2011 Heat Transfer Final Exam

June 10th 2011
17:30 — 21:30

NO NOTES OR BOOKS; NO CALCULATOR THAT CAN BE USED TO STORE THE SOLUTIONS (eg. TI-89); USE HEAT TRANSFER TABLES THAT WERE DISTRIBUTED; ALL QUESTIONS HAVE EQUAL VALUE; ANSWER ALL 6 QUESTIONS.

Question #1

Consider a lightly loaded journal bearing using oil having the constant properties $\rho = 800$ kg/m^3, $\mu/\rho = 10^{-5}$ m^2/s, and $k = 0.13$ W/m·K. The journal diameter is 75 mm; the clearance (i.e. gap width) is 0.25 mm, and the bearing operates at 5000 rpm.

(a) Determine the temperature distribution in the oil film assuming that there is no heat transfer into the journal and that the bearing surface is maintained at 75°C.

(b) What is the rate of heat transfer from the bearing, and how much power is needed to rotate the journal?

Question #2

Water at 43° C enters at a rate of 6 kg/s a 5-cm-internal-diameter pipe having a relative roughness e/D of 0.002. If the pipe is 2 m long and the pipe walls are maintained at 71° C, calculate the exit bulk temperature of the water and the total heat transfer.

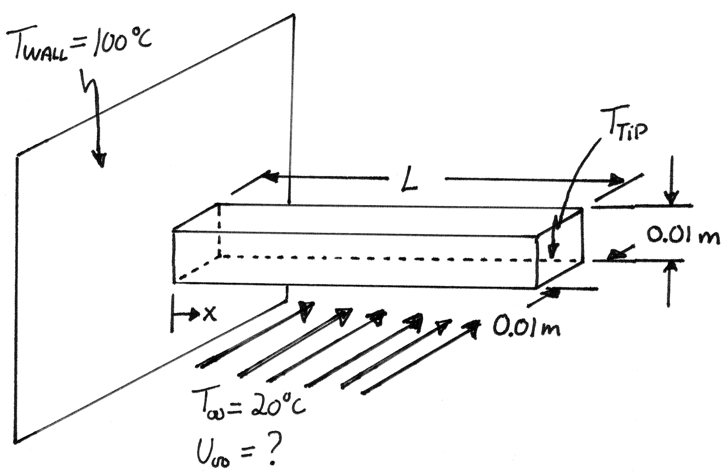
Question #3

You are working in the Hypersonic Branch at ADD (Korean Agency for Defense Development) in Daejeon and are the engineer in charge of installing the power generator on-board a ramjet flight vehicle. The power generator is needed to feed a megawatt-class energy weapon. Because of the high power requirements of the energy weapon and because of the necessity to minimize the weight of the power generating device, it is decided to use a MHD (magneto-hydro-dynamic) power generator rather than fuel cells or other alternatives. The MHD generator operates by converting some of the flow kinetic energy to electrical power through the Lorentz force. The Lorentz force appears when a magnetic field is present and when the airflow is sufficiently ionized to permit the flow of current.

Your task is to design the cables linking the MHD generator located in the engine to the energy weapon located in the tail of the aircraft. When the energy weapon is activated, the power produced by the MHD generator is of 1 MW with a voltage difference of 600 Volts. Noting that the MHD generator is located 2 m away from the energy weapon, it is desired to find the optimal cable design that minimizes weight while keeping the temperature of the polyethylene insulator below melting point. The cable is located in an enclosed area in which there is stagnant air at a pressure of 0.05 atm and at a temperature of -10° C. For safe operation the polyethylene layer is given a thickness of 0.5 cm. The electrical resistivity of copper at 20° C can be taken as 16.8 n$\Omega \cdot$ m. The melting point and the thermal conductivity of polyethylene can be taken as 120° C and 0.5 W/m$^\circ$ C, respectively. Design the cable with a safety margin: take into consideration that the convective heat transfer coefficient may have an error of 30% and do not let the maximum temperature within the polyethylene approach its melting point by less than 20° C.

