NATIONAL EXAMINATIONS MAY 2010

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 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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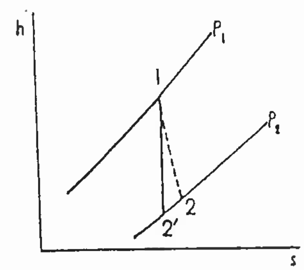
PART A - THERMODYNAMICS

1. Steam expands in a turbine from 7.0 MPa and 450°C to 7.5 kPa. The inlet steam velocity is 45 m/s. The outlet enthalpy and velocity are 2250 kJ/kg and 90 m/s.



(a) Determine the actual turbine work assuming that any transfer of heat with the environment is negligible.

(b) Determine the maximum turbine work if the turbine exchanges heat with the environment at 0.1 MPa and 15°C.

(c) Determine the work achievable by adiabatic expansion from the initial state 7.0 MPa and 450°C to a pressure of 7.0 kPa.

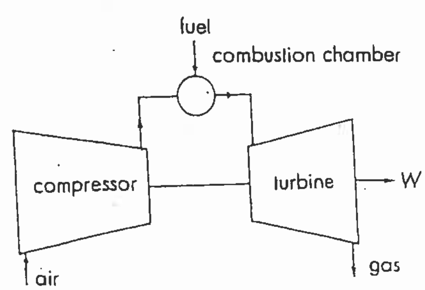
(d) Explain why it is more appropriate to define thermodynamic efficiency of the turbine as the ratio of actual turbine work to the adiabatic turbine work rather than ratio of actual turbine work to the maximum turbine work.

2. Air enters a centrifugal compressor at 300 K and 0.1 MPa at a flowrate of 9 kg/min through a pipe located 0.6 m above the ground with a flow area of 0.0195 m^2. The air leaves at 450 K and 0.34 MPa through a pipe located 1.2 m above the ground that has a flow area of 0.0065 m^2. The surface area of the compressor is about 2.75 m^2, the surface temperature is approximately 305 K and the heat transfer coefficient at the surface is estimated to be 11 $W/m^2\,°C$.

(a) Draw the process on p-v coordinates and indicate how the process differs from an ideal process by drawing isentropic curves through the initial and final points.

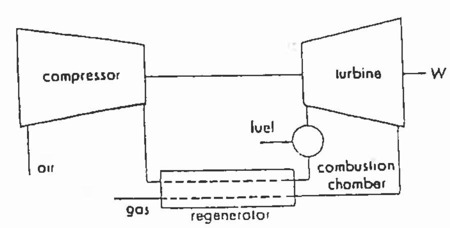
(b) Determine the rate at which work is done on the air by the air compressor.

3. Air at 100 kPa enters a gas turbine power plant with a 6:1 pressure ratio which operates on the air-standard Brayton cycle between 15°C and 840°C.



(a) Determine the thermal efficiency of the cycle, the heat supplied, the net heat rejection, the compressor work, the turbine work and the net work.

(b) Assuming adiabatic compression and expansion processes, repeat the calculations for a compressor efficiency of 85% and a turbine efficiency of 90%.



(c) Calculate the thermal efficiency attainable if a regenerative heat exchanger were to be installed between the turbine exhaust and compressed air streams.

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4. A water chiller provides 100 tons @ 3.516 kW/ton of refrigeration to cool water to a temperature of 12.10°C for an air conditioning system. The heat extracted from the water is to be rejected in a cooling tower at 35.4°C. Assuming that the chiller operates on an ideal vapour refrigeration cycle with the temperature in the evaporator equal to the chilled water temperature and the saturation temperature in the condenser equal to the cooling tower water temperature, determine (a) the refrigeration effect in kJ/kg (b) the refrigerant circulation rate in kg/s (c) the power required to drive the compressor in kW (d) the heat rejected in kW and (e) the coefficient of performance COP using the thermodynamic tables for R134A accompanying this examination to determine the thermophysical properties of the refrigerant that are required in the analysis.

