NATIONAL EXAMINATIONS DECEMBER 2018

16-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) A closed vessel containing 0.06 m^3 at air at 40 atmospheres and 40°C is connected with another closed vessel containing 1.35 kg of argon at 7 atmospheres. When the valve separating these vessels is opened, the pressure of the mixture is 18 atmospheres and its temperature is 30°C. Determine the volume of the vessel containing the argon and the temperature of the argon prior to mixing.

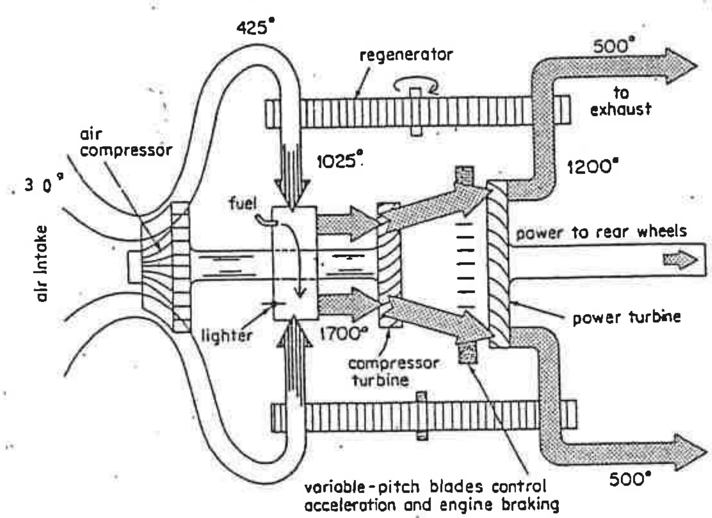
   (b) A machine operates on an ideal cycle comprised of isentropic compression of the working substance, isometric heat addition to the working substance, isentropic expansion of the working substance and isometric heat rejection from the working substance. The working substance is assumed to be air with γ = 1.4 and R = 0.287 kJ/kgK. At the beginning of the compression process, the pressure is 138 kPa and the temperature is 37°C. The compression ratio is 8:1 and the maximum temperature in the cycle is 1772 K. Compute the other temperatures and pressures and indicate these values on a P-v and a T-s diagram for the cycle. What is the thermal efficiency of the cycle ? Determine the power output corresponding to a heat addition of 370 W.

2. (a) Steam under a pressure of 1 MPa enters a throttling calorimeter and emerges as superheated steam at atmospheric pressure with a temperature of 150°C. What is the quality of the wet steam ?

   (b) The steam enters a turbine with a velocity of 1.5 m/s and leaves at 7.5 kPa and 78.3% quality with a velocity of 90 m/s while the heat loss is 527 W and the flowrate is 0.45 kg/s. What power will be developed ?

   (c) It can easily be seen by consulting the steam tables that the process is isentropic, despite the fact that heat was lost by the turbine. Explain how this is possible.

3. The diagram at the right is illustrative of a gas turbine power plant being developed for use in an automobile. Assuming that the temperatures indicated have been expressed in degrees Celsius (a) draw a schematic diagram for the gas turbine power plant (b) indicate each of the processes on a T-s diagram (c) calculate the thermal efficiency for the operating conditions given and (d) determine the air flowrate required to develop 50 kW at the rear axle of the car.



