INDIAN INSTITUTE OF TECHNOLOGY KHARAGPUR

Department of Mechanical Engineering

Date : Time : 2 hours Full Marks : 100 No. of students :

Mid-Sem. 2017 Sub. name: Applied Thermo-Fluids-I Sub.No.: ME40701

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All questions in Part-A and Part-B are compulsory. Wherever necessary, make suitable assumptions and state them clearly

Part-A (Internal Combustion Engines)
For air, R=0.287 kJ/kg-K; γ = 1.35

1. A single-cylinder four-stroke cycle CI engine with 12.9-cm bore and 18.0-cm stroke, operating at 800 RPM, uses 0.113 kg of fuel in four minutes while developing a torque of 76 N-m. The A/F ratio is 18. The ambient condition is 101 kPa and 27^{0}C.
Calculate:
a) Brake power. [kW]
b) Average piston speed. [m/s]
c) Volumetric efficiency. [%]
d) Brake specific fuel consumption. [gm/kW-hr]
e) Brake mean effective pressure. [kPa]

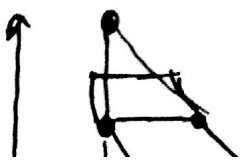
3x5=15

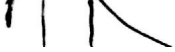
2. An in-line six, 3.3-liter CI engine using light diesel fuel at an air-fuel ratio of A/F = 20 operates on an air-standard Dual cycle. Half of the fuel can be considered burned at constant volume, and half at constant pressure with combustion efficiency η_c = 100%. Cylinder conditions at the start of compression are 60^{0}C and 101 kPa. Compression ratio r_c = 14:1. Take Q_{cv} = 42000 kJ/kg.
Calculate:
a) Temperature at each state of the cycle. [K]
b) Pressure at each state of the cycle. [kPa]
c) Cutoff ratio.
d) Indicated thermal efficiency. [%]
e) Heat added during combustion. [kJ/kg]
f) Net indicated work. [kJ/kg]

4+4+2+3+3+4=20

3. Answer the following:
a) Derive the indicated thermal efficiency of air-standard diesel cycle as a function of the cutoff ratio (β) and the compression ratio (r_c).
b) Otto cycle, dual cycle and Diesel cycle operate under same inlet conditions and same compression ratio; the amount of heat rejection is also same. With P-v and T-s diagrams, compare with proper justification the efficiencies of the three cycles.
c) Otto cycle, dual cycle and Diesel cycle operate under same inlet conditions and same maximum cycle pressure; the amount of heat rejection is also same. With P-v and T-s diagrams, compare with proper justification the efficiencies of the three cycles.

5+5+5=15





Part-B (Refrigeration & Air conditioning)

Data required may be obtained from the graph and tables provided.

4. A refrigerant R-22 vapour compression system includes a liquid-to-suction heat exchanger that superheats saturated vapour coming from the evaporator from -10°C to 5°C by subcooling of the liquid coming from the condenser at 30°C. The compression is isentropic in both the cases listed below.
   a) Draw the thermodynamic cycle as a *h-p* plot.
   b) Calculate the COP of the system without the liquid-to-suction heat exchanger but with condenser temperature of 30°C and evaporator temperature of -10°C.
   c) Calculate the COP of the system with the liquid-to-suction heat exchanger
   d) If the compressor is capable of pumping 12.0 L/s measured at the compressor suction, what is the refrigeration capacity of the system without the liquid-to-suction heat exchanger
   e) with the same compressor capacity as in (c), what is the refrigeration capacity of the system with the liquid-to-suction heat exchanger. **2+6+6+6+6=26**

5. The catalogue of a refrigerant R-22, 4-cylinder, hermetic compressor operating at 29 r/s, with a condensing temperature of 40°C, and a evaporating temperature of -4°C shows a refrigerating capacity of 115 kW. At this operating point the motor (whose efficiency shows 90%) draws 34.5kW. The bore diameter of the cylinder is 87mm and the piston stroke 70mm. The performance data are based on 8°C subcooling of the liquid leaving the condenser. Compute the following
   a) the amount of superheating in °C
   b) the actual volumetric efficiency
   c) the isentropic work of the compressor
   d) isentropic compression efficiency η_c **6+6+6+6=24**

