

NATIONAL EXAMINATIONS MAY 2002

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. Candidates are required to attempt five questions. Each candidate must attempt either three questions from Part A and two questions from Part B or two questions from Part A and three questions from Part B in order to complete the examination.
6. Candidates must indicate the questions in each section that they wish to have graded on the cover of the first examination book.
7. All questions carry the same value. Indicate which five questions are to be graded on the cover of the first examination workbook.

Continued on Page 2



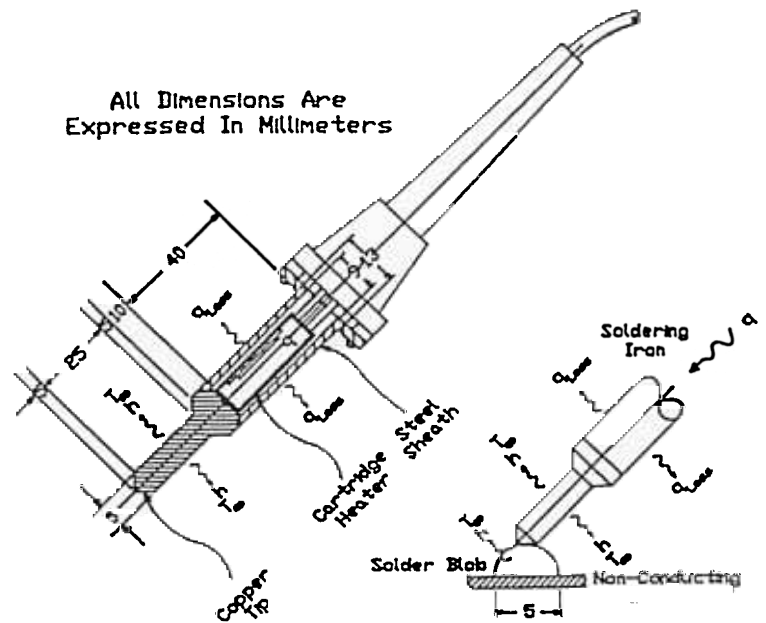
**PART B            HEAT TRANSFER**

See appendix 1 of 3 for a bigger diagram

5. The illustration at the right depicts a soldering iron used for making circuit board connections comprised of a cartridge heater bonded to a copper tip and surrounded by a steel sheath. The steel sheath may be considered to transfer heat similar to an infinite fin for which  $q_{Loss}$  is given by the relationship

$$q_{Loss} = \sqrt{hPkA_{cs}} [T_{Root} - T_{\infty}]$$

where  $h$  is the heat transfer coefficient at the outer surface of the sheath,  $P$  is the periphery (circumference) of the outer surface of the sheath,  $k$  is the thermal conductivity of the steel,  $A_{cs}$  is the cross sectional area of the sheath,  $T_{Root}$  is the temperature of the sheath at the point at which it is attached to the copper tip and  $T_{\infty}$  is the temperature of the ambient air. For the analysis purposes, use the thermophysical properties listed below.



$q = 30 \text{ W}$	$h = 80 \text{ W/m}^2 \cdot \text{C}$	$T_{\infty} = 20 \text{ }^{\circ}\text{C}$
$\rho_{steel} = 7850 \text{ kg/m}^3$	$C_{steel} = 435 \text{ J/kg} \cdot \text{C}$	$k_{steel} = 40 \text{ W/m} \cdot \text{C}$
$\rho_{copper} = 8930 \text{ kg/m}^3$	$C_{copper} = 385 \text{ J/kg} \cdot \text{C}$	$k_{copper} = 400 \text{ W/m} \cdot \text{C}$

When the copper tip touches the hemispherical solder blob depicted in the illustration, the temperature of the copper tip will drop and the temperature of the solder blob will rise consistent with the heat input from the cartridge heater and the various convective heat losses but eventually the copper tip and solder blob will attain the same temperature and steady state will be attained. Given that  $\rho_{solder} = 8950 \text{ kg/m}^3$ ,  $C_{solder} = 175 \text{ J/kg} \cdot \text{C}$ ,  $k_{solder} = 13 \text{ W/m} \cdot \text{C}$  and that  $T_{Melt} = 190 \text{ }^{\circ}\text{C}$ , is it possible that the soldering iron might not be capable of generating enough heat to melt the solder blob ?

6. 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. The heat transfer analyst who undertook the design of the apparatus, whose heat transfer calculations are shown below, assumed the duct to be isothermal at a temperature of 525 K.

