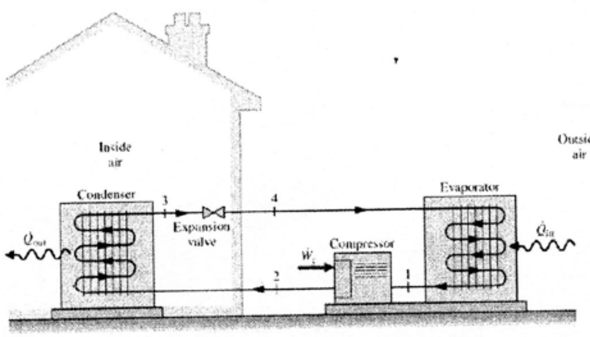
MULTIPLE CHOICE SECTION, PROBLEMS 1-4 [2 POINTS EACH]
Please select one answer for all questions.

(1) The major performance gain of an absorption refrigeration system is:
a) Replacing a vapor compressor with a liquid pump
b) The use of a regenerator between the generator and absorber
c) Heating of the generator with an external heat source
d) Cooling of the absorber with an external energy sink

Please refer to the cycle below for problems 2.



A vapor-compression heat pump cycle with **R134a** as the working fluid maintains a building at **20°C** when the outside temperature is **5°C.** The refrigerant mass flow rate is **0.1 kg/s.** Additional steady state operating data are provided in the table.

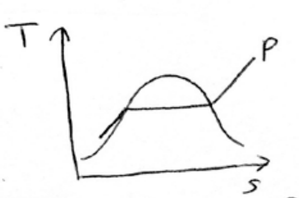
State	Temperature	Enthalpy
1	-10 C	244.1 kJ/kg
2	35 C	272.0 kJ/kg
3	30 C	93.4 kJ/kg

(2) The coefficient of performance is
a) 5.4
b) 6.4
c) 10.3
d) 19.5

$$COP_{HP} = \frac{\dot{Q}_H}{\dot{W}_{net}} = \frac{\dot{m}(h_2 - h_3)}{\dot{m}(h_1 - h_2)} = \frac{(272 - 93.4)\ kJ/kg}{(272 - 244.1)\ kJ/kg} = 6.4$$

(3) The Clapeyron equation is used to
a) Derive the Maxwell equations
b) Determine the enthalpy change associated with phase transformations
c) Compute the relation between the specific heats c_v and c_p
d) Compute the thermal expansion coefficient

(4) According to the Gibbs relations, which of the following is true for the entropy of vaporization?
a) $s_{fg} = u_{fg} / T$
b) $s_{fg} = u_{fg} / P$
c) $s_{fg} = h_{fg} / T$
d) $s_{fg} = h_{fg} / P$

