07-Mec-A1 Applied Thermodynamics and Heat Transfer

3 Hours Duration

Notes :

1. If doubt exists concerning the interpretation of any question, the candidate is urged to make assumptions and clearly explain what has been assumed along with the answer to the question.

2. The examination is open book. As a consequence, candidates are permitted to make use of any textbooks, references or notes.

3. Any non-communicating calculator is permitted. However, candidates <u>must</u> indicate the type of calculator(s) that they have used by writing the name and model designation of the calculator(s) on the inside of the cover of the first examination book.

4. It is expected that each candidate will have copies of <u>both</u> a thermodynamics text <u>and</u> a heat transfer text in order to make use of the information presented in the tables and graphs contained.

5. The answers to <u>five</u> questions, <u>either</u> three questions from Part A and two questions from Part B <u>or</u> two questions from Part A and three questions from Part B, comprise a complete examination.

6. Candidates <u>must</u> indicate the answers that they wish to have graded on the cover of the first examination book. Otherwise the answers will be graded in the order in which they appear in the examination book(s) up to a maximum of three answers per section.

7. The answer to any question carries the same value in the grading.

PART A - THERMODYNAMICS

1.   (a) A small capsule having a volume of 5 cm³ contains liquid water
     at 7.5 MPa and 60°C. The capsule is located inside an evacuated
     container having a volume of 0.025 m³. Subsequently, the capsule is
     broken by some appropriate mechanism so that the water is able to
     evaporate and fill the large container. Calculate the final density
     of the water/vapour mixture, assuming that water/vapour mixture can
     exchange heat with the surroundings through the walls of the
     container. Determine the heat exchange with the surroundings.

     (b) An air compressor takes air in at 1 atmosphere and 20°C and
     discharges it into a line having inside diameter of 1 cm. The air
     velocity in the line close to the discharge is 7 m/s and the
     discharge pressure is 3.5 atmospheres. Assuming that the
     compression occurs adiabatically and that the inlet air velocity
     is small, calculate the power required to drive the compressor.

2.   Steam enters the high pressure turbine of a reheat cycle power
     plant at 3.5 MPa and 350°C in which it is expanded to 0.5 MPa after
     which it is reheated to 350°C. The steam is then expanded through
     the low pressure turbine to 7.5 kPa. Liquid leaving the condenser
     at 30°C is pumped to 3.5 MPA and returned to the boiler. Each
     turbine is adiabatic, with an efficiency of 85%. The pump
     efficiency is 80%. If the total power output of the turbines is
     1000 kW, determine (a) the mass flowrate of steam (b) the pump
     power and (c) the thermal efficiency of the power plant.

3.   A stationary gas turbine power plant operates on the Brayton cycle
     and delivers 20,000 kW to an electric generator. The maximum
     temperature is 1200 K and the minimum temperature is 290 K. The
     maximum pressure is 380 kPa and the minimum pressure is 95 KPa.
     Determine (a) the power output of the turbine (b) the fraction of
     the output of the turbine used to drive the compressor and (c) the
     mass and volumetric flowrate of the air entering the compressor.

4.   An ideal vapour-compressor refrigeration cycle operates with Freon-
     12 as the working fluid. The evaporator temperature is 15°C and the
     condenser pressure is 1.4 MPa. The mass flowrate of the refrigerant
     is 0.008 kg/s. The compressor efficiency is 80% and the liquid
     leaves the compressor at 48 °C. Determine (a) the power required
     to drive the compressor (b) the capacity of the refrigerator and
     (c) the coefficient of performance.

PART B - HEAT TRANSFER

5. A self cleaning oven is being designed by a leading manufacturer of household appliances which features a composite window in the door of the oven comprised of two pieces of high temperature resisting plastic A and B bonded together. The thicknesses of the plastic are such that $L_A = 3 L_B$ and the thermal conductivities are $k_A = 0.18$ W/m°C and $k_B = 0.10$ W/m°C respectively. During the self cleaning process, the temperatures of the walls of the oven T_w and the air in the oven T_a may be considered to be 500°C and the temperature of the air in the room T_∞ may be considered to be 25°C. The coefficients of convection h_{ci} and radiation h_r inside of the oven as well as the coefficient of convection outside of the oven h_{co} may all be taken to be 25 W/m²°C. Determine the minimum thickness of the composite window $L_A + L_B$ needed to ensure that the temperature of the outside surface T_o is 50°C or less for safety reasons ?

