INDIAN INSTITUTE OF TECHNOLOGY KHARAGPUR

Department of Mechanical Engineering

Date : Time : **2 hours** Full Marks : **100** No. of students : **120**

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

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

Useful data: Universal gas constant = **8.314 kJ/mol.K**, Molecular weight of air = **28.97 kg/kmol**

c_p of dry air = **1.005 kJ/kg.K**, c_p of water = **4.2 kJ/kg.K** (Liquid), **1.88 kJ/kg.K** (Vapour)

Latent heat of vaporization of water (at 0°C) = **2501 kJ/kg**

Part-A (60 marks)

1. Consider an ideal regenerative Rankine cycle with a single closed feedwater heater with **condensate drain cascaded forward.** In this system condensate from the condenser and feedwater heater are pumped separately to the boiler pressure using two individual pumps. After pumping, the condensate from condenser is heated in the feedwater heater and is then mixed with the feedwater condensate in the mixing box. The net power output of the cycle is **100 MW**. The following are the operating conditions of the cycle:

Location	t (°C)	P (bar)	Quality, x	h (kJ/kg)	s (kJ/kg.K)
Turbine Inlet	410	120	Superheated	3085	6.124
Feedwater Heater Inlet	243	35	1.0	2803	6.124
Feedwater Heater Exit	243	35	0.0	1050	2.725
Condenser Inlet	45.8	0.1	0.73	1938	6.124
Condenser Pump Inlet	45.8	0.1	0.0	191.8	0.649

The terminal temperature difference in the feedwater heater for both feedwater and condensate is **0 K**. The liquid water is incompressible with a density of **998 kg/m³** and a specific heat of **4.31 kJ/kg.K**.

From the above data, find a) Thermal efficiency of the regenerative cycle, b) Steam flow rate through the condenser and boiler, c) Entropy generation rate in feedwater heater, and d) For the same boiler flow rate, boiler and pump inlet conditions, compare the net power output and thermal efficiency of a simple Rankine cycle with the given regenerative cycle. **(20)**

2. A process industry that is not connected to electrical grid requires electrical power, chilled water and hot water, simultaneously. The industry has natural gas resources which can be used for producing power, chilled and hot water. With a neat sketch (with all the sub-systems properly labeled), suggest a suitable thermodynamic system that can meet the above requirement. Assuming the system suggested to be completely ideal, for a specified refrigeration capacity required for producing chilled water (***Q_1***) and power output (***W***), arrive at an expression for overall efficiency of the system in terms of the three operating temperatures (heat source, T_3; heat sink, T_2; and refrigeration, T_1), and ***Q_1*** and **W**, i.e.,

$$\eta_{overall} = f(T_1, T_2, T_3, Q_1, W) \quad \textbf{(12)}$$

3. An ideal Brayton cycle using air (γ =1.4) operates between maximum and minimum cycle temperatures of 1200 K and 300 K, respectively. For this cycle, find a) the maximum possible pressure ratio for finite net work output, and b) the pressure ratio at which net work output is maximum. Also find the corresponding efficiencies for (a) and (b) (8)

4. Find the chemical formula of the hydrocarbon (C_aH_b) fuel and the stoichiometric ratio for the combustion process from the volumetric composition (on dry basis) of the products of combustion given below (8)

Volumetric Composition of products of combustion			
CO_2	CO	O_2	N_2
12.2	0.8	1.8	85.2

5. Find the velocity of products of combustion when **liquid octane at standard state** burns with 120 % Theoretical Air that enters the combustion chamber at 600 K. The products of combustion are at 1200 K. Clearly state the assumptions that are to be made to arrive at the answer. Use the data given below. (12)

Δh_f^0, *(kJ/kg)*: Octane (liquid) = **–2189.5**, H_2O (vapour): **–13430.8**, CO_2: –8946.8

c_p *(kJ/kg.K)*: H_2O (vapour): **2.359**; CO_2: **1.322**; N_2: **1.113**; O_2: **1.031**

End of Part-A

Part-B (40 marks)

Density of water **1000 kg/m³**, **acceleration due to gravity 9.81 m/sec²**.

6. In a gas turbine, there are m stages each having the same stage pressure ratio (p_s). The static pressure at the inlet to the turbine is p_1 whereas the static pressure at the outlet is p_{m+1}. The stage efficiency is η_s whereas the turbine overall efficiency is η_t. The ratio of the specific heats is given by γ. (a) Draw the process in the h-s plane. (b) Derive an expression for the turbine overall efficiency η_t as a function of stage pressure ratio (p_s), stage efficiency η_s, number of stages (m). (4+8=12)

7. A water turbine is facing some amount of losses while producing certain amount of output power. Though the height of the reservoir dam is **110** m of water column, the available head is only **103 m** water. The volume flow rate is **3m³/s** and the water exit velocity is **30m/s**. Due to leakage, **0.06 m³/s** of water does not pass through the rotor and that is a volumetric loss. The loss due to fluid friction in the rotor is **125 kW** whereas the mechanical losses are **140 kW**. (a) With a neat sketch, explain how the losses are taking place one after another. Find out the (b) volumetric efficiency (%); (c) hydraulic efficiency (%); (d) mechanical efficiency (%); (e) overall efficiency (%) of the turbine. (2+4+4+4+2=16)

8. A pump running at N rpm produces H m head while handling Q m³/s of fluid. (a) Write down the non-dimensional flow coefficient, head coefficient for the pump. (b) From this, derive the non-dimensional shape number. This pump handling water, develops a head of **70 m** while the volume flow rate is **50 litres per second**. The pump runs at a speed of **1450 rpm**. (c) Find out the shape number of the pump in rad/sec. (d) Based on your experience, comment (with justification) on the type of pump to be appropriate for maximum efficiency. (4+3+3+2=12)

End of Part-B