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Flow in a porous media

A porous media can be looked at as a bundle of capillaries having an uneven cross-section. Surface tension plays an important role here. If a capillary is partially immersed in a fluid, the liquid inside the capillary may rise or fall depending upon the contact angle. If contact angle is less than $90°$ the fluid inside the capillary would rise. In such cases, one might be interested in knowing the time taken for the fluid to rise or the rate of penetration. A few cases are explained in this section.

Horizontal capillary

An understanding of this phenomenon finds applications in the secondary and tertiary oil recovery

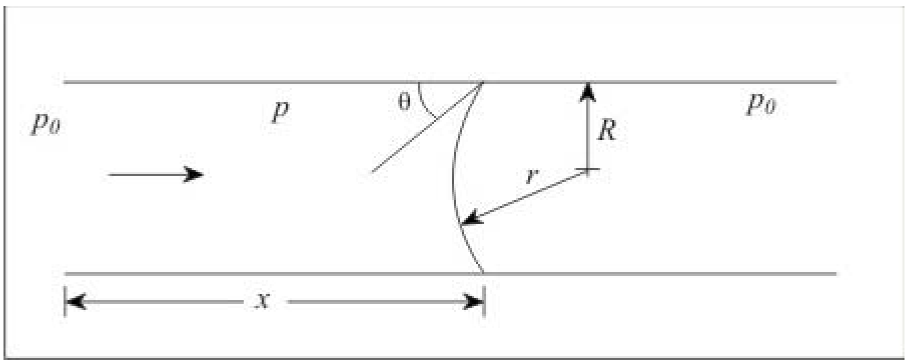

Figure 3.7. Horizontal capillary

The driving force behind the flow is the reduction in interfacial energy. This force overcomes the resistance due to friction. Spontaneous penetration occurs for $\theta < 90°$, whereas spontaneous retraction occurs for $\theta > 180°$.

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Assuming quasi-steady state,

$$p_0 - p = \frac{2\gamma}{R}\cos\theta$$

The assumptions we make are

1. The meniscus is part of a sphere, which will happen if we neglect gravity.
2. Shape of meniscus remains same despite movement.
3. Contact angle θ is independent of velocity.

And the capillary being narrow, the effects due to gravity can be neglected. This leads to Huygen-Poiseuille flow for which the velocity profile is parabolic. The entrance effects have also been neglected. Huygen-Poiseuille flow is valid for low Reynolds number flow in a circular pipe at steady state with a fully developed velocity profile.

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$$p_0 - p = \Delta p = \frac{8\mu x}{R^2}\bar{v}$$

$$= \frac{8\mu x}{R^2}\frac{dx}{dt}$$

$$\frac{8\mu}{R^2}\frac{xdx}{dt} = \frac{2}{R}\gamma\cos\theta$$

$$\frac{d(x^2)}{dt} = \frac{R}{2\mu}\gamma\cos\theta$$

$$x = \left[\frac{R\gamma}{2\mu}(\cos\theta)t\right]^{1/2} \qquad (3.19)$$

$$t = 0, x = 0$$

$$x \propto \sqrt{t}$$

Since as time increases, velocity decreases we have

$$v \rightarrow 0 \; as \; t \rightarrow \infty$$

This means that the velocity of the fluid goes to zero as it reaches the far-end of the capillary.

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A question now arises. Can the fluid really come out of the capillary? (If so, laws of thermodynamics will be violated!)
Assume that the fluid flows out of the capillary. In that case, the shape of meniscus will change from bulging inward to bulging outwards. But this will not be energetically favorable. So, the fluid will not flow out and thermodynamic laws are not violated..

If p_a is the atmospheric pressure at the inlet, then

$$\frac{8\mu x}{R^2}\frac{dx}{dt} = p_a - p_0 + \frac{2\gamma}{R}\cos\theta$$

We can see that penetration can occur even if $p_a < p_0$ for $\theta < 90°$. But for $\theta > 90°$, p_a has to be greater than p_0 for penetration to occur.

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Vertical capillary

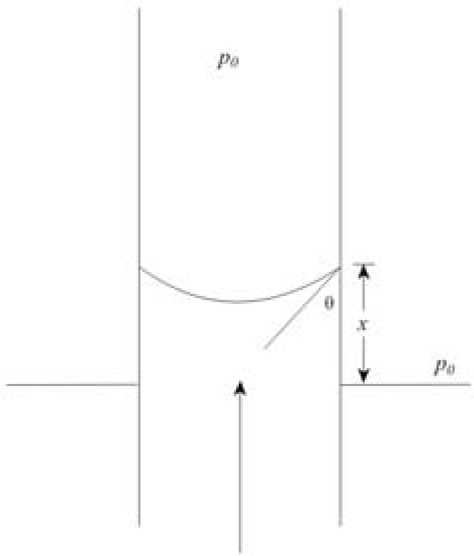

Figure 3.8. Vertical capillary

In the case of a vertical capillary, gravity also plays a significant role. The equation obtained is-

$$\frac{8\mu x}{R^2}\frac{dx}{dt} = \frac{2\gamma}{R}\cos\theta - \rho g x$$

From this expression it can be deduced that an equilibrium state will be observed.

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