PAPER-I (Conventional)

1. a.

10 kg of pure ice at –10 ºC is separated from 6 kg of pure water at +10 ^{O}C in an adiabatic chamber using a thin adiabatic membrane. Upon rupture of the membrane, ice and water mix uniformly at constant pressure. At this pressure, the melting temperature of ice is 0 ^{O}C and the latent heat of melting is 335 kJ/kg. The mean specific heat at constant pressure for ice and water are respectively 2.1 kJ/kg-K and 4.2 kJ/kg-K.

i. Sketch the systems before and after mixing

ii. What is the final equilibrium temperature of the system after the completion of the mixing process?

iii. Estimate the change of entropy of the universe due to the mixing.

iv. Is the final phase of the system solid ice, liquid water or ice-water mixture?

1. b.

An inventor claims to have developed a device requiring no energy transfer by heat or work, yet able to produce hot and cold streams of air from a single stream of air at an intermediate temperature. Steady-state test data provided by the inventor indicate that the air enters the device at a pressure and temperature, respectively of 5 bars and 39 ^{O}C and leaves the device as cold airstream at -21 ^{O}C and as hot air-stream at 79 ^{O}C each at a pressure of 1 bar. Further, it is also noted that 40% of the mass of air is entering the device as cold stream. Neglecting any changes in kinetic and potential energies of the streams at inlet and exit sections and using ideal gas model with C_P and R for air, respectively at 1.005 kJ/kg-K and 0.287 kJ/kg-K, evaluate the claim using energy and entropy balances. Sketch the device as a control volume.

1. c.

Using Maxwell's relations and the thermodynamic definitions for C_p and C_v in terms of gradients, show the following:

(i) $$Tds = C_v dT + T\left(\frac{\partial p}{\partial T}\right)_v dv$$

$$= C_p dT - T\left(\frac{\partial v}{\partial T}\right)_p dp$$

(ii) Joule-Thomson coefficient

$$\mu_j = \frac{1}{C_p}\left[T\left(\frac{\partial v}{\partial T}\right)_p - v\right]$$

(iii) There is no change in temperature when an ideal gas is made to undergo Joule-Thomson expansion.

1. d.

Describe the step-by-step procedure to experimentally determine the calorific value of a solid fuel using bomb calorimeter. Draw a sectional view of the calorimeter.

2. **a.**

A four-cylinder engine of an automobile is converted to run on propane $\left(C_3H_8\right)$ fuel. A dry analysis of engine exhaust gives volumetric percentage of CO, CO2 and O_2, respectively at 9.79%, 4.90% and 2.45%. Write the resulting chemical reaction and find the equivalence ratio.

2. **b.**

The spark plug is fixed at 18º before top dead centre (TDC) in an SI engine running at 1800 r.p.m. It takes 8º of rotation to start combustion and get into flame propagation mode. Flame termination occurs at 12^O after TDC.

Flame front can be approximated as a sphere moving out from the spark plug which is offset 8 mm from the centre line of the cylinder whose bore diameter is 8.4 cm. Calculate the effective flame front speed during flame propagation. The engine speed is increased to 3000 r.p.m. and subsequently as a result of which the effective flame front speed increases at a rate such that it is directly proportional to 0.85 times of engine speed. Flame development after spark plug firing still takes 8^O of engine rotation. Calculate how much engine rotation must be advanced such that the flame termination again occurs at 12^O after TDC.

2. **c.**

Discuss the basic properties that a lubricant should possess to meet the lubrication requirement of internal combustion engines.

2. **d.**

Using a layout diagram, describe the functions of various components of a turbojet engine.

3. **a.**

Explain Reynolds analogy and derive the expression to evaluate the heat-transfer coefficient using it. Give physical meaning of the expression.

3. **b.**

Differentiate between fin efficiency and fin effectiveness.