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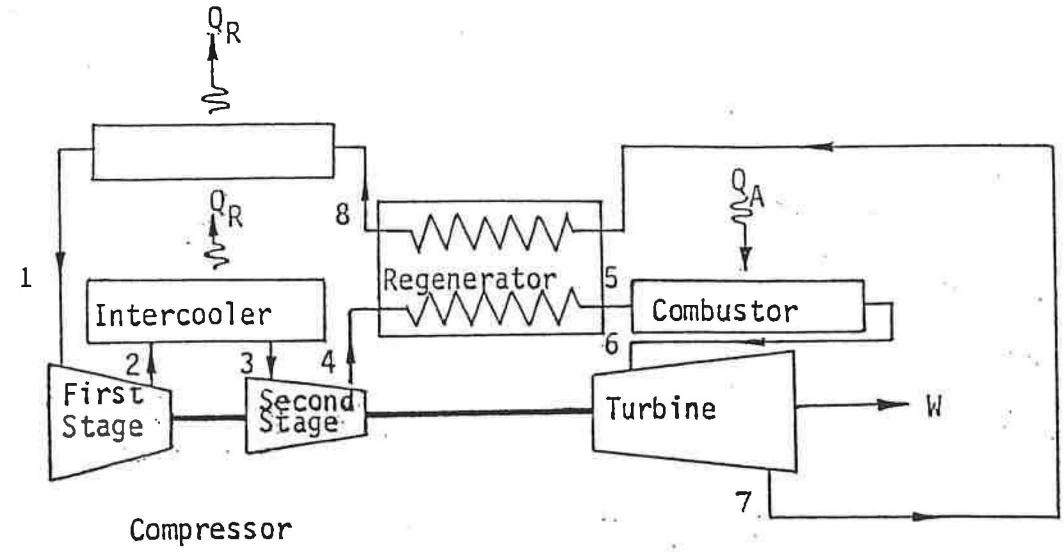

4. An ice-making refrigeration plant having a capacity of 70 kW of refrigeration operates with ammonia as the refrigerant. The evaporator operates at -15°C and the ammonia condenses at 31°C. Assuming that the compressor has an efficiency of 95% and neglecting piping losses, determine the power required per kW of refrigeration and the coefficient of performance. If cooling water enters the condenser at 20°C and leaves the condenser at 27°C, what cooling water flowrate is required ?

PART B - HEAT TRANSFER

5. A steel tube 150 mm I.D. x 10 mm W.T. conveys wet steam at 200°C and is surrounded by air at 27°C. The loss of heat under these conditions is 2000 W per metre of length. Determine the loss of heat when the pipe is covered by a 50 mm thick layer of insulation, when the conductivities of the insulation and the pipe are respectively 0.35 W/m°C and 45 W/m°C and the heat transfer coefficient between metal and air is 40% greater than the heat transfer coefficient between insulation and air.

6. Heat is generated in a 75 mm diameter cylindrical electrical conductor made of a material having a thermal conductivity of 70 W/m°C which is located in a fluid having a temperature of 27°C. The surface heat transfer coefficient is 568 W/m²°C and the temperature must not exceed 540°C anywhere in the cylinder.

   (a) Determine the maximum heat generation rate per unit length.

   (b) Determine the surface temperature under these conditions.

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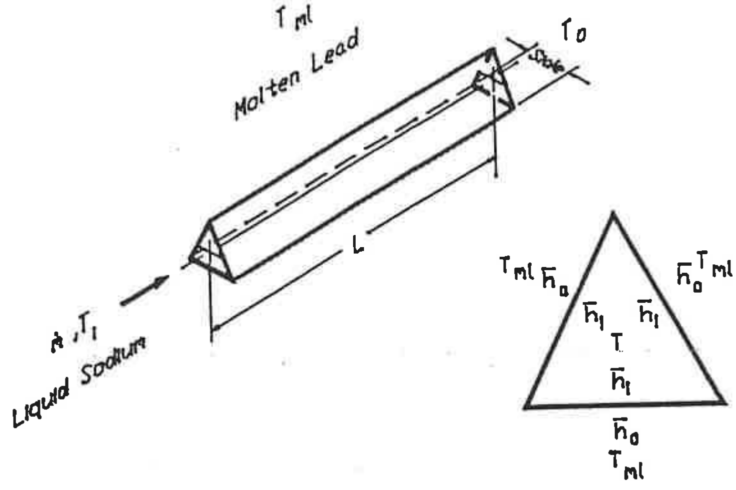
7. A device is to be built that will be capable of transferring heat from a pool of molten lead at 600 K to liquid sodium at 478 K entering an equilateral triangular duct immersed in the pool which is 4 m long by 3 cm on a side. The liquid sodium flows through the duct at 3.6 kg/s and the specific heat of liquid sodium is 1340 J/kg°C. Given that the heat transfer coefficient inside the duct $\bar{h}_i$ = 89,140 W/m²°C and that the heat transfer coefficient outside the duct $\bar{h}_o$ = 8687 W/m²°C, determine



