Exam 2 Review

Formula Sheet

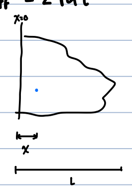
3 ways to solve transient heat cond.

1. Lumped capacitance
   - $Bi \leq 0.1$ condition
   - Yes → · Internal conduction resistance within object is negligible when compared w/ conv & rad
     - ⇒ Isothermal material
   - No → use semi-infinite

     or

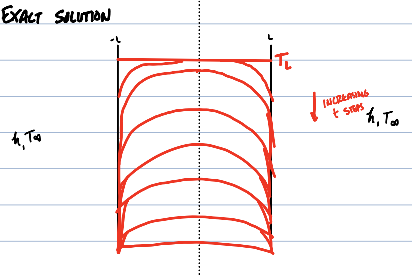
     one term approximation

2. Semi-infinite heat solution
   - $L_{DIFF} = 2\sqrt{\alpha t}$ $\quad$ L_{DIFF} = length of diffusion



   - If thermal wave has not travelled L @ time t, then we can use semi-infinite

3. Exact solution



   - Solved by series $\sum_{n=1}^{\infty}$
   - For $Fo > 0.2$, we can truncate w/ one-term approximation

   ζ are eigenvals that solve eqn.

   Table 5.1

Example of 3rd solution (2019 exam)

4. **(15 points)** An acrylic sheet of thickness L = 5 mm is used to coat a hot, isothermal metal substrate at T_b = 300°C. The properties of the acrylic are ρ = 1990 kg/m³, c_p = 1470 J/kg-K, and k = 0.21 W/m-K. The softening temperature of the acrylic is 90°C. Neglect any thermal contact resistance between the acrylic and the metal substrate. The initial acrylic temperature is T_i = 20°C. The goal of the problem is to determine whether the insulated back side of the acrylic has started to soften after 75 seconds.

Hint: For a constant surface temperature boundary condition, the corresponding Biot number can be approximated to be infinite.

a) **(2 points)** Determine the Fourier number Fo.

b) **(1 point)** Can the one-term approximation be used?

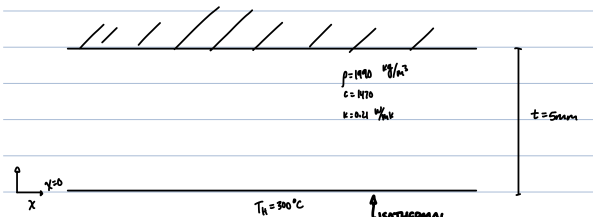
c) **(1 point)** Determine the associated coefficient C_1.

d) **(1 point)** Determine the associated eigenvalue ζ_1, in radians.

e) **(4 points)** Calculate the temperature of the insulated back side of the acrylic, in °C, at t = 75 seconds.

f) **(2 points)** Has the acrylic at the insulated surface begun to soften?

g) **(4 points)** What is the temperature of the mid-plane of the acrylic, in °C, at t = 75 seconds.



$Bi = \frac{hL}{k}$

$q''_{conv} = h(T_s - T_\infty)$

$h = \infty$ (IF YOU HAVE CONSTANT T @ BASE)

$\Rightarrow Bi \to \infty$

A) $Fo = \frac{\alpha t}{L^2}$ $\qquad \alpha = \frac{k}{\rho c} = 7.178 \cdot 10^{-8} \frac{m^2}{s}$

$Fo = \left.\frac{\alpha t}{(0.005)^2}\right|_{t=75s} = 0.215$

B) $Fo > 0.2 \Rightarrow$ OTA CAN BE USED

C) TABLE 5.1 GIVEN ON EXAM (IF WE NEED IT) ← DEFINITION OF Bi ≠ GIVEN IN TBL 5.1

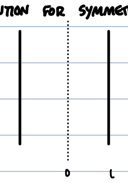
$Bi = \frac{hL}{k}$ FOR PLANE WALL

$Bi = \infty \Rightarrow C_1 = 1.2733$

D) $\xi_1 = 1.5078$ [RAD]