End of Question Paper

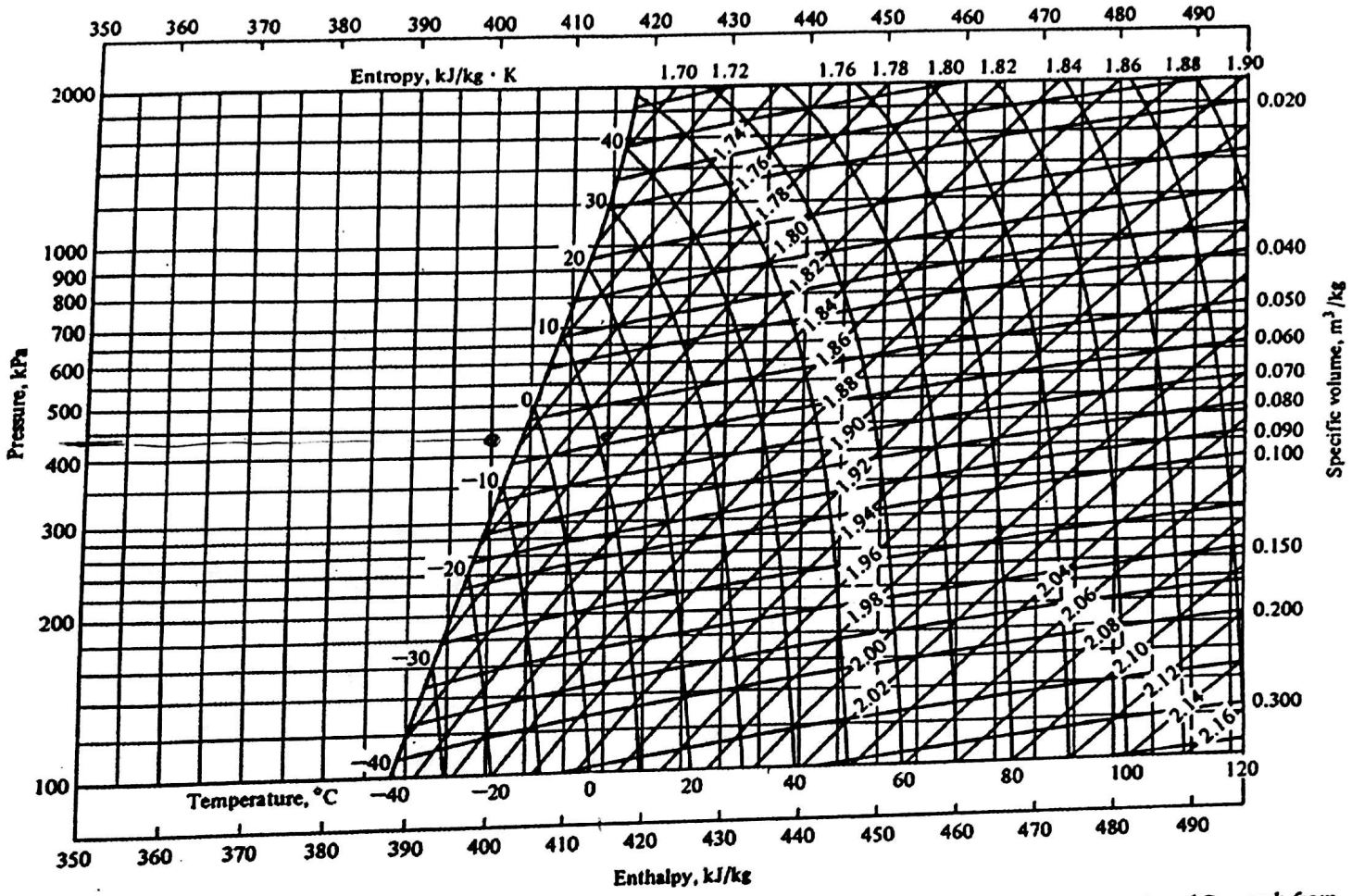


Figure A-4 Pressure-enthalpy diagram of superheated refrigerant 22 vapor. *(Prepared for this book by the Technical University of Denmark from data in Ref. 9.)*

