**Thermodynamics**

## Caution: Students please read before starting

(1) You should be provided with a set of thermodynamics properties tables for use during this exam.

(2) The exam consists of three (3) problems on three (3) separate pages. Check NOW to verify that your exam is complete.

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If you are missing the properties tables or any of the three (3) exam pages stop work NOW and advise your proctor immediately.

## Problem 1

A rigid tank with a volume of 2 $m^3$ contains 82.9 kg of water substance at 3 MPa pressure. The tank is equipped with a safety/vent valve that is closed during normal operation, and has a set point of 5 MPa. The valve opens automatically when pressure reaches the set point.

a) In one process the tank is inadvertently heated while the vent valve remains closed until the pressure reaches the valve's set point. Calculate the amount of heat that has been absorbed by the tank's content, and the temperature in the tank when the set point is reached.

b) The vent valve is opened when the pressure set point is reached. Drainage continues at a very slow rate. During the drainage, only vapor leaves the tank and the pressure in the tank remains constant. Measurement shows that 30% of the mass content of the tank has been lost during the venting process. Calculate the amount and direction of heat transfer between the tank and its surroundings during the venting process.

c) Suppose the tank described in parts (a) and (b) is in zero gravity conditions, and as a result the water and vapor remain well mixed everywhere, including in the vent valve. How would you solve part (b)? Write and discuss the equations that need to be solved.

**Problem 2**

An industrial process produces ice at $-20°\mathrm{C}$ at a steady rate of 60 kg per hour from water at ambient temperature and pressure of $25°\mathrm{C}$ and 100 kPa, respectively. The environment can thermally interact with the refrigeration system, as shown below.

Take the specific heat of liquid water to be $c_{p,f} = 4.18\ \mathrm{kJ/kg \cdot K}$

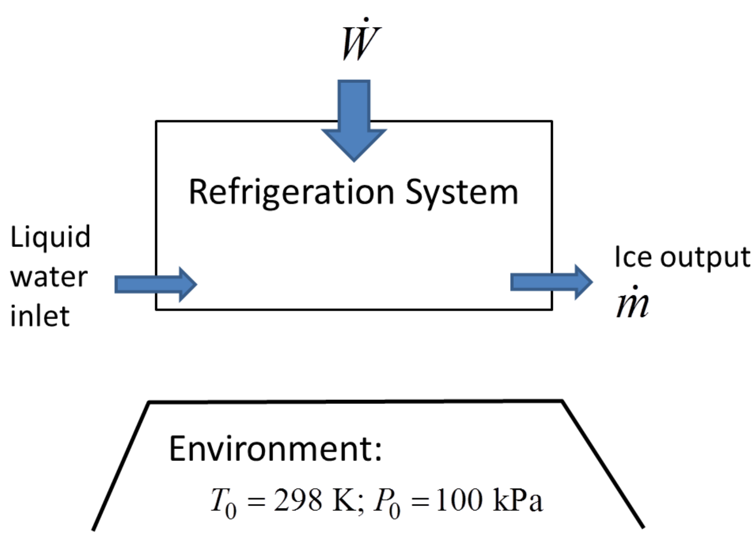
and the specific heat of ice to be $c_{p,s} = 2.01\ \mathrm{kJ/kg \cdot K}$.

Take the specific enthalpy (latent heat) of melting to be $h_{sf} = 334\ \mathrm{kJ/kg}$

and the specific entropy of melting to be $s_{sf} = 1.223\ \mathrm{kJ/kg \cdot K}$.

(a) Find the least electrical power that is required to operate this refrigeration system: $\dot{W}_{\min}$.

(b) If twice the electrical power is actually consumed ($\dot{W} = 2\dot{W}_{\min}$), what is the entropy generation rate in the refrigeration process?



**Problem 3**

A modified air-standard Otto cycle consists of the following four processes:

P1-2: Polytropic compression

P2-3: Constant volume heating

P3-4: Polytropic expansion

P4-1: Constant volume cooling

For the polytropic processes, the polytropic exponent is n=1.3 (e.g., $pv^n$=constant) for this closed system. The compression ratio is 15 and the cycle begins at $p_1$ = 1 bar and $T_1$=310 K. The maximum temperature is 2200 K. Air can be treated as an ideal gas.

Determine:

(a) the heat transfer and work in kJ per kg of air for each process of the modified air-standard Otto cycle.

(b) the thermal efficiency of this modified air-standard Otto cycle.