(i) the temperature at which the liquid sodium leaves the duct

(ii) the heat transfer between the molten lead and the liquid sodium

8. Water flowing at 10 kg/s through 50 brass tubes 2.3 cm ID by 2.6 cm OD heats air flowing at 1.6 kg/s through a shell within which the tubes are located in parallel. Each tube is 6.7 m long. The heat transfer coefficients inside and outside the tubes are 470 W/m²°C and 210 W/m²°C respectively. The water enters the tubes at 75°C and the air enters the shell at 15°C. Determine the heat exchanger effectiveness, the rate of heat transfer between the water and the air and the outlet temperatures of the water and the air.

The End

Thermodynamic Properties of Ammonia

Saturated Ammonia

Temp. °C	Abs. Press. kPa P	Specific Volume m³/kg Sat. Liquid v_f	Evap. v_{fg}	Sat. Vapor v_g	Enthalpy kJ/kg Sat. Liquid h_f	Evap. h_{fg}	Sat. Vapor h_g	Entropy kJ/kg K Sat. Liquid s_f	Evap. s_{fg}	Sat. Vapor s_g
−50	40.88	0.001 424	2.6239	2.6254	−44.3	1416.7	1372.4	−0.1942	6.3502	6.1561
−48	45.96	0.001 429	2.3518	2.3533	−35.5	1411.3	1375.8	−0.1547	6.2696	6.1149
−46	51.55	0.001 434	2.1126	2.1140	−26.6	1405.8	1379.2	−0.1156	6.1902	6.0746
−44	57.69	0.001 439	1.9018	1.9032	−17.8	1400.3	1382.5	−0.0768	6.1120	6.0352
−42	64.42	0.001 444	1.7155	1.7170	−8.9	1394.7	1385.8	−0.0382	6.0349	5.9967
−40	71.77	0.001 449	1.5506	1.5521	0.0	1389.0	1389.0	0.0000	5.9589	5.9589
−38	79.80	0.001 454	1.4043	1.4058	8.9	1383.3	1392.2	0.0380	5.8840	5.9220
−36	88.54	0.001 460	1.2742	1.2757	17.8	1377.6	1395.4	0.0757	5.8101	5.8858
−34	98.05	0.001 465	1.1582	1.1597	26.8	1371.8	1398.5	0.1132	5.7372	5.8504
−32	108.37	0.001 470	1.0547	1.0562	35.7	1365.9	1401.6	0.1504	5.6652	5.8156
−30	119.55	0.001 476	0.9621	0.9635	44.7	1360.0	1404.6	0.1873	5.5942	5.7815
−28	131.64	0.001 481	0.8790	0.8805	53.6	1354.0	1407.6	0.2240	5.5241	5.7481
−26	144.70	0.001 487	0.8044	0.8059	62.6	1347.9	1410.5	0.2605	5.4548	5.7153
−24	158.78	0.001 492	0.7373	0.7388	71.6	1341.8	1413.4	0.2967	5.3864	5.6831
−22	173.93	0.001 498	0.6768	0.6783	80.7	1335.6	1416.2	0.3327	5.3188	5.6515
−20	190.22	0.001 504	0.6222	0.6237	89.7	1329.3	1419.0	0.3684	5.2520	5.6205
−18	207.71	0.001 510	0.5728	0.5743	98.8	1322.9	1421.7	0.4040	5.1860	5.5900
−16	226.45	0.001 515	0.5280	0.5296	107.8	1316.5	1424.4	0.4393	5.1207	5.5600
−14	246.51	0.001 521	0.4874	0.4889	116.9	1310.0	1427.0	0.4744	5.0561	5.5305
