PART 1

QUESTION 1

(a) Give the general definition of an equation of state [2 marks]

(b) Express the equation of state of an ideal gas and the physical assumption on which it is based and indicate on a P-V thermodynamic diagram the area where it is valid [2 marks]

(c) Express the equation of state of an incompressible liquid [2 marks]

(c) Express the Van-Der-Waals equation of state indicating the assumptions on which it is based. [4 marks]

QUESTION 2

(a) Derive the 1st and 2nd Gibbs equations (Tds relations) and apply them in an ideal gas in order to prove the following relations for any isentropic process between two states 1 and 2:

\[(T_2/T_1)_{\text{isentropic}}=(P_2/P_1)^{(k-1)/k}\text{ and }\]
\[(T_2/T_1)_{\text{isentropic}}=(V_1/V_2)^{k-1}\]

where T is the absolute temperature, P the pressure, V the specific volume, Cp the specific heat under constant pressure, Cv the specific heat under constant volume and k = Cp/Cv. [5 marks]

(b) Show that for an incompressible liquid any isentropic process takes place under constant temperature. [5 marks]

QUESTION 3

(a) Draw on the Mollier (h-s) diagram of steam the isobaric, isothermal and isentropic process. [5 marks]

(b) Prove that the thermal equilibrium condition T_1 = T_2 (where T stands for the temperature) between two systems 1 and 2 in thermal contact, corresponds to the state of maximum entropy of the combined system. [5 marks]
PART 2

QUESTION 4

A 5-cm-diameter spherical ball whose surface is maintained at a temperature of 70°C is suspended in the middle of a room temperature at 20°C. If the convection heat transfer coefficient is 15W/(m²·°C) and the emissivity of the surface is 0.8, determine the total rate of heat transfer from the ball. The Boltzmann’s constant is given to be \( =5.6710^{-8} \text{W/(m}^2\text{·K}^4) \)

[20 marks]

QUESTION 5

A 50kg iron and a 20kg copper block, both initially at 80°C are dropped into a large lake at 15°C. Thermal equilibrium is established after a while as a result of heat transfer between the blocks and the lake water. Determine the total entropy generation for this process. The specific heats of iron and copper are \( C_{\text{IRON}}=0.45\text{kJ/kg °C} \) and \( C_{\text{COPPER}}=0.38\text{kJ/kg °C} \), respectively.

[20 marks]

QUESTION 6

Using the Clapeyron equation \( h_{fg} = T v_{fr} \left( \frac{dP}{dT} \right)_{sat} \), estimate the value of enthalpy of vaporization \( h_{fg} \) of refrigerant-134a at 293K. It is given that \( P_{\text{sat@297K}}=645.6\text{kPa} \), \( P_{\text{sat@289K}}= 504.15\text{kPa} \), \( v_{g@293K}=0.0358\text{m}^3/\text{kg} \) and \( v_{l@293K}=0.0008157\text{m}^3/\text{kg} \).

[20 marks]

QUESTION 7

Air is compressed from 80kPa and 27°C to 480kPa by a 10kW compressor. Determine the mass flow rate of air through the compressor, assuming the compression process to be (a) isentropic, (b) polytropic with \( n=1.3 \) and (c) isothermal.
QUESTION 8

In Carnot engines, it is assumed that the engine is in thermal equilibrium with the source and the sink during the heat addition and heat rejection processes, respectively. That is, it is assumed that $T^*_{H} = T_{H}$ and $T^*_{L} = T_{L}$ so that there is no external irreversibility. In that case, the thermal efficiency of the Carnot engine is $\eta_C = 1 - T_L/T_H$. In Reality, however, we must maintain a reasonable temperature difference between the two heat transfer media in order to have an acceptable heat transfer rate through a finite heat exchanger surface area. The heat transfer rates in that case can be expressed as:

$$Q_H = (h \cdot A)_H (T_H - T^*_{H})$$
$$Q_L = (h \cdot A)_L (T^*_{L} - T_L)$$

where $h$ and $A$ are the heat transfer coefficient and heat transfer surface area, respectively. When the values of $h, A, T_H$ and $T_L$ are fixed, show that the power output will be maximum when:

$$T^*_{L} / T^*_{H} = (T_L/T_H)^{0.5}$$
Internal Examiners: Dr. M. Gavaises
Prof. N. Stosic