# National Exams May 2004

## 98-Agric-A3 Heat Engineering

**3 hours duration**

**NOTES**

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made;

2. This is a Open Book Exam and candidates make bring any textbook they want.

3. Do SIX out of the following seven questions. Unless otherwise specified on the cover, the first six solutions in the answer booklet will be graded.

4. All questions have equal value.

5. Candidates may use one of the Casio or Sharp approved calculator models.

1. The decorative film on a solid copper sphere of 10-mm diameter is cured in an oven at 75°C. Upon removal from the oven, the sphere is subjected to an airstream at 101 kPa and 23°C having a velocity of 10 m/s. Assume negligible radiation effects and negligible thermal resistance and capacitance of the thin plastic film. Estimate the time required to cool the sphere to 35°C.

2. You are designing an operating room heat exchange device to cool blood (bypassed from a patient) from 40 to 30°C by passing the fluid through a coiled tube sitting in a vat of water-ice mixture. The volumetric flow rate ($Q$) is $10^{-4}$ m$^3$/min; the tube diameter ($D$) is 2.5 mm; and $T_{m,\,i}$ and $T_{m,\,o}$ represent the inlet and outlet temperatures of the blood. Neglect heat transfer enhancement associated with the coiling.

   (a) At what temperature would you evaluate the fluid properties in determining the heat transfer coefficient ($h$) for the entire tube length?

   (b) If the properties of blood evaluated at the temperature for part (a) are: density $\rho = 1000$ kg/m$^3$, viscosity $\nu = 7 \times 10^{-7}$ m$^2$/s, $k = 0.5$ W/m.K, and heat capacity $c_p = 4.0$ kJ/kg.K, what is the Prandtl number for the blood?

   (c) Is the blood flow laminar or turbulent?

   (d) Neglecting all entrance effects and assuming fully developed conditions, calculate the value of $h$ for heat transfer from the blood.

   (e) What is the total heat loss rate from the blood as it passes through the tube?

   (f) When free-convective effects on the outside of the tube are included, the average overall heat transfer coefficient $\bar{U}$ between the blood and the ice-water mixture can be approximated at 300 W/m$^2$.K. Determine the tube length L required to obtain the outlet temperature $T_{m,\,o}$.

3. A current of 200 A is passed through a stainless steel wire which has a 2-mm diameter and a 1-m length. The electrical resistance of the wire is 0.125 Ω and its thermal conductivity is 17 W/m·K. The temperature of the outer surface of the wire is measured at 150°C:

   (a) State the governing equation for the steady-state temperature, T(r), in the wire.
   (b) State the governing boundary conditions.
   (c) Solve the differential equation.
   (d) Calculate the wire centerline temperature.
   (e) Assume that you wish to add insulation (thermal conductivity k = 0.15 W/m·K) to the

surface of the wire and that the convective-heat-transfer coefficient on the insulation is 60 $W/m^2 \cdot K$.

Could the current in the wire be increased, or would it have to be decreased, assuming that the outer surface of the wire is at a constant temperature of 150°C?

4. Suppose that you are asked to select between two materials that are being considered for use as the external surface of a large office building. One material transmits 60% of the incident radiation between $0.3x10^{-6}$ and $0.6x10^{-6}$ m and 20% between $0.6x10^{-6}$ and $40x10^{-6}$ m. A second material transmits 40% of the incident energy between $0.3x10^{-6}$ and $2x10^{-6}$ m and 30% between $2x10^{-6}$ and $30x10^{6}$ m. At other wavelengths both materials are opaque. The building is located where approximately 80% of the energy consumed is used for air-conditioning purposes and only 20 is consumed in heating. Which material would you select and for what reasons?

5 A 10m x 2m solar collector consists of cooling tubes that circulate a fluid through the base of the collector. The collector is covered with a single pane of glass, and the space between the glass and collector plate is evacuated. The collector plate is black and the side walls are refractory surfaces. The bottom surface of the collector is well insulated. The glass properties are $\alpha=0.05$, $\tau=0.88$ for short-wavelength radiation and $\alpha=0.90$, $\tau=0.04$ for long-wavelength radiation. The coolant flow rate is adjusted to maintain the surface of the collector plate at 55°C. When the solar intensity is 950 $W/m^2$, calculate:

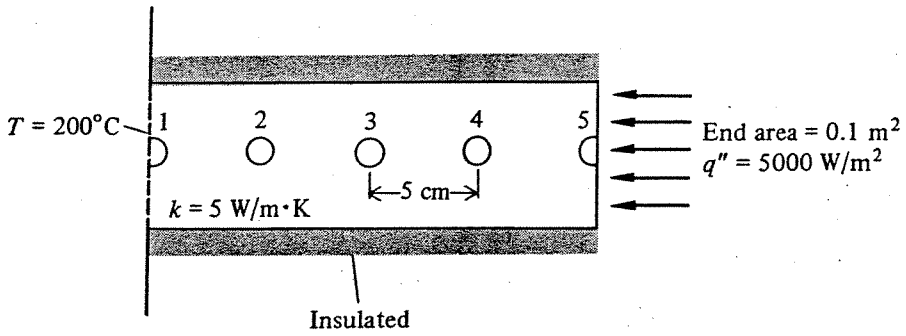
(a) the glass temperature, neglecting conduction and convection effects; and
(b) the net radiative energy gain of the collector plate.

6. Steam at 125°C is condensed on the outside of the tubes in a shell-and-tube heat exchanger. Water enters the tubes at 35°C with a mass flow rate of 1.3 kg/s. the mass flow rate of the steam is 2.5 kg/s and the overall hear transfer coefficient is 1650 $W/m^2 \cdot K$ based on a surface area of 3.7 $m^2$. Calculate

a) the effectiveness of the heat exchanger;
b) the actual heat transfer rate to the water; and
c) the outlet water temperature.

7. The fin shown in the figure has a base temperature of 200°C. A source of energy is incident on the tip of the fin with an energy flux of 5000 $W/m^2$. The exterior surface of the fin is insulated.

a) derive the residual equation for node 5; and
b) estimate the temperatures of at nodes 1 through 5 using the relaxation technique.


T = 200°C
1
2
3
4
5
End area = 0.1 m²
q″ = 5000 W/m²
5 cm
k = 5 W/m·K
Insulated