The Open University of Sri Lanka
Faculty of Engineering Technology
Department of Mechanical Engineering

Study Programme	:	Bachelor of Technology Honours in Engineering
Name of the Examination	:	Final Examination
Course Code and Title	:	**DMX5205 Applied Thermodynamics II**
Academic Year	:	2021/22
Date	:	3rd March 2023
Time	:	1400 - 17000hrs
Duration	:	**3 hours**

General instructions

1. Read all instructions carefully before answering the questions.
2. This question paper consists of **Eight (8)** questions in **five (5)** pages.
3. Answer any **Five (5)** questions.
4. All questions carry equal marks.
5. Answer for each question should commence from a new page.
6. This is a Closed Book Test (CBT).
7. Answers should be in clear handwriting.
8. Do not use red colour pen.
9. Relevant charts are provided.

Question 01

(i) An ideal vapour compression refrigeration cycle operates between saturation temperatures of -12°C and 40°C. The working fluid is R12. The evaporator exit is dry saturated, and the condenser exit is saturated liquid.

Specific heat capacity of R12 in the superheated region is 0.762 kJ/kgK.
Specific heat capacity of liquid R12 is 1.03 kJ/kgK.
Mass flowrate of the refrigerant is 4kg/min.

a) Draw the T-S or P-h diagram for the cycle
b) Calculate the refrigeration capacity in TR
c) Estimate the COP
d) Calculate the compressor power

Use refrigerant properties given below

Sat. Temperature (K)	*Pressure (bar)*	*Enthalpy (kJ/kg)*		*Entropy (kJ/kgK)*	
		liquid	*vapour*	*liquid*	*vapour*
-12	2.034	188.95	347.25	0.9589	1.5651
40	9.5909	239.03	368.81	1.1315	1.5459

(ii) The ideal refrigeration cycle used in part (i) is used in an actual refrigerator. It experiences the following effects.

- Refrigerant leaving the evaporator is superheated to 0°C.
- Refrigerant leaving the condenser is subcooled to 30°C.

a) Draw the T-S diagram for the actual refrigeration cycle
b) Estimate the COP

Question 02

A vapour compression refrigeration plant uses R12 and has a condenser pressure of 10bar and the evaporator pressure of 1.4bar. The compression is carried out isentropically in two stages. The vapour is dry saturated on entering the LP compressor and there is no undercooling of the condensate. Liquid inter-cooling is done at 4bar in a flash chamber. Mass flow rate through the evaporator is 25kg/min. Refrigeration cycle is shown in Figure Q2

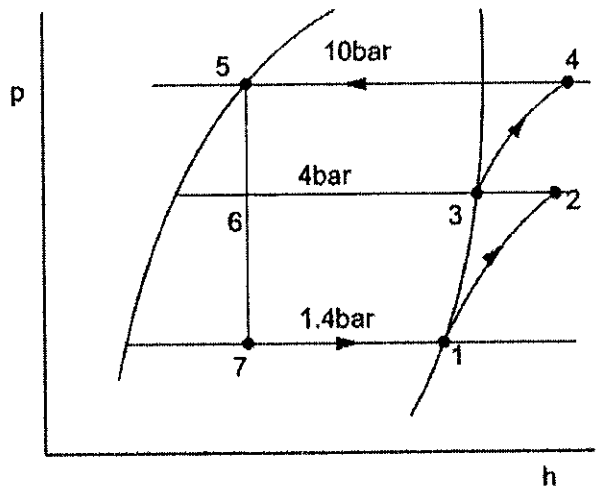

Figure Q2

Calculate the following.

a) temperatures at the end of LP compressor (T_2)
b) temperature at the end of HP compressor (T_4)
c) power of the LP and HP compressors.
d) the refrigeration capacity in ton of refrigeration.
e) coefficient of performance

You are given the following data with reference to the cycle shown in Figure Q2.

