1. [20 pts] A solid, 0.5% carbon steel, 2-in diameter by 2.5-in long cylinder, initially at 1200^oF, is quenched during heat treatment in a fluid at 200^oF. The surface heat transfer coefficient is 150 $Btu/h{\cdot}ft^2{\cdot}{}^oF$. At 700 ^oF, carbon steel has k=25 $Btu/h{\cdot}ft{\cdot}{}^oF$, α=0.46 ft^2/h, at 68^oF, k=81 $Btu/h{\cdot}ft{\cdot}{}^oF$, α=0.57 ft^2/h.

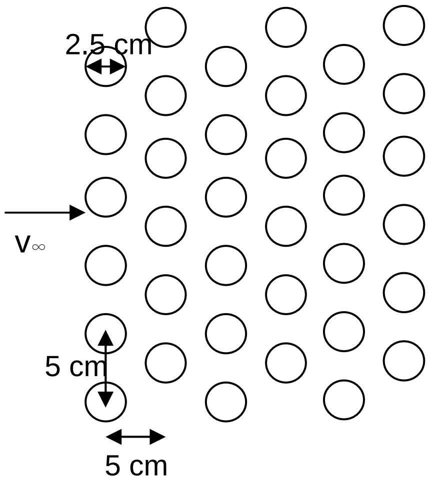
(i) Determine the centerline temperature at the midpoint of length 2.7 min after immersion in the fluid.

(ii) Determine the time required for the temperature at the center (radially and axially) of the solid cylinder to reach $205^{o}F$.

2. [20 pts] Castor oil at 38^{o}C flow over a wide, 6 m long, heated plate at 0.06 m/s. For a surface temperature of 93^{o}C, determine: (a) Film temperature to evaluate the fluid properties, (b) the hydrodynamic boundary layer thickness δ at the end of the plate, (c) the total drag on the surface per unit width, (d) the thermal boundary layer thickness δ_t at the end of the plate, (e) the local heat transfer coefficient h_x at the end of the plate, and (f) the total heat flux from the surface per unit width. Assume the thermal diffusivity α to be 7.22 x 10^{-8} m^2/s and the thermal conductivity k to be 0.213 W/m·K, dynamic viscosity ν=6.0x10^{-5} m^2/s, density ρ=1000 kg/m^3 at the film temperature.

3. [20 pts] For fully developed velocity profile, approximate the length of 0.10-in i.d. tube required to raise the bulk temperature of benzene from 60 ^{o}F to 100 ^{o}F. The tube wall temperature is constant at 150 ^{o}F, and the average velocity is 1.6 fps. At T_m, benzene has ρ=54.6 lb_m/ft^3, k=0.092 Btu/h·ft·^{o}F, C_p=0.42 Btu/lb_m·^{o}F, μ=3.69x10^{-4} lb_m/ft·s, Pr=6.5.

4. [20 pts] Pressurized liquid water at 40°C flows (without phase change) across a 46-cm-wide (tube-length direction) staggered tube bank, carrying combustion gases which keep the tube surfaces at 120°C. For each 30 cm in height of tube bank, water is supplied in a 15-cm-ID pipe, flowing at a velocity of 1 m/s.



(i) What temperature would you use to evaluate fluid properties?

(ii) Assume that at the temperature you use in (i), ν = 0.364x10^{-6} m^2/s, k=0.668 W/m·K, and Pr=2.22, Pr_s=1.34, ρ=994.6 kg/m^3, c_p=4175.6 J/kg·K. Estimate the temperature of the water after passing through the tube bank.

5. [20 pts] Saturated liquid water at T_m=20^oC flows inside the annular region formed by two concentric circular tubes. The outer tube has ID=25mm, while the inner tube has OD=10mm. The mass flow is 0.02 kg/s. The outer surface is insulated and the inner surface is kept at constant $T_{s,i}$=50^oC. Determine the average heat transfer coefficient from the inner surface to the water, h_i, for fully developed velocity and temperature flow. Saturated water at T_m has ν=1.006x10^{-6} m^2/s, ρ=1000.5 kg/m^3, k=0.597 W/m·K, Pr=7.02.

6. [Optional, 20 pts] In a laboratory demonstration ethylene glycol, at $T_m=60^oC$ and mass flow 0.045kg/s, flows through a triangular duct having equal sides s=20mm. The flow is fully developed with respect to velocity and temperature. What is the average heat transfer coefficient if the duct surfaces are maintained at a constant $T_s=80^oC$? At $T_{m,}$ ethylene glycol has $\nu=4.747\text{x}10^{-6}$ m2/s, $\rho=1087.6$ kg/m^3, k=0.0.259 W/m·K.