Fall 2014 Qualifying Exam – Thermodynamics – Closed Book

Saturated ammonia vapor at *200^{O}F* flows through a 0.250 in diameter tube. The ammonia passes through a small orifice causing the pressure to drop very rapidly to *30 psia*. The mass flow rate is *36.22 lbm/hr*. Determine the temperature of the ammonia just downstream of the orifice to the nearest *0.1^{O}F*. You may assume that the process from just upstream to just downstream of the orifice is adiabatic.

In addition to the ammonia property tables provided, you may find the following conversions helpful.

$$1\,Btu = 778.1693\,lbf\text{-}ft$$

$$1\,lbf = 32.17\,lbm\text{-}ft/s^2$$

Fall 2014 Qualifying Exam – External Forced Convection – Closed Book

The velocity profile $u(y)$ in the laminar boundary layer for flow of air over a flat plate (with a free stream velocity (U) of 1m/s) at a distance of 1m from the leading edge of the plate is given by:

$$u(y) = 79y - 72900y^3 \qquad \text{in m/s}$$

Using Reynolds-Colburn analogy,

$$\frac{h_x}{\rho c_p U} Pr^{2/3} = \frac{c_{fx}}{2}$$

where c_{fx} is the skin-friction coefficient and h_x is the local heat transfer coefficient,

find (1) the wall shear stress, (2) the local heat transfer coefficient, and (3) the local Nusselt number at this location.

Use the following properties for air.

ρ=1.1777 kg/m^3; μ = 0.2 x 10^{-4} Pa·s; c_p = 1009 J/kg·K; k= 0.029 W/m·K; Pr = 0.7

Fall 2014 Qualifying Exam – Internal Forced Convection – Closed Book

Air flowing through a heat sink channel (with a velocity of u_m = 0.5 m/s) is used to cool electronics in a PC running Xbox One. The thermal boundary condition for air flow can be assumed as uniform heat flux from the electronics surrounding the channel. Calculate the heat transfer coefficient if the heat sink channel is rectangular with a height of 1 cm and a width of 2 cm. For the same problem, if a square channel of side 1.414 cm is used instead of a rectangular channel, estimate the heat transfer coefficient for this case.

If a performance metric is defined as, $PF = \dfrac{\left[\dfrac{Nu_{rectangular}}{Nu_{square}}\right]}{\left[\dfrac{f_{rectangular}}{f_{square}}\right]^{0.33}}$ that compares the heat transfer performance in both the channels for the same pumping power, then use the equation for *PF* to find which shape is better for designing the heat sink channel. In the above equation, *Nu* represents the Nusselt number and *f* represents the friction factor (subscripts imply the corresponding channel geometries). Note that if *PF* is less than 1, then square channel performs better and vice versa. Assume air properties as: $\nu = 20.76 \times 10^{-6}$ m^2/s; k = 0.03 W/m·K; ρ = 1.1777 kg/m^3.

	Nu_{D_h}		
Cross Section	Constant Axial Wall Heat Flux	Constant Axial Wall Temperature	$f Re_{D_h}$
Equilateral triangle	3.1	2.4	53
Circle	4.364	3.657	64
Square (1 × 1)	3.6	2.976	57
Rectangle (1 × 1.4)	3.8	3.1	59
(1 × 2)	4.1	3.4	62

Fall 2014 Qualifying Exam – Heat Conduction – Closed Book

For a thin plate of length 1 m and height 1 m, the left and bottom sides are maintained at a uniform temperature of T_1, while temperature profiles of $T_1 + 100 \cdot \sin(\pi x)$ and $T_1 + 25 \cdot \sin(\pi y)$ are maintained on the right and top sides respectively. Assuming no heat generation in the plate and 2D steady state heat transfer, develop an expression for the temperature distribution $T(x,y)$ in the plate.

Energy equation:

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} + \frac{\dot{e}_{gen}}{k} = \frac{1}{\alpha}\frac{\partial T}{\partial t}$$

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Qualifying Exam: Heat Transfer

CLOSED BOOK

This portion of the qualifying exam is **closed** book. You may have a calculator.

Work 3 of the 4 problems. Be very clear which 3 you want graded (see below). It is not acceptable to work all 4 problems and hope that the graders pick out the best worked three.

I want problems #____, #____, and #____ graded.

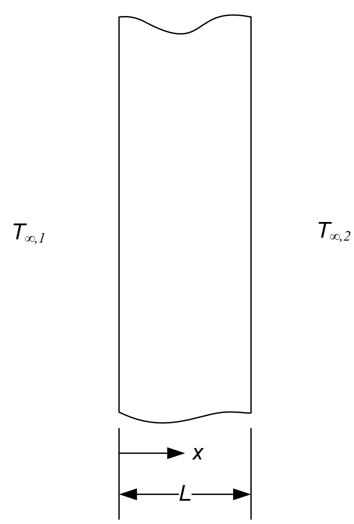
Be sure to put your name on all papers handed in, including this cover sheet.

1. A hollow sphere with a constant heat generation source, $\mathbf{Q}^*$ (kw/m^3) inside has a constant surface temperature maintained on the outside. The inner radius is R_i and the outer radius is R_o and the temperature distribution in the hollow sphere is found to be:

   $T = A/r^3$ where "A" here is a known constant.

   The thermal conductivity of the sphere material is not necessarily constant. How does the thermal conductivity here vary with position? Express your answer mathematically in terms of the sphere radius and known constants given above.

2. A plate subjected to 1-D steady-state heat transfer has a thickness L, and a temperature dependent thermal conductivity given by $k = k_0\left(1 + aT\right)$, where k_0 and a are constants. The left side of the plate is subjected to convection with ambient temperature $T_{\infty,1}$ and heat transfer coefficient h. The right side is also subjected to convection heat transfer with ambient temperature $T_{\infty,2}$ and heat transfer coefficient h. In terms of the parameters given, determine the heat flux through the plate.



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Qualifying Exam: Heat Transfer

CLOSED BOOK

3. A radiation thermometer is a radiometer calibrated to indicate the temperature of a blackbody. A steel billet having a diffuse, gray surface of emissivity 0.8 is heated in a furnace whose walls are at 1250 °C. Determine the temperature of the steel billet when the radiation thermometer viewing the billet through a small hole in the furnace indicates 1175 K.

4. A steel plate is heated in a furnace and then processed between two rollers to reduce its thickness. The plate is supported by rollers underneath it as at cools. If the reduced thickness plate has a constant velocity V and temperature T_i where it exits the compression rollers, describe in equations and words how to solve for the temperature as a function of time and/or location. The plate may be treated as thin with temperature varying only in the direction of motion (plate is very wide compared to its thickness). You may assume that the ambient conditions are uniform and that the supporting rollers may be neglected as far as heat transfer in concerned. The plate thickness is δ, with density and specific heat ρ and c_p. The initial temperature is quite high so the radiation needs to be considered. Let the emissivity be $\varepsilon(T)$. Be sure to state any assumptions you choose to make.

   Please comment on possible solution techniques.