$h_1 = h_{g1} = 342.59$ (kJ/kg)
$h_{g2} = h_3 = h_{g3} = 356.19$ (kJ/kg)
$h_{g4} = 369.49$ (kJ/kg)

$s_{g2} = s_3 = s_{g3} = 1.5557$ (kJ/kgK)
$s_{g4} = 1.5454$ (kJ/kgK)
$s_1 = s_{g1} = 1.5715$(kJ/kgK)

$T_{g2} = 281K$
$T_{g4} = 315K$

C_p for vapour at 4bar = 0.653 kJ/kgK
C_p for vapour at 10bar = 0.771 kJ/kgK

Question 03

(i) What is enthalpy of combustion? How does it differ from the enthalpy of reaction?

(ii) What is enthalpy of formation?

(iii) Calculate the enthalpy of combustion (in kJ/kmol) for gaseous propane (C_3H_8) at 25°C, 1atm with liquid water in the products. Enthalpy of formation values are given in below table.

Substance	$\bar{h}_f^\circ$ (kJ/mol)
$C_3H_8(g)$	-103.850
$H_2O(l)$	-285.830
CO_2	-393.520

(iv) Butane (C_4H_{10}) is burned with dry air at an air-fuel ratio (on mass basis) of 20.
Assume:
Each mole of oxygen in the combustion air is accompanied with 3.76 moles of nitrogen.
The nitrogen is inert.
Combustion is complete.

(a) Write down the equation for complete combustion of Butane
(b) Calculate the theoretical Air/Fuel ratio on mass basis.
(c) Determine the percentage of excess air
(d) Find the total moles in the products of combustion.
(e) Find the volume percentage of CO_2 in the product

Molecular weight of Butane (C_4H_{10}) = 58.12 kg/kmol
Molecular weight of Nitrogen (N_2) = 29 kg/kmol))

Question 04

(i) When a choice has to be made between parallel flow and counter flow arrangement for a heat exchanger, which arrangement would you prefer? Justify your answer giving reasons.

(ii) Draw the temperature distribution of hot and cold fluids flowing through a parallel flow heat exchanger and define Logarithmic Mean Temperature Difference (LMTD).

(iii) In a double pipe heat exchanger hot water flows at a rate of 50,000kg/h and gets cooled from 95°C to 65°C. At the same time 50,000kg/h of cooling water at 30°C enters the heat exchanger. The flow conditions are such that overall heat transfer coefficient remains constant at 2270 W/m^{2}K. Determine the heat transfer area required and the effectiveness of the heat exchanger. Assume two streams are in parallel flow. Assume for both the streams Cp = 4.2kJ/kgK.

Question 05

(i) Define Nusselt Number (Nu) and Prandtl Number (Pr) with usual notations and identify each term.

(ii) A metal plate 0.6 m in height forms the vertical wall of an oven and its surface temperature is at a temperature of 200°C. Within the oven, air is at a temperature of 90°C and the atmospheric pressure.

Assume following data:
Thermal conductivity air close to oven = 33 x 10^{-6} kW/mK
Kinematic Viscosity of air = 2.7 x 10^{-5} m^2/s
Specific heat capacity of air = 1.005 kJ/kgK
Coefficient of cubic expansion of air = 2.5 x 10^{-3} K^{-1}

For free convection the heat transfer coefficient (h) is given by,

$$h = \frac{k}{l} C(p_r G_r)^m$$

C and m are constants that are found using experimental data and given in below table.

Object	Flow type	C	m
vertical plates and cylinders	Laminar	0.59	1/4
	Turbulent flow	0.13	1/3
Horizontal cylinder	Laminar	0.53	1/4
	Turbulent	0.13	1/3

a) Determine whether the flow is laminar or turbulent
b) Find the mean convection heat transfer coefficient
c) Calculate the heat loss rate from a unit area of the wall

For laminar flow conditions

$$10^4 < G_r P_r < 10^9$$

For turbulent flow condition

$$G_r P_r > 10^9$$

Question 06

(i) Describe the various mechanisms of mass transfer.