6. A water heater comprised of a tube 10 mm diameter by 4 m long is subject to a uniform heat flux of 1000 W/m² at the surface. Water entering at 10°C flows through the tube at 12 kg/hr. Considering that the heat transfer coefficient varies with length along the tube as thermodynamic conditions develop, determine the rate of heat transfer and the temperature of the tube at the exit.

7. A power amplifier which may be modelled as a thin rectangular plate 40 mm high by 50 mm long for the purposes of analysis is oriented vertically in air at 25°C. The case of the power amplifier is made of anodized aluminum for which the surface emissivity is 0.82. The heat generated within the power amplifier is 7 W. Determine the temperature of the surface of the power amplifier when both natural convection and radiation heat transfer act to remove the heat.

8. Water flowing at 3.8 kg/s is heated from 38°C to 55°C in the tubes of a one shell pass / two tube pass heat exchanger. Water flowing at 1.9 kg/s enters the heat exchanger at 94°C and passes once through the shell side. The overall heat transfer coefficient is 1420 W/m²°C. The density of the water flowing in the 1.905 cm diameter tubes is 961 kg/m³ and the average water velocity is 0.386 m/s. Because of space limitations, the heat exchanger cannot exceed 2.44 m in length. Determine the number of tubes and the number of tube passes required consistent with this limitation.

The End

Thermodynamic Properties of Freon-12 (Dichlorodifluoromethane)[a]

