NATIONAL EXAMINATIONS DECEMBER 2010

98-Nav-B1, Applied Thermodynamics & 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. An internal combustion gasoline engine operates at a 8.3 to 1 compression ratio. Assuming that the actual thermal efficiency is 40% percent of the ideal thermal efficiency and that the mechanical efficiency is 85%, calculate the fuel consumption in kg/hr when the engine is producing a torque of 115.9 Nm at 2300 rev/min. Use 1.0035 kJ/kgK and 0.7165 kJ/kgK as the specific heats of air at constant pressure and constant volume respectively and 45,400 kJ/kg for the calorific value of gasoline.

2. A reciprocating compressor receives atmospheric air at 101.3 kPa and 20°C and discharges it at 345.0 kPa. The clearance volume is 5 percent of the piston displacement and the expansion and compression occurs isentropically. Compute

(a) The piston displacement in m^3/min required to compress the air entering the air compressor at 3.0 m^3/min referred to the initial conditions.

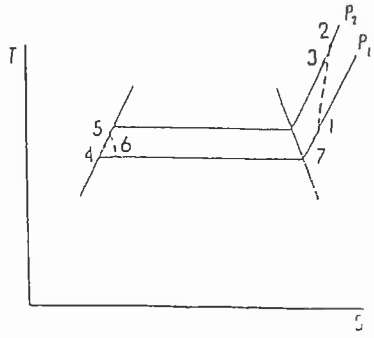
(b) The volumetric efficiency defined as the ratio of the actual mass of the air compressed to the mass of the air occupying the piston during displacement.

(c) The power required of the motor to drive the reciprocating air compressor.

3. A two stage turbine receives steam at 4.50 MPa and 350°C. The high pressure stage exhausts at 150 kPa and 10,900 kg of steam is extracted at this point for processes purposes. The remaining steam is reheated at 150 kPa to 300°C and then expanded through the low pressure stage to a condenser pressure of 7.5 kPa. The power produced by the turbine is 3730 kW. The isentropic efficiencies of the high pressure and low pressure stages of the turbine are 84% and 81% respectively. Determine the boiler capacity required in kilograms of steam per second. Sketch the process on a temperature entropy diagram.

4. The following test data were obtained from a R134A vapour-compression refrigeration system.

Condenser pressure	0.9 MPa
Evaporator pressure	0.6 MPa
Temperature at compressor inlet	30°C
Temperature at compressor outlet	120°C
Temperature at condenser inlet	110°C
Temperature at condenser outlet	25°C
Temperature at expansion valve inlet	30°C
Temperature at evaporator outlet	20°C



During compression, 3.5 kJ/kg was transferred from the fluid. Determine the coefficient of performance and perform an energy balance on the system.

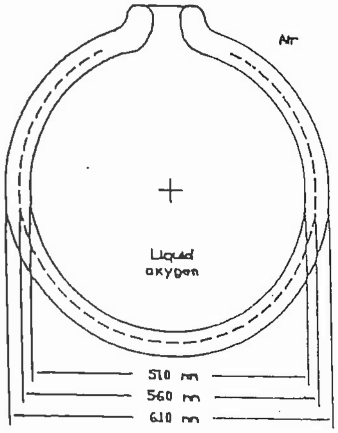
Continued on Page 3

PART B - HEAT TRANSFER

5. The Bruce Nuclear Generating Station proposes to sell surplus steam at a good price to industries willing to locate at the Bruce Energy Centre. The steam line $D_o = 60$ mm outside diameter by $D_i = 50$ mm inside diameter is made of steel covered with a layer of fibreglass insulation $\delta = 100$ mm in thickness having thermal conductivity $k_i = 0.047$ W/m°C enclosed by a shiny aluminum cover having emissivity $\epsilon = 0.06$. The steam line stretches 4 km from the Bruce Nuclear Generating Station to the Bruce Energy Centre. Compute the cost of the heat lost per 24 hour day when the temperature of the steam is $T_s = 180°C$ and the temperature of the quiescent air surrounding the steam line is $T_\infty = -10°C$. Consider both convection heat transfer and radiation heat transfer in your analysis and assume that value of the energy lost is \$3.70 per million kJ.

6. A water chiller circulates a water stream at $\dot{m} = 0.1$ kg/s through a thin walled pipe D = 10 mm in diameter by L = 10 m long immersed in a bath of crushed ice and water. For this reason, the pipe wall temperature may be assumed to be constant at $T_w = 0°C$. The inlet temperature of the water $T_i = 40°C$ and the outlet temperature of the water $T_o = 6°C$. The pipe is long enough that the flowing water may be assumed to be hydrodynamically and thermally fully developed over the entire length. If the original pipe were replaced by a pipe half the diameter and the mass flowrate $\dot{m} = 0.1$ kg/s, the inlet temperature T_i and the outlet temperature T_o were to remain the same, what length of pipe L′ would be required ?