PART B - HEAT TRANSFER

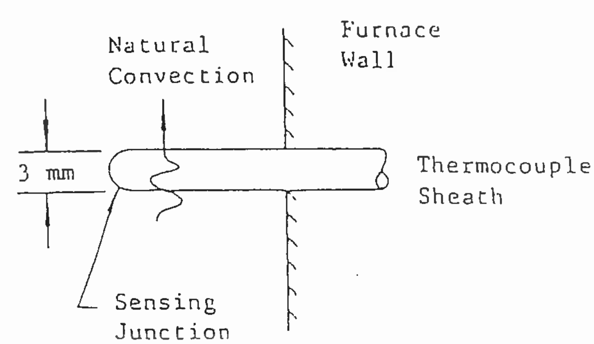
5. Liquid refrigerant at 15°C leaves the compressor and goes to the throttling valve in a refrigeration system through a 2.5 cm outside diameter copper tube which passes through surroundings at 29°C. You have been asked to give advice on minimizing the transfer of heat between the surroundings and the refrigerant. There are three possible courses of action available to you which are respectively (a) to insulate the tube with a foam rubber sleeve 19.5 mm thick having thermal conductivity 0.16 W/m°C (b) to mould a cylindrical covering of asbestos impregnated plastic insulation having thermal conductivity 0.25 W/m°C around the tube of any thickness that you deem to be suitable or (c) to do nothing at all. The outside heat transfer coefficient is estimated to be about 7.0 W/m^2°C. What thickness of asbestos impregnated plastic insulation would give the same value of heat transfer ? What course of action do you recommend ?

6. Water at T_{bi} = 60°C flows through a thin walled electrically heated cylindrical tube D = 40 mm in diameter by L = 5 m long at a mass flowrate of $\dot{m}$ = 1 kg/s. Heat is transferred uniformly along the length of the tube. In order that boiling be prevented, the maximum surface temperature must not exceed T_{max} = 95°C. For the purposes of analysis, use ρ = 989 kg/m^3, k = 0.637 W/m°C, C_p = 4176 J/kg°C, ν = 0.59x10^{-6} m^2/s and Pr = 3.83. Under the conditions described above, determine

(a) The maximum allowable rate of heat transfer per unit length q/L.

(b) The bulk temperature of the water at the outlet of the tube T_{bo}.

7. A thermocouple enclosed in a 3 mm diameter sheath (ϵ = 0.60) protrudes horizontally into a furnace in order to measure the temperature of the air inside. The walls of the furnace are at 650°C and the true air temperature is 565°C. Disregarding conduction heat transfer along the sheath, determine the temperature that the thermocouple will indicate ?



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8. Flue gas with a specific heat of 1.05 kJ/kg°C flows through the shell of a single shell pass four tube pass counterflow heat exchanger at 0.51 kg/s and exchanges heat with water with a specific heat of 4.18 kJ/kg°C which flows through the tubes at 0.38 kg/s. The flue gas enters at 260°C and leaves at 150°C when the water enters the heat exchanger at 125°C. Subsequently, a change in the operating conditions occurs after which the water flows at 0.31 kg/s and enters the heat exchanger at 65°C. Determine the new outlet water temperature.

