HVAC PROBLEM SHEET # 03 (VAPOURE COMPRESSION CYCLE)

1. An ammonia refrigerator produces 20 tonnes of ice per day from and at0℃. The condensation and evaporation take place at 20 ℃ and -20 ℃ respectively. The temperature of vapour at the end of isentropic compression is 50℃ and there is no under-cooling of the liquid. The actual COP is 70% of the theoretical COP. Determine; (1) The rate of NH_3 circulation; (2) The size of single acting-compressor when running at 240 r.p.m., assuming L=D and volumetric efficiency of 80%. Take h_{fg}(fusion of ice) 335 kJ/kg. Use the properties of NH_3 as listed below: Take v_g at -20℃ =0.624m^3/kg and Cps=2.8kJ/kg℃ (0.097kg/s, 28.9cm, 28.9cm)

Temp. (℃)	Enthalpy (kJ/kg)		Entropy (kJ/kg K)	
	(h_f)	(h_{fg})	(s_f)	(s_g)
20	274.98	1461.58	1.04341	5.0919
-20	89.72	1419.05	0.3682	5.6204

2. A food storage locker requires a refrigeration capacity of 50 kW. It works between a condenser temperature of 35℃ and an evaporator temperature of –10℃. The refrigerant is ammonia. It is sub cooled by 5℃ before entering the expansion valve by the dry saturated vapour leaving the evaporator. Assuming a single- cylinder single –acting compressor operating at 1000 r.p.m. with stroke equal to 1.2 times the bore, Determine: (1) The power required, and (2) The cylinder dimensions. Properties of ammonia are: (10.1kW, 0.19m, 0.228m)

T (℃)	$P_s$bar)	Enthalpy (kJ/kg)		Entropy (kJ/kg K)		Specific Volume (m^3/kg)		Specific heat (kJ/KgK)	
		Liquid	Vapour	Liquid	Vapour	Liquid	Vapour		
-10	2.9157	154.056	1450.22	0.82965	5.7550	----	0.417477	-----	2.492
35	13.522	366.072	1488.57	1.56605	5.2086	1.7023	0.095629	4.556	2.903

3. A food storage locker requires a refrigeration system of 2400 kJ/min. capacity at an evaporator temperature of 263 K and a condenser temperature of 303 K. The refrigerant used is Freon-12 and sub cooled by 6℃ before entering the expansion valve and vapour is superheated by 7℃ before leaving the evaporator coil. The compression of refrigerant is reversible adiabatic. The refrigeration compressor is two cylinders single-acting with stroke equal to 1.25 times the bore and operates at 1000 r.p.m. Properties of Freon-12

T(K)	P(bar)	v(m^3/kg)	h_f (kJ/kg)	h_g (kJ/kg)	s_f(kJ/kg K)	s_g (kJ/kg K)
263	2.19	0.0767	26.9	183.2	0.1080	0.7020
303	7.45	0.0235	64.6	199.6	0.2399	0.6854

Take: Liquid specific heat = 1.235 kJ/KgK, vapour specific heat = 0.733 kJ/KgK. Determine: (1) Refrigerating effect per kg, (2) Mass of refrigerant to be circulated per minute, (3) Theoretical piston displacement per minute, (4) Theoretical power required to run the compressor, in kW, (5) Heat removed through condenser per min., and (6) Theoretical bore and stroke of compressors. (131.14kJ/kg, 18.3kg/min, 1.441m^3/min, 6.79kW, 2807.4kJ/min, 0.7205 m^3/min, 112.5mm)

4. In an ammonia vapour compression refrigerator condensation and evaporation take place at 11.28 bar and 2.57 bar respectively. The temperature at the end of compression is 50℃ and there is no undercooling. One tone of ice is to be formed per hour at -5℃ from water at 10℃ . Assuming specific heat of ice as 2.09 the latent heat 335 kJ/kg and c_p of the super heated ammonia vapour as 2.93, calculate the power required to drive the machine; neglect mechanical losses. For ammonia: (20.6kw)

P (bar)	T(°C)	Enthalpy kJ/kg		Entropy kJ/kg K	
		Liquid	Latent	Liquid	Latent
11.28	30	322.2	1146.4	1.203	3.77
2.57	-12.25	124.7	1297	0.505	4.99

5. A single-cylinder, single-acting compressor having bore and stroke of 16cm and 24 cm respectively runs at a speed of 110 r.p.m. and the indicated mean effective pressure is 2.06 bars. The pressure limits of the refrigerant are 9.66 bar and 2.66 bar and the temperatures at entry to and at exit from condenser are 37.7℃ and 16℃ , flow of cooling water is 14 kg/min and ther inlet and outlet termperature are 16℃ and24℃ . The weight of ice produced per hour from water at 20℃ is 56 kg. Assuming the latent heat of ice as 335 kJ/kg and using the following table, find the following: (1) The coefficient of performance; (2) The mass of flow of ammonia/min, and; (3) The condition of ammonia entering the compressor, neglecting leakage.(3.57, 0.376kg/min, 0.899)

Pressure (bar)	Saturation temp.(℃)	Enthalpy kJ/kg		Specific heat	
		Liquid	Vapour	Liquid	Vapour
9.66	24	292.88	1462.2	4.60	2.84
2.66	-12.2	124.68	1426.74	----	-----

6. Following results were obtained in a test conducted on a vapour compression refrigerator: Evaporator temperature = −28.5℃ , condenser pressure = 2.75 bar; Refrigerant entering the condenser is 3℃ superheat, refrigerant leaving the condenser is at 12.8℃ . Determine the C.O.P. The following properties are given: (5.32)