7. An evacuated Dewar vessel comprised of thin spherical stainless steel shells is used for storing liquid oxygen at 90 K. The outer and inner shells are 610 mm diameter and 510 mm diameter respectively. Determine how much energy the liquified oxygen contained within the inner shell will gain when another spherical shell 560 mm diameter is located between the inner and outer shells to act as a thermal radiation shield. The temperature of the outer shell is 45°C. Neglect the opening in the Dewar vessel and assume that all stainless steel surfaces have an emissivity of 0.3.



8. A heat exchanger is to be designed to raise the temperature of water flowing at 2.5 kg/s from 15°C to 85°C using engine oil at 160°C which is to pass through the shell side of the heat exchanger. For the purposes of the design, the average convection coefficient of the oil at the outer surface of the tubes will be assumed to be 400 W/m²°C. The water will flow through ten thin walled tubes 25 mm in diameter, each tube making eight passes through the shell of the heat exchanger. At what rate must the oil flow if it is to leave the heat exchanger at 100°C ? How long must the tubes be to achieve the heat exchange ?

End

Thermodynamic Properties of R134A

Saturated R134A

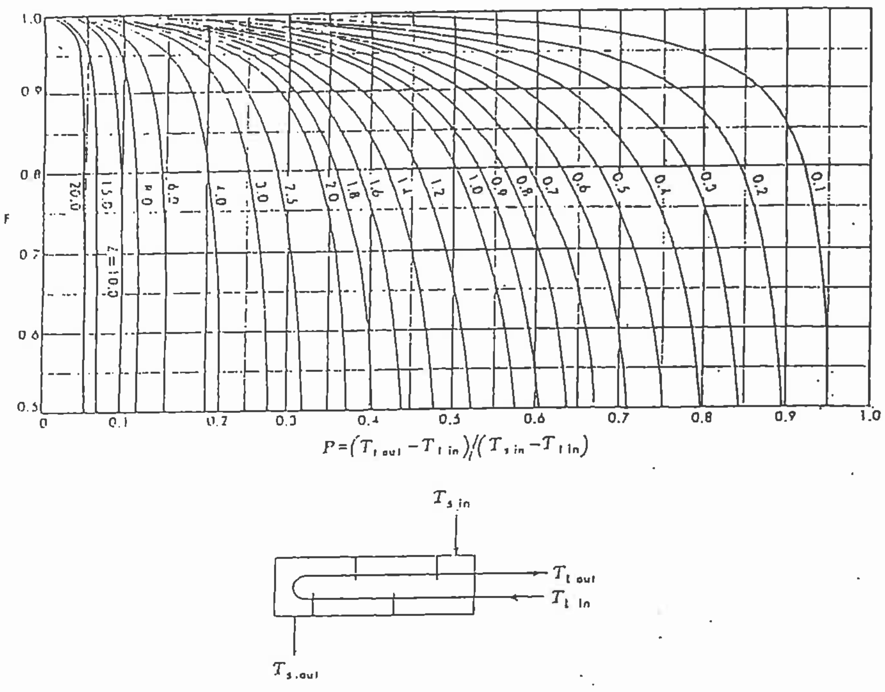
		Specific Volume m³/kg		Internal Energy kJ/kg		Enthalpy kJ/kg			Entropy kJ/kg · K		
Temp. °C	Press. bars	Sat. Liquid $v_f \times 10^3$	Sat. Vapor v_g	Sat. Liquid u_f	Sat. Vapor u_g	Sat. Liquid h_f	Evap. h_{fg}	Sat. Vapor h_g	Sat. Liquid s_f	Sat. Vapor s_g	Temp. °C
−40	0.5164	0.7055	0.3569	−0.04	204.45	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

