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Frank White Fluid Mechanics 7th Edition Solutions


38 Solutions Manual • Fluid Mechanics, Fifth Edition

The complete (small-slope) solution to this problem is:

$$\eta = h \cos \theta = (\rho g \gamma^2)^{1/3} x^{2/3}, \text{ where } h = (\gamma / \rho g)^{1/3} \cos \theta. \text{ Ans.}$$

The formula clearly satisfies the requirement that $\eta = 0$ if $x = 0$. It requires "small slope" and therefore the contact angle should be in the range $70^\circ < \theta < 110^\circ$.

1.69 A solid cylindrical needle of diameter d , length L , and density ρ_s may "float" on a liquid surface. Neglect buoyancy and assume a contact angle of 0° . Calculate the maximum diameter needle able to float on the surface.




Solution: The needle "feels" the surface downward and the surface tension forces are upward, as shown. If these tensions are nearly vertical, a vertical force balance gives:

$$\sum F_y = 0 = 2\gamma L - \rho_s \frac{\pi d^2}{4} L, \text{ or: } d_{\max} = \sqrt{\frac{8\gamma}{\rho_s}}. \text{ Ans. (a)}$$

(b) Calculate d_{\max} for a steel needle ($\rho_s = 7.84$) in water at 20°C . The formula becomes:

$$d_{\max} = \sqrt{\frac{8\gamma}{\rho_s}} = \sqrt{\frac{8(0.073 \text{ N/m})}{(7.84 \times 998 \text{ kg/m}^3)(9.81 \text{ m/s}^2)}} = 0.00156 \text{ m} = 1.6 \text{ mm}. \text{ Ans. (b)}$$

1.70 Derive an expression for the capillary height change h , as shown, for a fluid of surface tension γ and contact angle θ between two parallel plates W apart. Evaluate h for water at 20°C if $W = 0.5$ mm.



Solution: With θ the width of the plates into the paper, the capillary forces on each wall together balance the weight of water held above the reservoir free surface:

$$\rho g W h b = 2(\gamma b \cos \theta), \text{ or: } h = \frac{2\gamma \cos \theta}{\rho g W}. \text{ Ans.}$$