8 In a refrigeration system, a fluid known as a refrigerant undergoes alternating changes in its physical state and volume to produce cooling. In this question, you will be guided to design a simple refrigeration system using the data provided.

Fig. 8.1 is a pressure vs volume graph showing the refrigerant cycling through four states P, Q, R and S. The four phases of the cyclic process are evaporation, condensation, compression and throttling (pressure releasing).

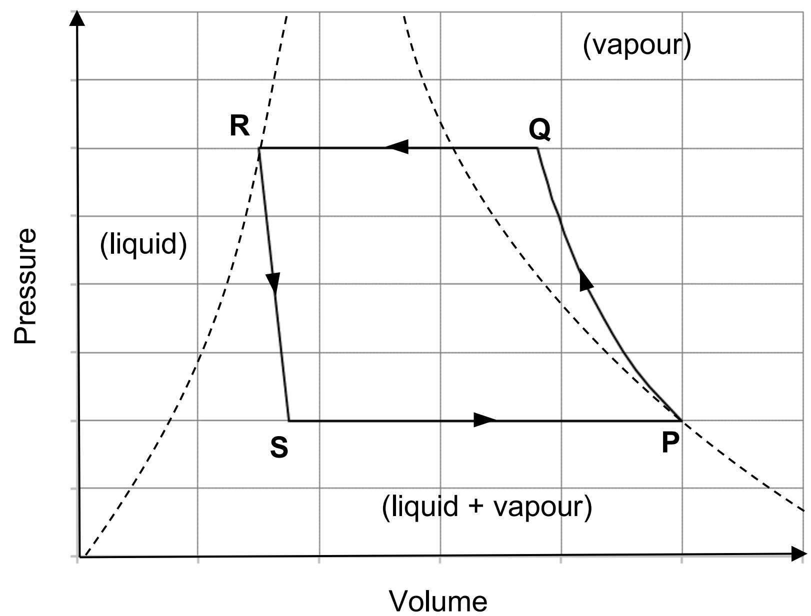

Fig. 8.1

(a) Using the information provided in Fig. 8.1, match each phase in the cycle with its description in the chart below. P→Q has been matched.

Phase	*Description*
P→Q	Evaporation
Q→R	Condensation
R→S	Compression
S→P	Throttling (Pressure release)

[2]

Fig. 8.2 is a table showing the thermal properties of the refrigerant as a saturated vapour and as a saturated liquid at various pressures.

Pressure P (kPa)	Temperature T (K)	Enthalpy h (kJ kg^{-1})		Entropy s (kJ kg^{-1} K^{-1})	
		Saturated Liquid	Saturated Vapour	Saturated Liquid	Saturated Vapour
100	246.8	17.3	234.5	0.072	0.952
200	263.1	38.5	244.5	0.155	0.938
300	273.9	52.8	250.9	0.208	0.931
400	282.1	64.0	255.6	0.248	0.927
500	288.9	73.4	259.3	0.280	0.924
600	294.8	81.5	262.4	0.308	0.922
700	299.9	88.8	265.1	0.332	0.920
800	304.5	95.5	267.3	0.354	0.918
900	308.7	101.6	269.3	0.374	0.917
1000	312.6	107.4	271.0	0.392	0.916
1200	319.5	117.8	273.9	0.425	0.913
1400	325.6	127.3	276.2	0.453	0.911
1600	331.1	136.0	277.9	0.479	0.908
1800	336.1	144.1	279.2	0.503	0.905
2000	340.7	151.8	280.1	0.525	0.902

Fig. 8.2

A saturated vapour is one which a small compression will cause it to condense.

(b) Deduce what a saturated liquid is.

....

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[1]

(c) By referring to Fig. 8.1, identify the state (P, Q, R or S) at which the refrigerant is a saturated vapour, and another at which it is a saturated liquid.

saturated vapour: .... , saturated liquid: .... [2]

Fig. 8.3 is an incomplete table showing the thermal properties of the refrigerant at states P, Q, R and S in the cyclic process.