E) $T_{x=5mm,\, t=75s}$

WE CAN USE SOLUTION FOR SYMMETRICAL B.C. ON PLATE



WE TREAT INSULATED WALL LIKE CENTERLINE

$\theta_0^* = C_1 e^{-\xi_1^2 Fo} = 0.748$

$\theta_0^* = \frac{T - T_\infty}{T_i - T_\infty} \Rightarrow \frac{T - T_\infty}{T_i - T_\infty} = 0.748$

$T = 90.4\,°C$

F) YES $T > 90°C$

G) $T_{x=2.5mm,\, t=75s}$

$\theta^* = \theta_0^* \cos(\xi_1 x^*)$ $\qquad x^* = \frac{L/2}{L} = 0.5$

$\theta^* = 90.4 \cos(\xi_1\, 0.5)$

$\Rightarrow \boxed{T_{MID} = 152\,°C}$

1^{ST} QUESTION WILL BE EXTERNAL FLOW + TRANSIENT HEAT

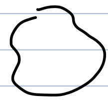
- WE'LL BE GIVEN A PROBLEM:
    - 1. CALCULATE h
        - EXTERNAL FLOW
            - PLATE, CYLINDER, SPHERE

              T_f, Re, Pr, Nu
                - Nu $\rightarrow$ h

                  $\bar{h}$ OR h

    2. MODEL TEMP CHANGE IN SOLID FROM 3 WAYS OF TRANSIENT HEAT

h, T_∞



PROBLEM FROM LAST CLASS

ME EN 4610 Heat Transfer
Department of Mechanical Engineering
University of Utah
Fall 2019

Mid-Term Exam 2 **Name:**________________________________
11/11/2019
4 questions, 11 pages **uID:**________________________________
Total of 40 points
Time: 60 minutes

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1. (4 points) True or False (Circle your answers in the box below)

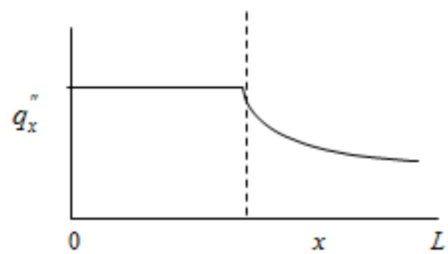
(a)	True	False
(b)	True	False
(c)	True	False
(d)	True	False

(a) Consider the effect of the Reynolds number on the character of the flow over an object. If the Reynolds number increases, then the extent of the region around the object that is affected by viscosity decreases. True or False?

$Re = \frac{xD}{\nu}$ TRUE

$\nu =$

(b) Consider flow over a flat plate with an unheated starting length. Figure 1 shows the correct heat flux variation. True or False?



$q'' = h(T - T$

h

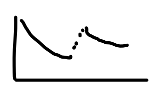
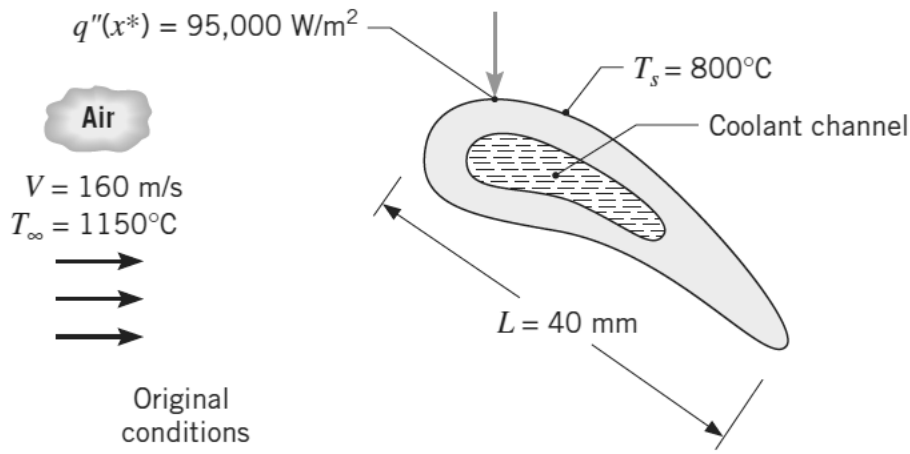


Figure 1

(c) For laminar flow of air in a circular tube where the inlet temperature is lower than the constant surface temperature of the tube, if the mass flow rate were decreased, then both the outlet temperature and the heat transfer rate would increase. True or False?

