

NATIONAL EXAMINATIONS MAY 2003

98-Mec-A1 Applied Thermodynamics and Heat Transfer

3 Hours Duration

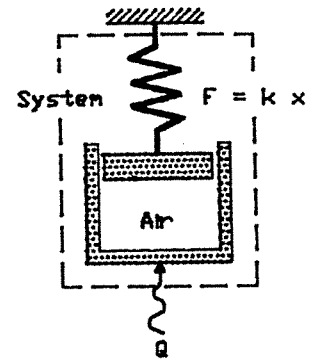
Notes :

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 must 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 both a thermodynamics text and a heat transfer text in order to make use of the information presented in the tables and graphs contained.
5. The answers to five questions, either three questions from Part A and two questions from Part B or two questions from Part A and three questions from Part B, comprise a complete examination.
6. Candidates must 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.

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PART A - THERMODYNAMICS

1.(a) Air is contained in a piston cylinder arrangement as depicted with a cross sectional area of 0.04 cm^2 and an initial volume of 20 cm^3 . The air is initially at 1 atmosphere pressure and 20°C . A spring having a spring constant of 100 N/cm which is connected to the piston is initially undeformed. How much heat must be added to the air to increase the pressure to 3 atmospheres? The apparatus is surrounded by air at 1 atmosphere.



(b) Water is pumped adiabatically from $T_1 = 40^\circ\text{C}$ and $p_1 = 6.8$ atmospheres to $p_2 = 68.0$ atmospheres at the rate of $\dot{w} = 35 \text{ kg/min}$. Assuming that water is very nearly incompressible, derive the relationship $\dot{w} \approx \dot{m} v_1 (p_2 - p_1)$ for the power required to pump the water and show that $\dot{w} = 3772 \text{ W}$ under these circumstances.

2. A reciprocating compressor receives atmospheric air at 1 atmosphere and 20°C which it discharges at 3 atmospheres. The clearance volume is 5 percent of the piston displacement and the compression and expansion processes are assumed to occur isentropically. Determine
 - (a) The piston displacement in cubic meters per minute required to compress 2.85 cubic meters of air / minute at inlet conditions.
 - (b) The volumetric efficiency of the ideal air compressor cycle.
 - (c) The power required to compress the air under these conditions.

3. A Brayton cycle receives air at a pressure of 1 atmosphere and a temperature of 20°C . The upper pressure and temperature limits of the cycle are 4 atmospheres and 815°C respectively. The efficiency of the compressor is 85% and the efficiency of the turbine is 90%.
 - (a) Determine the thermal efficiency of the Brayton cycle.
 - (b) Determine the thermal efficiency of the Brayton cycle after a regenerator having an efficiency of 83% has been installed.

4. An automobile air conditioner uses a Freon 12 refrigeration system. The evaporator temperature at high speed driving conditions may be as low as -7°C while the saturation temperature in the condenser may be as high as 60°C . Calculate the power required to produce 10 kW of cooling with a compressor efficiency of 80%. What is the coefficient of performance under these conditions?

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PART B HEAT TRANSFER

5. A hot steam pipe 0.3 m outside diameter was covered with a 0.025 m thick layer of insulation A and a 0.04 m thick layer of insulation B. The temperature of the outer surface of the pipe was found to be 400°C and the temperature of the outer surface of insulation B was found to be 40°C under these conditions. After an additional 0.02 m thick layer of insulation C having thermal conductivity 0.2 W/m°C was added to the outer surface of insulation B, the temperature of the outer surface of the pipe was found to be 500°C, the temperature of the outer surface temperature of insulation B was found to be 180°C and the temperature of the outer surface of insulation C was found to be 30°C. Determine the rate of heat loss per meter length before and after the addition of insulation C.

6. A 0.3 m square stainless steel hot gas duct 30 m in length with a wall thickness of 2 mm is coated with ceramic 38 mm thick. The heat transfer coefficient at the surface between the gas and the stainless steel is 100 W/m²°C and the heat transfer coefficient at the surface between the ceramic and the surroundings is 10 W/m²°C. The temperature of the surroundings is 20°C. The thermal conductivity of the stainless steel and the ceramic are 25 W/m°C and 0.2 W/m°C respectively and the specific heat of the gas is 1100 J/kg°C. The gas flows at 1.5 kg/s and enters the duct at 800°C. Determine bulk mean temperature of the gas at the exit.

7. Frost forms on a grapefruit when the temperature of its surface reaches 0°C. At night, the grapefruit is assumed to be completely surrounded by the night sky acting as a black body at -45°C. The emissivity of the grapefruit is approximately 0.93 while the heat transfer coefficient between the grapefruit and the air surrounding it is 17 W/m²°C. The grapefruit may be assumed to be at steady state without internal heat generation and energy conduction up the stem may be neglected. Determine the lowest temperature to which the air can fall during the night without frost formation occurring.

8. A fluid having a specific heat of 800 J/kg°C flowing at 2.4 kg/s enters a counterflow heat exchanger at 300°C where it is heated to 700°C by a fluid having a specific heat of 960 J/kg°C flowing at 2.0 kg/s which enters the counterflow heat exchanger at 1000°C. If all of these values and the overall heat transfer coefficient remain the same, determine by how much the heat exchanger surface area would have to be increased in order for the cooler fluid to be heated to 800°C.

The End

Thermodynamic Properties of Freon-12 (Dichlorodifluoromethane)*

Saturated Freon-12

Temp. °C	Abs. Press. MPa P	Specific Volume m ³ /kg			Enthalpy kJ/kg			Entropy kJ/kg K		
		Sat. Liquid <i>v_f</i>	Evap. <i>v_{fg}</i>	Sat. Vapor <i>v_g</i>	Sat. Liquid <i>h_f</i>	Evap. <i>h_{fg}</i>	Sat. Vapor <i>h_g</i>	Sat. Liquid <i>s_f</i>	Evap. <i>s_{fg}</i>	Sat. Vapor <i>s_g</i>
-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

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