Saturated Freon-12

Temp. °C	Abs. Press. MPa P	Specific Volume m³/kg			Enthalpy kJ/kg			Entropy kJ/kg K		
		Sat. Liquid v_f	Evap. v_{fg}	Sat. Vapor v_g	Sat. Liquid h_f	Evap. h_{fg}	Sat. Vapor h_g	Sat. Liquid s_f	Evap. s_{fg}	Sat. Vapor s_g
−90	0.0028	0.000 608	4.414 937	4.415 545	−43.243	189.618	146.375	−0.2084	1.0352	0.8268
−85	0.0042	0.000 612	3.036 704	3.037 316	−38.968	187.608	148.640	−0.1854	0.9970	0.8116
−80	0.0062	0.000 617	2.137 728	2.138 345	−34.688	185.612	150.924	−0.1630	0.9609	0.7979
−75	0.0088	0.000 622	1.537 030	1.537 651	−30.401	183.625	153.224	−0.1411	0.9266	0.7855
−70	0.0123	0.000 627	1.126 654	1.127 280	−26.103	181.640	155.536	−0.1197	0.8940	0.7744
−65	0.0168	0.000 632	0.840 534	0.841 166	−21.793	179.651	157.857	−0.0987	0.8630	0.7643
−60	0.0226	0.000 637	0.637 274	0.637 910	−17.469	177.653	160.184	−0.0782	0.8334	0.7552
−55	0.0300	0.000 642	0.490 358	0.491 000	−13.129	175.641	162.512	−0.0581	0.8051	0.7470
−50	0.0391	0.000 648	0.382 457	0.383 105	−8.772	173.611	164.840	−0.0384	0.7779	0.7396
−45	0.0504	0.000 654	0.302 029	0.302 682	−4.396	171.558	167.163	−0.0190	0.7519	0.7329
−40	0.0642	0.000 659	0.241 251	0.241 910	−0.000	169.479	169.479	−0.0000	0.7269	0.7269
−35	0.0807	0.000 666	0.194 732	0.195 398	4.416	167.368	171.784	0.0187	0.7027	0.7214
−30	0.1004	0.000 672	0.158 703	0.159 375	8.854	165.222	174.076	0.0371	0.6795	0.7165
−25	0.1237	0.000 679	0.130 487	0.131 166	13.315	163.037	176.352	0.0552	0.6570	0.7121
−20	0.1509	0.000 685	0.108 162	0.108 847	17.800	160.810	178.610	0.0730	0.6352	0.7082
−15	0.1826	0.000 693	0.090 326	0.091 018	22.312	158.534	180.846	0.0906	0.6141	0.7046
−10	0.2191	0.000 700	0.075 946	0.076 646	26.851	156.207	183.058	0.1079	0.5936	0.7014
−5	0.2610	0.000 708	0.064 255	0.064 963	31.420	153.823	185.243	0.1250	0.5736	0.6986
0	0.3086	0.000 716	0.054 673	0.055 389	36.022	151.376	187.397	0.1418	0.5542	0.6960
5	0.3626	0.000 724	0.046 761	0.047 485	40.659	148.859	189.518	0.1585	0.5351	0.6937
10	0.4233	0.000 733	0.040 180	0.040 914	45.337	146.265	191.602	0.1750	0.5165	0.6916
15	0.4914	0.000 743	0.034 671	0.035 413	50.058	143.586	193.644	0.1914	0.4983	0.6897
20	0.5673	0.000 752	0.030 028	0.030 780	54.828	140.812	195.641	0.2076	0.4803	0.6879
25	0.6516	0.000 763	0.026 091	0.026 854	59.653	137.933	197.586	0.2237	0.4626	0.6863
30	0.7449	0.000 774	0.022 734	0.023 508	64.539	134.936	199.475	0.2397	0.4451	0.6848
35	0.8477	0.000 786	0.019 855	0.020 641	69.494	131.805	201.299	0.2557	0.4277	0.6834
40	0.9607	0.000 798	0.017 373	0.018 171	74.527	128.525	203.051	0.2716	0.4104	0.6820
45	1.0843	0.000 811	0.015 220	0.016 032	79.647	125.074	204.722	0.2875	0.3931	0.6806
50	1.2193	0.000 826	0.013 344	0.014 170	84.868	121.430	206.298	0.3034	0.3758	0.6792
55	1.3663	0.000 841	0.011 701	0.012 542	90.201	117.565	207.766	0.3194	0.3582	0.6777
60	1.5259	0.000 858	0.010 253	0.011 111	95.665	113.443	209.109	0.3355	0.3405	0.6760
65	1.6988	0.000 877	0.008 971	0.009 847	101.279	109.024	210.303	0.3518	0.3224	0.6742
70	1.8858	0.000 897	0.007 828	0.008 725	107.067	104.255	211.321	0.3683	0.3038	0.6721
75	2.0874	0.000 920	0.006 802	0.007 723	113.058	99.068	212.126	0.3851	0.2845	0.6697
80	2.3046	0.000 946	0.005 875	0.006 821	119.291	93.373	212.665	0.4023	0.2644	0.6667
85	2.5380	0.000 976	0.005 029	0.006 005	125.818	87.047	212.865	0.4201	0.2430	0.6631
90	2.7885	0.001 012	0.004 246	0.005 258	132.708	79.907	212.614	0.4385	0.2200	0.6585
95	3.0569	0.001 056	0.003 508	0.004 563	140.068	71.658	211.726	0.4579	0.1946	0.6526
100	3.3440	0.001 113	0.002 790	0.003 903	148.076	61.768	209.843	0.4788	0.1655	0.6444
105	3.6509	0.001 197	0.002 045	0.003 242	157.085	49.014	206.099	0.5023	0.1296	0.6319
110	3.9784	0.001 364	0.001 098	0.002 462	168.059	28.425	196.484	0.5322	0.0742	0.6064
112	4.1155	0.001 792	0.000 005	0.001 797	174.920	0.151	175.071	0.5651	0.0004	0.5655

Superheated Freon-12

Temp. °C	v m³/kg	h kJ/kg	s kJ/kg K	v m³/kg	h kJ/kg	s kJ/kg K	v m³/kg	h kJ/kg	s kJ/kg K
	0.05 MPa			0.10 MPa			0.15 MPa		
−20.0	0.341 857	181.042	0.7912	0.167 701	179.861	0.7401	0.114 716	184.619	0.7318
−10.0	0.356 227	186.757	0.8133	0.175 222	185.707	0.7628	0.119 866	190.660	0.7543
0.0	0.370 508	192.567	0.8350	0.182 647	191.628	0.7849	0.124 932	196.762	0.7763
10.0	0.384 716	198.471	0.8562	0.189 994	197.628	0.8064	0.129 930	202.927	0.7977
20.0	0.398 863	204.469	0.8770	0.197 277	203.707	0.8275	0.134 873	209.160	0.8186
30.0	0.412 959	210.557	0.8974	0.204 506	209.866	0.8482	0.139 768	215.463	0.8390
40.0	0.427 012	216.733	0.9175	0.211 691	216.104	0.8684	0.144 625	221.835	0.8591
50.0	0.441 030	222.997	0.9372	0.218 839	222.421	0.8883	0.149 450	228.277	0.8787
60.0	0.455 017	229.344	0.9565	0.225 955	228.815	0.9078	0.154 247	234.789	0.8980
70.0	0.468 978	235.774	0.9755	0.233 044	235.285	0.9269	0.159 020	241.371	0.9169
80.0	0.482 917	242.282	0.9942	0.240 111	241.829	0.9457	0.163 774	248.020	0.9354
90.0	0.496 838	248.868	1.0126	0.247 159	248.446	0.9642			

Temp. °C	v m³/kg	h kJ/kg	s kJ/kg K	v m³/kg	h kJ/kg	s kJ/kg K	v m³/kg	h kJ/kg	s kJ/kg K
	0.20 MPa			0.25 MPa			0.30 MPa		
0.0	0.088 608	189.669	0.7320	0.069 752	188.644	0.7139	0.057 150	187.583	0.6984
10.0	0.092 550	195.878	0.7543	0.073 024	194.969	0.7366	0.059 984	194.034	0.7216
20.0	0.096 418	202.135	0.7760	0.076 218	201.322	0.7587	0.062 734	200.490	0.7440
30.0	0.100 228	208.446	0.7972	0.079 350	207.715	0.7801	0.065 418	206.969	0.7658
40.0	0.103 989	214.814	0.8178	0.082 431	214.153	0.8010	0.068 049	213.480	0.7869
50.0	0.107 710	221.243	0.8381	0.085 470	220.642	0.8214	0.070 635	220.030	0.8075
60.0	0.111 397	227.735	0.8578	0.088 474	227.185	0.8413	0.073 185	226.627	0.8276
70.0	0.115 055	234.291	0.8772	0.091 449	233.785	0.8608	0.075 705	233.273	0.8473
80.0	0.118 690	240.910	0.8962	0.094 398	240.443	0.8800	0.078 200	239.971	0.8665
90.0	0.122 304	247.593	0.9149	0.097 327	247.160	0.8987	0.080 673	246.723	0.8853
100.0	0.125 901	254.339	0.9332	0.100 238	253.936	0.9171	0.083 127	253.530	0.9038
110.0	0.129 483	261.147	0.9512	0.103 134	260.770	0.9352	0.085 566	260.391	0.9220

Temp. °C	v m³/kg	h kJ/kg	s kJ/kg K	v m³/kg	h kJ/kg	s kJ/kg K	v m³/kg	h kJ/kg	s kJ/kg K
	0.40 MPa			0.50 MPa			0.60 MPa		
20.0	0.045 836	198.762	0.7199	0.035 646	196.935	0.6999			
30.0	0.047 971	205.428	0.7423	0.037 464	203.814	0.7230	0.030 422	202.116	0.7063
40.0	0.050 046	212.095	0.7639	0.039 214	210.656	0.7452	0.031 966	209.154	0.7291
50.0	0.052 072	218.779	0.7849	0.040 911	217.484	0.7667	0.033 450	216.141	0.7511
60.0	0.054 059	225.488	0.8054	0.042 565	224.315	0.7875	0.034 887	223.104	0.7723
70.0	0.056 014	232.230	0.8253	0.044 184	231.161	0.8077	0.036 285	230.062	0.7929
80.0	0.057 941	239.012	0.8448	0.045 774	238.031	0.8275	0.037 653	237.027	0.8129
90.0	0.059 846	245.837	0.8638	0.047 340	244.932	0.8467	0.038 995	244.009	0.8324
100.0	0.061 731	252.707	0.8825	0.048 886	251.869	0.8656	0.040 316	251.016	0.8514
110.0	0.063 600	259.624	0.9008	0.050 415	258.845	0.8840	0.041 619	258.053	0.8700
120.0	0.065 455	266.590	0.9187	0.051 929	265.862	0.9021	0.042 907	265.124	0.8882
130.0	0.067 298	273.605	0.9364	0.053 430	272.923	0.9198	0.044 181	272.231	0.9061

Temp. °C	v m³/kg	h kJ/kg	s kJ/kg K	v m³/kg	h kJ/kg	s kJ/kg K	v m³/kg	h kJ/kg	s kJ/kg K
	0.70 MPa			0.80 MPa			0.90 MPa		
40.0	0.026 761	207.580	0.7148	0.022 830	205.924	0.7016	0.019 744	204.170	0.6982
50.0	0.028 100	214.745	0.7373	0.024 068	213.290	0.7248	0.020 912	211.765	0.7131
60.0	0.029 387	221.854	0.7590	0.025 247	220.558	0.7469	0.022 012	219.212	0.7358
70.0	0.030 632	228.931	0.7799	0.026 380	227.766	0.7682	0.023 062	226.564	0.7575
80.0	0.031 843	235.997	0.8002	0.027 477	234.941	0.7888	0.024 072	233.856	0.7785
90.0	0.033 027	243.066	0.8199	0.028 545	242.101	0.8088	0.025 051	241.113	0.7987
100.0	0.034 189	250.146	0.8392	0.029 588	249.260	0.8283	0.026 005	248.355	0.8184
110.0	0.035 332	257.247	0.8579	0.030 612	256.428	0.8472	0.026 937	255.593	0.8376
120.0	0.036 458	264.374	0.8763	0.031 619	263.613	0.8657	0.027 851	262.839	0.8562
130.0	0.037 572	271.531	0.8943	0.032 612	270.820	0.8838	0.028 751	270.100	0.8745
140.0	0.038 673	278.720	0.9119	0.033 592	278.055	0.9016	0.029 639	277.381	0.8923
150.0	0.039 764	285.946	0.9292	0.034 563	285.320	0.9189	0.030 515	284.687	0.9098

Temp. °C	v m³/kg	h kJ/kg	s kJ/kg K	v m³/kg	h kJ/kg	s kJ/kg K	v m³/kg	h kJ/kg	s kJ/kg K
	1.00 MPa			1.20 MPa			1.40 MPa		
50.0	0.018 366	210.162	0.7021	0.014 483	206.661	0.6812			
60.0	0.019 410	217.810	0.7254	0.015 463	214.805	0.7060	0.012 579	211.457	0.6876
70.0	0.020 397	225.319	0.7476	0.016 368	222.687	0.7293	0.013 448	219.822	0.7123
80.0	0.021 341	232.739	0.7689	0.017 221	230.398	0.7514	0.014 247	227.891	0.7355
90.0	0.022 251	240.101	0.7895	0.018 032	237.995	0.7727	0.014 997	235.766	0.7575
100.0	0.023 133	247.430	0.8094	0.018 812	245.518	0.7931	0.015 710	243.512	0.7785
110.0	0.023 993	254.743	0.8287	0.019 567	252.993	0.8129	0.016 393	251.170	0.7988
120.0	0.024 835	262.053	0.8475	0.020 301	260.441	0.8320	0.017 053	258.770	0.8183
130.0	0.025 661	269.369	0.8659	0.021 018	267.875	0.8507	0.017 695	266.334	0.8373
140.0	0.026 474	276.699	0.8839	0.021 721	275.307	0.8689	0.018 321	273.877	0.8558
150.0	0.027 275	284.047	0.9015	0.022 412	282.745	0.8867	0.018 934	281.411	0.8738
160.0	0.028 068	291.419	0.9187	0.023 093	290.195	0.9041	0.019 535	288.946	0.8914

Temp. °C	v m³/kg	h kJ/kg	s kJ/kg K	v m³/kg	h kJ/kg	s kJ/kg K	v m³/kg	h kJ/kg	s kJ/kg K
	1.60 MPa			1.80 MPa			2.00 MPa		
70.0	0.011 208	216.650	0.6959	0.009 406	213.049	0.6794			
80.0	0.011 984	225.177	0.7204	0.010 187	222.198	0.7057	0.008 704	218.859	0.6909
90.0	0.012 698	233.390	0.7433	0.010 884	230.835	0.7298	0.009 406	228.056	0.7166
100.0	0.013 366	241.597	0.7651	0.011 526	239.155	0.7524	0.010 035	236.760	0.7402
110.0	0.014 000	249.264	0.7859	0.012 126	247.264	0.7739	0.010 615	245.154	0.7624
120.0	0.014 608	257.035	0.8059	0.012 697	255.228	0.7944	0.011 159	253.341	0.7835
130.0	0.015 195	264.742	0.8253	0.013 244	263.094	0.8141	0.011 676	261.584	0.8037
140.0	0.015 765	272.406	0.8440	0.013 772	270.891	0.8332	0.012 172	269.327	0.8232
150.0	0.016 320	280.044	0.8623	0.014 284	278.642	0.8518	0.012 651	277.201	0.8420