2013 Heat Transfer Final Exam

June 16th 2013
14:00 — 17:00

NO NOTES OR BOOKS; USE HEAT TRANSFER TABLES THAT WERE DISTRIBUTED; ALL QUESTIONS HAVE EQUAL VALUE; ANSWER ALL 6 QUESTIONS.

Question #1

Show that the general solution of the heat equation for 2D transient problems corresponds to:

$$\frac{T-T_\infty}{T_\mathrm{i}-T_\infty}=\left(\frac{T_1-T_\infty}{T_\mathrm{i}-T_\infty}\right)\left(\frac{T_2-T_\infty}{T_\mathrm{i}-T_\infty}\right)$$

with:

$$\frac{1}{\alpha}\frac{\partial T_1}{\partial t}=\frac{\partial^2 T_1}{\partial x^2}\quad\text{and}\quad\frac{1}{\alpha}\frac{\partial T_2}{\partial t}=\frac{\partial^2 T_2}{\partial x^2}$$

Question #2

Starting from the energy equation for a constant density fluid in axisymmetric coordinates:

$$\rho\left(\frac{\partial e}{\partial t}+u\frac{\partial e}{\partial x}+v\frac{\partial e}{\partial r}\right)=\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right)+\frac{1}{r}\frac{\partial}{\partial r}\left(kr\frac{\partial T}{\partial r}\right)+\mu\left(\frac{\partial u}{\partial x}\right)^2$$
$$+\mu\left(\frac{\partial u}{\partial r}\right)^2+\mu\left(\frac{\partial v}{\partial x}\right)^2+\mu\left(\frac{\partial v}{\partial r}\right)^2$$

In the thermally fully-developed region of a pipe of diameter D, show that

$$\mathrm{Nu}_D=\frac{hD}{k}=\frac{48}{11}$$

$$h\equiv\frac{q''_\mathrm{w}}{T_\mathrm{w}-T_\mathrm{b}}$$

with T_b the bulk temperature. Outline all assumptions. Note: you can make use of the velocity profile in the fully-developed region $u=2u_\mathrm{b}(1-r^2/R^2)$ with u_b the bulk velocity.

Question #3

Consider the wing of an aircraft as a flat plate of 2.5 m length in the flow direction. The plane is moving at 100 m/s in air that is at a pressure of 0.7 bar and a temperature of -10° C. If the top surface of the wing absorbs solar radiation at a rate of 800 W/m^2, estimate its steady-state temperature with and without the effect of viscous dissipation. Assume the wing to be of solid construction and to have a single, uniform temperature. Ignore incident radiation on the bottom surface and take $\epsilon = 0.4$ on the top and bottom surfaces of the wing.

Question #4

A thin-wall copper pipe in which a cooling fluid flows is used to condensate steam. The steam incoming temperature is of 100° C, the pipe length is of 2 m, the pipe diameter is of 0.05 m, and the cooling fluid has the following properties:

$$c = 4000 \text{ J/kgK}, \quad k = 0.5 \text{ W/m°C}, \quad \rho = 1000 \text{ kg/m}^3, \quad \mu = 2.5 \times 10^{-4} \text{ kg/ms}$$

You conduct a first experiment in which the mass flow rate of the cooling fluid is of 1 kg/s, and the temperature of the cooling fluid entering the pipe is of 20° C. For a measured rate of condensation of the steam of 0.002 kg/s, and knowing that $T_{\text{sat}} = 100°\text{C}$ and $\Delta H_{\text{vap}} = 2260$ kJ/kg find $h_{\text{condensate}}$.

Taking the latter into consideration, and assuming that $h_{\text{condensate}}$ does not depend significantly on the cooling fluid inflow temperature and mass flow rate, estimate the bulk temperature at the exit should the temperature and mass flow rate of the cooling fluid entering the pipe be of 40° C and 0.01 kg/s, respectively.

Question #5

A circumferential fin is attached to a *vertical* pipe for cooling purposes. The fin has a diameter of 0.3 m and a thickness of 0.03 m while the pipe has a diameter of 0.03 m. Knowing that the outer wall temperature of the pipe is of 100° C and that the surrounding air has a temperature of 20° C and a pressure of 1 atm, that the fin and the pipe are made of bronze, estimate as well as possible the heat transfer between the pipe and the fin.

Question #6

Consider a 30 m long pipe with a diameter of 1 cm and with a smooth interior wall surface. The pipe wall temperature is kept constant at 60° C.

(a) Some liquid enters the pipe with a temperature of 20° C and exits the pipe with a mixing cup (bulk) temperature of 57° C. Knowing that the mass flow rate of the liquid is of 0.015 kg/s, that the liquid density is of 1000 kg/m^3, that the friction force exerted on the pipe due to the motion of fluid is equal to 0.144 N, determine the viscosity and the Prandtl number of the liquid.

(b) Using the Prandtl number and viscosity found in part (a), estimate the bulk temperature at the exit of the pipe for the same inflow temperature as in (a) but with the mass flow rate increased to 0.15 kg/s.

Hint: When the flow in a pipe is fully-developed, the friction factor is equal to:

$$f = \frac{(-\mathrm{d}P/\mathrm{d}x)D}{\rho u_\mathrm{b}^2/2}$$

Answers

3. -8.13°C, -3.66°C.
4. 192 W/m^2 $^\circ$C, 54.6°C.
5. 64 W.
6. 0.001 kg/ms, 8.88, 60°C.