The company for which you work has been awarded the contract to build the device. However, before beginning the work, your employer would like to have the calculations checked and you have been assigned the task. After studying the calculations carefully, you have come to the realization that the analyst has made a mistake.

From physical considerations, why is it not possible for the outlet temperature that the analyst calculated to be correct? Identify the error(s) in the calculations that the analyst performed, formulate the problem correctly and given that the heat transfer coefficient at the interface between the molten lead and the duct is  $8387 \text{ W/m}^2 \cdot ^\circ\text{C}$ , determine

$$\begin{aligned}
 \text{SIDE} &= 3 \text{ cm} ; L = 1 \text{ m} ; T_i = 178 \text{ K} ; T_w = 525 \text{ K} \\
 D_h &= \frac{4A}{P_w} ; A = 3.90 \times 10^{-4} \text{ m}^2 \\
 D_h &= \frac{4 \times 3.90 \times 10^{-4}}{3 \times 0.03} = 1.73 \times 10^{-2} \text{ m} \\
 \nu &= 4.60 \times 10^{-7} \text{ m}^2/\text{s} ; k = 80.3 \text{ W/m}\cdot\text{K} ; \rho = 902 \text{ kg/m}^3 ; \mu = 0.0072 \\
 C_p &= 1340 \text{ J/kg}\cdot\text{K} \\
 Pe &= Re Pr = \frac{v D_h \rho}{\mu} Pr = \frac{3.6 \times 1.73 \times 10^{-2} \times 902}{0.0072} \times 1340 \\
 &= 2774 \\
 Nu_D &= 5 + 0.025 (Pe)^{0.8} = 5 + 0.025 (2774)^{0.8} = 19.2 \\
 \bar{h} &= \frac{Nu_D k}{D_h} = \frac{19.2 \times 80.3}{1.73 \times 10^{-2}} = 89.14 \text{ kW/m}^2\cdot\text{K} \\
 q &= \bar{h} A \Delta T = \dot{m} C_p \Delta T \\
 89.14 \times 10^3 (3 \times 0.03 \times 4) (525 - \frac{T_o + 178}{2}) &= 3.6 \times 1340 (T_o - 178) \\
 \Rightarrow T_o &= \boxed{550.3 \text{ K}} \\
 q &= \dot{m} C_p \Delta T = 3.6 \times 1340 (550.3 - 178) = \boxed{349 \text{ kW}}
 \end{aligned}$$

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

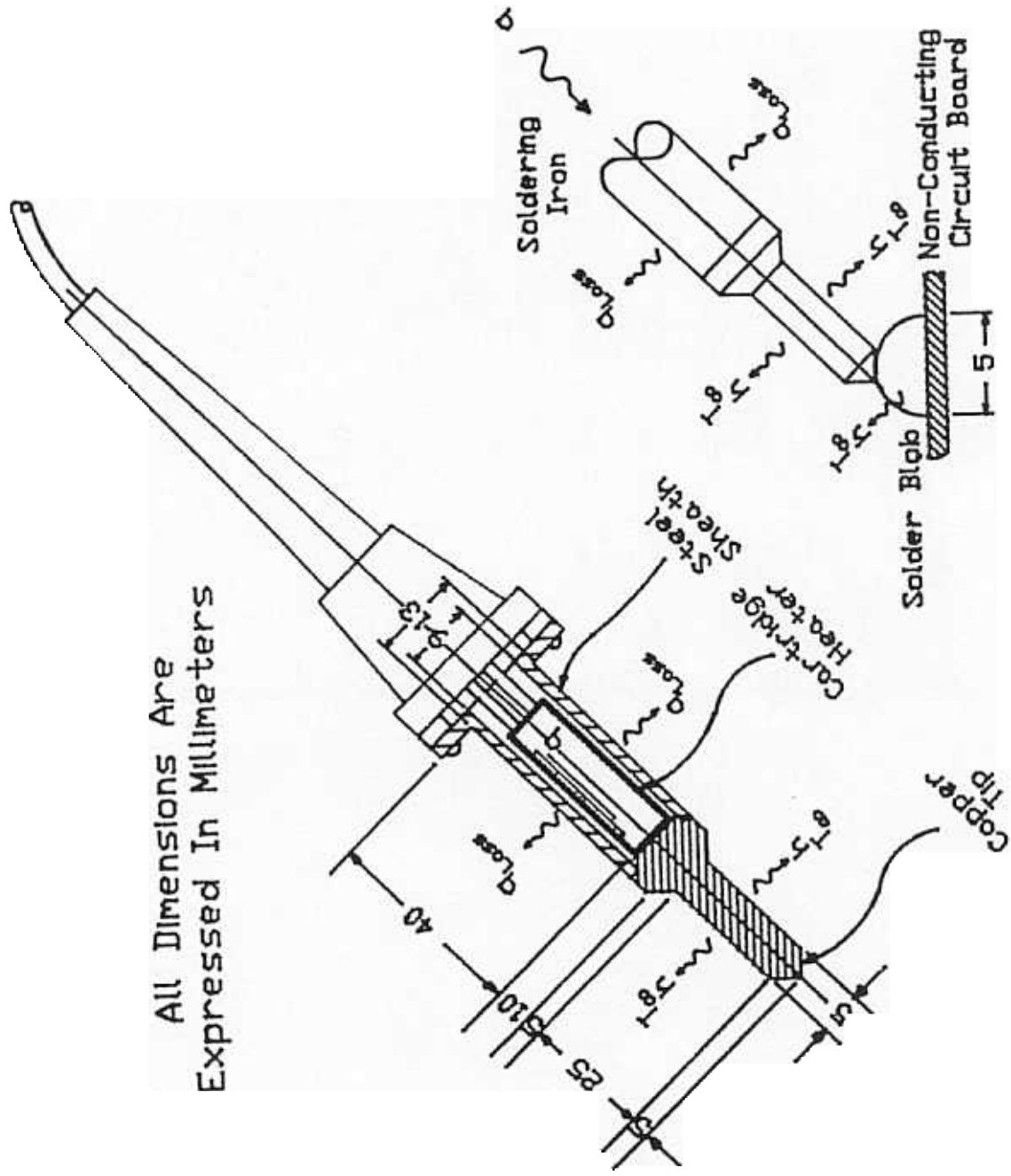
(ii) the heat transfer between the molten lead and liquid sodium.

