**ChBE 3210A**
**Transport Processes II**
**Spring 2015**

**Exam #1,**
**February 10, 2015**
**6:00 – 8:00pm**

**The exam consists of two parts. The first part is closed notes, no calculator. After 30 minutes, the first answer sheets will be collected. At that point, cheat sheet (one sided, 8.5 x 11”), hand-out and calculators may be used for the second part of the exam.**

**The use of wireless devices (*e.g.*, cell phones, IR transmitters/receivers) is not permitted at any time during the exam.**

**To receive full credit on each problem, it is advised to start with the (appropriate) full form of the balance equation(s) needed to solve the problem. Label all variables and equations. Include a brief word description to explain each step in your problem, stating *all assumptions.* Present your solution clearly. Numerical answers without units or explanations will not receive credit.**

**NAME: ______________________________**

**The work presented here is solely my own. I did not receive any assistance nor did I assist other students during the exam. I pledge that I have abided by the above rules and the Georgia Tech Student Code of Conduct.**

**Signed: ______________________________**

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|---|---|
| **Problem I** | **_____/14** |
| **Problem II** | **_____/11** |
| **Problem III** | **_____/30** |
| **Problem IV** | **_____/17** |
| **Problem V** | **_____/28** |
| **Total** | **_____/100** |

## Problem I (14 points)

Answer the following TRUE/FALSE questions by circling the correct answer. If you want to change your answer, scratch out the old answer, rewrite “TRUE / FALSE” and circle the correct answer. Make sure that it is clear to which question your answer belongs.

***Each correct answer is worth 2 points, leaving the question blank yields no points and incorrect answers lead to a penalty of -1 point.***

**A/** For forced convection of air (Pr ≈ 0.70) over a flat plate, the thermal boundary layer is always thinner than the hydrodynamic boundary layer.

TRUE / FALSE

**B/** For turbulent flow of a fluid in a long pipe (L/D > 500), the convective heat transfer coefficient $h$ between the pipe wall and fluid does not vary significantly along the length of the pipe.

TRUE / FALSE

**C/** Stable film boiling of water occurs at a higher surface temperature than nucleate boiling.

TRUE / FALSE

**D/** For flow across a flat plate, both the local friction factor $C_{f,x}$ and the local convective heat transfer coefficient $h_x$ decrease with increasing distance $x$ from the leading edge of the plate.

TRUE / FALSE

**E/** Two identical copper plates with uniform temperatures, one at 5ºC and one at 45ºC, are placed on separate tables made from an insulating material so that only their top surfaces are exposed to stagnant air at 25ºC. The warm copper plate will reach room temperature faster than the cold one.

TRUE / FALSE

**F/** The correction factor for a cross-flow heat exchanger can be greater than 1.

TRUE / FALSE

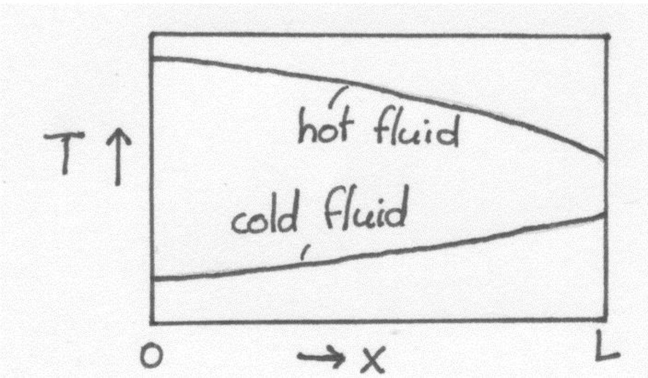
**G/** In a condenser, saturated steam is used to preheat a reagent before it enters a chemical reactor. The condenser can be operated in co- and counter-flow mode. Provided that inlet temperatures and flow rates of both streams remain unchanged, the log-mean temperature difference $\Delta T_{LM}$ is the same in co-flow and counter-flow operation.

TRUE / FALSE

**Problem II (11 points)**

**A/** The figure below shows the temperature profiles for a co-flow double-pipe heat
(3) exchanger. In the same graph, sketch the temperature profiles that will be found if the flow rate of the hot stream is increased significantly, while the inlet temperatures of both the hot and the cold stream remain the same.

Briefly describe key features of your new sketch to receive full credit.




**B/** Two analytical approaches were presented in Chapter 19 for the analysis of heat transfer in
(2) boundary layers: *i)* the exact analysis method of Blasius, *ii)* the approximate integral analysis method of Von Karman. Name one advantage for each of these two approaches.

## Problem II (continued)

**C/** In a lab, you find an old plate-and-frame heat exchanger with four hose connections; two of
(4) these are labeled “inlet” and the other two “outlet”, but it is not clear which inlet corresponds to which outlet. Based on the overall design, you are pretty sure that it is a single-pass device, but you cannot figure out whether it was designed for co-flow or counter-flow operation.

In the lab, you have hot (60°C) and cold (10°C) water available to hook up to the two marked inlet ports; you can vary the flow rates of both streams from very low to quite high. Additionally, you can measure the fluid temperatures at both outlets.

Describe two experiments (*i.e.* high/low flow rates for one or both streams) that can help you to:

*1)* identify which inlet corresponds to which outlet.
*2)* figure out if the heat exchanger was designed for co-flow or counter-flow.

Describe the experimental settings as well as the outcomes that would lead to a conclusion one way or another.

**D/** In Chapter 21 of the textbook, no correlation was presented for convective heat transfer
(2) due to condensation on a cooled horizontal plate. This is no coincidence; no universal correlation exists for that scenario. Explain why not.