P (bar)	T(℃)	Enthalpy kJ/kg		Entropy vapour (kJ/kg K)	Specific heat at constant pressure	
		Liquid	Vapour		Liquid	Vapour
2.75	14	438.48	802.9	5.5287	1.381	0.669
0.412	-28.5	381.58	783.24	5.6852	----	-----

7. A vapour compression heat pump is driven by a power cycle having a thermal efficiency of 25%. For the heat pump, refrigerant-12 is compressed from saturated vapour at 2.0 bars to the condenser pressure of 12 bars. The isentropic efficiency of the compressor is 80%. Saturated liquid enters the expansion valve at 12 bars. For the power cycle 80% of the heat rejected by it is transferred to the heated space which has a total heating requirement of 500 kJ/min. Determine the power input to the heat pump compressor. The following date for refrigerant-12 may be used: (3.2kW)

P (bar)	T(℃)	Enthalpy kJ/kg		Entropy (kJ/kg K)	
		Liquid	Vapour	Liquid	Vapour
20	-12.53	24.57	182.07	0.0992	0.7035
12.0	49.31	84.21	206.24	0.3015	0.6799

8. A refrigerator operating on standard vapour compression cycle has a coefficient of performance of 6.5 and is driven by a 50kW compressor. The enthalpies of saturated liquid and saturated vapor refrigerant at the operating condensing temperature of 35℃ are 69.55 kJ.kg and 201.45 kJ/kg respectively. The saturated refrigerant vapor leaving evaporator has an enthalpy of 187.53 kJ/kg. Find the refrigerant temperature at compressor discharge. The c_p of refrigerant vapour may be taken to be 0.6155 kJ/kg℃. (41.87˚C)

9. A refrigeration cycle uses Freon-12 as the working fluid. The temperature of the refrigerant in the evaporator is -10 °C. The condensing temperature is 40 °C. The cooling load is 150 W and the volumetric efficiency of the compressor is 80%. The speed of the compressor is 720 r.p.m Calculate the mass flow rate of the refrigerant and the displacement volume of the compressor. Properties of Freon-12:(0.001382kg/s, 0.0001382m^3/s

T (°C)	P (MPa)	h_f (kJ/kg)	h_g(kJ/kg)	V_g (m^3/kg)
-10 40	0.22 0.96	26.8 74.5	183.0 203.1	0.08 0.02

10. A refrigerator is to be designed to operate between -45 ℃ and 0℃. You are asked to select one among the three given refrigerants, namely Freon-12, and NH_3 and CO_2, on the basis of the factors (1) COP, (2) Power required per ton, and (3) the condenser and evaporator pressures. The properties of the refrigerants are as given below:

Refrigerants	T_s(°C)	$P_s(bar)$	h_f (kJ/kg)	h_g(kJ/kg)	s_f(kJ/KgK)	s_g(kJ/KgK)	c_{pg}
F-12	-45	0.505	-4.4	167.84	0.0190	0.7360	---
	0	3.09	36.2	188.69	0.1420	0.7008	0.62
NH_3	-45	0.535	-22.4	1387.76	0.0961	6.0475	----
	0	4.24	180.88	1443.34	0.7139	5.3368	2.72
CO_2	-45	8.218	-10.68	319.38	0.0456	1.4043	---
	0	34.81	85.58	320.47	0.3257	1.1878	1.26

Determine the values for the above factors and suggest your choice for the most suitable refrigerant.

11. For a vapour compression refrigeration system using R-22 as refrigerant, condenser outlet temperature is 40℃ and evaporator inlet temperature is -20℃. In order to avoid flashing of refrigerant, a liquid-suction vapour heat-exchanger is provided where liquid is sub cooled to26℃. The refrigerant leaves the evaporator as saturated vapor. The compression process is isentropic. Find the power requirement and coefficient of performance if capacity of the system is 10kW at -20℃ . Show cycle on pressure-enthalpy diagram.c_p of vapour is 1.03 kJ/kg K. The thermodynamic properties are given below:

T(°C)	P(bar)	v_f (m^3/kg)	v_g (m^3/kg)	h_f (kJ/kg)	h_g (kJ/kg)	s_f (kJ/kg K)	s_g (kJ/kg K)
-20	2.448	0.741	0.0928	177.1	397.5	0.9139	1.784
26	10.723	0.840	0.0220	231.6	413.5	1.109	1.717
40	15.335	0.884	0.0151	249.7	416.6	1.167	1.699

12. A compressor having a stroke volume of 500 c.c. runs at 500 r.p.m. and works with CO_2refrigerant. The evaporator and condenser temperatures are -15℃ and25℃, respectively. The condenser liquid is sub cooled to 15℃ before passing on to the expansion valve. Assume wet compression with an initial quality x of CO_2 as 0.9. Assuming isentropic compression and volumetric efficiency of the compressor as 0.85, calculate the following: (1) The COP, (2) The power required by the compressor (kW), and (3) The refrigerating capacity of the compressor in tones of refrigeration. The following date for CO_2may be used:

T(°C)	P(bar)	V(m^3/kg)		h(kJ/kg)		s(kJ/kg K)	
		Liquid	Vapour	Liquid	Vapour	Liquid	Vapour

-15	22.88	0.00101	0.0166	49.62	322.86	0.1976	1.2567
15	50.92	0.00130	0.0063	127.73	308.08	0.4697	1.0959
25	64.32	0.00147	0.0042	164.17	283.63	0.5903	0.9912

Take specific heat C_p of CO_2 gas = 2.4 kJ/kg K.