INDIAN INSTITUTE OF TECHNOLOGY KHARAGPUR

Department of Mechanical Engineering

Date :	Time : **3** hours	Full Marks : **100**	No. of students : **105**
End-Sem. 2015	Sub. name: **Applied Thermo-Fluids II**		Sub.No.: **ME40701**

Both Part-A and Part-B are compulsory

Part-A (60 marks)

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

1. A coal based, **1000 MW**, steam power plant has a Net Plant Heat Rate of **10 MJ/kWh**. The coal used in the plant has a Higher Heating Value of **24 MJ/kg** and contains **4 %** of **hydrogen** (by mass). The combustion chamber operates with an air-fuel ratio of **14:1**. The fan used for maintaining the required air flow has to overcome a resistance of **360 Pa** and has an efficiency of **85 %**. The plant operates at a boiler pressure of **165 bar** and a condensing pressure of **0.07 bar**. The enthalpy change across the boiler is **3000 kJ/kg** and the temperature rise of cooling water across the condenser is **8 K**. The feedwater and cooling water pumps have an efficiency of **90 %**, and the cooling water pump has to overcome a pressure drop of **0.3 bar**. Assume: a) Density of liquid water = **998 kg/m^3**, b) Density of air = **1.2 kg/m^3**, c) c_p of water = **4.2 kJ/kg.K**, d) Latent heat of water at exhaust gas conditions = **2200 kJ/kg**. From the given data, find:

a) The power required for the fan

b) The power required for pumping feedwater and cooling water

c) If coal is transported to the plant using goods train consisting of **40 wagons**, each wagon having a carrying capacity of **60 tons**, find how many such goods trains are required per day to meet the fuel demand of the plant. **(15)**

2. In a frictionless steam nozzle, superheated steam with a flow rate of **1.2 kg/s** enters the nozzle at a total pressure and total temperature of **25 bar and 330°C**, respectively. The steam leaves the nozzle at **14 bar** pressure. Find the shape (i.e., converging or converging-diverging) and area of the nozzle at the exit, if the expansion process through the nozzle obeys the equation $pv^{1.3} = constant$. The critical pressure ratio $\left(\frac{p^*}{p_{oi}}\right)$ is equal to **0.55**.

At 25 bar and 330°C, ***h*** **= 3079 kJ/kg**, ***s*** **= 6.68 kJ/kg.K** and ***v*** **= 0.1 m^3/kg**. **(10)**

3. A single stage, impulse turbine rotor has a mean diameter of **1.6 m** and rotates at **3000 RPM**. Steam from the nozzle impinges on the turbine at an angle of **18°**. The blade speed-to-inlet velocity ratio is **0.5**, and the ratio of relative velocity at the outlet to relative velocity at the inlet is

0.92. The blade outlet angle is **5° less** than the blade inlet angle. The mass flow rate of steam from the nozzle is **8 kg/s**. From the given data find:

a) The blade angles

b) Power developed by the turbine

c) Blade efficiency, and

d) Axial thrust on the end bearings **(10)**

4. A **500 MW** power plant requires **520 kg/s** of steam at rated power and **25 kg/s** at no load. If the enthalpy change across the boiler is **3200 kJ/kg**, find the efficiency of the plant at **100 %, 75 %, 50 % and 25 %** loads. Assume that the steam flow rate vs. load follows the **Willan's line**. What are the conclusions drawn from this example, and whether this fact has any relation to the concept of electrical grids? **(10)**

5. A power plant cooling tower has to reject **2000 MW** of heat. The range and approach of the induced draft type cooling tower are **6 K and 4 K**, respectively. Atmospheric air (molecular weight = **28.97 kg/kmol**) at **101 kPa**, **38°C** and **45 %** relative humidity enters the cooling tower, and exits as **saturated air** at **35°C** after exchanging heat with the cooling water. The cooling tower fan has an efficiency of **85 %** and has to take care of a pressure drop of **0.1" Hg**, while the cooling water pump has to overcome a pressure drop of **8" Hg** and has an efficiency of **90 %**. Assuming the atmospheric air to behave as an ideal gas mixture, estimate: a) Power consumption of cooling tower fan, b) Power consumption of cooling water pump, and c) Make-up water requirement if **2 %** of cooling water supplied to the condenser is lost due to bleed-off and drift losses. Use the following property data:

a) Density of water = **1000 kg/m^3**, b) c_p of water = **4.2 kJ/kg.K**, c) c_p of dry air = **1.005 kJ/kga.K**, d) c_p of water vapour = **1.88 kJ/kgw.K**, e) Latent heat of water at **0°C** = **2501 kJ/kg**, f) ρ_{Hg} = **13.6 g/cm^3**, and **g = 9.81 m/s^2**. The saturation pressure (p_{sat}) of water can be calculated using the equation:

$$\ln p_{sat}\,(\text{in kPa}) = 16.54 - \frac{3985}{T-39}. \qquad \text{T is in K.}$$ **(15)**

End of Part-A

Part-B (40 marks)

6. Derive the theoretical expression for head developed by a centrifugal pump as a function of the flow rate (assuming radial entry at inlet). Explain with diagram the effect of the blade outlet angle on the head developed. **4**

<u>Answer any 3 questions</u>

Take density of water 1000 kg/m^3, acceleration due to gravity 9.81 m/sec^2.

7. A single jet Pelton turbine is required to drive a generator to develop 10MW of power. The turbine is located at a height of 780 m down the reservoir level. However, due to pipe friction, 18 m of water head is lost at the entry to the turbine. The electric generator efficiency and the Pelton wheel efficiencies are 95% and 87% respectively. The coefficient of velocity for nozzle is 0.97 and the friction of the bucket reduces the relative velocity by 15%. The mean bucket velocity if 0.46 times the jet velocity, outlet angle of the buckets is 15^0. Find : (a) the diameter of the jet (in cm); (b) the rate of flow of water through the turbine (in m^3/s); (c) the force exerted by the jet on the buckets; (d) the specific speed of turbine (in rad/s).

3x4=12

8. A run-of-the-river power house has a potential of a steady flow of 95 m^3/s; and the head that can be arranged is 5.5 m of water. A Kaplan turbine that can be assumed to have an overall efficiency of 87% and hydraulic efficiency of 95%. The flow velocity (normal component) is 7.8 m/s. The speed of turbine is 100 rpm. Make all the calculation at mean diameter. The hub diameter is 0.35 times the tip diameter of the runner. The flow component of velocity remains constant. Calculate (a) power of the turbine; (b) tip and hub diameter; (c) specific speed in (rad/s); (d) inlet and outlet blade angle at mean diameter along with the velocity diagrams at inlet and outlet with proper labels.

3x4=12

9. A Francis turbine of a dam power house develops 450 kW of power. The head available is 100 m; however, 15 m of head is lost at the inlet to the turbine due to the frictional loss in the penstock. The turbine runs at a speed of 1000 rpm with an overall efficiency of 85%. The ratio of runner wheel diameter at outlet to the width is 12. The guide vane angle is 20^0. The runner diameter at the outlet is half that at the inlet. The flow component remains constant at inlet and outlet. The discharge of water is without any whirl component. Determine (a) the mass flow rate of water (in m^3/s); (c) diameter of runner at inlet and at outlet (in m) (d) blade angle at inlet and at outlet along with the velocity diagram at inlet and at outlet with proper labels.

3x4=12

10. The impeller of a radial flow pump has diameters of 4.5 cm and 10 cm at the inlet and outlet. The blades are bent backwards, at 65^0 to the blade velocity at the outlet. Water enters the impeller radially at a velocity of 10 m/s. The flow component of the velocity gets reduced to 60% from inlet to outlet, in the rotor due to the variation of the area. The speed of the rotor is 2500 rpm. (a) Draw the velocity triangles and (b) calculate the specific work (kJ/kg). (c) Also determine the power required to drive the pump (in kW) with an overall efficiency of 87.5%, and (d) the degree of reaction. The flow rate is 30 kg/s.

3x4=12

End of the Question Paper