3. **c.**

Show that the differential equation governing conduction heat transfer in a solid sphere with heat generation is given by $\frac{d^2T}{dr^2}+\frac{2}{r}\frac{dT}{dr}+\frac{q'''}{k}=0$, where T is the temperature at any radius r, q''' is the eat generated per unit volume and k is the thermal conductivity of the solid sphere. Show the general nature of the temperature distribution in this case.

3. **d.**

A counterflow heat exchanger is to be designed to cool 900 kg/hr of oil from 60 ^{O}C to 32 ^{O}C using a fluid with sp. heat 1.0 kJ/kg-K at 15 ^{O}C. The sp. heat of the oil is 0.5 kJ/kg-K and the maximum allowable exit temperature of the cooling fluid is 27 ^{O}C. Work out the following:

(i) Sketch the system and show the temperature distribution.

(ii) Find NTU.

If the diameter of the tube is 2 cm through which the cooling fluid passes and the overall heat-transfer coefficient is 200 W/m^2-K, find the number of tubes required and the tube length,. Assume density of the cooling fluid is 250 kg/m^3. If the maximum velocity through the tube cannot exceed 2 m/s and the maximum length of the exchanger is limited to 12 m due to space restriction, find the configuration of the exchanger and sketch the final design.

3. **e.**

Find the average film coefficient heat transfer on the water side a single-pass steam condenser. The inner diameter of the tube is 23 mm and cooling water enters at 15 ^{O}C and leaves at 25 ^{O}C. The average water velocity is 2.1 m/s. Sketch the system and show the temperature distribution. Properties of water are given below. Find the heat transfer per metre length of the tube for the above case:

Temp (^{O}C)	Density (kg/m^3)	SP. heat (kJ/kg-K)	Thermal conductivity x 10^2 (W/m-k)	Viscosity x 10^2 (kg/hr)	Pr	v x 10^6 (m^2/s)
10	1000	4.192	57.498	469	9.52	1.306
20	1000	4.183	59.780	361.892	7.02	1.006
30	1000	4.174	61.345	288.650	5.42	0.805

4. **a.**

Saturated ammonia vapour enters a 15 cm dia x 14 cm stroke twin-cylinder single-acting compressor at 0.2365 MPa whose volumetric efficiency is 79% and speed 420 r.p.m. The delivery pressure is 1.1672 MPa. Liquid NH_3 at 21 ^{O}C enters the expansion valve. For ideal cycle, find (i) the ammonia circulated in kg/min (ii) the refrigeration in tons and (iii) COP of the cycle. Assume sp. heat of NH_3 as 2.19 kJ/kg-K and density 0.77 kg/m^3. Properties of NH_3 are given below:

Pressure (MPa)	Sat. temp. (^{O}C)	Sp. volume of vap. At sat. (m^3/kg)	Enthalpy (kJ/kg)		Entropy (kJ/kg-K)	
			Sat liq.	Sat vap	Sat liq.	Sat vap.
0.2365	-15	0.5106	-831.46	481.52	5.4387	10.526
1.1672	+30	0.11084	-620.70	523.42	6.1853	9.9606

4. b.

The Bell-Coleman refrigeration system is used to produce 10 tons of refrigeration. The cooler and refrigerator pressure are 4.2 bars and 1.4 bars. Air is cooled in the cooler to 45^{O}C and temperature of air at the inlet of the compressor is -20^{O}C. For an ideal cycle, calculate COP, mass of air circulated/min, theoretical piston displacement of compressor and power required per ton of refrigeration. Assume C_p for air as 1.005 kJ/kg-K. Find the cylinder dimensions if the compressor is single-acting single-cylinder with L/D ratio of 1.2 and runs at 600 r.p.m.

4. c.

With a neat sketch, explain the winter air-conditioning system. Why a single psychrometric process cannot be applied in winter air-conditioning?

4. d.

