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, each starting on a new page. Check NOW to verify that your exam is complete.

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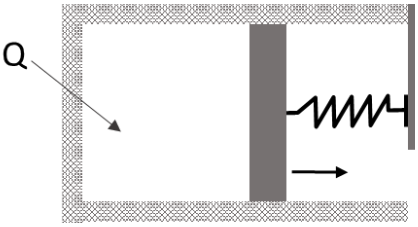
If you are missing the properties tables or any of the three (3) exam problems, stop work NOW and advise your proctor immediately.

Problem 1

A closed piston-cylinder system is connected to a spring as shown in the figure. The spring has spring constant k=100 kN/m. When the spring is uncompressed the enclosed volume is zero. The cylinder contains an ideal gas at an initial volume of 0.1 m^3 and a pressure of 250 kPa. The piston has a cross-sectional area of 0.2 m^2, a thickness of 0.02 m and a density of 8,000 kg/m^3. The pressure on the spring-side of the piston is zero. The gas in the cylinder is heated quasistatically until its volume doubles.

Commented [SJL1]: The spring has to be compressed in the initial state because the spring force is what is containing the gas at the given pressure.

1. What is the final pressure inside the cylinder?
2. Sketch the process on a p-V diagram.
3. Calculate the work done by the gas.
4. What fraction of the work done by the gas is stored as potential energy in the spring?



Problem 2

In a proposal, icebergs (at a temperature $T_1 = -15°\mathrm{C}$) in the North Atlantic Ocean are to be pulled to an offshore power plant where they will be used to generate electricity and to provide fresh water as well. In the simple model, treat the ice as an incompressible solid with the same density as pure water (incompressible liquid), i.e., $\rho_{ice} = 1000\ \mathrm{kg/m^3}$. The environment can be treated as a constant-temperature reservoir at a temperature $T_0 = 20°\mathrm{C} = 293\ \mathrm{K}$. In addition, you are given the following:

- specific heat of ice: $c_{ice} = 2.1\ \mathrm{kJ/kg\text{-}K}$
- enthalpy of fusion (melting ice) at $0°\mathrm{C}$ (1 atm): h_{melt} = 334 $\mathrm{kJ/kg}$
- entropy change upon melting: $\Delta s_{melt} = h_{melt} / T_{melt}$

(1) In this power plant, the ice is heated up to $T_2 = 0°\mathrm{C}$ and then melted to liquid (also at $0°\mathrm{C}$) in a large container. By taking heat from the surrounding environment, work is produced through a heat engine that can also thermally interact with the iceberg system. Assuming that the ice consumption is 100 $\mathrm{m^3}$ per minute. What is the maximum amount of work that can be produced in one hour?

(2) If no such work is produced and the ice is melted by receiving heat from the environment, what is the entropy generation rate for the same amount of ice that is melted as in Part (1)?

(3) If only half of the maximum work, predicted by Part (1), is produced with the same rate of ice consumption, what is the entropy generation rate?

Problem 3

The accompanying schematic shows a conventional vapor compression cooling or heat pump cycle. Note that 8 stations are shown and that 1 and 8 are identical. Heat is rejected to air between stations 2 and 5 (the "condenser"), and heat is adsorbed between stations 6 and 8 (the "evaporator"). Two compressor and motor arrangements are possible:

- (type-1) the compressor and motor are in the same adiabatic pressure vessel (represented by the **double** line rectangle) such that the waste heat of the motor is absorbed by the refrigerant

- (type-2) the compressor itself is an adiabatic pressure vessel (represented by the **dotted** line rectangle) and is shaft driven by the external motor, which is air cooled. Note that motor efficiency equals shaft power / electric power input.

The results of thermodynamic analysis for a reversible and adiabatic type-2 compressor are given in the accompanying table. A plot of this ideal thermodynamic cycle on the pressure-enthalpy plane is also given below. It should **not** be necessary for you to consult any other tables of refrigerant properties, which in any case might not be exactly consistent with the tabulated data. If the compressor is changed, assume its performance only affects the properties of the refrigerant at station 2 (without changing the pressure at the compressor outlet). For the "cycle COP" ignore any fan power consumption.

Determine the following:

Part 1

(a) the cycle cooling COP for the ideal case in the table ___________

(b) the cycle heating COP for the ideal case in the table ___________

Part 2: assume the compressor is a type-2 (dotted line) design with 70% efficiency and determine

(a) the enthalpy at station 2 = _____________

(b) the cycle cooling COP for this case ___________

(c) the cycle heating COP for this case ___________

Part 3: assume the compressor is a type-1 (double line, compressor and motor in same pressure vessel) design with 70% compressor efficiency driven by a 90% efficient electric motor and determine

(a) the enthalpy at station 2 = _____________

(b) the cycle cooling COP for this case ___________

(c) the cycle heating COP for this case ___________

Part 4: assume the compressor is a type-2 (dotted line, compressor is shaft driven by external motor) design with 70% compressor efficiency driven by a 90% efficient electric motor cooled by air and determine

