Tutorial Problems –1 (Applied Thermofluids-1 (Refrigeration & Air conditioning))

1. A window air conditioner of 2.0 TR cooling capacity has a COP of 3.3under a design space temperature of 25^{o}C and an ambient temperature of 35^{o}C. If the design temperature difference for heat transfer in evaporator and condenser are 10 K and 8 K, respectively, find the rate at which entropy is generated (in kW/K) due to irreversibilities in the condenser, evaporator, compressor+expansion valve. Assume there are no other losses in the AC.

2. A single stage vapour compression system that uses propane (R290) as refrigerant consists of a Liquid-to-Suction Heat Exchanger (LSHX). The system operates at an evaporator temperature of 7^{o}C and a condensing temperature of 54^{o}C. The refrigerant at a mass flow rate of 0.1 kg/s leaves the evaporator as saturated vapour (h_g = 582.4 kJ/kg) and is superheated by 10K by exchanging heat with the liquid refrigerant in the LSHX. The state of refrigerant at the exit of condenser is saturated liquid (h_f = 349.9 kJ/kg). The specific heat of vapour at evaporator pressure is 1.84 kJ/kg.K and the isentropic work of compression 58 kJ/kg. The compressor has an isentropic efficiency of 70%. From the data given, find a) Refrigeration capacity in kW, and b) COP.

3. Find whether the data given below pertains to a power cycle or a refrigeration cycle or a combined cycle. Also find whether the cycle is feasible or not, and if feasible whether it is reversible or irreversible.

$$Q_2 = +250 \text{ kW}, Q_1 = -400 \text{ kW}, Q_0 = +170 \text{ kW}; W = -20 \text{ kW}, t_2 = 110^oC, t_1 = 40^oC, t_0 = 0^oC$$

<u>Sign convention:</u> Energy supplied to the cycle is Positive and energy extracted is negative.

4. A room air conditioner maintains a room at 25°C when the ambient temperature is 43°C. At these conditions the system has a cooling capacity of 3.5 kW and its compressor consumes 1.2 kW of power. The measured refrigerant mass flow rate is 27 grams/second and the entropic average temperatures of refrigerant in evaporator and condenser are 7°C and 55°C, respectively. The actual isentropic efficiency of the compressor is 0.65. Assume that system irreversibility is due to heat transfer in evaporator and condenser, non-isentropic compression and throttling only. Contribution of all other processes (including superheat horn) to irreversibility is negligible. Using this data find the entropy generation rate (in W/K) and irreversibility (in W) due to evaporator, compressor, condenser and expansion valve.

5. A dairy plant uses a vapour compression refrigeration system for chilling milk from 14^{o}C to 4^{o}C. The cooling water used for heat extraction enters the condenser at 31^{o}C and leaves at 36^{o}C. If the refrigeration system used has a refrigeration capacity of 120 kW and the compressor consumes 18 kW, find the 2nd law efficiency and total entropy generation rate of the system. What is the water flow rate in the condenser?

6. An engineer wishes to design a domestic refrigerator whose energy consumption is less than or equal to 1 kWh per day. On an average the refrigerator compressor runs for 10 hours a day and the average refrigeration load is 150 W. The average refrigerated space and external ambient temperatures are –20^{o}C and 35^{o}C, respectively. To achieve the design goal of 1 kWh per day, what should be the maximum allowable entropy generation rate of the refrigerator (in W/K)?

7. Saturated liquid water at 25^oC is throttled in a valve so that its pressure drops by 1 kPa. Find the dryness fraction (quality) of water at the exit of the valve assuming an average latent heat of vaporization of 2450 kJ/kg, average liquid specific heat of 4.19 kJ/kg.K and an average vapour specific heat of 1.9 kJ/kg.K. The following equation relates the saturation pressure, p_{sat} (in kPa) with temperature, T (in K) of water.

$$\ln(p_{sat}) = 16.54 - \frac{3985}{T - 39}$$

Assuming the water vapour to behave as an ideal gas, find the void fraction (volume occupied by the vapour to the total volume) at the exit of the valve. Take the density of liquid water as 998 kg/m^3.

8. It is proposed to convert solar energy. into electricity using a system consisting of photovoltaic (PV) cells and a storage battery, and use the electricity for driving a vapour compression refrigeration system based air conditioner. The air conditioner has a cooling capacity of 0.5 TR and runs for 8 hours a day. Solar energy is available at a rate of 24 MJ per day per m^2 of solar collector area. The solar-to-electrical energy conversion efficiency is 10 percent. The air conditioner is designed to maintain the conditioned space at 27^oC when the outside temperature is 43^oC. Find a) the minimum solar collector area required in m^2, b) collector area required if the air conditioner generates entropy at a rate of 1.5 W/K, and c) the maximum allowable entropy generation rate of the air conditioner if the collector area is not to exceed 3 m^2.

9. A refrigeration system operates at a condensing temperature of 38^oC and an evaporator temperature of –36^oC. Assuming isentropic compression and saturated liquid at the exit of the condenser, find how the COP of the system varies as the quality at evaporator exit condition (=inlet to compressor) varies from inlet quality to dry saturated condition ($x = x_{evp,in}$ to $x = 1$) for the following refrigerants: a) NH_3, b) R22, c) R134a. Plot *COP* vs $x_{evp,exit}$ for these refrigerants.

10. In a domestic refrigerator, refrigerant R134a evaporates at **–25^oC** and condenses at **55^oC**. The compressor used has an isentropic efficiency of **55%.** A liquid-to-suction heat exchanger is used such that the state of refrigerant vapour at the inlet to the compressor is **32^oC.** There is a refrigerant vapour pressure drop of **0.2 bar** in the evaporator and a pressure drop of **0.12 bar** in the LSHX. The exit condition of refrigerant at condenser and evaporator is saturated. Find the energy consumption of this refrigerator per day in kWh, if the refrigeration capacity of the refrigerator is **180 W**.

****