7. The pipes through which thick liquids such as asphalt or waxes are conveyed are often heated by passing an electric current through them in order to reduce the viscosity of the liquid and the associated pumping costs. Consider such a liquid flowing through a 30 cm diameter pipe situated in calm ambient air at  $20^\circ\text{C}$ . The emissivity of outer surface of the pipe is 0.8 and the effective temperature of the surroundings is  $25^\circ\text{C}$ . Disregarding the heat transferred to the flowing liquid, determine the power required per unit length of pipe to maintain its temperature constant at  $30^\circ\text{C}$ .

8. A crossflow heat exchanger is comprised of 40 thin-walled tubes 1 cm in diameter located in a duct 1 m x 1 m in cross section. Cold water ( $C_p = 4180 \text{ J/kg}\cdot^\circ\text{C}$ ) enters the tubes at  $18^\circ\text{C}$  with an average velocity of 3 m/s while hot air ( $C_p = 1010 \text{ J/kg}\cdot^\circ\text{C}$ ) enters the channel at  $130^\circ\text{C}$  and 105 kPa with an average velocity of 12 m/s. If the overall heat transfer coefficient is  $80 \text{ W/m}^2\cdot^\circ\text{C}$ , determine the temperatures at which the water and the air leave the heat exchanger and the rate of heat transfer.

