National Exams December 2011

04-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 an OPEN BOOK EXAM.
   Any non-communicating calculator is permitted.

3. Answer SIX of the NINE questions.

   If you attempt more than six questions, please indicate clearly which questions are to be marked. Failure to indicate this will result in grading of the first six questions encountered in the answer book.

4. It is important to make clearly labeled diagrams for each problem as part of the solution. Also, state any assumptions that you make to solve the problem.

1. Geothermal water (C_p=4250 J/kg.K) at 75°C is to be used to heat fresh water (C_p=4180 J/kg.K) at 17°C in a double-pipe, counter-flow heat exchanger. The heat transfer surface is 27.2 m^2 and the overall heat transfer coefficient is 480 W/m^2.K. The mass flow rate of geothermal water is larger than that of fresh water (1.25 kg/s).

   If the effectiveness of the heat exchanger is 0.80, determine the mass flow rate of geothermal water and the outlet temperature of the fresh water.

2. Research has shown that a clothed or unclothed person feels comfortable when the skin temperature is about 33°C. Consider an average man (surface area = 1.8 m^2) wearing summer clothing whose thermal resistance is 0.6 clo (1 clo = 0.155 m^2.K/W). He feels very comfortable while standing in a room at 22°C. The air motion in the room is negligible (natural convective heat transfer coefficient, h=4.0 W/m^2.K), and the interior surface temperature of the room is about the same as the air temperature (radiation heat transfer coefficient, h_r =4.7 W/m^2.K).

   If the man were to stand in that room unclothed, determine the temperature at which the room must be kept for him to feel thermally comfortable.

3. Your cat likes to sleep on the sheet metal roof (ϵ = 0.65, short wavelength absorptivity α = 0.8) of the shed. The shed roof is well-insulated on the backside. On a day that the air temperature is 10°C and the convective heat transfer coefficient can be calculated using h = $\Delta T^{1/3}$, where ΔT is the difference between the surface and ambient temperatures, the sky temperature can be assumed to be -40°C, and solar irradiation is 600 W/m^2, will be the roof be too hot or too cold for the cat? (Note the cat is comfortable when the roof temperature is about 40°C.).

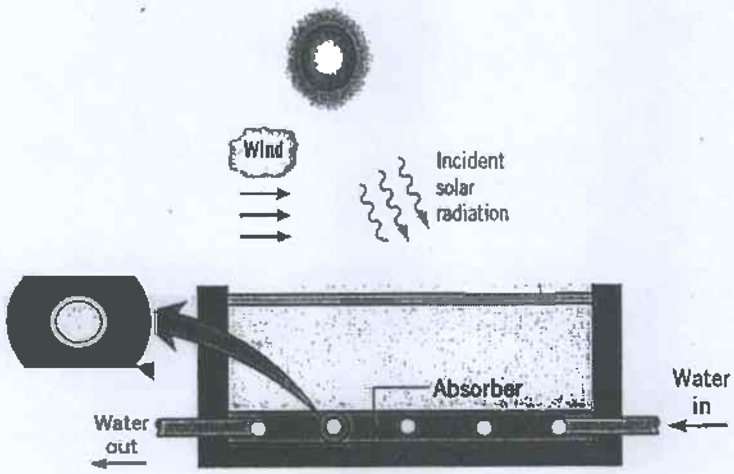
4. At certain times of the year concrete sidewalks are very wet early in the morning even though it has not rained at night. Given: air temperature = 290K, air velocity = 10 m/s; relative humidity = 70%, the side walk is 1 m wide in the airflow direction, the emissivity of water = 0.96 and the surface temperature of the water = 275K.

   Determine the heat loss per unit area by i) radiation, ii) convection, and iii) evaporation.

5. A 10 m x 2 m solar collector consists of cooling tubes that circulate a fluid through the base of the absorber plate. The collector is covered with a single pane of glass, and the space between the glass and absorber plate is evacuated as shown in the figure. The absorber plate is black and the side walls are refractory surfaces. The bottom surface of the collector is well insulated. The glass properties are α = absorptivity =0.05, τ= transmissivity = 0.88 for short-wavelength radiation, and α=0.90, τ=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.
b) The net radiative energy gain of the collector plate.



6. A hot dog (250 mm long x 20 mm diameter) taken from a refrigerator has a temperature of 6°C before being immersed in boiling water. If the thermal conductivity of the hot dog = 0.52 W/m.K, density = 880 kg/m^3 and heat capacity = 3350 J/kg.K, and the heat transfer coefficient is 100 W/ m^2.K, how long will it take for the centre line of the hot dog to reach 80°C?

   a) Write the differential equation describing the temperature of the hot dog as a function of position and time.
   b) Write the boundary conditions for the problem.
   c) How long will it take for the centreline of the hot dog to reach 80°C?
   d) How much energy is required to reach a centreline temperature of 80°C?

7. Heating requirements for a room are 5 kW. The heat is to be supplied by pressurized hot water that flows at a rate of 0.8 kg/s through a 2.9-cm o.d. copper pipe and enters the pipe at 110°C. Estimate

   a) the length of pipe needed if the room temperature is 25°C;
   b) the water temperature as it leaves the pipe; and
   c) the average temperature of the pipe.

8. During a fire, the trunks of some dry oak trees (k=0.17 W/m.K and α=1.28x10^{-7} m^2/s) that are initially at a uniform temperature of 30°C are exposed to hot gases at 520°C for a period of 5 hours with a heat transfer coefficient of 68 W/m^2.K on the surface. The ignition temperature of the trees is 410°C. Treating the trunks of the trees as a long cylinder of diameter 20 cm, determine if the dry trees will ignite as the fire sweeps through them.

a) Write the differential equation describing the temperature of the hot dog as a function of position and time.
b) Write the boundary conditions for the problem.
c) Treating the trunks of the trees as a long cylinder of diameter 20 cm, determine if the dry trees will ignite as the fire sweeps through them.

9. During a cold winter, the surface of a lake develops a layer of ice of unknown thickness L. The lake water temperature is 4°C, the atmospheric air temperature is -30°C, and the temperature of the underside of the ice layer is 0°C. The thermal conductivity of ice is 2.25 W/m.K and the convective heat transfer coefficients on the water and air sides of the ice layer are 500 $W/m^2.K$ and 100 $W/m^2.K$, respectively.

   a) State the differential equation describing heat conduction across the ice layer.
   b) State the corresponding boundary conditions.
   c) Calculate the temperature of the upper surface of the ice layer and the ice thickness.