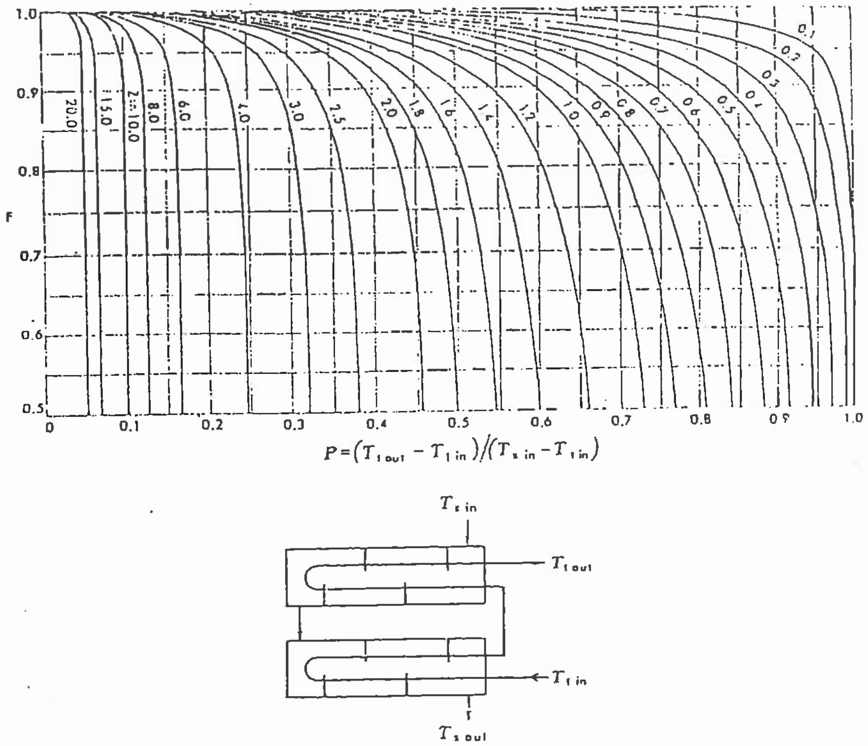
Superheated R134A

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

	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



Correction factor to counterflow LMTD for heat exchanger with one shell pass and two, or a multiple of two, tube passes. (Courtesy of the Tubular Exchange Manufacturer's Association)



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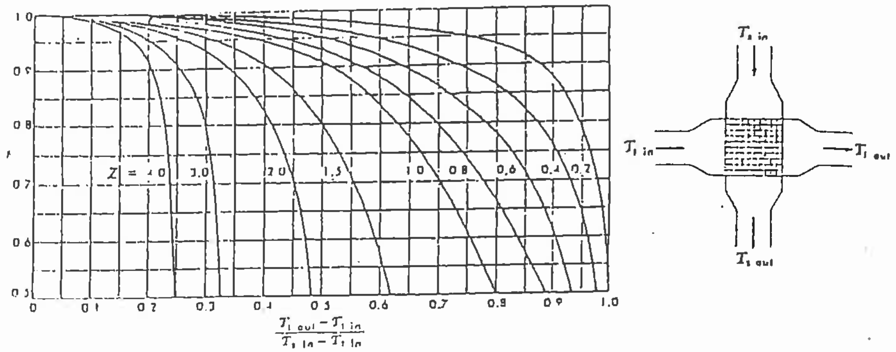
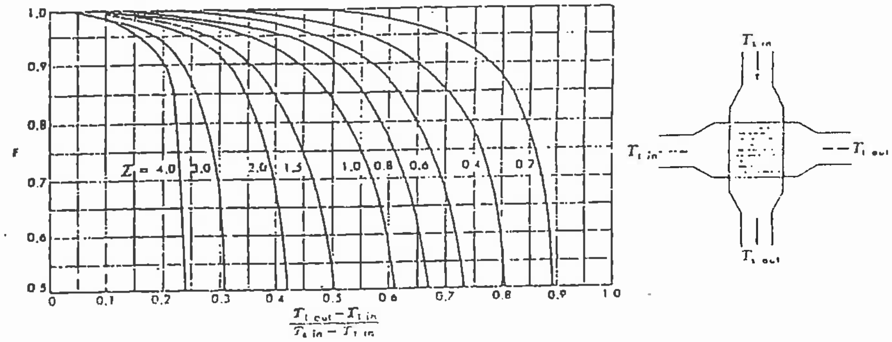


Correction factor to counterflow LMTD for crossflow heat exchanger, both fluids unmixed, one tube pass. (Extracted from "Mean Temperature Difference in Design," by R. A. Bowman, A. C. Mueller, and W. M. Nagel, published in *Trans. ASME*, Vol. 62, 1940, with permission of the publishers, The American Society of Mechanical Engineers)



Correction factor to counterflow LMTD for crossflow heat exchangers, fluid on shell side mixed, other fluid unmixed, one tube pass. (Extracted from "Mean Temperature Difference in Design," by R. A. Bowman, A. C. Mueller, and W. M. Nagel, published in *Trans. ASME*, Vol. 62, 1940, with permission of the publishers, The American Society of Mechanical Engineers)