Table A-6 Refrigerant 22: properties of liquid and saturated vapor[6]

		Enthalpy, kJ/kg		Entropy, kJ/kg · K		Specific volume, L/kg	
t, °C	P, kPa	h_f	h_g	s_f	s_g	v_f	v_g
−60	37.48	134.763	379.114	0.73254	1.87886	0.68208	537.152
−55	49.47	139.830	381.529	0.75599	1.86389	0.68856	414.827
−50	64.39	144.959	383.921	0.77919	1.85000	0.69526	324.557
−45	82.71	150.153	386.282	0.80216	1.83708	0.70219	256.990
−40	104.95	155.414	388.609	0.82490	1.82504	0.70936	205.745
−35	131.68	160.742	390.896	0.84743	1.81380	0.71680	166.400
−30	163.48	166.140	393.138	0.86976	1.80329	0.72452	135.844
−28	177.76	168.318	394.021	0.87864	1.79927	0.72769	125.563
−26	192.99	170.507	394.896	0.88748	1.79535	0.73092	116.214
−24	209.22	172.708	395.762	0.89630	1.79152	0.73420	107.701
−22	226.48	174.919	396.619	0.90509	1.78779	0.73753	99.9362
−20	244.83	177.142	397.467	0.91386	1.78415	0.74091	92.8432
−18	264.29	179.376	398.305	0.92259	1.78059	0.74436	86.3546
−16	284.93	181.622	399.133	0.93129	1.77711	0.74786	80.4103
−14	306.78	183.878	399.951	0.93997	1.77371	0.75143	74.9572
−12	329.89	186.147	400.759	0.94862	1.77039	0.75506	69.9478
−10	354.30	188.426	401.555	0.95725	1.76713	0.75876	65.3399
−9	367.01	189.571	401.949	0.96155	1.76553	0.76063	63.1746
−8	380.06	190.718	402.341	0.06585	1.76394	0.76253	61.0958
−7	393.47	191.868	402.729	0.97014	1.76237	0.76444	59.0996
−6	407.23	193.021	403.114	0.97442	1.76082	0.76636	57.1820
−5	421.35	194.176	403.496	0.97870	1.75928	0.76831	55.3394
−4	435.84	195.335	403.876	0.98297	1.75775	0.77028	53.5682
−3	450.70	196.497	404.252	0.98724	1.75624	0.77226	51.8653
−2	465.94	197.662	404.626	0.99150	1.75475	0.77427	50.2274
−1	481.57	198.828	404.994	0.99575	1.75326	0.77629	48.6517
0	497.59	200.000	405.361	1.00000	1.75279	0.77834	47.1354
1	514.01	201.174	405.724	1.00424	1.75034	0.78041	45.6757
2	530.83	202.351	406.084	1.00848	1.74889	0.78249	44.2702
3	548.06	203.530	406.440	1.01271	1.74746	0.78460	42.9166
4	565.71	204.713	406.793	1.01694	1.74604	0.78673	41.6124
5	583.78	205.899	407.143	1.02116	1.74463	0.78889	40.3556
6	602.28	207.089	407.489	1.02537	1.74324	0.79107	39.1441
7	621.22	208.281	407.831	1.02958	1.74185	0.79327	37.9759
8	640.59	209.477	408.169	1.03379	1.74047	0.79549	36.8493
9	660.42	210.675	408.504	1.03799	1.73911	0.79775	35.7624
10	680.70	211.877	408.835	1.04218	1.73775	0.80002	34.7136
11	701.44	213.083	409.162	1.04637	1.73640	0.80232	33.7013
12	722.65	214.291	409.485	1.05056	1.73506	0.80465	32.7239
13	744.33	215.503	409.804	1.05474	1.73373	0.80701	31.7801
14	766.50	216.719	410.119	1.05892	1.73241	0.80939	30.8683
15	789.15	217.937	410.430	1.06309	1.73109	0.81180	29.9874
16	812.29	219.160	410.736	1.06726	1.72978	0.81424	29.1361
17	835.93	220.386	411.038	1.07142	1.72848	0.81671	28.3131
18	860.08	221.615	411.336	1.07559	1.72719	0.81922	27.5173
19	884.75	222.848	411.629	1.07974	1.72590	0.82175	26.7477
20	909.93	224.084	411.918	1.08390	1.72462	0.82431	26.0032

