**Name** _____

## Chemical Engineering 150A
## Mid-term Examination 1 – Spring 2013

<u>**Show your work.**</u> **Clearly identify any assumptions you are making, indicate your reasoning, and clearly identify any variables that are not identified in the problem statement.**

**The exam is closed book and closed notes.  A sheet of useful equations is attached as the last sheet of the exam.  If you make notes on it that you feel will affect the grading, be sure your name is on the equation sheet and clearly indicate which problem the notes correspond to.**

There are <u>3 problems</u>.  Please note the point values for each problem in the table below and plan your time accordingly.

**Your exam should have 8 numbered pages (including this coversheet) plus the equation sheet.**

| PROBLEM | Score |
|---|---|
| #1 (**33 pts**) | |
| | |
| #2 (**34 pts**) | |
| | |
| #3 (**33 pts**) | |
| | |
| **Total** | /100 |

1) (33 pts total) Consider a scenario called free convection. An example of such is the behavior of lava lamp wax. The movement of the wax is due to its temperature-dependent density instead of any externally-imposed conditions. Here we will consider a simpler one-phase system with free convection taking place between two infinite plates held at their respective temperatures, assuming constant coefficient of volume expansion (β) and constant thermal conductivity (k). The macron (‾) indicates the average quantities. Below, several relevant equations are given.
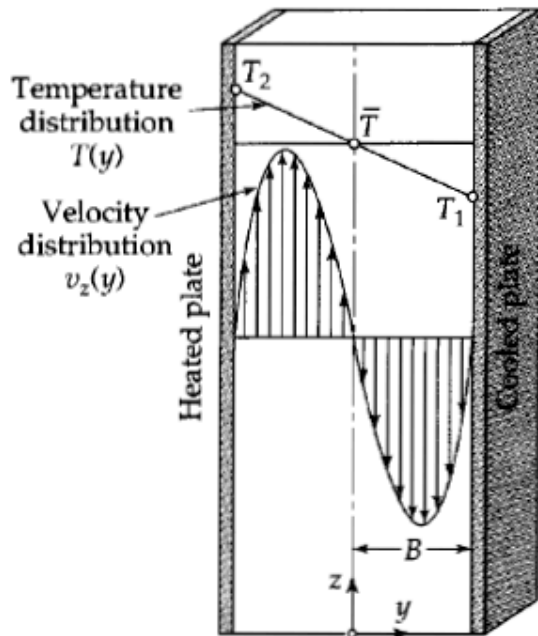


$$k\frac{d^2T}{dy^2} = -\frac{dq}{dy} = 0$$

$$\beta = -\frac{1}{\rho}\left(\frac{\partial\rho}{\partial T}\right)_p$$

$$\eta\frac{d^2v_z}{dy^2} = -\bar{\rho}g\beta(T-\bar{T})$$

$$c_p = \frac{-\int_0^\tau qA\,dt}{m\Delta T}$$

| k | thermal conductivity |
|---|---|
| T | temperature |
| y, z | Cartesian coordinates |
| τ | total amount of time heat is inputted |
| q | heat flux = heat/(area·time) |
| $c_p$ | specific heat capacity |
| m | mass |
| β | coefficient of volume expansion |
| ρ | density |
| p | pressure |
| η | viscosity |
| $v_z$ | z component of velocity |
| A | Area of heated plate |
| B | Half width of slot |
| g | gravitational acceleration |

(a) (12 pts) What are the dimensions of k, $c_p$ and $\beta$?

(b) (4 pts) For the situation pictured, the variables $\boxed{k, \quad B, \quad \beta, \quad \bar{\rho}, \quad \Delta T, \quad \eta, \quad g, \quad q, \quad y}$ are thought to be important in determining $v_z$. How many dimensionless groups does the Buckingham Pi method tell us we need to describe this situation?

(c) (9 pts) Choosing $\boxed{\beta, \quad \bar{\rho}, \quad B, \quad \eta}$ as the variables that will potentially appear in all dimensionless groups, form the dimensionless group involving g.

(d) (8 pts) Ultimately, physical arguments and more sophisticated analysis reveals that the dimensionless relationship below governs the problem:

$$\boxed{\frac{\bar{\rho} v_z B}{\eta} = \frac{\bar{\rho} v_z B}{\eta}\left(\frac{y}{B}, \frac{\bar{\rho}^2 g\beta(\Delta T)B^3}{\eta^2}\right)}$$