(d) For steady flow of fluid in a circular tube, the mean temperature represents the average temperature of the fluid across the flow. True or False?

2. (6 points) Experimental tests using air as the working fluid are conducted on a portion of the turbine blade shown in the sketch. The heat flux to the blade at a particular point (x^*) on the surface is measured to be $q'' = 95{,}000\ \mathrm{W/m^2}$. To maintain a steady-state surface temperature of 800°C, heat transferred to the blade is removed by circulating a coolant inside the blade.



a) (3 points) Determine the heat flux to the blade at x^* if its temperature is reduced to $T_{s,1} = 700°\mathrm{C}$ by increasing the coolant flow.

b) (3 points) Determine the heat flux at the same dimensionless location x^* for a similar turbine blade having a chord length of $L = 80$ mm, when the blade operates in an airflow at $T_\infty = 1150°\mathrm{C}$ and $V = 80$ m/s, with $T_s = 800°\mathrm{C}$.

A) $q'' = 95{,}000 \frac{W}{m^2}$

$T_\infty = 1150\,°C$ $V = 160\ m/s$

$q_1'' = h(T_\infty - T_{s,1})$ $q_2'' = h(T_\infty - T_{s,2})$

$h(1150-700)$ $h(1150-800)$

$q_2'' = h(1150-800)$

$q_2 = 95000 \frac{W}{m^2}$

95000

B) $L = 80mm$ $T_\infty = 1150\,°C$ $T_s = 800\,°C$

$V = 80\ m/s$

$$Re_{L,2} = \frac{V x_2}{\nu} = \frac{80 \cdot 80}{\nu}$$

$$Re_{L,1} = \frac{V x_1}{\nu} = \frac{160 \cdot 40}{\nu}$$

3. (15 points) An electric air heater consists of a horizontal array of thin metal strips that are each 0.1 m long in the direction of the airstream that is in parallel flow over the tops of the strips. Each strip is 0.2 m wide, and 25 strips are arranged side by side, forming a continuous smooth surface over which the air flows at 20 m/s. During operation, each strip is maintained at 500°C and the air is at 25°C. Assume all heater surfaces, other than those in contact with the airstream are perfectly insulated. Use the following properties of air:

ν [m^2/s]	4.00×10^{-5}
k [W/m-K]	4.29×10^{-2}
ρ [kg/m^3]	1.2
Pr [-]	0.628

a) **(3 points)** Sketch the variation of the local heat transfer coefficient along the entire heater bank (i.e., $x = 0$ to 2.5 m). Make sure to label x positions where convective heat transfer mechanisms are expected to change.

b) (**4 points**) Determine the average heat transfer coefficient from $x = 0$ to 2.5 m

c) **(4 points)** Compare the average heat transfer coefficient calculated in (b) with the average heat transfer coefficient from x = 0 to 0.8 m. **Explain** why these average heat transfer coefficients are different.

d) **(2 points)** Determine the heat transfer to the air, in W/m over from $x = 0.8$ to 2.5 m?

e) **(2 points)** What is the total wall shear stress (N/m^2) at the heater surface from $x = 0$ to 0.8

4. **(15 points)** Consider the flow of oil at 20°C in a 30-cm diameter pipeline at an average velocity of 2 m/s. The internal surface of the pipe is smooth. A 200-m-long section of the pipeline passes through icy waters of a lake at 0°C. Measurements indicate that the surface temperature of the pipe is very nearly 0°C. Disregard the thermal resistance of the pipe material. **Assume fully developed conditions (both hydrodynamic and thermal)**

ρ **[kg/m^3]**	888
c_p **[J/kg-K]**	1880
ν **[m^2/s]**	901×10^{-6}
μ **[N.s/m^2]**	0.800
k **[W/m.K]**	0.145
Pr **[-]**	10,400

a) **(1 points)** Determine the Reynolds number *Re*.

b) **(1 point)** Is the flow laminar or turbulent?

c) **(2 point)** Determine the mass flow rate of oil through the tube.

d) **(3 point)** Determine the heat transfer coefficient for the cooling process in the submerged section of the tube.

e) **(3 points)** Determine the exit temperature of the oil when the pipe leaves the lake.

f) **(3 points)** Determine the rate of heat transfer from the oil.

g) **(2 points)** We neglected the entry region by assuming that fully developed conditions were prevailing in the submerged portion of the tube. Is it a good assumption? Justify your answer.