Question #4

A metal bar ($k_{\text{bar}} = 50$ W/m$\cdot^\circ$C) of square cross section (0.01 m $\times$ 0.01 m) and a length of $L = 0.0975$ m is attached to a wall that is maintained at a temperature of $T_{\text{w}} = 100^\circ$C:



There is a cross-flow of a fluid over the bar as shown in the figure above: $T_\infty = 20^\circ$ C, and U_∞ is unknown. The fluid properties may be assumed constant at the following values:

$k = 0.01$ W/m $\cdot^\circ$ C
$\rho = 1$ kg/m^3
$c_p = 1000$ J/kg $\cdot^\circ$ C
$\mu = 10^{-5}$ kg/m $\cdot$ s

(a) In one experiment, the rod has an excellent thermal contact with the wall, and the temperature of the tip of the rod is measured to be $T_{\text{tip}} = 40^\circ$ C. Calculate the free-stream velocity of the fluid: U_∞ =?

(b) In another experiment, $T_{\text{w}} = 100^\circ$C, $T_\infty = 20^\circ$ C, and U_∞ is the same as in part (a), but there is a thermal contact resistance at the interface between the base of the rod and the wall: $h_{\text{contact}} = 1000$ W/m^2·°C. Calculate the total convective heat loss from the rod.

Question #5

On a cold winter day, water in a river flows with an average velocity of 0.5 m/s. The bulk temperature of the river water is essentially constant at 0.2°C. The air temperature is −30°C. Under steady-state conditions, a continuous layer of ice forms on the top surface of the river. The depth of the river below the ice layer is 1 m, and its width is much larger than its depth. The convective heat transfer coefficient at the ice-air interface is $h_o = 40$ W/m^2·°C. The thermal conductivity of the ice may be assumed constant: $k_{\text{ice}} = 2.0$ W/m·°C. The properties of the river water may be assumed constant at the following values:

$$\rho = 1000 \text{ kg/m}^3$$
$$\mu = 8.6 \times 10^{-4} \text{ kg/m} \cdot \text{s}$$
$$k = 0.60 \text{ W/m} \cdot {}^\circ\text{C}$$
$$c_p = 4186 \text{ J/kg} \cdot {}^\circ\text{C}$$

Estimate the thickness of the ice layer. Hints: (i) Water freezes at 0°C; (ii) The hydraulic diameter of a channel is equal to twice its height.

Question #6

A solid sphere made of a radioactive material ($k_s = 0.50$ W/m·°C) is cooled by suspending it in a large room with $T_{\text{walls}} = 20$°C. The room is filled with an inert gas with the gas temperature far from the sphere $T_\infty = 20$°C. The diameter of the sphere is 0.02 m. The surface of the sphere is smooth and diffuse-gray. There is a volumetric rate of heat generation inside the sphere that is given by $S = S_0(1 - 2000\,r^2)$ W/m^3 where r is the radial coordinate measured in meters. Under steady-state conditions, measurements show the following: the surface temperature of the sphere is $T_{r=0.01\text{ m}} = 120$°C, and the temperature at its centre is $T_{r=0} = 139.74$°C. The properties of the inert gas may be assumed constant at the following values:

$$k = 0.025 \text{ W/m} \cdot {}^\circ\text{C}$$
$$\rho = 1 \text{ kg/m}^3$$
$$c_p = 1000 \text{ J/kg} \cdot {}^\circ\text{C}$$
$$\mu = 2.0 \times 10^{-5} \text{ kg/m} \cdot \text{s}$$
$$\beta = 0.003 \text{ K}^{-1}$$

The acceleration due to gravity is $g = 9.81$ m/s^2. Do the following:

(a) Calculate the value of S_0 in the expression for S

(b) Calculate the emissivity, ϵ, of the surface of the sphere

Answers

1. 2926 W/m
2. 48.95 C, 149 kW
3. 0.025 m
4. 11.45 m/s, 4.05 W
5. 0.237 m
6. 0.63 MW/m^3, 0.86