**PART II** **Name:** ____________________

## Problem III: Steam pipe (30 points)

At a chemical plant, an uninsulated steam line with outer diameter $D$ = 9 cm is used to transport saturated steam at 200°C between buildings. The temperature of the surrounding air is $T_\infty$ = 15°C.

Assume a uniform pipe wall temperature $T_p$ = 200°C and ignore effects of radiation.

**A/** Calculate the heat loss per meter of exposed pipe on a calm day without wind.
(9)

**B/** By which factor does the heat loss from the bare pipe increase on a breezy day
(6) with wind velocity of 8 m/s perpendicular to the pipe?

**C/** The plant engineer decides to add a layer of insulation to the steam pipe to reduce heat loss.
(9) If the thickness of the insulating layer around the pipe is $t$ = 2 cm, what should be its thermal conductivity $k_{ins}$ to reduce the surface temperature of the insulation, $T_S$, to 40°C on a calm day?

**D/** Without doing any serious calculations, explain whether the effect of wind on the insulated
(4) pipe will be greater or less than on the bare pipe? In other words, if you repeated the calculation from part B/ for the insulated pipe, would you find a larger or smaller factor than for the bare pipe? Explain your answer.

**E/** Was it realistic to assume a uniform pipe wall temperature for the bare steam pipe
(2) in parts A/ and B/? Explain your answer.

**Note: Many parts of this problem can be answered independently.**

## Problem IV: Heat exchanger analysis (17 points)

Hot oil is cooled by water in a shell-and-tube heat exchanger with four tube passes and one shell pass.

Water flows through the tubes at a total rate of 0.6 kg/s and oil flows through the shell at 1.0 kg/s. The average temperature of the water and oil in the heat exchanger are 40ºC and 75ºC, respectively. The outside of the shell is well-insulated.

**A/** If the inlet temperature of the oil is 90ºC, determine the correction factor *F* of the heat
(9) exchanger.

**B/** Determine $U \cdot A$ for the heat exchanger.
(6)

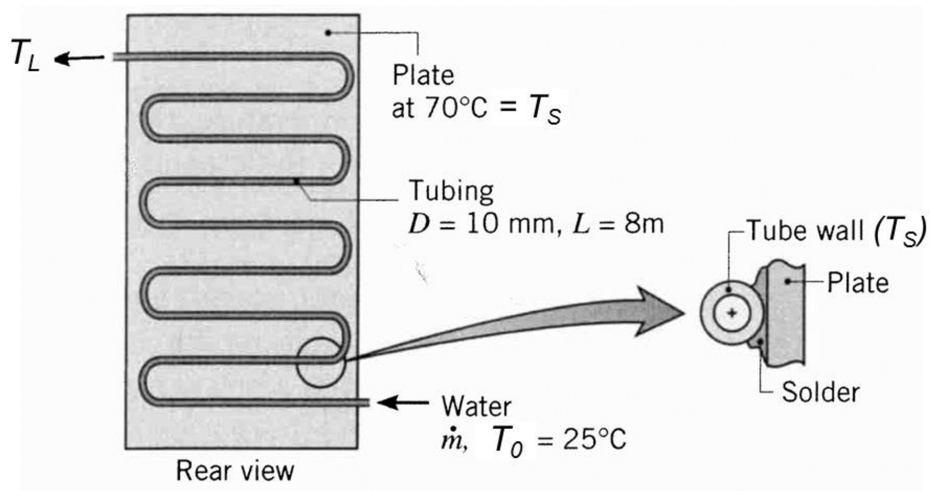
**C/** How do you expect $U \cdot A$ to change (increase/decrease/remain same) if the water flow rate is
(2) increased? Explain your answer.

***NOTE:***
Oil properties at 75ºC:

$\rho$ = 800 kg/m$^3$
$\nu = 4.0 \cdot 10^{-5}$ m$^2$/s
$k$ = 0.15 W/m·K
$c_p$ = 2000 J/kg·K

## Problem V: Solar collector (28 points)

In a solar collector, heat from sunlight is absorbed by a flat plate made out of a heat-absorbing and conducting material. The heat is then transferred to water that flows through copper tubing soldered onto the back of the collector plate (see Figure below). Heat transfer from the collector plate to the copper tubes is very efficient: the thermal resistance associated with conduction through the solder layer and the tube wall can be neglected. The effect of the 180 degree bends on the water flow in the tube (inner diameter $D$ = 10 mm, length $L$ = 8 m) can also be ignored: the serpentine tube can be treated as a straight pipe. You may assume fully developed flow, steady state conditions and a constant plate temperature $T_S$ = 70°C.




**A/** In a graph, sketch the water temperature $T_w$ as a function of distance $x$ from the tube inlet.
(3) Briefly describe key features of the graph to receive full credit.

**B/** For $T_0$ = 25°C and a water flow rate of 0.01 kg/s, estimate the average convective heat
(10) transfer coefficient inside the tube, without trying to actually calculate the unknown exit temperature of the water, $T_L$. List any assumptions you make.

**C/** In Chapter 19, the following equation was derived for the relation between $T_0$,$T_L$ and $T_S$ for
(8) a fluid flowing through a pipe with constant wall temperature:

$$\ln\left(\frac{T_S - T_L}{T_S - T_0}\right) = -\frac{h}{\rho \cdot v_{ave} \cdot c_P} \cdot \frac{4L}{D}$$

Alternatively, you can also use a heat-exchanger-like equation to describe the heat transfer rate to the water:

$$q = h \cdot A \cdot \Delta T_{LM}.$$

Using these two equations, derive the correct expression for $\Delta T_{LM}$ in terms of $T_0$,$T_L$ and $T_S$.

**D/** Use the estimated $h$ value from part B/ to calculate the heat flow $q$ from the collector plate
(7) to the water. ***If you did not solve B/, use h = 300 W/m²·K.***