NR-212
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Indian Institute of Technology Kharagpur
Mid-Autumn Semester 2022 – 2023

Date of Examination: Session: Duration 2 hrs Full Marks 60
Subject Number: CH21201 Subject: Chemical Engineering Thermodynamics
Department: Chemical Engg.

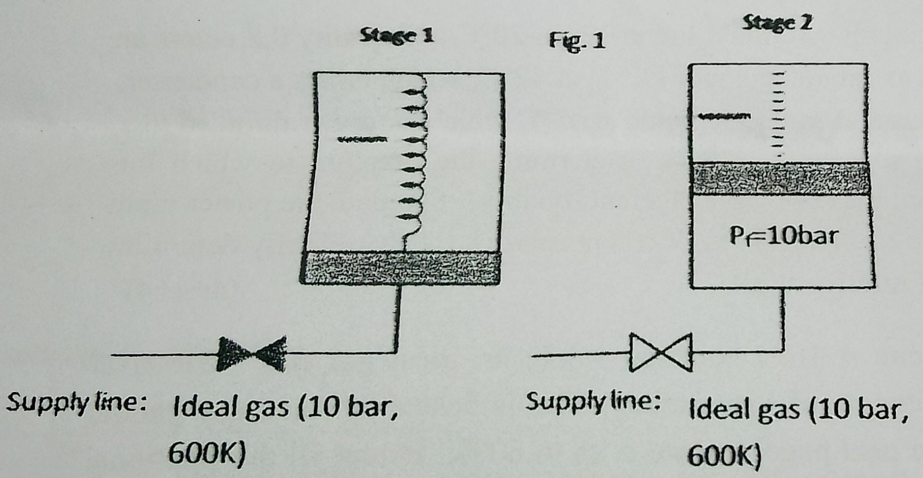
Specific Instructions: Assume and write any assumption and data that you feel are missing.

IGNORE macroscopic kinetic energy and gravitational potential energy for all the questions.

1. A thermally insulated empty tank contains a spring piston arrangement as shown in fig.1 below. This tank is connected with a supply line through which an ideal gas ($C_v = 5R/2$) is flowing at pressure 10 bar and temperature 600 K. Initially the spring is just touching the piston (no compression) and the valve is closed (stage-1). Now the valve is opened and ideal gas enters the tank, pushing the piston in upward direction till pressure inside the tank (below piston) becomes 10bar. Determine the final temperature of gas in tank (below piston). 1 bar = 100 kPa.

(10 marks)

Fig. 1



2. An inventor claims to have designed a device as shown in fig. 2 (next page), which takes in 2kmol/s of air at 250kPa and 355K and delivers equal amounts of hot stream and cold stream of air. The hot stream is at 100kPa and 455K while the cold stream of air is at 100kPa and 255K. He further claims that his device does not require any additional energy as heat or work to operate. Judge whether such a device is feasible or not with proper mathematical justification. Consider air as ideal gas with $C_p = \frac{7R}{2}$. (Hint: a feasible device must not violate first and second law of thermodynamics).

(10 marks)

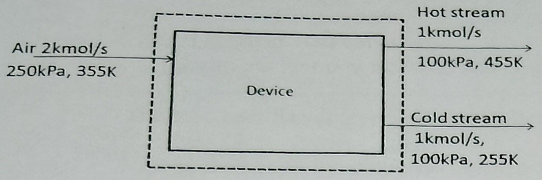


Fig.2

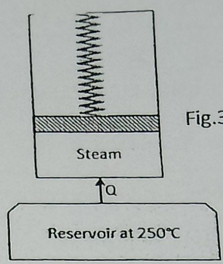


Fig.3

3. One kilogram of saturated steam (X=1) at 25°C, contained in a cylinder with spring-piston arrangement, shown in fig. 3. Heat is added from a reservoir at 250°C until the final pressure and temp. of steam becomes 3 bar, 200°C. Find the work done by the steam, and total entropy generation (system + surrounding), assuming the expansion process of steam is quasistatic. (steam is trapped only below piston) **(10)**

4. In a vapor compression refrigerator, saturated Freon-12 at -20°C and quality 0.8 enters an adiabatic compressor and leaves as saturated vapor (X=1) at 42°C, which enters a condenser. The refrigerant leaves the condenser at saturated liquid at 42°C which is further throttled to a low pressure refrigerant having temperature -30°C. Determine the pressure to which the refrigerant is throttled and find out the state of refrigerant (quality). Estimate the power input to the compressor if the flow rate of Freon through compressor is 1 kg/s. Finally determine the Coefficient of Performance of referigerator. **(4+4+4)**

5. An insulated rigid tank (volume = 1m^3) contains 1mole an ideal gas (C_v = 5R/2) at T_0=300K (which is also the temperature of surrounding). Gas is heated by rotating a paddle wheel, as shown in figure 4(a) (on next page) to heat it up to 600K. Innore all the froctional losses in paddle wheel, so that it can be treated as a work reservior.

a) calculate the work done by paddle wheel (W_{paddle}). **(3)**

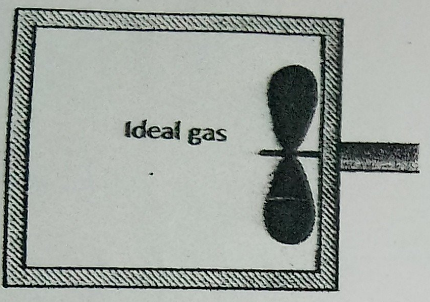
b) calulate the total entropy change (ΔS) of gas + surrounding **(4)**