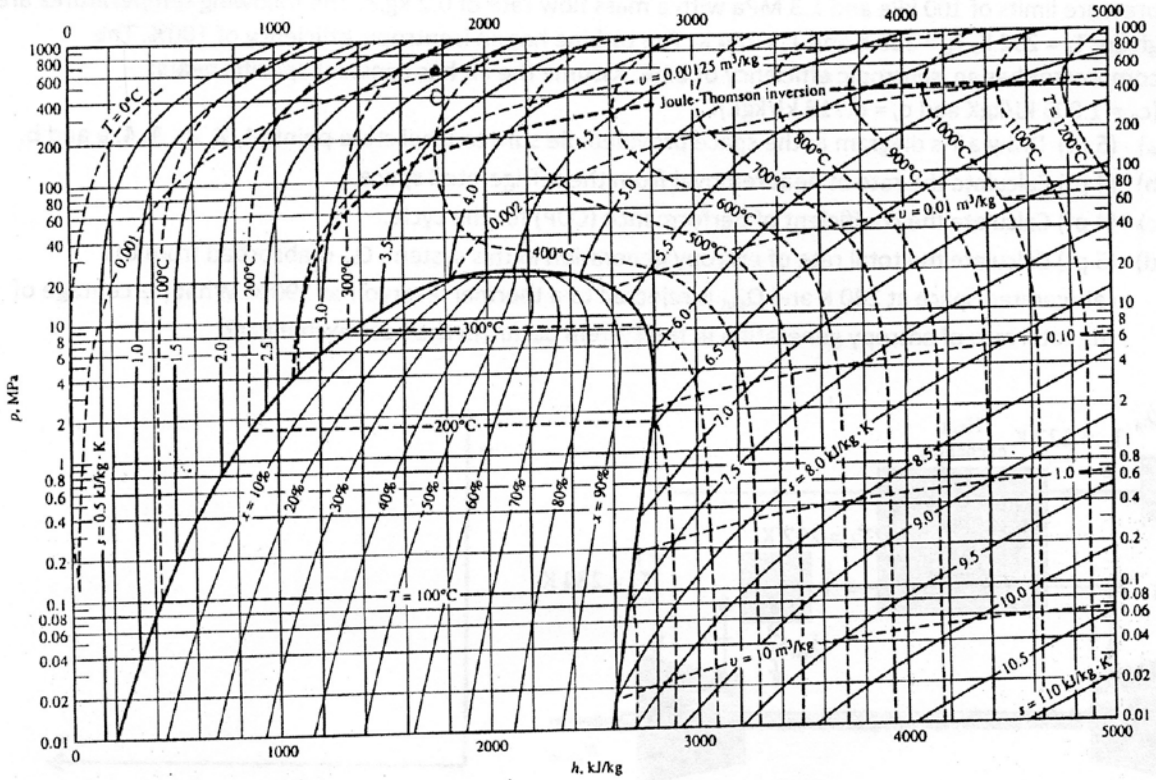


The process of vaporization is at constant T and P

$dh = Tds + v\,dP$
constant pressure: $dP = 0$
$dh = Tds$
$\int_f^g dh = T\int_f^g ds$
$h_{fg} = T s_{fg}$
$s_{fg} = \frac{h_{fg}}{T}$

1-4	
5	
6	
Total	

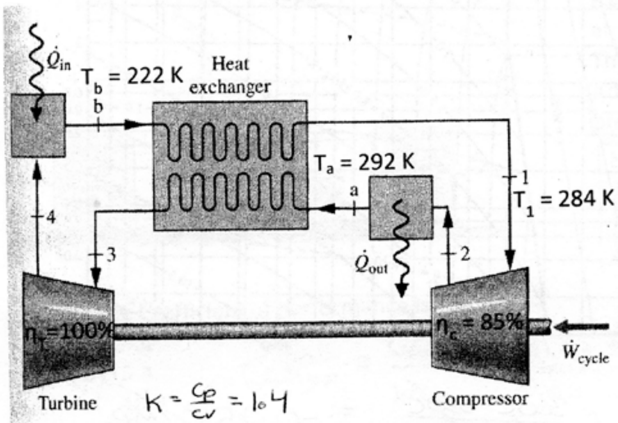
(5) [4 points] Use the below water P-h chart, estimate the Joule-Thomson coefficient at P=600 MPa and T=350°C.



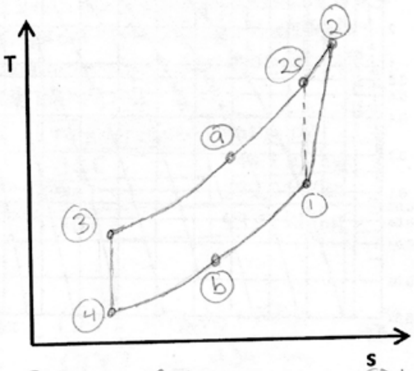
$$\mu_{JT} = \left(\frac{\partial T}{\partial P}\right)_h \approx \left(\frac{T_2 - T_1}{P_2 - P_1}\right)_h = \frac{375C - 350C}{400MPa - 600MPa} = -0.125\ ^\circ C/MPa$$

(6) [18 points] The air standard refrigeration cycle shown in the figure below incorporates a well-insulated heat exchanger to cool the air before it enters the turbine. The cycle operates between the pressure limits of 100 kPa and 1.3 MPa with a mass flow rate of 0.2 kg/s. The following temperatures are given: $T_a = 292$ K, $T_b = 222$ K and $T_1 = 284$ K. The turbine has an isentropic efficiency of 100%. The compressor has an isentropic efficiency of 85%. Assume the air has constant specific heats: ($c_p = 1.005$ kJ/kgK and $c_v = 0.718$ kJ/kgK).

a) (5 pt) Draw a T-s diagram in the space provided. Be sure to label state points **1, 2, 2s, 3, 4, a** and **b.**
b) (4 pt) Calculate the rate of heat removal from the refrigerated space.
c) (4 pt) Calculate the coefficient of performance (COP) for the cycle.
d) (5 pt) Calculate the total rate of entropy generation in this system. Q_{in} is absorbed from the refrigerated space at 230 K and Q_{out} is rejected to a thermal reservoir at 290 K. What percentage of the total rate of entropy generation in the system occurs in the heat exchanger?