−12	267.95	0.001 528	0.4505	0.4520	126.0	1303.5	1429.5	0.5093	4.9922	5.5015
−10	290.85	0.001 534	0.4169	0.4185	135.2	1296.8	1432.0	0.5440	4.9290	5.4730
−8	315.25	0.001 540	0.3863	0.3878	144.3	1290.1	1434.4	0.5785	4.8664	5.4449
−6	341.25	0.001 546	0.3583	0.3599	153.5	1283.3	1436.8	0.6128	4.8045	5.4173
−4	368.90	0.001 553	0.3328	0.3343	162.7	1276.4	1439.1	0.6469	4.7432	5.3901
−2	398.27	0.001 559	0.3094	0.3109	171.9	1269.4	1441.3	0.6808	4.6825	5.3633
0	429.44	0.001 566	0.2879	0.2895	181.1	1262.4	1443.5	0.7145	4.6223	5.3369
2	462.49	0.001 573	0.2683	0.2698	190.4	1255.2	1445.6	0.7481	4.5627	5.3108
4	497.49	0.001 580	0.2502	0.2517	199.6	1248.0	1447.6	0.7815	4.5037	5.2852
6	534.51	0.001 587	0.2335	0.2351	208.9	1240.6	1449.6	0.8148	4.4451	5.2599
8	573.64	0.001 594	0.2182	0.2198	218.3	1233.2	1451.5	0.8479	4.3871	5.2350
10	614.95	0.001 601	0.2040	0.2056	227.6	1225.7	1453.3	0.8808	4.3295	5.2104
12	658.52	0.001 608	0.1910	0.1926	237.0	1218.1	1455.1	0.9136	4.2725	5.1861
14	704.44	0.001 616	0.1789	0.1805	246.4	1210.4	1456.8	0.9463	4.2159	5.1621
16	752.79	0.001 623	0.1677	0.1693	255.9	1202.6	1458.5	0.9788	4.1597	5.1385
18	803.66	0.001 631	0.1574	0.1590	265.4	1194.7	1460.0	1.0112	4.1039	5.1151
20	857.12	0.001 639	0.1477	0.1494	274.9	1186.7	1461.5	1.0434	4.0486	5.0920
22	913.27	0.001 647	0.1388	0.1405	284.4	1178.5	1462.9	1.0755	3.9937	5.0692
24	972.19	0.001 655	0.1305	0.1322	294.0	1170.3	1464.3	1.1075	3.9392	5.0467
26	1033.97	0.001 663	0.1228	0.1245	303.6	1162.0	1465.6	1.1394	3.8850	5.0244
28	1098.71	0.001 671	0.1156	0.1173	313.2	1153.6	1466.8	1.1711	3.8312	5.0023
30	1166.49	0.001 680	0.1089	0.1106	322.9	1145.0	1467.9	1.2028	3.7777	4.9805
32	1237.41	0.001 689	0.1027	0.1044	332.6	1136.4	1469.0	1.2343	3.7246	4.9589
34	1311.55	0.001 698	0.0969	0.0986	342.3	1127.6	1469.9	1.2656	3.6718	4.9374
36	1389.03	0.001 707	0.0914	0.0931	352.1	1118.7	1470.8	1.2969	3.6192	4.9161
38	1469.92	0.001 716	0.0863	0.0880	361.9	1109.7	1471.5	1.3281	3.5669	4.8950
40	1554.33	0.001 726	0.0815	0.0833	371.7	1100.5	1472.2	1.3591	3.5148	4.8740
42	1642.35	0.001 735	0.0771	0.0788	381.6	1091.2	1472.8	1.3901	3.4630	4.8530
44	1734.09	0.001 745	0.0728	0.0746	391.5	1081.7	1473.2	1.4209	3.4112	4.8322
46	1829.65	0.001 756	0.0689	0.0707	401.5	1072.0	1473.5	1.4518	3.3595	4.8113
48	1929.13	0.001 766	0.0652	0.0669	411.5	1062.2	1473.7	1.4826	3.3079	4.7905
50	2032.62	0.001 777	0.0617	0.0635	421.7	1052.0	1473.7	1.5135	3.2561	4.7696