You have a small model (M) of the full scale (FS) system you are interested in, with $B_M = B_{FS}/10$. (Thus, the model is 1/10 the size of the full scale system.)
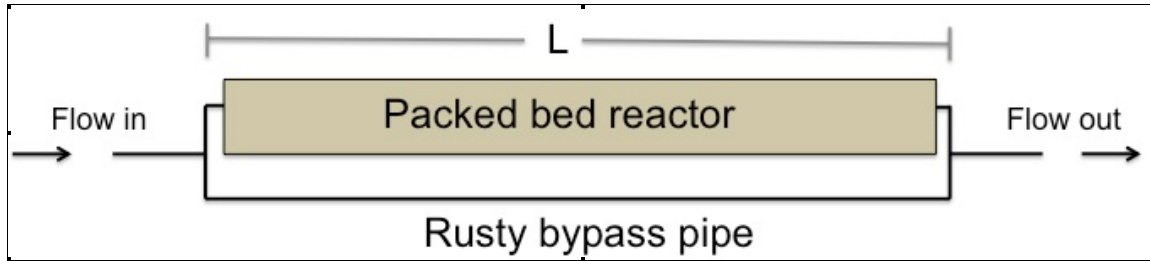
If the same fluid is to be used in both systems, what must the ratio $\Delta T_M/\Delta T_{FS}$ be to use results from the model to determine the behavior of the full scale system?

More space for your Problem 1 solution…

2)(34 pts total)



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                                  L
Flow in     ┌────────────────────────────────────────────┐     Flow out
──→         │            Packed bed reactor               │      ──→
            └────────────────────────────────────────────┘
                        Rusty bypass pipe
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The 3 meter bypass pipe on one of your plant's packed bed reactors has rusted, leading to an unacceptable pressure drop along the length of pipe. A coworker suggests lining the pipe with a smooth plastic tube as a solution to the problem. The inner diameter of the rusted pipe is 8 cm with a surface roughness of 0.24cm, and the inner diameter of the plastic tubing is 7cm with a smooth surface.

Fluid: $\rho$= 1100 kg/m$^3$, $\eta$= 0.0011 Pa·s
Packed bed: $\varepsilon$= 0.38, $D_p$ = 0.7mm, L=3m, D=1m

a) (14 pts) Assuming conditions are adjusted so that the flow rate through the bypass is maintained at 0.10 m$^3$/s, is the pressure drop along the bypass lowered by inserting the plastic tube? Calculate the pressure drop for the rusty pipe and for the plastic tube to support your answer.

b) (20 pts) Given that the flow rate through the plastic tube bypass is equal to 0.10 m$^3$/s, what is the superficial velocity in the packed bed under these conditions? Show your work, and clearly indicate your reasoning.

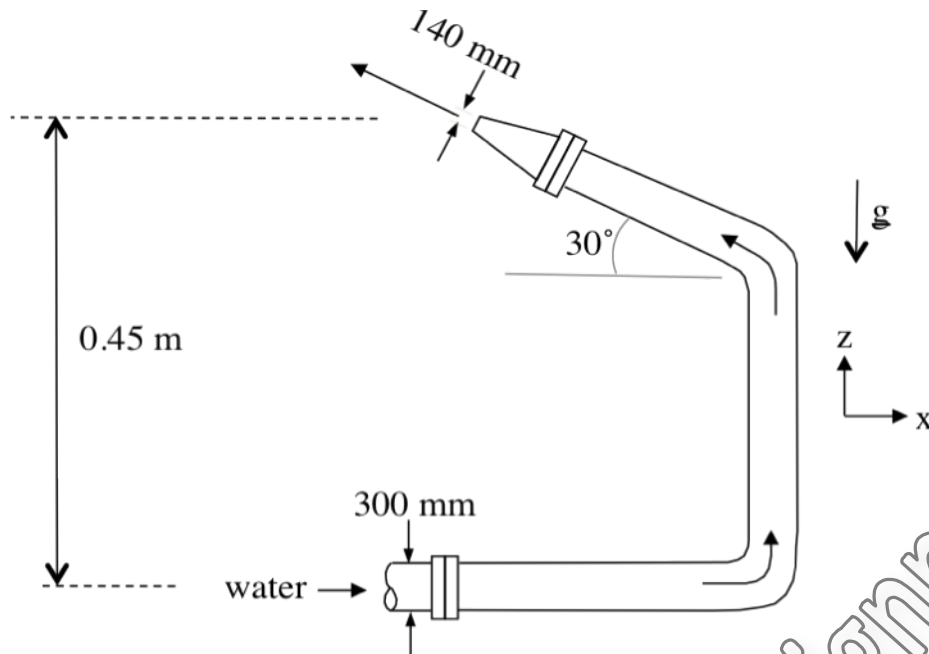More space for your problem 2 solution….

3) (33 pts total)  The elbow and nozzle combination shown in the figure below is oriented vertically as indicated.  Water is discharged through the nozzle into the atmosphere at a steady rate of 120 kg/s.  The mass of the empty elbow-nozzle combination is 25 kg; the mass of water in the filled combination is 85 kg.

Determine the forces exerted by the fluid and the elbow-nozzle combination on the surroundings at steady state, neglecting any viscous losses.  The density of water is 1000 kg/m³, the viscosity of water is 1.0 mPa·s.  Atmospheric pressure is 100 kPa.

More space for your Problem 3 solution….