Now let us heat up the gas from 300 to 600K by another method, we will use a reversible heat pump, such that heat pump transfers heat from surroundding (at 300K) to gas (kept in insulated tank) by taking work input from external agent. As we are using a reversible heat pump (fig. 4b on next page), let us call work input by external agent as W_{rev}. COP of a reversible pump is given by, COP $= 1/\left(1 - \frac{T_0}{T}\right)$, where T is the gas temperature at any general instant of time during heating process, and T_0 is surrounding temperature. Answer the following:

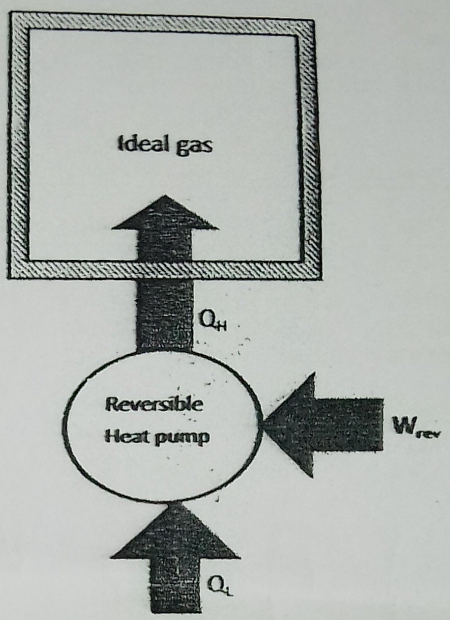
c) calculate W_{rev} for heating up process. **(7)**

d) Show that $W_{paddle} - W_{rev} = T_0 \Delta S$, ($\Delta S$ already calculated in part **b**) **(4)**

(This example cleraly shows that indeed an irreversible method of doing a procees leads to entropy generation, which is directly connected to degradtion of quality of energy. In other words, while performing a task in more reversible manner, minimum energy input is required due to minimization of entropy generation).



Surrounding at T_o=300K
Fig. 4(a)



Surrounding at T_o=300K
Fig. 4(b)

Saturated Freon-12 table:

T (°C)	P (kPa)	v_f (m³/kg)	v_g (m³/kg)	h_f (kJ/kg)	h_g (kJ/kg)	s_f (kJ/kg K)	s_g (kJ/kg K)
−30.0	100.341	0.000 672	0.159553	8.9215	174.3361	0.0374	0.7177
−28.0	109.193	0.000 675	0.147 433	10.7185	175.2557	0.0447	07159
−26.0	188.643	0.000 677	0.136420	12.5201	176.1723	0.0520	0.7142
−24.0	128.715	0.000 680	0.126 400	14.3261	177.0856	0.0592	0.7125
−22.0	139.436	0.000 683	0.117 268	16.1366	177.9955	0.0665	0.7109
−20.0	150.836	0.000 685	0.108 931	17.9517	178.9017	0.0736	0.7094
−18.0	162.940	0.000 688	0.101 311	19.7713	179.8040	0.0807	0.7080
−16.0	175.778	0.000 691	0.094 335	21.5957	180.7022	0.0878	0.7066
−14.0	189.379	0.000 694	0.087 938	23.4249	181.5959	0.0949	0.7052
−12.0	203.771	0.000 697	0.082 065	25.2589	182.4851	0.1019	0.7039
40.0	960.255	0.000 798	0.018 093	75.1134	203.1063	0.2738	0.6825
42.0	1008.379	0.000 803	0.017 202	77.1464	203.7598	0.2801	0.6819
44.0	1058.266	0.000 808	0.016 359	79.1921	204.3982	0.2865	0.6813

Saturated Steam Table:

Temp. t (°C)	Pressure P (bar)	Specific volume v_f (m³/kg)	v_g (m³/kg)	Specific enthalpy h_f (kJ/kg)	h_g (kJ/kg)	Specific entropy s_f (kJ/kg K)	s_g (kJ/kg K)
10	0.012 270	0.001 0003	106.4000	41.99	2519.9	0.1510	8.9020
15	0.017 039	0.001 000 8	77.9800	62.94	2529.1	0.2243	8.7826
20	0.023 37	0.001 001 7	57.8400	83.86	2538.2	0.2963	8.6684
25	0.031 66	0.001 002 9	43.4000	104.77	2547.3	0.3670	8.5592
30	0.042 41	0.001 004 3	32.9300	125.66	2556.4	0.4365	8.4546

Pressure P (bar)	Temperature t (°C)	Specific volume v_f (m³/kg)	v_g (m³/kg)	Specific enthalpy h_f (kJ/kg)	h_g (kJ/kg)	Specific entropy s_f (kJ/kg K)	s_g (kJ/kg K)
2.5	127.43	0.001 067 5	0.7184	535.34	2716.4	1.6071	7.0520
3.0	133.54	0.001 073 5	0.6056	561.43	2724.7	1.6716	6.9909
3.5	138.87	0.001 078 9	0.5240	584.27	2731.6	1.7273	6.9392

Super heated steam table:

P = 3 bar at T= 200°C,

v= 0.7164 m³/kg,   h = 2865.5 kJ/kg,   s = 7.3119 kJ/(kg.K)