Outline of ta3220, cont.

II. Turbulence and friction factors
   A. Nature of turbulence - film
   B. friction factor in tube flow
      1. momentum balance → eq. relating f to $\Delta\mathscr{P}$ and v
         cf. *FTI,* which leaves out gravity
      2. correlation for f
         Beware that figure in *FTI* is for "4f"
         When working with other books, beware of 2 definitions of friction factor
      3. conduits of noncircular cross-section: hydraulic radius
      4. trial-and-error solution if D, v, ρ or μ are unknown
   C. friction factor for flow around sphere
      (note that "f" in my notes is C_D in *FTI*)
      1. momentum balance → eq. for f (or for C_D)
         what if sphere is lighter than surrounding fluid?
      2. correlation for f (or C_D)
   D. flow in packed beds
      1. chart - useful mainly for seeing conditions at which laminar flow breaks down
      2. Eq. at low Re - corresponds to Darcy's law for packed bed
      3. single quadratic equation works for all Re - no need for trial-and-error solutions

[most of this material is already in FTI, so there will be few handouts for this section of the course.]

Summary of friction-factors

Nature of turbulence and why shell balances don't work anymore
- lecture and film

key insight: turbulent eddies increase transport across streamlines
    much greater transport that "molecular transport" through sides of control volume
    transport of momentum here, but also transport of heat and mass (to be discussed later in course)

Friction factors for tube flow

Derivation: class notes, plus text section 5.3.1
    (text derivation excludes gravity)

key equation in book: Eq. 5.30

key chart in book: Fig. 5.10
    note this is a chart for "4f" for purposes of equation in book.
    Note that f in *FT* is Fanning friction factor, which is 4 times Moody friction factor. The chart is actually a Moody friction-factor chart, but by defining this as "4f", the book gives value of f for Fanning friction factor. Homework solutions use chart from another book for f directly. *BSL* uses Fanning friction factor, which agrees with *FT* as long as one recalls that the chart gives *4f*.
    Beware in career of two definitions of friction factor. If you keep with same book for equation and chart, you should be OK

note definition of "hydraulic diameter" (Eq. 5.26; example Fig. 5.9, Eq. 5.27);
    - how to solve for turbulent flow in conduits with noncircular cross-section; this approach does not work for laminar flow

method of solving problems where Re can't be calculated in advance:
    trial and error (get the steps in correct order!)

how might one extend this to non-Newtonian fluids? (students not responsible for this)

Sphere falling or rising in Newtonian fluid

derivation: lecture notes, plus text, culminating in Eq. 2.83
    note what *FT* text calls C_D is called "f" in homework solutions.
    what to do if sphere is less dense than fluid?

key chart in book: Fig. 2.15 ("bol" = sphere. This chart also include behavior of cylinder (aligned perpendicular to flow) and disk (held in plane perpendicular to flow); see text for definitions of C_D for those cases if interested)

(approximate) application of equations to separations of dispersed viscous liquid droplets in less-viscous fluid

how to solve if Re can't be computed in advance: trial and error

Flow through packed bed

relevance to flow in geological formations

chart (Fig. 5.115) - good for distinguishing where Darcy's law breaks down

- Def. of Re for packed beds: Eq. 5.62
- Def. of C_D: Eq. 5.51

Simpler equation from *BSL*, handed out in class; applies to whole range of Re

- ε = porosity
- v_o = "Darcy" or "superficial" velocity, Q/A; *not* actual physical velocity
- D_p = grain diameter
- $Go = \rho v_o$
- L = length of packed bed; Eq. 6.4-14 in *BSL* is equation for $\nabla\mathscr{P}$
- (recall how to solve quadratic equations)

estimate of permeability for sandpacks and packed beds of uniform spheres:

- $k = (D_p^2/150)[\varepsilon^3/(1-\varepsilon)^2]$

how to estimate conditions at which Darcy's law breaks down