Calculate all the psychrometric properties of air at 1 bar and 25 ^{O}C dbt and 15^{O}C wbt. The following properties of water may be assumed:

Temp (°C)	Sat. Pressure (bar)	Sp. volume of vapour (m^3/kg)	Enthalpy (kJ/kg)	
			Sat. liq.	Sat. Vap.
25	0.03166	43.40	-	2547.3
15	0.01703	77.98	62.94	-
10	0.01078	-	-	-
0	0.01002	-	-	-

The following expression may be used, if necessary:

$$p_v = \left(p_{vsat}\right)_{t_{wbt}} - \frac{\left(P - p_{vsat}\right)\left(dbt - wbt\right)\times 1.8}{2854 - 1.325\left(1.8t_{dbt} + 32\right)}$$

5. a.

Considering the T-s diagram of Rayleigh flow and using the differential forms of the conservation equations and property relations, show that the (i) Mach number is unity at the point of maximum entropy and (ii) Mach number is $\frac{1}{\sqrt{\gamma}}$ at the point at maximum temperature.

5. **b.**

Air at 1 MPa and 600 ^{O}C enters a conserving nozzle with a velocity of 150 m/s. Determine the mass flow rate through the nozzle for a nozzle throat area of $50cm^2$ when the back pressure is (i) 0.7 MPa and (ii) 0.4 MPa.

Assume that the flow through the nozzle is steady, one-dimensional and isentropic.

You may use the following table for one-dimensional isentropic flow (for an ideal gas with $\gamma = 1.4$):

M	$\frac{p}{p_0}$	$\frac{\rho}{\rho_0}$	$\frac{T}{T_0}$	$\frac{A}{A*}$	$M*$
0.74	0.695	0.771	0.901	1.068	0.770
0.76	0.682	0.761	0.896	1.057	0.788
0.78	0.669	0.750	0.892	1.047	0.807
0.80	0.656	0.740	0.887	1.038	0.825
0.82	0.643	0.729	0.881	1.030	0.843

5. **c.**

Explain the phenomenon of boundary layer separation over a curved surface. Discuss various methods of controlling boundary layer separation.

6. **a.**

Explain what you mean by the specific speed of turbine. Using Buckingham $-\pi$ theorem and variables such as power (P), speed (N), head (H), diameter of turbine (D), density of fluid (ρ) and acceleration due to gravity (g), obtain the expression for the specific speed for a turbine.

6. **b.**

Explain what you mean by momentum correction factor. The velocity distribution in a pipe is given by $\frac{u}{U} = \left(1 - \frac{r}{R}\right)^n$

where, U = maximum velocity at the centre of the pipe

u = local velocity along r

R = radius of the pipe

Find the momentum correction factor, if n = 0.20.

6. c.

(i) Define degree of turbulence

(ii) Explain, for boundary layer flow, whether the curve representing δ (boundary layer thickness) as a function of X over a flat plate is a streamline of flow or not.

6. d.

Distinguish, with the help of neat sketches, between a hydrodynamically rough surface and a hydrodynamically smooth surface.

7. a

Give a neat sketch of practical feed heating arrangement of a 660 MW unit of steam turbine. Write the salient features of this system with reasonings for selecting its main parts.

7. b.

Discuss the need of governing of steam turbine. With the help of a neat sketch, discuss the working principle of hydro-mechanical speed-governing loop of a steam turbine by showing the characteristics on torque and frequency versus time and torque or load versus frequency.

7. c.