Table A-6 (continued)

		Enthalpy, kJ/kg		Entropy, kJ/kg · K		Specific volume, L/kg	
t, °C	P, kPa	h_f	h_g	s_f	s_g	v_f	v_g
21	935.64	225.324	412.202	1.08805	1.72334	0.82691	25.2829
22	961.89	226.568	412.481	1.09220	1.72206	0.82954	24.5857
23	988.67	227.816	412.755	1.09634	1.72080	0.83221	23.9107
24	1016.0	229.068	413.025	1.10048	1.71953	0.83491	23.2572
25	1043.9	230.324	413.289	1.10462	1.71827	0.83765	22.6242
26	1072.3	231.583	413.548	1.10876	1.71701	0.84043	22.0111
27	1101.4	232.847	413.802	1.11290	1.71576	0.84324	21.4169
28	1130.9	234.115	414.050	1.11703	1.71450	0.84610	20.8411
29	1161.1	235.387	414.293	1.12116	1.71325	0.84899	20.2829
30	1191.9	236.664	414.530	1.12530	1.71200	0.85193	19.7417
31	1223.2	237.944	414.762	1.12943	1.71075	0.85491	19.2168
32	1255.2	239.230	414.987	1.13355	1.70950	0.85793	18.7076
33	1287.8	240.520	415.207	1.13768	1.70826	0.86101	18.2135
34	1321.0	241.814	415.420	1.14181	1.70701	0.86412	17.7341
35	1354.8	243.114	415.627	1.14594	1.70576	0.86729	17.2686
36	1389.2	244.418	415.828	1.15007	1.70450	0.87051	16.8168
37	1424.3	245.727	416.021	1.15420	1.70325	0.87378	16.3779
38	1460.1	247.041	416.208	1.15833	1.70199	0.87710	15.9517
39	1496.5	248.361	416.388	1.16246	1.70073	0.88048	15.5375
40	1533.5	249.686	416.561	1.16659	1.69946	0.88392	15.1351
41	1571.2	251.016	416.726	1.17073	1.69819	0.88741	14.7439
42	1609.6	252.352	416.883	1.17486	1.69692	0.89097	14.3636
43	1648.7	253.694	417.033	1.17900	1.69564	0.89459	13.9938
44	1688.5	255.042	417.174	1.18315	1.69435	0.89828	13.6341
45	1729.0	256.396	417.308	1.18730	1.69305	0.90203	13.2841
46	1770.2	257.756	417.432	1.19145	1.69174	0.90586	12.9436
47	1812.1	259.123	417.548	1.19560	1.69043	0.90976	12.6122
48	1854.8	260.497	417.655	1.19977	1.68911	0.91374	12.2895
49	1898.2	261.877	417.752	1.20393	1.68777	0.91779	11.9753
50	1942.3	263.264	417.838	1.20811	1.68643	0.92193	11.6693
52	2032.8	266.062	417.983	1.21648	1.68370	0.93047	11.0806
54	2126.5	268.891	418.083	1.22489	1.68091	0.93939	10.5214
56	2223.2	271.754	418.137	1.23333	1.67805	0.94872	9.98952
58	2323.2	274.654	418.141	1.24183	1.67511	0.95850	9.48319
60	2426.6	277.594	418.089	1.25038	1.67208	0.96878	9.00062
62	2533.3	280.577	417.978	1.25899	1.66895	0.97960	8.54016
64	2643.5	283.607	417.802	1.26768	1.66570	0.99104	8.10023
66	2757.3	286.690	417.553	1.27647	1.66231	1.00317	7.67934
68	2874.7	289.832	417.226	1.28535	1.65876	1.01608	7.27605
70	2995.9	293.038	416.809	1.29436	1.65504	1.02987	6.88899
75	3316.1	301.399	415.299	1.31758	1.64472	1.06916	5.98334
80	3662.3	310.424	412.898	1.34223	1.63239	1.11810	5.14862
85	4036.8	320.505	409.101	1.36936	1.61673	1.18328	4.35815
90	4442.5	332.616	402.653	1.40155	1.59440	1.28230	3.56440
95	4883.5	351.767	386.708	1.45222	1.54712	1.52064	2.55133