Thermodynamic Properties of R134A

Saturated R134A

Temp. °C	Press. bars	Specific Volume m^3/kg		Internal Energy kJ/kg		Enthalpy kJ/kg			Entropy kJ/kg · K		Temp. °C
		Sat. Liquid $v_f \times 10^3$	Sat. Vapor v_g	Sat. Liquid u_f	Sat. Vapor u_g	Sat. Liquid h_f	Evap. h_{fg}	Sat. Vapor h_g	Sat. Liquid s_f	Sat. Vapor s_g	
−40	0.5164	0.7055	0.3569	−0.04	204.45	0.00	222.88	222.88	0.0000	0.9560	−40
−36	0.6332	0.7113	0.2947	4.68	206.73	4.73	220.67	225.40	0.0201	0.9506	−36
−32	0.7704	0.7172	0.2451	9.47	209.01	9.52	218.37	227.90	0.0401	0.9456	−32
−28	0.9305	0.7233	0.2052	14.31	211.29	14.37	216.01	230.38	0.0600	0.9411	−28
−26	1.0199	0.7265	0.1882	16.75	212.43	16.82	214.80	231.62	0.0699	0.9390	−26
−24	1.1160	0.7296	0.1728	19.21	213.57	19.29	213.57	232.85	0.0798	0.9370	−24
−22	1.2192	0.7328	0.1590	21.68	214.70	21.77	212.32	234.08	0.0897	0.9351	−22
−20	1.3299	0.7361	0.1464	24.17	215.84	24.26	211.05	235.31	0.0996	0.9332	−20
−18	1.4483	0.7395	0.1350	26.67	216.97	26.77	209.76	236.53	0.1094	0.9315	−18
−16	1.5748	0.7428	0.1247	29.18	218.10	29.30	208.45	237.74	0.1192	0.9298	−16
−12	1.8540	0.7498	0.1068	34.25	220.36	34.39	205.77	240.15	0.1388	0.9267	−12
−8	2.1704	0.7569	0.0919	39.38	222.60	39.54	203.00	242.54	0.1583	0.9239	−8
−4	2.5274	0.7644	0.0794	44.56	224.84	44.75	200.15	244.90	0.1777	0.9213	−4
0	2.9282	0.7721	0.0689	49.79	227.06	50.02	197.21	247.23	0.1970	0.9190	0
4	3.3765	0.7801	0.0600	55.08	229.27	55.35	194.19	249.53	0.2162	0.9169	4
8	3.8756	0.7884	0.0525	60.43	231.46	60.73	191.07	251.80	0.2354	0.9150	8
12	4.4294	0.7971	0.0460	65.83	233.63	66.18	187.85	254.03	0.2545	0.9132	12
16	5.0416	0.8062	0.0405	71.29	235.78	71.69	184.52	256.22	0.2735	0.9116	16
20	5.7160	0.8157	0.0358	76.80	237.91	77.26	181.09	258.36	0.2924	0.9102	20
24	6.4566	0.8257	0.0317	82.37	240.01	82.90	177.55	260.45	0.3113	0.9089	24
26	6.8530	0.8309	0.0298	85.18	241.05	85.75	175.73	261.48	0.3208	0.9082	26
28	7.2675	0.8362	0.0281	88.00	242.08	88.61	173.89	262.50	0.3302	0.9076	28
30	7.7006	0.8417	0.0265	90.84	243.10	91.49	172.00	263.50	0.3396	0.9070	30
32	8.1528	0.8473	0.0250	93.70	244.12	94.39	170.09	264.48	0.3490	0.9064	32
34	8.6247	0.8530	0.0236	96.58	245.12	97.31	168.14	265.45	0.3584	0.9058	34
36	9.1168	0.8590	0.0223	99.47	246.11	100.25	166.15	266.40	0.3678	0.9053	36
38	9.6298	0.8651	0.0210	102.38	247.09	103.21	164.12	267.33	0.3772	0.9047	38
40	10.164	0.8714	0.0199	105.30	248.06	106.19	162.05	268.24	0.3866	0.9041	40
42	10.720	0.8780	0.0188	108.25	249.02	109.19	159.94	269.14	0.3960	0.9035	42
44	11.299	0.8847	0.0177	111.22	249.96	112.22	157.79	270.01	0.4054	0.9030	44
48	12.526	0.8989	0.0159	117.22	251.79	118.35	153.33	271.68	0.4243	0.9017	48
52	13.851	0.9142	0.0142	123.31	253.55	124.58	148.66	273.24	0.4432	0.9004	52
56	15.278	0.9308	0.0127	129.51	255.23	130.93	143.75	274.68	0.4622	0.8990	56
60	16.813	0.9488	0.0114	135.82	256.81	137.42	138.57	275.99	0.4814	0.8973	60
70	21.162	1.0027	0.0086	152.22	260.15	154.34	124.08	278.43	0.5302	0.8918	70
80	26.324	1.0766	0.0064	169.88	262.14	172.71	106.41	279.12	0.5814	0.8827	80
90	32.435	1.1949	0.0046	189.82	261.34	193.69	82.63	276.32	0.6380	0.8655	90
100	39.742	1.5443	0.0027	218.60	248.49	224.74	34.40	259.13	0.7196	0.8117	100