A steam power plant generating 500 MW of electrical power employs a natural circulation boiler which supplies steam at a pressure of 150 bars and temperature of 550 ^{O}C. The condenser pressure is 0.05 bar. The turbine, mechanical and generator efficiencies are 87%, 98% and 99% respectively. The boiler uses pulverized coal having a calorific value of 26 MJ/kg and yields 92% efficiency. The feedwater passing through the feed heaters enters the boiler at 160^{O}C. The risers of the furnace are 55 m high while the downcomers are placed outside the furnace for producing natural circulation. The quality of steam at the top of the riser is 12% and a minimum exit velocity of mixture leaving the risers and entering the drum is 1.4 m/s. The dimensions of the riser tubes are 65 mm OD and 3 mm wall thickness while the dimensions of downcomers are 185 mm OD and 8 mm thick. Assume no pressure drop and heat loss to the risers. Work out the following:

i. Sketch the layout of natural circulation boiler unit showing furnace, drum, risers, downcomers, superheater, reheater and economizers, and show the process on T-s diagram

ii. The generation of rate of steam ignoring the amount of steam bled off to feed heaters in kg/s

iii. The rate of fuel flow required in kg/s

iv. The evaporation factor

v. The circulation ratio

vi. The number of riser tubes

vii. The number of downcomers

viii. State reasons for selecting fewer in number and bigger in diameter as downcomers while more in number and smaller in diameter as riser tubes in natural circulation boiler

Take the following properties:

h_1 = 3448.6 kJ/kg, h_{2s} = 1987 kJ/kg

h_{f3} = 137.8 kJ/kg, h_{f5} = 675.5 kJ/kg

$\rho_{riser,\ top}$ = 396 kg/m^3

$\rho_{downcomer,\ inlet}$ = 603 kg/m^3

where suffixes 1, 2, 3 and 5 denote boiler exit (or turbine inlet), condenser exit, pump inlet and boiler inlet respectively.

7. d.

With the help of a neat sketch, discuss in brief the working principle of steam pressure control system used in modern steam boilers.

8. a

What do you mean by cavitation phenomena associated with hydraulic turbomachines? Discuss the causes of cavitation and its prevention with reference to hydraulic turbines. Mention the location of cavitation in hydraulic turbopumps and turbines, and give reasons for this.

8. b.

An axial-flow compressor employed in gas turbine plant delivers air at the rate of 300 kg/s and develops a total pressure ratio of 20. The inlet stagnation conditions are 300 K and 1 bar. The isentropic efficiency of the compressor is 87%. The compressor is having 18 stages and the blade speed is kept at 200 m/s to minimize noise generation. The stage degree of reaction at the mean blade height is 50%. The axial velocity of flow is 160 m/s. the work done factor is 0.88. The hub-tip diameter ratio is 0.8. Assume actual temperature rise in each stage. Take R = 0.287 kJ/ kg-K and C_P = 1.005 kJ/kg-K. Work out the following:

i. Sketch the system, show the process on T-S diagram and draw velocity diagrams

ii. All the fluid angles of the first stage

iii. The hub and tip diameters including blade height

iv. State the reasons why the pressure rise per stage in axial-flow compressor is less than that of centrifugal compressor

8. c.

A gas turbine power plant developing 250 MW of electrical power employs a single-shaft gas turbine reheat cycle having the following data:

Total compressor pressure ratio = 30

Total ambient conditions = 1 bar and 300 K

Polytropic efficiencies for both compressor and turbine = 0.9 each

Total turbine inlet temperature of both turbines = 1600 K each

Pressure loss in both combustors = 2% of entry pressure each

Total turbine exhaust pressure = 1.05 bars

Mechanical efficiency of assembly = 0.98

Combustion efficiency of both combustors = 0.97

Alternator efficiency = 0.97

Alternator power output = 250 MW

Actual air-fuel ratio = 25

Lower calorific value of fuel = 42 MJ/kg

Take, $C_{P_a} = 1.005 \ kJ/kg-K$ and $C_{P_g} = 1.16 \ kJ/kg-K$

Work out the following:

i. Sketch the system and show the process on T-s diagram

ii. The plant specific work in kJ/kg

iii. The mass flow rate of air required in kg/s

iv. The specific fuel consumption in kg/kWh

v. The actual thermal efficiency

8. d.

With the help of a simple sketch, discuss in brief the working principle of hydromechanical speed-governing system (prime control) of a water reaction turbine.