INDIAN INSTITUTE OF TECHNOLOGY KHARAGPUR
End-Autumn Semester 2017-18

Date of Examination : ______ **Session (FN/AN)** ____ **Duration:** 3 hrs **Full Marks:** 100
Subject No. : ME40701/ME40603 **Subject:** Applied Thermofluids-2
Department/Center/School: Mechanical Engineering
Specific charts, graph paper, log book etc., required: None
Special Instructions (if any): Nil

Answer all questions. Make suitable assumptions, if required, but state them clearly

Make sure that wherever applicable, the correct units mentioned clearly

Part-A (60 marks)

1. A coal based, **1200 MW**, steam power plant has a Net Plant Heat Rate (NPHR) of **9 MJ/kWh. The NPHR is based on lower heating value of the fuel.** The coal used in the plant has a Higher Heating Value of **21 MJ/kg** and contains **4 %** of **hydrogen** (by mass). The combustion chamber operates with an air-fuel ratio of **15:1**. The fan used for maintaining the required air flow through the draft system has to overcome a resistance of **420 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 (assumed to be **100 % efficient**) is **3000 kJ/kg** and the temperature rise of cooling water across the condenser is **6 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/m³**, b) Density of air and flue gases = **1.2 kg/m³**, c) c_p of water = **4.2 kJ/kg.K**, *d) Latent heat of water at exhaust gas conditions =* **2200 kJ/kg**, e) Total isentropic enthalpy drop across the turbine as **1266 kJ/kg**. *From the given data, find:*

a) The power input to the draft system fan

b) The power input to the feedwater and cooling water pumps

c) If coal is transported to the plant using goods train consisting of **59 wagons**, each wagon having a coal carrying capacity of **54.4 tons**, find how many such goods trains are required **per day** to meet the fuel demand of the plant.

d) Find the minimum number of turbine stages required, if the power plant uses **ideal 50 % Reaction turbines** optimized **for maximum efficiency** with maximum **tip speed of the blade** not exceeding **360 m/s**.

e) For the power plant described above, find the **number of stacks** (chimneys) required if each of the stack is of **200 m** height with an exit diameter of **5 m**. For stack calculations, assume: i) Atmospheric pressure = **100 kPa**, ii) Atmospheric air temperature = **288 K**, iii) Average stack gas temperature = **373 K**, iv) density of flue gases = **0.855 kg/m³**, v) gas constant = **0.2867 kJ/kg.K**, vi) Acceleration due to gravity = **9.81 m/s²**. The stacks are designed such that the pressure loss of flue gases as they flow through the stack is equal to **20 %** of the buoyancy head generated by the stack and are given by the equation:

$$\Delta P_{stack,loss} = 1.16\frac{\rho V^2}{2}$$

In the above equation, the pressure loss, $\Delta p_{stack,loss}$ is in Pa, ρ is density of flue gases (kg/m³) and V is the exit velocity of the flue gases (m/s).

(5 x 5 = 25)

2. At a particular lower stage of a turbine, steam enters the turbine with an absolute velocity of **360 m/s** and at a nozzle exit angle of **18°**. The **mean diameter** of the turbine blade is **0.9 m** and the rotational speed is **3000 RPM**. A) Find the turbine blade height if the mass flow rate of steam is **8 kg/s** and its specific volume is **9 m³/kg**. B) Keeping the specific work and nozzle exit angle fixed, find the blade inlet angle at the root, mean diameter and tip diameter of the blade. Assume that the **fluid exits the turbine axially**

at all these locations (no tangential component at exit). C) From the results justify the statement that "**at lower pressures, the velocity diagram at the root resembles that of an impulse turbine, while the velocity diagram at the tip resembles that of a reaction turbine**". Also state how the blade appears. **(5+5+5=15)**

3a. In terms of operating conditions and heat exchanger design, what are the **similarities** and **major differences** between **closed feedwater heaters** and **water cooled steam condensers** of power plants? What practical problems are encountered in water cooled steam condensers and how they are handled in practice? **(5)**

