 10^5 \times 3 \log_e\left(\frac{6}{1}\right)$

$= 32.25 \times 10^5$ KJ

		ΔU = internal energy ΔU = zero as constant temp. process. ∴ Heat tranfer $Q = U + W$ $Q = W$ $Q = 32.25 \times 10^5$ kJ	**01 mark**
	d)	Explain construction and working of shell and tube type heat exchanger. A ice plant producing 2000 Kg ice per day required the condenser. Suggest the type of condenser with justification.	
Sol.		 Shell and tube heat exchanger consist of a bundle of round tubes placed inside the cylindrical shell.Tube axis parallel to that of shell. One fluid inside the tubes while the other over the tubes. The main components of this type of heat exchanger are: i. Shell ii. Tube bundle iii. Front and rear headers of shell iv. baffles The baffles provide the support to tubes and also deflect the fluid flow approximately normal to tubes. This increase the turbulence of shell side fluid and improves heat transfer. The various types of baffles are existing and their type, spacing, shape, will depend on the flow rate, shell side pressure drop, required tube support, flow vibrations etc. The fluid combination may be : 1 Liquid to liquid 2 Liquid to gas 3 Gas to gas	**02 marks** **01 mark**

		A ice plant producing 2000 Kg ice per day required the evaporative condenser is used. **Justification:** The evaporative condenser is essentially a combination of a water-cooled condenser and an air-cooled condenser, utilizing the principle of heat rejection by the evaporation of water into an air stream traveling across the condensing coil.	**01 mark**
Q.5.		**Attempt any TWO of the following:**	**12 Marks**
	a)	(i) Suggest the methods to improve the performance of steam turbine. Explain anyone in brief. (ii) Identity the different losses occurred in steam turbine.	
	Sol.	**i) Methods to improve turbine efficiency** 1) Reheating of Steam 2) Regenerative feed heating 3) Binary Vapour Plant **Regenerative feed heating System** The process of draining steam from turbine at certain points during it's expansion and using this steam for heating feed water supplied to boiler is known as regenerative feed heating. It increases the thermal efficiency of plant, The temperature stresses in the boiler are reduced due to decreased range of working temperature.  **ii) Losses occurred in steam turbine** **Residual velocity loss-** The steam leaves the turbine with a certain absolute velocity which results in loss of KE. This loss is about 10 to 12% .It can be reduced by multistaging. **Losses in regulating valves-**Due to throttling action in valve , steam pressure drop occurs. Hence	**01 mark** **01 mark** **01 mark**

		steam pressure at entry to turbine is less than the boiler pressure. **Losses due to friction in nozzle-**Friction occurs both in nozzle and turbine blades. In nozzle, nozzle efficiency is considered, whereas in turbines, blade velocity coefficient is taken into account. This loss is about 10% **Loss due to leakage-**The leakage occurs between the shaft, bearings and stationary diaphragms carrying the nozzles in case of impulse turbines. In reaction turbine the leakage occurs at blade tips. This is about 1-2%. **Loss due to mechanical friction-**This occurs in bearings and may be reduced by lubrication **Loss due to wetness of steam-**In multistage turbine, condensation occurs at last stage ,so in dragging water particles with steam, some KE of stem is lost **Radiation loss-**As turbines are heavily insulated to reduce the heat loss to surroundings by radiation and so these losses are negligible	**03 marks** **(Any 3 Point)**
	b)	**An exterior wall of house consists 10.6 cm layer of common brick. It is followed by 3.8 cm layer of gypsum plaster and 5.83 cm of rock wool insulation. Estimate the amount of heat transferred through structure it.** **Thermal conductivity of brick = 0.7 *W/mK*** **Thermal conductivity of Plaster = 0.48 *W/mK*** **Thermal conductivity of Insulation = 0.065 *W/mK***	
	Sol.	**Note:** **1. Temperature gradient not mentioned.** **(If student assume a data and solve the numerical with correct procedure then gives appropriate marks)**	

	Given :-  $K_A = 0.065\ W/mK$, $L_A = 5.83\times10^{-2}\ m$ $K_B = 0.48\ W/mK$, $L_B = 3.8\times10^{-2}\ m$ $K_C = 0.7\ W/mK$, $L_C = 10.6\times10^{-2}\ m$ Temprature's are not given Assuming $T_2 = 24^\circ C$ wall of house $T_1 = 18^\circ C$ $\frac{Q}{A} = \frac{(T_1 - T_2)}{\frac{L_A}{K_A} + \frac{L_B}{K_B} + \frac{L_C}{K_C}}$ $= \frac{18 - 24}{\frac{5.83\times10^{-2}}{0.065} + \frac{3.8\times10^{-2}}{0.48} + \frac{10.6\times10^{-2}}{0.7}}$ $= \frac{-6}{0.8969 + 0.0791 + 0.1514}$ $\frac{Q}{A} = -5.3219\ W/m^2$ → Negative sign indicates Heat flow's from outside to inside	03marks 03marks
c)	**The initial condition of steam is 15% wet at a pressure of 7 bar It expands to 1.2 bar by $PV^{1.3} = C$. Find** **(i) Quality of steam at the end of expansion** **(ii) Work done.**	
Sol.		