Table A-7 Refrigerant 22: properties of superheated vapor[6]

t, °C	v, L/kg	h, kJ/kg	s, kJ/kg · K	v, L/kg	h, kJ/kg	s, kJ/kg · K	v, L/kg	h, kJ/kg	s, kJ/kg · K
	Saturation temperature, −20°C			Saturation temperature, −10°C			Saturation temperature, 0°C		
−20	92.8432	397.467	1.7841						
−15	95.1474	400.737	1.7969						
−10	97.4256	404.017	1.8095						
−5	99.6808	407.307	1.8219	65.3399	401.555	1.7671			
0	101.915	410.610	1.8341	67.0081	404.983	1.7800			
5	104.130	413.926	1.8461	68.6524	408.412	1.7927	47.1354	405.361	1.7518
10	106.328	417.258	1.8580	70.2731	411.845	1.8052	48.3899	408.969	1.7649
15	108.510	420.606	1.8697	71.8785	415.283	1.8174	49.6215	412.567	1.7777
20	110.678	423.970	1.8813	73.4644	418.730	1.8295	50.8328	416.159	1.7903
25	112.832	426.353	1.8928	75.0346	422.186	1.8414	52.0259	419.649	1.8026
				76.5904	425.653	1.8531	53.2028	423.339	1.8148
	Saturation temperature, 5°C			Saturation temperature, 10°C			Saturation temperature, 15°C		
5	40.3556	407.143	1.7446						
10	41.4580	410.851	1.7578	34.7136	408.835	1.7377			
15	42.5379	414.542	1.7708	35.6907	412.651	1.7511	29.9874	410.430	1.7311
20	43.5979	418.222	1.7834	36.6454	416.442	1.7642	30.8606	414.362	1.7556
25	44.6401	421.894	1.7958	37.5804	420.215	1.7769	31.7114	418.260	1.7578
30	45.6665	425.562	1.8080	38.4981	423.974	1.7894	32.5427	422.133	1.7707
35	46.6786	429.229	1.8200	39.4002	427.724	1.8017	33.3568	425.985	1.7833
40	47.6779	432.897	1.8319	40.2884	431.469	1.8137	34.1556	429.823	1.7956
45	48.6656	436.569	1.8435	41.1642	435.211	1.8256	34.9409	433.650	1.8078
50	49.6427	440.247	1.8550	42.0286	438.954	1.8373	35.7139	437.470	1.8197
	Saturation temperature, 20°C			Saturation temperature, 25°C			Saturation temperature, 30°C		
20	26.0032	411.918	1.7246						
25	26.7900	415.977	1.7383	22.6242	413.289	1.7183			
30	27.5542	419.991	1.7517	23.3389	417.487	1.7322	19.7417	414.530	1.7120
35	28.2989	423.970	1.7646	24.0306	421.627	1.7458	20.3962	418.881	1.7262
40	29.0264	427.922	1.7774	24.7027	425.721	1.7590	21.0272	423.159	1.7400
45	29.7389	431.852	1.7899	25.3575	429.779	1.7718	21.6381	427.378	1.7534
50	30.4379	435.766	1.8021	25.9974	433.807	1.7844	22.2316	431.549	1.7664
55	31.1250	439.668	1.8141	26.6239	437.813	1.7967	22.8101	435.683	1.7791