(ii) State the Fick's law of diffusion.

(iii) Hydrogen gas is maintained at pressures of 2.4 bar and 1 bar on opposite sides of a plastic membrane 0.3 mm thick. The binary diffusion coefficient of hydrogen in the plastic is 8.6×10^{-8} m^2/s and solubility of hydrogen in the membrane is 0.00145 kg mole/m^3 bar. Calculate the following, under uniform temperature conditions of 24°C

a) Molar concentrations of hydrogen at the opposite faces of the membrane
b) Molar diffusion flux of hydrogen through the membrane

Question 07

(i) In relation to moist air properties briefly explain the following terms.
a) Dew point temperature
b) Wet bulb temperature

(ii) The air in a room has a dry-bulb temperature of 22°C and a wet-bulb temperature of 16°C. The total pressure of the room air is 100kPa. Calculate the following with the use of relationships of different moist air properties. [Note: Use given property table for water where necessary]
a) specific humidity,
b) relative humidity, and
c) dew-point temperature

Question 08

(i) Name two main types of load components that you need to estimate when sizing an air conditioning plant.

(ii) Categorize the air conditioning plants considering the cooling method of the condenser. Differentiate the situations where these two different types are required.

(iii) A chiller uses a water cooled condenser with a wet cooling tower. The water flow rate is 60 kg/s and is required to cool it from 40°C to 26°C. Atmospheric air enters the tower at 1 atm with dry- and wet-bulb temperatures of 22 °C and 16°C respectively, and leaves at 34°C with a relative humidity of 90 percent. **Using the Psychrometric chart**, find the volume flow rate of air into the cooling tower and the mass flow rate of the required make up water. [Note: Use given property table for water where necessary]

Table 3 Thermodynamic Properties of Water at Saturation (*Continued*)

