INDIAN INSTITUTE OF TECHNOLOGY KHARAGPUR

Department of Mechanical Engineering

Date : | Time : **3 hours** | Full Marks : **100** | No. of students : **120**

End-Sem. 2016 | Sub. name: **Applied Thermo-Fluids II** | Sub.No.: **ME40701**

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Both Part-A and Part-B are compulsory

Part-A (60 marks)

Answer all questions. Make suitable assumptions, and state them clearly

1) A **2100 MW**, steam power plant has a thermal efficiency of **0.40**. The plant uses coal which has a Heating Value of **24 MJ/kg** and the combustion chamber operates with an air-fuel ratio of **15:1**. A forced draft fan system used for maintaining the required air flow through the combustion chamber has to develop a fan total pressure rise of **480 Pa** at an efficiency of **85 %**. The exhaust gas temperature at the entrance and exit of the chimney are **140°C** and **110°C**, respectively, while the average ambient air temperature is **21°C** and pressure is **1.01 bar**. The chimney height should be such that it develops a buoyancy pressure of **600 Pa**. Assume: a) Density of air = **1.1 kg/m³**, b) Specific heat, c_p of exhaust gases = **1.12 kJ/kg.K,** c) Gas constant of air and exhaust gases = **0.287 kJ/kg.K**. From the given data, find:

a) The power input to the forced draft fan system **(in MW)**

b) Height of the chimney **(in m)**

c) Heat loss from the exhaust gases in **(MW)** **(10)**

2) The riser tube of a natural circulation, drum type boiler receives saturated liquid water at a velocity of **1.2 m/s** from the downcomer. Water leaves the riser tube with an **exit void fraction** of **0.85** after absorbing **4.5 MW** of heat from the furnace gases. The boiler operates at **160 bar.** The saturated liquid and vapour densities at 160 bar are **585 kg/m³** and **108 kg/m³**, respectively, and the latent heat of vapourization is **930 kJ/kg**. At any section in the riser tube, the velocity of vapour is equal to **1.5 times** that of the liquid. The riser tube has to be sized such that it develops a pressure rise of **32 kPa** due to buoyancy. From the given data and using the equations given below, find a) the required riser diameter (in m), b) riser height (in m), and c) average heat flux in the riser tube (in kW/m²). **(15)**

The **void fraction** α is related to the dryness fraction x as: $\alpha = \frac{1}{1+\left[\frac{(1-x)}{x}\right]\psi}$; where $\psi = \frac{\rho_g}{\rho_f} S$ and S is the slip ratio (ratio of vapour-to-liquid velocity). The average density of the two-phase mixture in the riser tube is given by:

$$\bar{\rho}_{2-\varphi,R} = \rho_f - \frac{(\rho_f - \rho_g)}{(1-\psi)}\left\{1 - \left[\frac{1}{\alpha_e(1-\psi)} - 1\right]\ln\frac{1}{(1-\alpha_e(1-\psi))}\right\}$$

where α_e is the **void fraction at the exit of the riser**. Acceleration due to gravity (g) is **9.81 m/s²**.

3a) Superheated steam is expanded in a steam nozzle from an initial pressure and temperature of **120 bar** and **400°C** to a final pressure of **12 bar**. Neglecting the velocity at the inlet to the nozzle, what should be the nozzle efficiency if the velocity required at the nozzle exit is **800 m/s**? Use the data given in the table. **(5)**

t, °C	p, bar	x	h (kJ/kg)	s (kJ/kg.K)
400	120	-	3051	6.074
188	12	0	798.7	2.217
188	12	1	2784	6.524

3b) The above nozzle is connected to an impulse turbine at a nozzle exit angle of 12°. The inlet and exit blade angles of the turbine are 30° and 36°, respectively. Assuming frictionless flow through the turbine blades, find the power developed by the turbine in MW, if the mass flow rate of steam through the turbine is 12 kg/s. **(10)**

3c) Using **suitable velocity diagrams** and **starting with Euler's turbo-machinery equation**, prove that the specific work developed by a steam turbine with frictionless flow through blades is given by:

$$w = \frac{1}{2}(V_1^2 - V_2^2)$$

where V_1 and V_2 are the absolute velocities of steam at inlet and exit of the turbine blade. **(5)**

4a) Steam at a flow rate of **60 kg/s** and **0.07 bar** pressure (saturation temperature = **39°C** and latent heat of vaporization = **2408 kJ/kg**) at an inlet quality of **0.85** condenses on the shell side of a **2-pass, shell-and-tube type**, power plant condenser. Cooling water (c_p = **4.2 kJ/kg.K**, ρ = **1000 kg/m³**) from a cooling tower enters the condenser at **30°C** and leaves at **35°C**. Cooling water flows through the tubes which have an inner diameter of **25.4 mm** and a wall thickness of **1.0 mm**. The condensation heat transfer coefficient on the shell side is **3000 W/m².K** and fouling resistance on water side is **0.0004 m².K/W**. Heat transfer resistance of the tube wall is neglected. If from tube erosion point of view, the velocity of cooling water is to be restricted to **2.5 m/s**, find the length of the condenser tubes. The heat transfer coefficient on cooling water side is equal to **4600 W/m².K.** **(10)**

4b) A natural draft cooling tower supplies cooling water to the above condenser. The condition of air at the inlet and exit of the cooling tower are: **35°C, 50 %** relative humidity (**W = 0.0178 kgw/kga & h = 81 kJ/kga**) and **30°C and 100 %** relative humidity (**W = 0.0273 kgw/kga & h = 100 kJ/kga**), respectively. Neglecting drift and bleed-off losses, find the make-up water requirement for the cooling tower in **kg/h?** The enthalpy of make-up water is **120 kJ/kg.** **(5)**

End of Part-A

Part-B (40 marks)

Answers should be brief and to the point. Drawings should be neat and clean with proper labels. *Answer all questions.* Make suitable assumption, wherever necessary.

5) (a) Draw backward, radial and forward curved vanes for a centrifugal impeller. Draw the velocity triangles on the diagram with proper labeling. (b) Derive the theoretical head (*H*) vs flowrate (*Q*) curve. Draw the theoretical pump characteristics for three blade angles. Assume whirl component at inlet is zero. (c) Step-by-step discuss the various losses occurring inside the impeller and finally obtain the actual pump characteristics curve. **[3+3+4=10]**

6) (a) Derive the relation between the ratio of kinetic to reaction component of energy with degree of reaction? (b) Find out the utilisation factor as a function of inlet flow angle and degree of reaction. (c) Derive speed ratio as a function of inlet flow angle and degree of reaction. Compare the speed ratio for fully impulse and 50% reaction machine. **[3+3+4=10]**

7) (a) Draw schematic and velocity diagrams of compressor cascade and turbine cascade. (b) For axial flow machine, derive the degree of reaction as a function of the mean tangential component of relative velocity by drawing suitable velocity triangles and (c) Draw three separate diagrams to explain degree of reaction (i) zero, (ii) 1 and (iii) 0.5. **[4+3+3=10]**

8) A Kaplan turbine has a rated output of 2600 kW at 600 rpm, the head being 40m of water. The velocity ratio is 1.25. The overall and hydraulic efficiencies are 0.86 and 0.9 respectively. The hub diameter is 0.6 times the tip diameter, Calculate the (a) engineering specific speed, (b) tip diameter and hub diameter, (c) blade inlet and outlet angles at the tip, and (d) blade inlet and outlet angles at the hub. **[1+3+3+3=10]**

End of the Question Paper