INDIAN INSTITUE OF TECHNOLOGY

Date: .... FN/AN Time: 3 hours Full Marks: 100 No. of Students: 271
Spring End-Sem Examination, 2011 Dept. Mechanical Engineering Subject No.: ME22002
2nd Year B.Tech (H) Subject Name: Thermodynamics
Answer all the questions. Marks for the questions are shown on the margin.

In situations involving air, air can be assumed as an ideal gas with constant specific heats of c_p=1.004 kJ/kgK and c_v=0.717 kJ/kgK.

Use of steam table, supplied with the question paper, is permitted.

1. A coal-fired power plant, operating on a *simple ideal* Rankine cycle, has a boiler pressure of 32 bar and a condenser pressure of 0.7 bar. The exit state from the steam turbine is dry saturated vapour. Do not neglect the pump work in your analysis.

(a) *Illustrate* the cycle on the T-s plane clearly identifying each state point

(b) What is the turbine inlet temperature?

(c) Estimate the *specific heat addition in the boiler* (in kJ/kg)

(d) Estimate the *net work output of the plant* (in kJ/kg).

(e) Estimate the *thermal efficiency of the plant.* **[2+3+3+3+2]**

A consultant suggests that the boiler pressure be raised to 140 bar to improve the plant performance while keeping the condenser pressure and the turbine inlet temperature the same. Please note that the turbine manufacturer has specified a minimum permissible quality for the steam in the turbine to be 90%.

f) *Comment* precisely and briefly, using thermodynamics based logic, on why raising boiler pressure typically would result in improvement of thermal efficiency.

g) *Quantitatively, check if the* turbine meets the manufacturer's recommendation for the stated operating condition. In case it does not, clearly and comprehensively *specify a corrective technique, illustrating it graphically* on a cycle diagram showing the original cycle and the newly proposed one as well, so that the higher pressure operation (at 140 bar) can still be sustained without violating the manufacturer's constraint.

h) *Do you expect* the thermal efficiency to increase / decrease for this proposed (140 bar) cycle with and without your suggested corrective technique? *Explain with justification.* **[3+6+3]**

2. A sample of moist air at a pressure of 1 bar has a dry bulb temperature of 30^0C and a dew point temperature of 25^0C. Treating the sample as an ideal gas mixture of air and water vapour, calculate the partial pressure of vapour, the humidity ratio and the relative humidity of the mixture. The sample of air is taken into a closed container and is heated under constant volume so that its dry bulb temperature is increased to 35^0C. What will be the pressure of the mixture? Find out the humidity ratio and the relative humidity of the mixture at this condition. Assume M_{air} = 29. **[3+3+3+3+2+3]**

3. Draw the thermodynamic cycle of a vapour compression refrigeration system on the *p-h* and *T-s* planes considering ideal processes. Assume that refrigerant enters the compressor at superheated condition and leaves the condenser at subcooled condition. Identify the physical components associated with each of the processes. **[4+2]**

4. Natural gas (methane, CH_4) is burned with 50% excess air in an automobile engine and undergoes complete combustion. The air and fuel mixture enter at 25°C and 1 atm and the exhaust products leave at 77°C and 1 atm. The heat loss from the engine wall is negligible. Ambient temperature, T_0, is 25°C. Make ideal gas assumption for all reactants and products.

The following properties are given at 1 atm pressure.

Substance	$\bar{h}_f^0$ (298 K) (kJ/kmol)	$\bar{h}$ (298 K) (kJ/kmol)	$\bar{h}$ (350 K) (kJ/kmol)	$\bar{s}^0$ (298 K) (kJ/kmolK)	$\bar{s}^0$ (350 K) (kJ/kmolK)
$CH_4(g)$	−74850	-	-	186.16	-
O_2	0	8682	10213	205.03	209.77
N_2	0	8669	10180	191.50	196.17
$H_2O(g)$	−241820	9904	11652	188.72	194.13
CO_2	−393520	9364	11351	213.69	219.83

C_p for CH_4 =1.05 kJ/kgK, for water at T_{sat}= 77°C, P_{sat}=42 kPa and h_{fg} = 2315 kJ/kg

a) Is the water in vapour form in the exhaust products of combustion?
b) What is the work output of the engine in kJ/kg of fuel?
c) What is the entropy generation in kJ/kg-K of fuel?
d) What is the maximum possible work output in kJ/kg of fuel? **[6+6+7+6]**

5. A regenerative gas turbine with intercooling and reheat operates at steady state. Air enters the compressor at 100 kPa, 300 K with a mass flow rate of 5.807 kg/sec. The pressure ratio across the two-stage compressor is 10. The pressure ratio across the two-stage turbine is also 10. The intercooler and reheater each operate at 300 kPa. At the inlet to the turbine stages, the temperature is 1400 K. The temperature at the inlet to the second compressor stage is 300 K. The isentropic efficiency of each compressor and turbine stage is 80%. The regenerator effectiveness is 80%. Assume air as an ideal gas with constant specific heats.

Determine: (a) the turbine work (in kJ/kg); (b) the compressor work (in kJ/kg); (c) the net power output (in kW); (d) the thermal efficiency (in %).

[5+5+5+5]

Draw the component diagram, *P-v* and *T-s* diagrams indicating the state points.

[2+3+2]