(a) the enthalpy at station 2 = ______________

(b) the cycle cooling COP for this case ___________

(c) the cycle heating COP for this case ___________

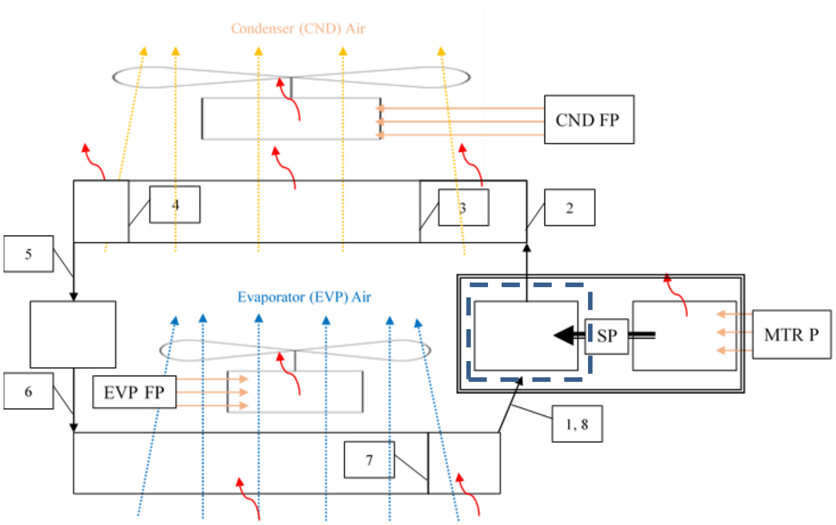
Part 5: For a practical heat pump, the fan power must be considered, and the cooling effect is the net enthalpy drop of the air passing over the evaporator and through the evaporator fan while the heating effect is the net enthalpy rise of the air passing over the condenser and through its fan. Note that all fan power is absorbed by the air stream. Assume the compressor is a type-1 (double line, compressor and motor in same pressure vessel) design with 70% compressor efficiency driven by a 90% efficient electric motor. Also assume the evaporator fan power is 5% of the power of the compressor motor and that the condenser fan power is 4% of the compressor motor power. Show your work on the work sheet for Part 5, and determine the following data:

(a) the enthalpy at station 2 = ______________

(b) the practical cooling COP for this case ___________

also

(c) sketch the location of station 2 on the accompanying pressure-enthalpy diagram reasonably accurately and estimate the entropy at station 2 ___________ kJ/kg-K



CND FP = condenser fan motor power

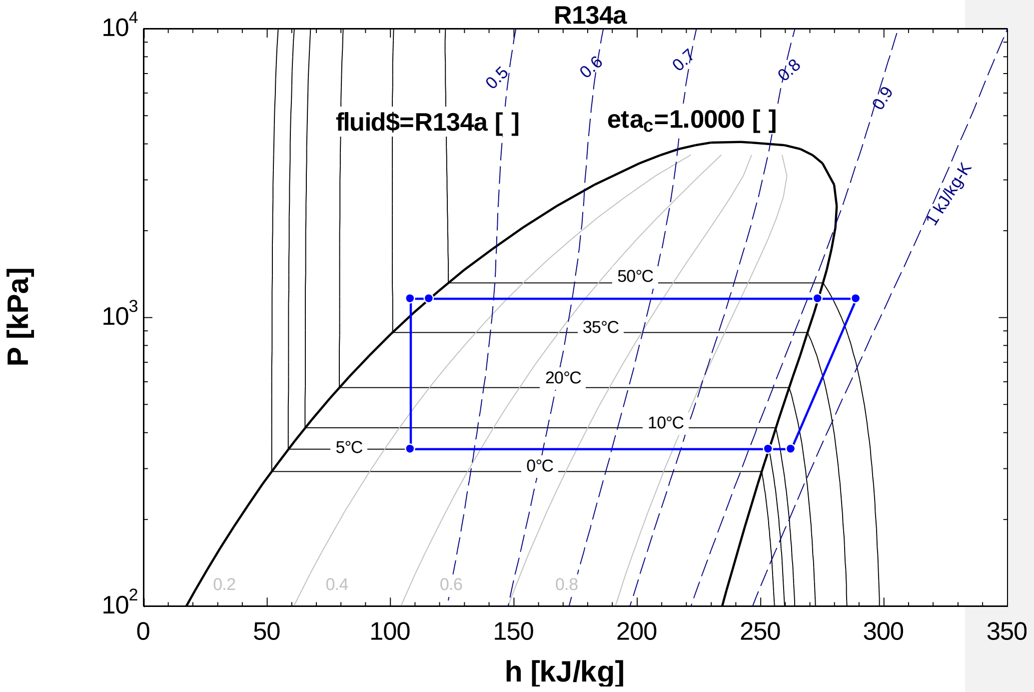
EVP FP = evaporator fan motor power

MTR P =

Table of Thermo Properties for CV System

Station	P[i]	T[i]	h[i]	s[i]	x_quality[i]	vol_sp[i]
	[kPa]	[C]	[kJ/kg]	[kJ/kg-K]		[m^3/kg]
1	349.9	15.00	262.46	0.9610	SHV	0.061367
2	1160.5	58.52	288.77	0.9610	SHV	0.019030
3	1160.5	45.00	273.36	0.9135	1.000	0.017331
4	1160.5	45.00	115.80	0.4183	0.000	0.000889
5	1160.5	40.00	108.24	0.3944	CL	0.000871
6	349.9	5.00	108.24	0.4071	0.255	0.015449
7	349.9	5.00	253.34	0.9288	1.000	0.058328
8 (8 = 1)	349.9	15.00	262.46	0.9610	SHV	0.061367

SHV = superheated vapor; CL = compressed liquid


R134a
fluid$=R134a [ ]
eta$_c$=1.0000 [ ]
P [kPa]
h [kJ/kg]
10^4
10^3
10^2
0
50
100
150
200
250
300
350
50°C
35°C
20°C
10°C
5°C
0°C
0.2
0.4
0.6
0.8
0.5
0.6
0.7
0.8
0.9
1 kJ/kg-K

Work sheet for parts 1 - 4:

Work sheet for Part 5: