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Rise or fall of A Liquid into A Capillary Tube Having Bore of Rectangular Cross-Section

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Abstract: *A tube, the bore of which is so small that it will only admit a hair (Latin Capilla) is called a capillary tube. When such a tube of glass is placed vertically with its lower end immerged in water, the water is observed to rise in the tube. The action between the capillary tube and the water has been called capillary action. The rise or fall of a liquid into a capillary tube having bore of circular cross section is well established. But, what if the cross section is not circular? Here an attempt is taken to calculate the rise or fall of a liquid into a capillary tube having bore of rectangular cross section.*
Key words: *capillarity, capillary tube, rectangular cross-section, capillary rise.*

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I. Introduction

The most familiar surface effect is the elevation of a liquid in an open tube of small cross section. [1]Such a manifestation of surface tension by which the portion of the surface of a liquid coming in contact with a solid is elevated or depressed, depending on the adhesive or cohesive properties of the liquid is known as capillarity. [2] A tube, the bore of which is so small that it will only admit a hair (Latin Capilla) is called a capillary tube. [3] In other words, a tube that has a small internal diameter of hair like thinness is defined as capillary tube. [4] When such a tube of glass, open at both ends, is placed vertically with its lower end immerged in water, the water is observed to rise in the tube, and to stand within the tube at a higher level than the water outside. The action between the capillary tube and the water has been called capillary action. [3]

The rise or fall of a liquid into a capillary tube having bore of circular cross section is well established. But, what if the cross section is not circular? Here an attempt is taken to calculate the rise or fall of a liquid into a capillary tube having bore of rectangular cross section.

Derivation

Consider a capillary tube having bore of rectangular cross-section. Let ‘a’ and ‘b’ are the length and width of the rectangular cross-section.

When dipped partially into a liquid of density ρ, let liquid rises a height of ‘h’ into the tube. Thus we have a liquid column of dimension h×a×b. (Figure-1)

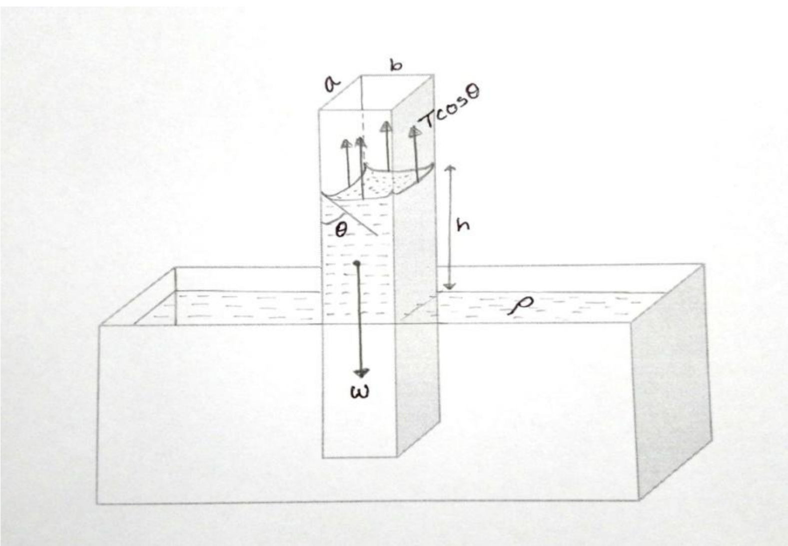

Figure 1: *Rise of liquid in a capillary tube having bore of rectangular cross section*