60	31.8012	443.561	1.8258	27.2386	441.801	1.8087	23.3733	439.787	1.7915
65	32.4678	447.450	1.8374	27.8427	445.777	1.8206	23.9288	443.867	1.8036
	Saturation temperature, 32°C			Saturation temperature, 34°C			Saturation temperature, 36°C		
35	19.0907	417.648	1.7182	17.8590	416.325	1.7099			
40	19.7093	422.014	1.7322	18.4675	420.792	1.7243	17.2953	419.483	1.7162
45	20.3062	426.310	1.7458	19.0526	425.174	1.7382	17.8708	423.961	1.7304
50	20.8847	430.549	1.7591	19.6178	429.487	1.7517	18.4247	428.358	1.7442
55	21.4471	434.743	1.7719	20.1660	433.747	1.7647	18.9603	432.690	1.7575
60	21.9956	438.900	1.7845	20.6994	437.963	1.7775	19.4802	436.970	1.7704
65	22.5318	443.028	1.7968	21.2199	442.143	1.7899	19.9865	441.207	1.7830
70	23.0571	447.133	1.8089	21.7289	446.294	1.8021	20.4807	445.410	1.7954
75	23.5726	451.219	1.8207	22.2278	450.424	1.8141	20.9643	449.586	1.8074
80	24.0794	455.292	1.8323	22.7176	454.535	1.8258	21.4385	453.739	1.8193
	Saturation temperature, 38°C			Saturation temperature, 40°C			Saturation temperature, 42°C		
40	16.1865	418.076	1.7080	15.1350	416.361	1.6995			
45	16.7545	422.664	1.7225	15.6982	421.274	1.7144	14.6964	419.779	1.7061
50	17.2991	427.155	1.7365	16.2355	425.871	1.7287	15.2286	424.496	1.7208
55	17.8240	431.568	1.7501	16.7514	430.374	1.7426	15.7373	429.101	1.7349
60	18.3320	435.918	1.7632	17.2491	434.803	1.7560	16.2264	433.617	1.7486
65	18.8255	440.218	1.7760	17.7313	439.171	1.7690	16.6987	438.062	1.7618
70	19.3063	444.477	1.7885	18.2001	443.491	1.7817	17.1568	442.449	1.7747
75	19.7760	448.703	1.8008	18.6571	447.771	1.7940	17.6024	446.788	1.7872
80	20.2358	452.901	1.8127	19.1038	452.019	1.8061	18.0371	451.090	1.7995
85				19.5412	456.241	1.8180	18.4622	455.360	1.8115
	Saturation temperature, 45°C			Saturation temperature, 50°C					
45	13.2841	417.308	1.6931						
50	13.8136	422.241	1.7084	11.6693	417.839	1.6864			
55	14.3154	427.025	1.7231	12.1721	423.028	1.7024			
60	14.7946	431.693	1.7372	12.6447	428.026	1.7175			
65	15.2550	436.268	1.7509	13.0932	432.877	1.7319			
70	15.6995	440.769	1.7641	13.5219	437.613	1.7458			
75	16.1303	445.209	1.7769	13.9342	442.258	1.7593			
80	16.5492	449.599	1.7895	14.3325	446.828	1.7723			
85	16.9578	453.950	1.8017	14.7187	451.337	1.7850			
90	17.3571	458.267	1.8137	15.0943	455.796	1.7973			