Superheated Ammonia

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
	p = 12.0 bars = 1.20 MPa (T_{sat} = 30.94°C)				p = 14.0 bars = 1.40 MPa (T_{sat} = 36.26°C)			
Sat.	0.10751	1337.52	1466.53	4.9625	0.09231	1339.56	1468.79	4.9050
40	0.11287	1359.73	1495.18	5.0553	0.09432	1349.29	1481.33	4.9453
60	0.12378	1404.54	1553.07	5.2347	0.10423	1396.97	1542.89	5.1360
80	0.13387	1445.91	1606.56	5.3906	0.11324	1440.06	1598.59	5.2984
100	0.14347	1485.55	1657.71	5.5315	0.12172	1480.79	1651.20	5.4433
120	0.15275	1524.41	1707.71	5.6620	0.12986	1520.41	1702.21	5.5765
140	0.16181	1563.09	1757.26	5.7850	0.13777	1559.63	1752.52	5.7013
160	0.17072	1601.95	1806.81	5.9021	0.14552	1598.92	1802.65	5.8198
180	0.17950	1641.23	1856.63	6.0145	0.15315	1638.53	1852.94	5.9333
200	0.18819	1681.05	1906.87	6.1230	0.16068	1678.64	1903.59	6.0427
220	0.19680	1721.50	1957.66	6.2282	0.16813	1719.35	1954.73	6.1485
240	0.20534	1762.63	2009.04	6.3303	0.17551	1760.72	2006.43	6.2513
260	0.21382	1804.48	2061.06	6.4297	0.18283	1802.78	2058.75	6.3513
280	0.22225	1847.04	2113.74	6.5267	0.19010	1845.55	2111.69	6.4488

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
	p = 16.0 bars = 1.60 MPa (T_{sat} = 41.03°C)				p = 18.0 bars = 1.80 MPa (T_{sat} = 45.38°C)			
Sat.	0.08079	1340.97	1470.23	4.8542	0.07174	1341.88	1471.01	4.8086
60	0.08951	1389.06	1532.28	5.0461	0.07801	1380.77	1521.19	4.9627
80	0.09774	1434.02	1590.40	5.2156	0.08565	1427.79	1581.97	5.1399
100	0.10539	1475.93	1644.56	5.3648	0.09267	1470.97	1637.78	5.2937
120	0.11268	1516.34	1696.64	5.5008	0.09931	1512.22	1690.98	5.4326
140	0.11974	1556.14	1747.72	5.6276	0.10570	1552.61	1742.88	5.5614
160	0.12663	1595.85	1798.45	5.7475	0.11192	1592.76	1794.23	5.6828
180	0.13339	1635.81	1849.23	5.8621	0.11801	1633.08	1845.50	5.7985
200	0.14005	1676.21	1900.29	5.9723	0.12400	1673.78	1896.98	5.9096
220	0.14663	1717.18	1951.79	6.0789	0.12991	1715.00	1948.83	6.0170
240	0.15314	1758.79	2003.81	6.1823	0.13574	1756.85	2001.18	6.1210
260	0.15959	1801.07	2056.42	6.2829	0.14152	1799.35	2054.08	6.2222
280	0.16599	1844.05	2109.64	6.3809	0.14724	1842.55	2107.58	6.3207

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
	p = 20.0 bars = 2.00 MPa (T_{sat} = 49.37°C)			
Sat.	0.06445	1342.37	1471.26	4.7670
60	0.06875	1372.05	1509.54	4.8838
80	0.07596	1421.36	1573.27	5.0696
100	0.08248	1465.89	1630.86	5.2283
120	0.08861	1508.03	1685.24	5.3703
140	0.09447	1549.03	1737.98	5.5012
160	0.10016	1589.65	1789.97	5.6241
180	0.10571	1630.32	1841.74	5.7409
200	0.11116	1671.33	1893.64	5.8530
220	0.11652	1712.82	1945.87	5.9611
240	0.12182	1754.90	1998.54	6.0658
260	0.12706	1797.63	2051.74	6.1675
280	0.13224	1841.03	2105.50	6.2665