MCL 241: ENERGY SYSTEMS AND TECHNOLOGIES

Major Exam

Date: May 3, 2017

Time: 2 hours | Marks: 40

Instructions:

1. Show all important and necessary steps used to obtain the final solution.
2. You are allowed the use of printed class handouts, class notes (written in your own handwriting) and thermodynamic tables only.

PROBLEM 1 (16 marks)

In the first stage of a high-pressure steam turbine using a two-row velocity compounding design, the walls of the nozzle are cooled to avoid excessive heating and thermal fatigue. Steam at 125 bar and 600 °C and mass flow rate of 2 kg/s enters the nozzle row and leaves at 100 bar and 550 °C with 30 kW of heat removed from the nozzle walls. Steam exits the nozzle row at an angle of 20° and enters the first-row of moving blades smoothly. The rotor rotates at a speed of 6000 rpm and all moving blades can be assumed to be located at the mean radius of 0.15 m. The blade velocity coefficient for each row of blades can be taken to be 0.9. Though all blades are symmetric, they are not of the same shape.

a) Determine the nozzle exit velocity. (2)
b) Calculate the blade angles for the first-row of moving, fixed and second-row of moving blades. (6)
c) Determine the angle of the absolute velocity of steam jet exiting the stage. (2)
d) Calculate the diagram efficiency. (2)
e) Using an energy balance, quantify the percentage of energy that is lost in overcoming friction in the turbine. (4)

PROBLEM 2 (8 marks)

Consider a rocket engine burning hydrogen and oxygen: the combustion chamber temperature and pressure are 3517 K and 25 atm, respectively. The molecular weight of the chemically reacting gas in the combustion chamber is 16, and $\gamma = 1.22$. The pressure at the exit of the convergent-divergent rocket nozzle is 1.174×10^{-2} atm. The area of the throat is 0.4 m^2. Assuming an ideal gas and isentropic flow, calculate:

a) The exit Mach number, (2)
b) The exit velocity, (2)
c) The mass flow rate through the nozzle, and (2)
d) The area of the exit. (2)

PROBLEM 3 (8 marks)

In an industrial refrigeration plant equipped with a flash chamber at 400 kPa using ammonia as the refrigerant, the evaporator is maintained at -30 °C and the condenser operates at a pressure of 1600 kPa. The compression processes can be considered to be isentropic and the total electrical power input is measured to be 5 kW.

a) Draw a neatly labelled schematic of the system and show all states on a pressure-enthalpy diagram. (2)
b) Determine the mass flow rate of refrigerant through the evaporator (in kg/h). Also calculate the mass flow rate through the condenser (in kg/h). (4)
c) Determine the cooling capacity of the plant in tons of refrigeration. (2)

You may choose to use the following data:

For 400 kPa: $h_f = 171.23$ kJ/kg, $h_g = 1440.2$ kJ/kg

For 1600 kPa: $h_f = 376.37$ kJ/kg

Enthalpy at condenser inlet is $h = 1784.11$ kJ/kg.

PROBLEM 4 (8 marks)

You are required to evaluate the design parameters of a desert cooler operating in Delhi (barometric pressure: 101 kPa) on a dry summer day. The design stipulates that fresh ambient air (state 1) with a volumetric flow rate of 4 m^3/min is drawn through a hay wetted by a recirculating water supply before passing through a blower. Subsequently, this air is supplied to a room. The following data is available:

Ambient condition: temperature is 40 °C with relative humidity of 10%.

Condition of air after passing through the wet hay: 22 °C and relative humidity of 71.6%

Final room condition: 30 °C with relative humidity of 80%.

The temperature rise across the blower is measured to be 2 °C. The process as air passes through the wet hay can be described using the following equation,

$$h_2 = h_1 + (\omega_2 - \omega_1) h_f (T_W)$$

where states 1 and 2 indicate inlet and exit, respectively, while $h_f(T_W)$ is the enthalpy of liquid water at temperature T_W. Make necessary assumptions and solve without using the psychrometric chart.

a) Schematically show all processes and states on a hand-drawn psychrometric chart. (2)
b) Determine the temperature T_W. (4)
c) Calculate the room load. (2)