
6.5 In flow past a body or wall, early transition to turbulence can be induced by placing a trip wire on the wall across the flow, as in Fig. P6.5. If the trip wire in Fig. P6.5 is placed where the local velocity is *U*, it will trigger turbulence if $Ud/\nu = 850$, where *d* is the wire diameter [Ref. 3 of Ch. 6]. If the sphere diameter is 20 cm and transition is observed at Re_D = 90,000, what is the diameter of the trip wire in mm?

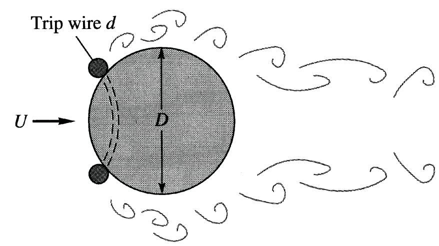

Fig. P6.5

Solution: For the same U and ν,

$$Re_d = \frac{Ud}{\nu} = 850; \quad Re_D = \frac{UD}{\nu} = 90000,$$

$$\text{or} \quad d = D\frac{Re_d}{Re_D} = (200\text{ mm})\left(\frac{850}{90000}\right) \approx \mathbf{1.9\ mm}$$

P6.6 For flow of a uniform stream parallel to a sharp flat plate, transition to a turbulent boundary layer on the plate may occur at $Re_x = \rho Ux/\mu \approx$ 1E6, where *U* is the approach velocity and *x* is distance along the plate. If *U* = 2.5 m/s, determine the distance *x* for the following fluids at 20°C and 1 atm: (*a*) hydrogen; (*b*) air; (*c*) gasoline; (*d*) water; (*e*) mercury; and (*f*) glycerin.

Solution: We are to calculate $x = (Re_x)(\mu)/(\rho U) = (1E6)(\mu)/[\rho\,(2.5\text{m/s})]$. Make a table:

FLUID	ρ – kg/m^3	μ - kg/m-s	x - meters
Hydrogen	0.00839	9.05E-5	43.
Air	1.205	1.80E-5	6.0
Gasoline	680	2.92E-4	0.17
Water	998	0.0010	0.40

Mercury	13,550	1.56E-3	0.046
Glycerin	1260	1.49	470.

Clearly there are vast differences between fluid properties and their effects on flows.

6.7 Cola, approximated as pure water at 20°C, is to fill an 8-oz container (1 U.S. gal = 128 fl oz) through a 5-mm-diameter tube. Estimate the minimum filling time if the tube flow is to remain laminar. For what cola (water) temperature would this minimum time be 1 min?

Solution: For cola "water", take $\rho = 998\ \text{kg/m}^3$ and $\mu = 0.001$ kg/m·s. Convert 8 fluid ounces = $(8/128)(231\ \text{in}^3) \approx 2.37\text{E–}4\ \text{m}^3$. Then, if we assume transition at Re = 2300,

$$\text{Re}_{\text{crit}} = 2300 = \frac{\rho V D}{\mu} = \frac{4\rho Q}{\pi\mu D}, \quad \text{or:} \quad Q_{\text{crit}} = \frac{2300\pi(0.001)(0.005)}{4(998)} \approx 9.05\text{E–}6\ \frac{\text{m}^3}{\text{s}}$$

Then $\Delta t_{fill} = \upsilon/Q = 2.37\text{E–}4/9.05\text{E–}6 \approx$ **26 s** *Ans.* (a)

(b) We fill in exactly one minute if $Q_{crit} = 2.37\text{E–}4/60 = 3.94\text{E–}6\ \text{m}^3/\text{s}$. Then

$$Q_{\text{crit}} = 3.94\text{E–}6\ \frac{\text{m}^3}{\text{s}} = \frac{2300\pi\nu D}{4} \quad \text{if } \nu_{\text{water}} \approx 4.36\text{E–}7\ \text{m}^2/\text{s}$$

From Table A-1, this kinematic viscosity occurs at **T ≈ 66°C** *Ans.* (b)

6.8 When water at 20°C ($\rho = 998\ \text{kg/m}^3$, $\mu = 0.001$ kg/m·s) flows through an 8-cm-diameter pipe, the wall shear stress is 72 Pa. What is the axial pressure gradient ($\partial p/\partial x$) if the pipe is (a) horizontal; and (b) vertical with the flow *up*?

Solution: Equation (6.9b) applies in both cases, noting that τ_w is negative:

$$\text{(a)} \quad \textit{Horizontal}: \quad \frac{dp}{dx} = \frac{2\tau_w}{R} = \frac{2(-72\ Pa)}{0.04\ m} = \mathbf{-3600}\ \frac{\mathbf{Pa}}{\mathbf{m}} \quad \textit{Ans.}\ \text{(a)}$$

$$\text{(b)} \quad \textit{Vertical, up}: \quad \frac{dp}{dx} = \frac{2\tau_w}{R} - \rho g \frac{dz}{dx}\Big|_{1} = -3600 - 998(9.81) = \mathbf{-13,400}\ \frac{\mathbf{Pa}}{\mathbf{m}} \quad \textit{Ans.}\ \text{(b)}$$
