PROPERTIES OF POROUS MEDIA AND FLUIDS

A. Porous Media Properties

(1) Density

For unconsolidated media, consider the density of individual particles (particle density):

$$\rho_p = \frac{M_p}{V_p}$$  \hspace{1cm} (silica sand $\sim 2.65 \text{ g/cm}^3$)

[Note that Si = silicon, SiO$_2$ = silica, and silicone is a polymer of silica and organic molecules]

For the bulk material (i.e., in a quantity at least equal to the REV), we consider the bulk density:

$$\rho_b = \frac{M_p}{V_T}$$  \hspace{1cm} (sand $\sim 1.7 \text{ g/cm}^3$)

(2) Porosity

Porosity is defined as the ratio of the volume of void spaces to the total volume:

$$\eta = \frac{V_v}{V_T}$$  \hspace{1cm} (usually in the range $\sim 0.1 - 0.5$)

The void volume is equal to the total volume minus the volume of the particles:

$$V_v = V_T - V_p$$

Porosity, particle density, and bulk density are then related as follows:

$$\eta = \frac{V_T - V_p}{V_T} = 1 - \frac{V_p}{V_T} = 1 - \frac{\rho_b}{\rho_p}$$  \hspace{1cm} (0.36 for sand)

Similar media properties are volumetric water content
Porosity, water content, and saturation are related as follows:

\[ \theta = \frac{V_w}{V_T} \]
and fluid saturation

\[ S_w = \frac{V_w}{V_V} \quad \text{(range 0 - 1.0)} \]

We are also interested in NAPL saturation

\[ S_N = \frac{V_N}{V_V} \quad \text{(usually has values < 0.2)} \]

B. Fluid Properties

We are interested in both physical and chemical properties of fluids. Physical properties of interest include density, viscosity, and interfacial (surface) tension: \( \rho, \mu, \sigma \). Viscosity and interfacial tension are discussed here; chemical properties (e.g., structure, polarity, solvency, osmosis?, etc) will be discussed as we progress.

1. Viscosity

The definition of a fluid is a substance that deforms continuously under the application of a shear stress. In solids, it is well known that “stress is proportional to strain”, where strain is the angular displacement. However, because fluids “deform continuously”, the angular displacement is not constant under a given stress. Therefore, we consider the rate of angular displacement (strain rate), which is proportional to stress.
Shear stress, $\tau \propto \frac{d\alpha}{dt} = \frac{(dl)}{dt} \frac{dr}{dy}$  

[Recall that for small angles, $\alpha \approx \tan \alpha = \frac{l}{y}$]

Therefore, the dimensions for $\mu$ are $\left[\frac{F}{A} \cdot \frac{L}{T} \cdot \frac{T}{L} \cdot \frac{L}{T} \cdot \frac{M}{L} \right] = \left[\frac{M}{L^2} \cdot \frac{L}{T^2} \cdot \frac{L}{T} \cdot \frac{M}{L} \right]$

The viscosity of water at standard temperature is approximately 1 cp. [1 poise = 1 g/cm/s] What happens to viscosity as temperature changes?

(2) Interfacial (Surface) Tension, Capillarity, and Wettability

A fluid-fluid interface is defined as a discontinuity in fluid properties. The existence of a fluid interface is a characteristic of immiscible fluids, whereas miscible fluids have no distinct boundary.

Why do fluid interfaces exist? Consider air and water molecules. Air molecules have minimal cohesion compared to water molecules (the molecules are much farther apart). [Cohesion is the intermolecular attraction of a single substance, whereas adhesion is the attraction of dissimilar substances.]
At the water surface, cohesive forces work to minimize the surface area and result in a net force towards the interior. Therefore, water in air forms a sphere.

The fluid-fluid interface can be thought of as a membrane under tension. Interfacial tension then acts in a direction tangent to the interface.

The dimensions for $\sigma$ are $[\frac{F}{L}] = [\frac{ML}{T^2}]$. At standard temperature and pressure, $\sigma_{a/w} = 72$ dyne/cm $[1$ dyne $= 1$ g cm/s$^2]$.

- **Wettability** refers to the polar attraction or nonpolar repulsion of a fluid and a solid phase. Is sand polar? How about glass? (What is glass made of?)
- **Capillarity** describes the tendency of water to rise in a small-diameter tube inserted into a free water surface.

Upward force caused by *adhesion* (attraction between the fluid molecules and the solid) is strong enough to overcome *cohesion* of fluid. The solid surface is wet by the fluid.

$$\rho gh\pi R^2 = 2\pi R \sigma \cos \theta$$

$$h = \frac{2\sigma \cos \theta}{\rho g R}$$

Note that as $R$ decreases, $h$ increases. For wetting fluids, $\theta < 90^\circ$ and thus, nonwetting $\theta > 90^\circ$ (for example, the contact angle for mercury and glass is $\sim 130^\circ$). Note that for $\theta > 90^\circ$, $\cos \theta < 0$ and $h < 0$. What does this indicate?