Temp., °C	Absolute Pressure, kPa	Specific Volume, m³/kg (water)			Specific Enthalpy, kJ/kg (water)			Specific Entropy, kJ/(kg · K) (water)			Temp., °C
		Sat. Liquid	Evap.	Sat. Vapor	Sat. Liquid	Evap.	Sat. Vapor	Sat. Liquid	Evap.	Sat. Vapor	
t	p	v_f	v_{fg}	v_g	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g	t
0	0.6112	0.001000	206.141	206.143	−0.04	2502.61	2500.77	−0.0002	9.1555	9.1553	0
1	0.6571	0.001000	192.455	192.456	4.16	2498.43	2502.61	0.0153	9.1134	9.1286	1
2	0.7060	0.001000	179.769	179.770	8.39	2496.05	2504.45	0.0306	9.0716	9.1022	2
3	0.7580	0.001000	168.026	168.027	12.60	2493.68	2506.28	0.0459	9.0302	9.0761	3
4	0.8135	0.001000	157.137	157.138	16.81	2491.31	2508.12	0.0611	8.9890	9.0501	4
5	0.8725	0.001000	147.032	147.033	21.02	2488.94	2509.96	0.0763	8.9482	9.0244	5
6	0.9353	0.001000	137.653	137.654	25.22	2486.57	2511.79	0.0913	8.9077	8.9990	6
7	1.0020	0.001000	128.947	128.948	29.42	2484.20	2513.62	0.1064	8.8674	8.9738	7
8	1.0726	0.001000	120.850	120.851	33.62	2481.84	2515.46	0.1213	8.8273	8.9488	8
9	1.1481	0.001000	113.326	113.327	37.82	2479.47	2517.29	0.1362	8.7878	8.9245	9
10	1.2280	0.001000	106.328	106.329	42.01	2477.11	2519.12	0.1511	8.7484	8.8995	10
11	1.3127	0.001000	99.812	99.813	46.21	2474.74	2520.95	0.1659	8.7093	8.8752	11
12	1.4026	0.001001	93.743	93.744	50.40	2472.38	2522.78	0.1806	8.6705	8.8511	12
13	1.4976	0.001001	88.038	88.039	54.59	2470.02	2524.61	0.1953	8.6319	8.8272	13
14	1.5987	0.001001	82.615	82.616	58.78	2467.66	2526.44	0.2099	8.5936	8.8035	14
15	1.7055	0.001001	77.897	77.898	62.97	2465.30	2528.26	0.2244	8.5556	8.7801	15
16	1.8184	0.001001	73.307	73.308	67.16	2462.93	2530.09	0.2389	8.5178	8.7568	16
17	1.9380	0.001001	69.021	69.022	71.34	2460.57	2531.92	0.2534	8.4804	8.7338	17
18	2.0643	0.001002	65.018	65.018	75.53	2458.21	2533.74	0.2678	8.4431	8.7109	18
19	2.1978	0.001002	61.273	61.273	79.72	2455.85	2535.56	0.2821	8.4061	8.6883	19
20	2.3388	0.001002	57.774	57.775	83.90	2453.48	2537.38	0.2964	8.3694	8.6658	20
21	2.4877	0.001002	54.450	54.500	88.08	2451.12	2539.20	0.3107	8.3329	8.6436	21
22	2.6448	0.001002	51.433	51.434	92.27	2448.75	2541.02	0.3249	8.2967	8.6215	22
23	2.8104	0.001003	48.562	48.563	96.45	2446.39	2542.84	0.3390	8.2607	8.5996	23
24	2.9851	0.001003	45.822	45.823	100.63	2444.02	2544.65	0.3531	8.2249	8.5780	24
25	3.1692	0.001003	43.350	43.351	104.81	2441.66	2546.47	0.3672	8.1894	8.5565	25
26	3.3631	0.001003	40.985	40.986	108.99	2439.29	2548.28	0.3812	8.1541	8.5352	26
27	3.5673	0.001004	38.766	38.767	113.18	2436.92	2550.09	0.3951	8.1190	8.5141	27
28	3.7822	0.001004	36.682	36.683	117.36	2434.55	2551.90	0.4090	8.0842	8.4932	28
29	4.0083	0.001004	34.726	34.727	121.54	2432.17	2553.71	0.4229	8.0496	8.4724	29
30	4.2460	0.001004	32.889	32.889	125.72	2429.80	2555.52	0.4367	8.0152	8.4519	30
31	4.4959	0.001005	31.160	31.161	129.90	2427.43	2557.32	0.4505	7.9810	8.4315	31
32	4.7585	0.001005	29.535	29.536	134.08	2425.05	2559.13	0.4642	7.9471	8.4112	32
33	5.0343	0.001005	28.006	28.007	138.26	2422.67	2560.93	0.4779	7.9133	8.3912	33