3b. The following data pertains to a power plant condenser, when it is brand new and after 6 months of its use. From the data, assuming all other parameters to remain constant, find the resistance due to fouling on cooling water side after **6 months of usage**. The total heat transfer area of the condenser based on cooling water side is **10263 m²**. **(5)**

Parameter	Brand new condenser	Condenser after 6 months
Mass flow rate of cooling water	8000 kg/s	8000 kg/s
Condensing steam temperature	40°C	40°C
Cooling water temperature at inlet	30°C	30°C
Cooling water temperature at outlet	36°C	34°C

4. A power plant cooling tower has to reject **200 MW** of heat. The tower is designed for a cooling water temperature rise of **6 K**. Atmospheric air at **35°C** and **40 %** relative humidity (W = **0.0142 kgw/kga**, h = **71.5 kJ/kga**) enters the cooling tower and leaves as saturated air at **33°C** (W = **0.0326 kgw/kga**, h = **116.8 kJ/kga**). From the data, a) find the rate at which water evaporates in the cooling tower (in kg/s) and b) Total make-up water requirement (in kg per day) if the loss due to drift and blow-down are **0.2 %** of the cooling water flow rate. Take c_p value of water as **4.2 kJ/kg.K**. Neglect energy carried by make-up water. **(5+5 = 10)**

End of Part-A

Part-B (40 marks)

5. A centrifugal pump is required to raise water by a static head of **25m** with a flow rate of **1500 liters per minute**. The length of the delivery pipe including the effective lengths of all the pipe fittings is **30 m** and its diameter is **7.5 cm**. The pipe friction factor **0.03**. The pump is running at a speed of **1440rpm**. The impeller diameter and width of the impeller passage at outlet are **35 cm** and **1 cm** respectively. Hydraulic efficiency of the pump is **0.94** and it is incurring a mechanical loss of **200W**.

Calculate: (a) manometric head, (b) power required to drive the pump, (c) engineering specific speed, (d) non-dimensional specific speed, (e) blade angle at outlet and (f) mechanical efficiency. **(2+2+2+2+2+2=12)**

6. A Kaplan turbine is working under head **42 m** of water at **800 rpm**, the flow rate being **6.5 m³/s**. The overall and hydraulic efficiencies are **0.88** and **0.94** respectively. The hub diameter to tip diameter ratio is **0.6**. The speed ratio is **1.25**. Find (a) the tip diameter and the hub diameter (in m); (b) blade inlet and outlet angles at the tip; (c) blade inlet and outlet angles at the hub; (d) engineering specific speed and non-dimensional specific speed. **(2+4+4+2=12)**

A draft tube connected at the exit of this turbine has inlet diameter which is same as the turbine tip diameter. The draft tube height is **3 m** out of which **50 cm** at the outlet side is within tailrace. The tapered draft tube has **4°** half-cone-angle. The draft tube *efficiency is* ***0.9****. Calculate (e) the gain in power due to the draft tube.* **(4)**

7. A Pelton turbine is connected to an alternator running at a speed of **600 rpm.** The working head of the turbine is **150 m of water** *the flow rate is* ***2 m³/s****. The Pelton cups turn the jet through an angle of* **160°** i.e. **β_2 = 20°**. Assume that the speed ratio is **0.5**, the *nozzle velocity coefficient is* **0.98** and the blade friction factor is **0.975**. Find out (a) the hydraulic efficiency, (b) specific speed, (c) *diameter of rotor, (d) number of jets, (e) jet diameter.* You are given that single-jet Pelton turbine is used for engineering specific *speed* ***05-35*** *and multi-jet Pelton turbine is used for engineering specific speed* **30-70**. The overall efficiency of the turbine is given *as* ***0.88****.* **(4+3+3+1+1=12)**

End of the paper