State	Pressure P (kPa)	Temperature T (K)	Enthalpy h (kJ kg^{-1})	Entropy s (kJ kg^{-1} K^{-1})
P	300			

Q	1200	322.0		
R				
S				0.443

Fig. 8.3

(d) Using Fig. 8.2 and your answer to **(c)**, fill in the missing values in Fig. 8.3 for state P. [2]

(e) At state Q, the refrigerant is a superheated vapour, and its thermal properties at various pressures are shown in the graphs in Fig. 8.4 (a) & (b).

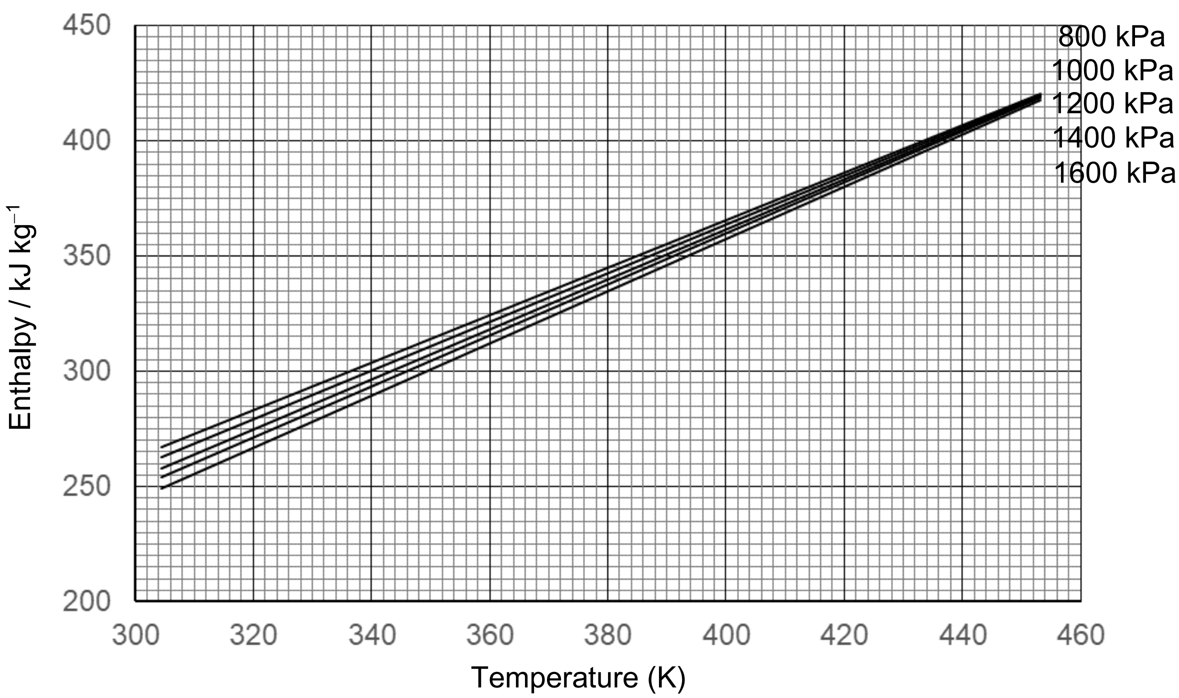

Fig. 8.4 (a)

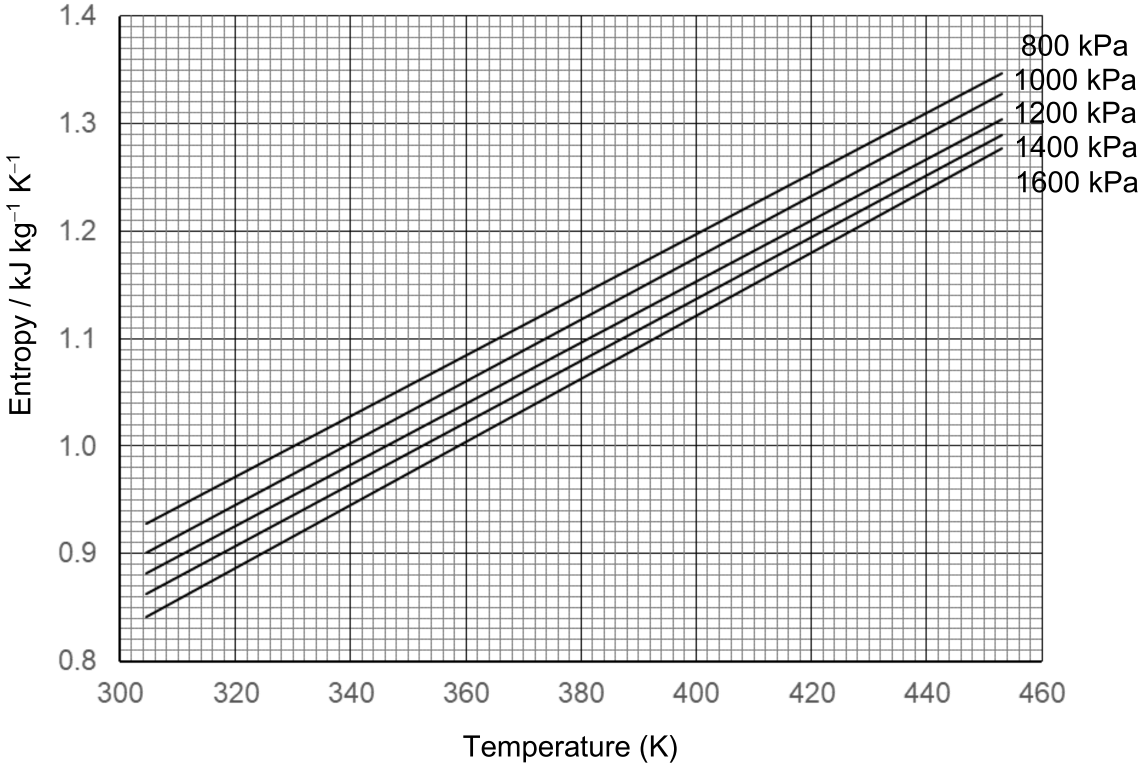
1.4
1.3
1.2
1.1
1.0
0.9
0.8
Entropy / kJ kg^{-1} K^{-1}
300
320
340
360
380
400
420
440
460
Temperature (K)
800 kPa
1000 kPa
1200 kPa
1400 kPa
1600 kPa

Fig. 8.4 (b)

The process P→Q is isentropic (entropy s is constant) and the pressure of the refrigerant is increased to 1200 kPa.

1. Explain how Fig. 8.4 (a) and/or (b) verifies that the temperature of the refrigerant at state Q is 322.0 K.

....

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[1]

2. Fill in the missing values in Fig. 8.3 for state Q. [1]

(f) The process Q→R is isobaric (pressure p is constant). Using Fig. 8.2 and your answer to **(c)**, fill in the missing values in Fig. 8.3 for state R. [2]

(g) The process R→S is isenthalpic (enthalpy h is constant). The process S→P is isothermal (temperature T is constant) and isobaric. Fill in the missing values in Fig. 8.3 for state S. [1]

(h) Energy is inputted during the compression phase of the refrigeration process. The rate of work done by the compressor is calculated using

$$W = m\ (\ h_f - h_i\ )$$

where m is the mass flow rate of the refrigerant, and h_f and h_i are the values of enthalpy after and before the compression respectively.

If the compressor compresses 3.20 kg of refrigerant in 1 second, calculate W the rate of work done by the compressor.

W = ... kW [2]

(i) Cooling is achieved in the evaporation phase of the process. The rate of heat removal during this phase is calculated using

$$Q = m\ (\ h_f - h_i\ )$$

where m is the mass flow rate of the refrigerant, and h_f and h_i are the values of enthalpy after and before the evaporation respectively.

For the same compressor in **(h)**, calculate Q the rate of heat removal by the refrigeration process.

Q = ... kW [2]

(j) The efficiency of a refrigeration system is measured using its coefficient of performance which is calculated using

$$C = Q\ /\ W$$

Calculate C the coefficient of performance for the refrigeration system you designed.

C = ... [1]

(k) A refrigeration system is regarded as efficient only if it has a coefficient of performance of above 4.

Explain with reference to the principle of conservation of energy, why, unlike the efficiency of a conventional mechanical system, a coefficient of performance of greater than 1 is possible.

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[2]

[Total: 19]

End of Paper