34	5.3239	0.001006	26.567	26.568	142.44	2420.29	2562.73	0.4915	7.8799	8.3713	34
35	5.6278	0.001006	25.212	25.213	146.62	2417.91	2564.53	0.5051	7.8465	8.3516	35
36	5.9466	0.001006	23.935	23.936	150.80	2415.53	2566.33	0.5186	7.8134	8.3320	36
37	6.2810	0.001007	22.733	22.734	154.98	2413.14	2568.12	0.5321	7.7805	8.3127	37
38	6.6315	0.001007	21.599	21.600	159.16	2410.76	2569.91	0.5456	7.7479	8.2934	38
39	6.9987	0.001008	20.529	20.530	163.34	2408.37	2571.71	0.5590	7.7154	8.2744	39
40	7.3835	0.001008	19.520	19.521	167.52	2405.98	2573.50	0.5724	7.6831	8.2555	40
41	7.7863	0.001008	18.567	18.568	171.70	2403.58	2575.28	0.5857	7.6510	8.2367	41
42	8.2080	0.001009	17.667	17.668	175.88	2401.19	2577.07	0.5990	7.6191	8.2181	42
43	8.6492	0.001009	16.818	16.819	180.06	2398.79	2578.85	0.6122	7.5875	8.1997	43
44	9.1107	0.001010	16.014	16.015	184.24	2396.39	2580.63	0.6254	7.5560	8.1814	44
45	9.5932	0.001010	15.255	15.256	188.42	2393.99	2582.41	0.6386	7.5247	8.1632	45
46	10.0976	0.001010	14.537	14.538	192.60	2391.59	2584.19	0.6517	7.4936	8.1452	46
47	10.6246	0.001011	13.858	13.859	196.78	2389.18	2585.96	0.6648	7.4626	8.1274	47
48	11.1751	0.001011	13.214	13.215	200.97	2386.77	2587.74	0.6778	7.4319	8.1097	48
49	11.7500	0.001012	12.606	12.607	205.15	2384.36	2589.51	0.6908	7.4013	8.0921	49
50	12.3499	0.001012	12.029	12.029	209.33	2381.94	2591.27	0.7038	7.3709	8.0747	50
51	12.9759	0.001013	11.482	11.483	213.51	2379.53	2593.04	0.7167	7.3407	8.0574	51
52	13.6290	0.001013	10.964	10.965	217.70	2377.10	2594.80	0.7296	7.3107	8.0403	52
53	14.3100	0.001014	10.473	10.474	221.88	2374.68	2596.56	0.7424	7.2809	8.0233	53
54	15.0200	0.001014	10.001	10.008	226.06	2372.26	2598.32	0.7552	7.2512	8.0064	54
55	15.7597	0.001015	9.563	9.5663	230.25	2369.83	2600.07	0.7680	7.2217	7.9897	55
56	16.5304	0.001015	9.147	9.1468	234.43	2367.39	2601.82	0.7807	7.1924	7.9731	56
57	17.3331	0.001016	8.744	8.7489	238.61	2364.96	2603.57	0.7934	7.1632	7.9566	57
58	18.1690	0.001016	8.3680	8.3700	242.80	2362.52	2605.32	0.8061	7.1342	7.9403	58
59	19.0387	0.001017	8.0094	8.0114	246.99	2360.08	2607.06	0.8187	7.1054	7.9240	59
60	19.944	0.001017	7.6677	7.6697	251.17	2357.63	2608.80	0.8313	7.0767	7.9079	60
61	20.885	0.001018	7.3418	7.3438	255.36	2355.19	2610.54	0.8438	7.0482	7.8920	61
62	21.864	0.001018	7.0317	7.0347	259.54	2352.73	2612.28	0.8563	7.0198	7.8761	62
63	22.882	0.001019	6.7397	6.7407	263.73	2350.28	2614.01	0.8688	6.9916	7.8604	63
64	23.940	0.001019	6.4599	6.4609	267.92	2347.82	2615.74	0.8812	6.9636	7.8448	64
65	25.040	0.001020	6.1935	6.1946	272.11	2345.36	2617.46	0.8936	6.9357	7.8293	65
66	26.180	0.001020	5.9397	5.9409	276.30	2342.89	2619.19	0.9060	6.9080	7.8140	66
67	27.366	0.001021	5.6982	5.6992	280.49	2340.42	2620.90	0.9183	6.8804	7.7987	67
68	28.596	0.001022	5.4680	5.4690	284.68	2337.95	2622.62	0.9306	6.8530	7.7836	68
69	29.873	0.001022	5.2485	5.2495	288.87	2335.47	2624.33	0.9429	6.8257	7.7686	69

ASHRAE PSYCHROMETRIC CHART NO. 1

NORMAL TEMPERATURE SEA LEVEL

BAROMETRIC PRESSURE 101.325 kPa