Thermodynamic Properties of R134A

Superheated R134A

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 = 6.0 bars = 0.60 MPa (T_{sat} = 21.58°C)				p = 7.0 bars = 0.70 MPa (T_{sat} = 26.72°C)			
Sat.	0.03408	238.74	259.19	0.9097	0.02918	241.42	261.85	0.9080
30	0.03581	246.41	267.89	0.9388	0.02979	244.51	265.37	0.9197
40	0.03774	255.45	278.09	0.9719	0.03157	253.83	275.93	0.9539
50	0.03958	264.48	288.23	1.0037	0.03324	263.08	286.35	0.9867
60	0.04134	273.54	298.35	1.0346	0.03482	272.31	296.69	1.0182
70	0.04304	282.66	308.48	1.0645	0.03634	281.57	307.01	1.0487
80	0.04469	291.86	318.67	1.0938	0.03781	290.88	317.35	1.0784
90	0.04631	301.14	328.93	1.1225	0.03924	300.27	327.74	1.1074
100	0.04790	310.53	339.27	1.1505	0.04064	309.74	338.19	1.1358
110	0.04946	320.03	349.70	1.1781	0.04201	319.31	348.71	1.1637
120	0.05099	329.64	360.24	1.2053	0.04335	328.98	359.33	1.1910
130	0.05251	339.38	370.88	1.2320	0.04468	338.76	370.04	1.2179
140	0.05402	349.23	381.64	1.2584	0.04599	348.66	380.86	1.2444
150	0.05550	359.21	392.52	1.2844	0.04729	358.68	391.79	1.2706
160	0.05698	369.32	403.51	1.3100	0.04857	368.82	402.82	1.2963

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 = 8.0 bars = 0.80 MPa (T_{sat} = 31.33°C)				p = 9.0 bars = 0.90 MPa (T_{sat} = 35.53°C)			
Sat.	0.02547	243.78	264.15	0.9066	0.02255	245.88	266.18	0.9054
40	0.02691	252.13	273.66	0.9374	0.02325	250.32	271.25	0.9217
50	0.02846	261.62	284.39	0.9711	0.02472	260.09	282.34	0.9566
60	0.02992	271.04	294.98	1.0034	0.02609	269.72	293.21	0.9897
70	0.03131	280.45	305.50	1.0345	0.02738	279.30	303.94	1.0214
80	0.03264	289.89	316.00	1.0647	0.02861	288.87	314.62	1.0521
90	0.03393	299.37	326.52	1.0940	0.02980	298.46	325.28	1.0819
100	0.03519	308.93	337.08	1.1227	0.03095	308.11	335.96	1.1109
110	0.03642	318.57	347.71	1.1508	0.03207	317.82	346.68	1.1392
120	0.03762	328.31	358.40	1.1784	0.03316	327.62	357.47	1.1670
130	0.03881	338.14	369.19	1.2055	0.03423	337.52	368.33	1.1943
140	0.03997	348.09	380.07	1.2321	0.03529	347.51	379.27	1.2211
150	0.04113	358.15	391.05	1.2584	0.03633	357.61	390.31	1.2475
160	0.04227	368.32	402.14	1.2843	0.03736	367.82	401.44	1.2735
170	0.04340	378.61	413.33	1.3098	0.03838	378.14	412.68	1.2992
180	0.04452	389.02	424.63	1.3351	0.03939	388.57	424.02	1.3245