Surface tension on the meniscus acts with a contact angle θ. All of the horizontal components of this tension cancels each other and the vertical components Tcosθ lie along the length 'a' and 'b'. Hence the upward force acting on the liquid column is,

$$F_u = (2a+2b)T\cos\theta$$

$$\text{or, } F_u = 2(a+b)T\cos\theta \qquad \ldots\ldots \text{(i)}$$

And the downward force is the weight of the liquid column, given by,

$$F_d = mg$$

$$\text{or, } F_d = \rho V g \qquad \ldots\ldots \text{(ii)}$$

But the volume of the liquid column, $V = abh$ … … (iii)

$$\text{Thus, } F_d = \rho abhg \ \ldots\ldots \text{(iv)}$$

Since the liquid column is in equilibrium,

$$F_d = F_u$$

$$\text{or, } \rho abhg = 2(a+b)T\cos\theta$$

$$\text{or, } h = \frac{2(a+b)\,T\cos\theta}{\rho abg} \qquad \ldots\ldots \text{(v)}$$

II. Result and Discussion

Equation (v) gives the rise or fall of a liquid through a capillary tube of rectangular cross section of dimension a×b. Now, let a = b = r, the radius of a capillary tube having circular cross-section. Then equation (v) gives,

$$h = \frac{2(r+r)\,T\cos\theta}{\rho(r\times r)g}$$

$$\text{or, } h = \frac{2\times 2r\,T\cos\theta}{\rho gr\times r}$$

$$\text{or, } h = \frac{2\times 2T\cos\theta}{\rho gr}$$

$$\text{or, } h = 2H \ \ldots\ldots \text{(vi)}$$

where, $H = \frac{2T\cos\theta}{\rho gr}$,[5] the rise or fall of a liquid of density ρ into a capillary tube of circular cross-section of bore radius r. Thus, the rise or fall of a liquid into a capillary tube of rectangular cross-section is double than that into a capillary tube having circular cross-section, provided the dimensions of the rectangular cross-section is equal to the radius of the circular cross-section. (Figure-2)

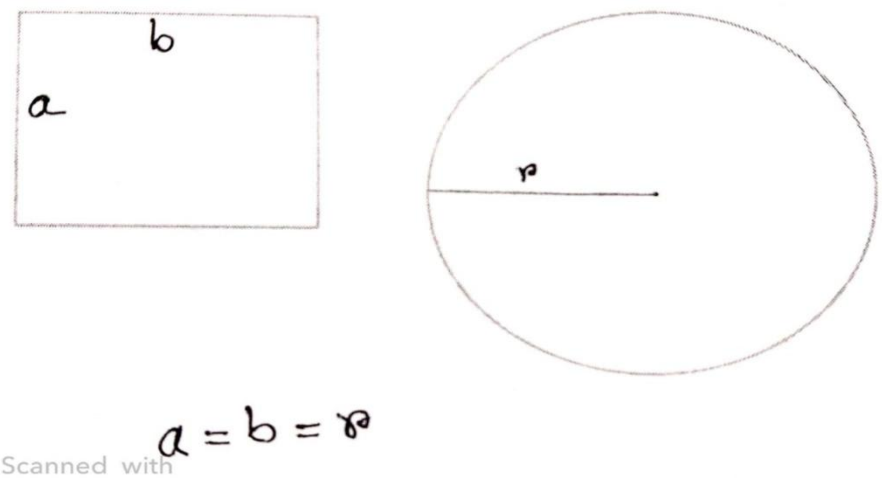

Figure 2

Now let,

H_1=Height of liquid column in capillary tube of circular cross-section= h

H_2=Height of liquid column in capillary tube of rectangular cross-section=2h

V_{cc} = Volume of liquid in capillary tube of circular cross-section

V_{rc} = Volume of liquid in capillary tube of rectangular cross-section

Considering the assumption, a=b=r, the ratio of the volumes of the liquid in two capillary tubes is,

$$\frac{V_{cc}}{V_{rc}} = \frac{\pi r^2 h}{r\times r\times 2h}$$

$$\text{or, } V_{cc} = \frac{\pi}{2} V_{rc} \ \ldots\ldots \text{(v)}$$

i.e., the volume of liquid column in capillary tube of circular cross-section is $\frac{\pi}{2}$ times then that in a capillary tube of rectangular cross-section.

Reference

[1]. Francis Weston sears, Mechanics, wave motion and heat, p-379.
[2]. dictionary.com/browse/capillarity.
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