The End

All Dimensions Are Expressed In Millimeters



Thermodynamic Properties of Freon-12 (Dichlorodifluoromethane)<sup>a</sup>

Saturated Freon-12

Temp. °C	Abs. Press. MPa P	Specific Volume m <sup>3</sup> /kg			Enthalpy kJ/kg			Entropy kJ/kg K		
		Sat. Liquid <i>v<sub>f</sub></i>	Evap. <i>v<sub>fg</sub></i>	Sat. Vapor <i>v<sub>g</sub></i>	Sat. Liquid <i>h<sub>f</sub></i>	Evap. <i>h<sub>fg</sub></i>	Sat. Vapor <i>h<sub>g</sub></i>	Sat. Liquid <i>s<sub>f</sub></i>	Evap. <i>s<sub>fg</sub></i>	Sat. Vapor <i>s<sub>g</sub></i>
-90	0.0028	0.000 608	4.414 937	4.415 545	-43.243	189.618	146.375	-0.2084	1.0352	
-85	0.0042	0.000 612	3.036 704	3.037 316	-38.968	187.608	148.640	-0.1854	0.9970	
-80	0.0062	0.000 617	2.137 728	2.138 345	-34.688	185.612	150.924	-0.1630	0.9609	
-75	0.0088	0.000 622	1.537 030	1.537 651	-30.401	183.625	153.224	-0.1411	0.9266	
-70	0.0123	0.000 627	1.126 654	1.127 280	-26.103	181.640	155.536	-0.1197	0.8940	
-65	0.0168	0.000 632	0.840 534	0.841 166	-21.793	179.651	157.857	-0.0987	0.8630	
-60	0.0226	0.000 637	0.637 274	0.637 910	-17.469	177.653	160.184	-0.0782	0.8334	
-55	0.0300	0.000 642	0.490 358	0.491 000	-13.129	175.641	162.512	-0.0581	0.8051	
-50	0.0391	0.000 648	0.382 457	0.383 105	-8.772	173.611	164.840	-0.0384	0.7779	
-45	0.0504	0.000 654	0.302 029	0.302 682	-4.396	171.558	167.163	-0.0190	0.7519	
-40	0.0642	0.000 659	0.241 251	0.241 910	-0.000	169.479	169.479	-0.0000	0.7269	
-35	0.0807	0.000 666	0.194 732	0.195 398	4.416	167.368	171.784	0.0187	0.7027	
-30	0.1004	0.000 672	0.158 703	0.159 375	8.854	165.222	174.076	0.0371	0.6795	
-25	0.1237	0.000 679	0.130 487	0.131 166	13.315	163.037	176.352	0.0552	0.6570	
-20	0.1509	0.000 685	0.108 162	0.108 847	17.800	160.810	178.610	0.0730	0.6352	
-15	0.1826	0.000 693	0.090 326	0.091 018	22.312	158.534	180.846	0.0906	0.6141	
-10	0.2191	0.000 700	0.075 946	0.076 646	26.851	156.207	183.058	0.1079	0.5936	
-5	0.2610	0.000 708	0.064 255	0.064 963	31.420	153.823	185.243	0.1250	0.5736	
0	0.3086	0.000 716	0.054 673	0.055 389	36.022	151.376	187.397	0.1418	0.5542	
5	0.3626	0.000 724	0.046 761	0.047 485	40.659	148.859	189.518	0.1585	0.5351	
10	0.4233	0.000 733	0.040 180	0.040 914	45.337	146.265	191.602	0.1750	0.5165	
15	0.4914	0.000 743	0.034 671	0.035 413	50.058	143.586	193.644	0.1914	0.4983	
20	0.5673	0.000 752	0.030 028	0.030 780	54.828	140.812	195.641	0.2076	0.4803	
25	0.6516	0.000 763	0.026 091	0.026 854	59.653	137.933	197.586	0.2237	0.4626	
30	0.7449	0.000 774	0.022 734	0.023 508	64.539	134.936	199.475	0.2397	0.4451	
35	0.8477	0.000 786	0.019 855	0.020 641	69.494	131.805	201.299	0.2557	0.4277	
40	0.9607	0.000 798	0.017 373	0.018 171	74.527	128.525	203.051	0.2716	0.4104	
45	1.0843	0.000 811	0.015 220	0.016 032	79.647	125.074	204.722	0.2875	0.3931	
50	1.2193	0.000 826	0.013 344	0.014 170	84.868	121.430	206.298	0.3034	0.3758	
55	1.3663	0.000 841	0.011 701	0.012 542	90.201	117.565	207.766	0.3194	0.3582	
60	1.5259	0.000 858	0.010 253	0.011 111	95.665	113.443	209.109	0.3355	0.3405	
65	1.6988	0.000 877	0.008 971	0.009 847	101.279	109.024	210.303	0.3518	0.3224	
70	1.8858	0.000 897	0.007 828	0.008 725	107.067	104.255	211.321	0.3683	0.3038	
75	2.0874	0.000 920	0.006 802	0.007 723	113.058	99.068	212.126	0.3851	0.2845	
80	2.3046	0.000 946	0.005 875	0.006 821	119.291	93.373	212.665	0.4023	0.2644	
85	2.5380	0.000 976	0.005 029	0.006 005	125.818	87.047	212.865	0.4201	0.2430	
90	2.7885	0.001 012	0.004 246	0.005 258	132.708	79.907	212.614	0.4385	0.2200	
95	3.0569	0.001 056	0.003 508	0.004 563	140.068	71.658	211.726	0.4579	0.1946	
100	3.3440	0.001 113	0.002 790	0.003 903	148.076	61.768	209.843	0.4788	0.1655	
105	3.6509	0.001 197	0.002 045	0.003 242	157.085	49.014	206.099	0.5023	0.1296	
110	3.9784	0.001 364	0.001 098	0.002 462	168.059	28.425	196.484	0.5322	0.0742	
112	4.1155	0.001 792	0.000 005	0.001 797	174.920	0.151	175.071	0.5651	0.0004	

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