$K = \frac{c_p}{c_v} = 1.4$



Common Mistake: Placing 3 higher than 1

State 2

$$\left(\frac{T_{2s}}{T_1}\right) = \left(\frac{P_2}{P_1}\right)^{(k-1)/k}$$

$$\frac{T_{2s}}{284K} = \left(\frac{1300 \text{ kPa}}{100 \text{ kPa}}\right)^{0.4/1.4}$$

$$T_{2s} = 591K$$

$$\eta_c = \frac{T_{2s} - T_1}{T_2 - T_1}$$

$$0.85 = \frac{591 - 284}{T_2 - 284}$$

$$T_2 = 645.18K$$

State 3

Conservation of Energy on Heat Exchanger

$$\dot{m}(h_a - h_3) = \dot{m}(h_1 - h_b)$$

$$\cancel{\dot{m}c_p}(T_a - T_3) = \cancel{\dot{m}c_p}(T_1 - T_b)$$

$$T_3 = T_a + T_b - T_1$$

$$T_3 = (292 + 222 - 284)K$$

$$T_3 = 230 K$$

state 4

$$\left(\frac{T_4}{T_3}\right) = \left(\frac{P_4}{P_3}\right)^{(k-1)/k}$$

$$\frac{T_4}{230K} = \left(\frac{100}{1300}\right)^{0.4/1.4}$$

$$T_4 = 110.52 K$$

b. $\dot{Q}_{in} = \dot{m}(h_b - h_4)$

$$\dot{Q}_{in} = \dot{m}c_p(T_b - T_4)$$

$$\boxed{\dot{Q}_{in} = 22.4 \text{ KW}}$$

c. Method 1:

$$\dot{Q}_{out} = \dot{m}(h_2 - h_a)$$

$$\dot{Q}_{out} = \dot{m}c_p(T_2 - T_a)$$

$$\dot{Q}_{out} = 70.99 \text{ kW}$$

$$\dot{W}_{net} = \dot{Q}_{out} - \dot{Q}_{in} = 48.58 \text{kW}$$

Method 2:

$$\dot{W}_{net} = \dot{m}(h_2 - h_1) - \dot{m}(h_3 - h_4)$$

$$\dot{W}_{net} = \dot{m}c_p(T_2 - T_1) - \dot{m}c_p(T_3 - T_4)$$

$$\dot{W}_{net} = 48.58 \text{kW}$$

$$COP_R = \frac{\dot{Q}_{in}}{\dot{W}_{net}} = \boxed{0.46}$$

d. Total rate of entropy generation:

$$\dot{S}_{gen,total} = \frac{\dot{Q}_{out}}{T_H} - \frac{\dot{Q}_{in}}{T_L}$$

$$\dot{S}_{gen,total} = \frac{70.99 \text{ kW}}{290 \text{ K}} - \frac{22.4 \text{ kW}}{230 \text{ K}}$$

$$\boxed{\dot{S}_{gen,total} = 0.147 \text{ kW/K}}$$

~~2nd~~ Entropy Balance for Heat Exchanger

$$\dot{S}_{in} - \dot{S}_{out} + \dot{S}_{gen} = \Delta \dot{S}_{sys} \overset{0}{} \text{ steady state}$$

$$\dot{S}_{gen,HX} = \dot{S}_{out} - \dot{S}_{in}$$

$$\dot{S}_{gen,HX} = \dot{m}(s_1 - s_b) + \dot{m}(s_3 - s_a)$$

$$\dot{S}_{gen,HX} = \dot{m}\left[c_p \ln\left(\frac{T_1}{T_b}\right) - R\ln\frac{P_1}{P_b}\right] + \dot{m}\left[c_p \ln\left(\frac{T_3}{T_a}\right) - R\ln\frac{P_3}{P_a}\right]$$

$$\dot{S}_{gen,HX} = 0.00154 \text{ kW/K}$$

$$\left(\frac{0.00154 \text{ kW/K}}{0.147 \text{ kW/K}}\right)(100\%) = \boxed{1.05\%}$$