CH EN 3453 – HEAT TRANSFER – FALL 2014

HOMEWORK #7

Due Friday, October 24 at 4:00 PM

Turn in to the CH EN 3453 basket at the main desk of the Chemical Engineering offices (MEB 3290)

Help session Wednesday, October 22 at 4:30 p.m. in MEB 2325

1. (20 pts) Three parts:

(a) Define the Reynolds, Nusselt, and Prandtl numbers in words and in symbols. What forces are involved and/or what ratios are considered?

(b) Describe the difference between laminar and turbulent flow regimes and where the transition state is for flow over a plate and in a pipe.

(c) Indicate the temperature at which fluid properties should be evaluated for the following cases:

(i) Flow over a flat plate
(ii) Flow around a cylinder (Hilpert relation)
(iii) Flow around a cylinder (Zukauskas relation)
(iv) Flow around a cylinder (Churchill and Bernstein relation)
(v) Flow around a sphere (Whitaker relation)
(vi) Flow through a bank of tubes (Zukauskas relation)

2.* (10 pts) A long, cylindrical, electrical heating element of diameter $D = 10$ mm, thermal conductivity $k = 240$ W/m·K, density $\rho = 2700$ kg/m^3, and specific heat $c_p = 900$ J/kg·K is installed in a duct for which air moves in cross flow over the heater at a temperature and velocity of 27°C and 10 m/s, respectively. For property evaluation, use $T_f \approx 450$ K.

(a) Neglecting radiation, estimate the steady-state surface temperature when, per unit length of the heater, electrical energy is being dissipated at a rate of 1000 Watts per meter.

(b) If the heater is activated from an initial temperature of 27°C, estimated the time required for the surface temperature to come within 10°C of its steady-state value.

3.* (10 pts) Hot water at 50°C is routed from one building in which it is generated to an adjoining building in which it is used for space heating. Flow between the buildings occurs in a steel pipe ($k = 60$ W/m·K) of 100-mm outside diameter and 8-mm wall thickness. During the winter, representative environmental conditions involve air at $T_\infty = -5$°C and $V = 3$ m/s in cross flow over the pipe.

(a) If the cost of producing the hot water is \$0.05 per kW·h, what is the representative daily cost of heat loss from an uninsulated pipe to the air per meter of pipe length? The convection resistance associated with water flow in the pipe may be neglected, but conduction through the pipe and insulation should not be neglected.

(b) Determine the savings associated with application of a 10-mm-thick coating of urethane insulation ($k = 0.026$ W/m·K) to the outer surface of the pipe.

4.* (10 pts) Atmospheric air at 25°C and a velocity of 0.5 m/s flows over a 50-W incandescent bulb whose surface temperature is at 140°C. The bulb may be approximated as a sphere of 50-mm diameter. What is the rate of heat loss by convection to the air?

More problems on the other side…

* Solutions for these problems are available on the course website: www.chen3453.com

5.* (10 pts) A preheater involves the use of condensing steam at 100°C on the inside of a bank of tubes to heat air that enters at 1 atm and 25°C. The air moves at 5 m/s in cross flow over the tubes. Each tube is 1 m long an has an outside diameter of 10 mm. The bank consists of 196 tubes in a square, aligned array (14 × 14 tubes) for which $S_T = S_L = 15$ mm. What is the total rate of heat transfer to the air?

6.* (10 pts) An oil preheater consists of a single tube of 10 mm diameter and 5 m length, with its surface maintained at 175°C by swirling combustion gases. The engine oil (new) enters at 75°C. What flow rate must be supplied to maintain an oil outlet temperature of 100°C? What is the corresponding heat transfer rate?

7.* (10 pts) In the final stages of production, a pharmaceutical is sterilized by heating it from 25 to 75°C as it moves at 0.2 m/s through a straight thin-walled stainless steel tube of 12.7-mm diameter. A uniform heat flux is maintained by an electric resistance heater wrapped around the outer surface of the tube. If the tube is 10 m long, what is the required heat flux? If fluid enters the tube with a fully developed velocity profile and a uniform temperature profile, what is the surface temperature at the tube exit and at a distance 0.5 m from the entrance? Fluid properties may be approximated as $\rho = 1000$ kg/m^3, $c_p = 4000$ J/kg·K, $\mu = 2 \times 10^{-3}$ kg/s·m, $k = 0.8$ W/m·K and $Pr = 10$.

8. (20 pts) An industrial heater is made up of horizontal tubes in a staggered array such that the tubes form equilateral triangles with a pitch-to-diameter ratio of 1.5. Each tube is 1 cm (0.01 m) diameter and 2 meters long. Water at 72°C flows at 6 m/s past the heater tubes, which have a constant surface temperature of 100°C. The tube bundle is 4 tubes deep (in the direction of water flow) 8 tubes "tall" in the vertical direction, for a total of 32 tubes.

(a) Sketch out the tube bundle arrangement.

(b) What is the effective heat transfer coefficient?

(c) What is the total heat transfer to the water?

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