ME EN 4610 Heat Transfer
Department of Mechanical Engineering
University of Utah
Fall 2018

Mid-Term Exam 2 **Name:**_______________________________________
11/14/2018
4 questions, 10 pages **uID:**_______________________________________
Total of 40 points

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1. (4 points) True or False (Circle your answers in the box below)

(a)	True	False
(b)	True	~~False~~ ?
(c)	True	False
(d)	True	False

(a) The Nusselt number is defined as $Nu = \dfrac{hL_{char}}{k_{solid}}$

FALSE

(b) Consider a thermally and hydrodynamically fully developed flow in a circular tube. The local Nusselt number is a constant.

(c) The transition to turbulence for internal flow occurs with a critical Reynolds number approximately equal to 2300.

(d) Consider a thermally and hydrodynamically fully developed flow over a flat plate. The local Nusselt number is a constant.

2. (6 points) Water flows at a velocity $u_\infty = 1$ m/s over a flat plate of length L = 0.6 m. Measurements indicate that the water temperature is approximately 350 K. In the laminar and turbulent regions, experimental measurements show that the local convection coefficients are well described by

$$h_{\text{laminar}}(x) = C_{\text{laminar}} x^{-0.5} \quad \text{and} \quad h_{\text{turbulent}}(x) = C_{\text{turbulent}} x^{-0.2}$$

$$C_{\text{laminar}} = 477 \text{ W/m}^{1.5} \cdot \text{K} \quad \text{and} \quad C_{\text{laminar}} = 3600 \text{ W/m}^{1.8} \cdot \text{K}$$

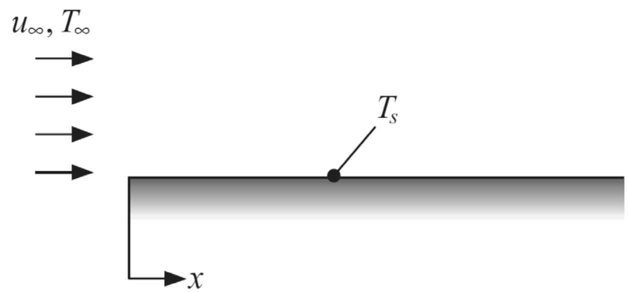
Use the following thermophysical properties for water:

ρ [kg/m^3]	974
μ [N.s/m^2]	365×10^{-6}

a) (2 points) This flow starts of first in the laminar regime and then transitions into turbulence. Find the location (x_c) along the plate where the transition occurs.

b) (4 points) Determine the average convection coefficient, $\bar{h}$, over the entire plate.

3. (15 points) Consider the flow of cool air over a hot plate as shown below. The hot-plate is maintained at a constant surface temperature, $T_s = 300$ °C. Ambient air at $T_\infty = 20$ºC is in parallel flow over the flat plate with a velocity $u_\infty = 10$ m/s. The length of the plate, $L_1 = 1$ m. The width of the plate into the page is $W = 1$ m.



Heat transfer due to convection occurs on just one side as shown in the figure above.

The properties of air to be used for this problem are given in the table below.

ν [m²/s]	30.4×10^{-6}
k [W/m·K]	36.1×10^{-3}
Pr [-]	0.688

(a) (2 points) Determine the Reynolds number for the flow at $x = L_1$

Hint: $\mu/\rho = \nu$

(b) (5 points) Determine the average heat transfer coefficient over the full length of the plate

(c) (3 points) What is the total convective heat transfer rate [W] experienced by the plate?

Based on these results, you need to analyze the heat transfer from a second plate, whose length, $L_2 = 2$ m and width, W = 1 m. The plate is exposed to a different air stream whose free stream velocity is, $v_\infty = 5$ m/s. The free stream temperature is still $T_\infty = 20$ºC. The surface temperature of the plate is unknown. Assume that all the thermophysical properties are still as presented in the table above.

(d) (2 points) Show that the Reynolds number for the second plate evaluated at $x = L_2$ is numerically equal to your answer from part (a).

(e) (3 points) Determine the convective heat transfer coefficient [W/m²-K], h_2 for the second plate based on the fact that $Nu = f(Re, Pr)$ for identical geometries.