Quiz III

This is a 50 minute closed-book exam; no notes. Please put your name on the top sheet. Answer all three questions. Explain your working and state any assumptions you have made.

1 (3 points) Circle the correct answer.

1. The Nusselt number
   - is independent of Reynolds number.
   - depends only on the material.
   - applies only to laminar flows.
   - is a non-dimensional version of the heat transfer coefficient.
   - is always less than 1.
2. Analogies for heat transfer
   - relate the Nusselt or Stanton number to the other non-dimensional parameters of the flow.
   - can always be obtained from boundary-layer analysis.
   - are independent of the geometry of the system.
   - are not useful for solving unsteady heat conduction problems.
   - are independent of Prandtl number.
3. One-term approximations for laminar heat transfer problems
   - are valid for $Re > 3000$.
   - are independent of geometry.
   - are valid sufficiently far from the entrance.
   - are obtained empirically.
   - hold near the entrance.

2 (7 points) A viscous oil ($Pr = 180$, $k = 0.2$ W/m·K, $\mu = 1.2$ Pa·s, $\rho = 920$ kg/m^3) is pumped through a circular pipe of diameter $D = 1.5$ cm, the surface of which is maintained at 500 K. What length of pipe is required to permit a flow of 8 m^3/h to be raised from 350 to 400 K?

3 (10 points) Explain the assumptions that lead to the result for cup-mixing temperature in pipe flow:

$$\frac{T - T_R}{T_1 - T_R} = \exp\left(-\frac{\pi D h z}{w C_p}\right).$$

Define the cup-mixing temperature.

Air at 20°C flows through a 6 m length of tube of diameter 5 cm at a mass flowrate of 30 kg/h. The tube is held at 120°C. Find the temperature at the end of the pipe, using the Colburn analogy and the Dittus–Boelter equation.

Correlations

j-factor: $j_H = \frac{\text{Nu}}{\text{RePr}^{1/3}}$.
Colburn analogy: $j_H = \frac{f}{2}$.
Use with turbulent flow friction factor: $f \approx 0.079\text{Re}^{-0.25}$.
Friend–Metzner (turbulent flow inside pipes): $\text{St} = \frac{\text{Nu}}{\text{RePr}} = \frac{h}{C_p \rho U} = \frac{f/2}{1.2+11.8(f/2)^{1/2}(\text{Pr}-1)\text{Pr}^{-1/3}}$.
Use with turbulent flow friction factor: $f = 0.0014 + \frac{0.125}{\text{Re}^{0.32}}$. The combination is valid in the range $3000 < \text{Re} < 3 \times 10^6$ and $0.46 < \text{Pr} < 590$. For fluids other than air, replace Nu with $\text{Nu}/\text{Pr}^{0.3}$.
Dittus–Boelter equation: $\overline{\text{St}} = 0.023\text{Re}^{-0.2}\text{Pr}^{-0.7}$ for fluid being cooled; the exponent of the Prandtl number is -0.6 for fluids being heated.
Laminar flow between parallel plates: cup-mixing temperature $\Theta_{cm} = 0.91 \exp(-1.89x^*)$ with $x^* = x\alpha/UH^2$, valid for $x^* > 0.1$. Local Nusselt number (one-term approximation): $\text{Nu}_{ln} = 7.55$; average Nusselt number: $\overline{\text{Nu}_L} = \frac{4}{x_L^*} \ln\left(\frac{1}{\Theta_{cm}(x_L^*)}\right)$.
Laminar tubular heat exchanger: $\Theta_{cm} = 0.82 \exp(-3.66z^*)$ with $z^* = \alpha z/UR^2 = 4(z/D)/\text{PrRe}_D$, valid for $z^* > 0.3$. Near entrance to tube, local Nusselt number $\text{Nu}_D(z^*) = 1.076((z/D)/\text{PrRe}_D)^{-1/3}$ for $(z/D)/\text{PrRe}_D < 0.01$. Average Nusselt number $\text{Nu}_D(L) = 1.614((L/D)/\text{PrRe}_D)^{-1/3}$ for $(L/D)/\text{PrRe}_D < 0.03$.

Temperatures

Internal flows. usually evaluate physical properties at the bulk temperature $T_m = \frac{1}{2}(\bar{T}_{in} + \bar{T}_{out})$. Film temperature $T_f = [\frac{1}{2}(\bar{T}_{in} + \bar{T}_{out}) + T_S]/2$
External flows: usually evaluate physical properties at the film temperature $T_f = \frac{1}{2}(T_a + T_s)$.

Properties of air