		→ Given : Steam is 15% wet ∴ dryness fraction = 85% $\therefore x = 0.85$ $P_1 = 7$ bar $P_2 = 1.2$ bar $PV^{1.3} = C$ polytropic process i> quality of steam at the end of expansion At initial condition, considering unit mass At 7 bar from steam table. $V_g = 0.273$ $\therefore V_1 = x V_g$ $= 0.85 \times 0.273$ $= 0.23205 \; m^3$ $\therefore P_1 V_1 = m R T_1$ $7 \times 10^5 \times 0.23205 = 1 \times 287 \times T_1$ $T_1 = \frac{162435}{287}$ $= 565.97$ K Now $PV^n = C$ $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}$ $\therefore T_2 = T_1 \times \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}$ $= 565.97 \times \left(\frac{1.2}{7}\right)^{\frac{1.3-1}{1.3}}$ $= 565.97 \times (0.1714)^{0.2307}$ $T_2 = 376.77 \; ^\circ K$ at 1.2 bar $T_3 = 104.81 \; ^\circ C$ $= 377.81 \; ^\circ K$ Saturated temprature is greater tan actual temp. ∴ The steam is in wet condition. ii> work done For $PV^{1.3} = C$ $W = \frac{mR}{n-1}(T_1 - T_2)$ $= \frac{01 \times 0.287}{1.3 - 1}(565.97 - 376.77)$ $= 0.9566 \, (189.2)$ $W = 180.98$ kJ	03 marks 03 marks
Q.6.		**Attempt any <u>TWO</u> of the following:**	**12 Marks**
	a)	**A mass of 0.8 Kg of air at 1 bar and *25°C* is contained in a gas tight frictionless piston cylinder device. The air is now compressed to a final pressure of 5 bar. During this process the heat is transferred from air such that the temperature inside the cylinder remains constant. Calculate the heat transferred and work done during process and direction of each in the process.**	

	Sol.	Given:- $m = 0.8\ kg$ $P_1 = 1\ bar$, $P_2 = 5\ bar$ $T_1 = 25^\circ C = 298\ ^\circ K$ Const Temp Process i.e. $T_1 = T_2$ For isothermal Process Heat Transfer $\Delta Q = m R T_1 \ln\left(\frac{P_1}{P_2}\right)$ Consider $R = 0.287\ kJ/kg\ ^\circ K$ $= 0.8 \times 0.287 \times 298 \times \ln\left(\frac{1}{5}\right)$ $= 68.420 \times (-1.6094)$ $= -110.11\ kJ$ Work Transfer $\Delta W = \Delta Q$ $\therefore \Delta W = -110.11\ kJ$ i) work done is negative it mean's work is done on the system from surrounding ii) Heat transfer is negative it mean's Heat is transfer from system to surrounding that mean's heat is rejected from system to surrounding	**01 mark** **02 marks** **02 marks** **01 mark**
	b)	**For steam power plant having capacity 600 MW capacity a cooling tower is required to set up with condenser. Suggest the type of condenser and cooling tower with justification.**	
	Sol.	For Steam power plant having Capacity 600 MW the requirement of condenser and cooling tower is as follow. 1) Condenser:- Given Capacity is medium to low capacity for this we can use **Jet Condenser** -Which cooling water and steam are mixed to each other , -Mainly it requires less quantity of cooling water. -It is simple in construction and less costly.	**3 marks**

		-Maintenance cost Is also less. 2) Cooling Tower :- For this Capacity we can use **Force draught cooling tower** - Less space is required -Cooling rate and efficiency of tower is high -Temperature of water coming out from tower can be controlled.	**3 marks**
	c)	**Suggest the type of heat exchangers for following applications -** **(i) Dairy plant (Milk Chilling Plant)** **(ii) Condenser of refrigeration system. (House hold system) Justify your answers.**	
	Sol.	Types of Heat Exchanger Used for 1) Dairy Plant (Milk Chilling Plant)- **Plate Type Heat Exchanger** Because , It is made up of aluminum alloy which provides higher rate of heat transfer. Due to larger surface area, It has more heat transfer as compare to other heat exchanger which is useful for dairy plant. It is lighter in weight. 2) Condenser of Refrigeration System:- **Counter Flow tube type heat Exchanger** Because , High performance due to large surface area Compact and light in weight In tubes generally turbulent flow is develop which reduces scale deposition. Less installation and maintenance cost.	**1 mark** **2 marks** **1 mark** **2 marks**