Fluid Mechanics (ME 201)

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Tutorial 1 – Introductory concepts

1. A body weighing 1000 N slides down at a uniform speed of 1 m/s along a lubricated inclined plane making a 30^o angle with the horizontal. The viscosity of the lubricant is 0.1 kg/ms, and contact area of the body is 0.25 m^2. Compute the lubricant thickness assuming linear velocity distribution. [0.05 mm]

2. Determine the torque and power required to turn a 10 cm long, 5 cm diameter shaft rotating at 500 RPM in a 5.1 cm diameter concentric bearing flooded with a lubricating oil of viscosity 100 centipoise. [0.1029 Nm, 5.387 W]

3. A futuristic micro-orbiter, having the characteristic length scale of 1 mm, revolves around the earth at an altitude of 70 km. The atmospheric properties at this altitude are $p = 5.2$ Pa, $\rho = 8.2 \times 10^{-5}$ kg/m^3, and dynamic viscosity, $\mu = 1.438 \times 10^{-5}$ Ns/m^2. The mean free path of air is given by, with $u = 0.4987445$ as a numerical factor,

$$\lambda = \sqrt{\frac{\pi}{8}}\frac{\mu}{u}\frac{1}{\sqrt{\rho p}}$$

   Is continuum hypothesis valid in this case? [No; Kn=0.87]

4. A toothpaste has an yield stress of 100 N/m^2. When it starts flowing, it behaves as a Newtonian fluid of viscosity 10 kg/ms. Compute the rate of strain experienced by this material when subjected to shear stress of (i) 50 N/m^2 and (ii) 200 N/m^2. [0; 10 s^{-1}]

5. Estimate the height to which water at 20^oC will rise in a capillary glass tube 3 mm in diameter that is exposed to the atmosphere. At this condition, the surface tension of a water-air interface is $\sigma = 0.073$ N/m. [9.92 mm]

6. By how much does the pressure in a cylindrical jet of water 4 mm in diameter exceed the pressure of the surrounding atmosphere if the surface tension of water-air interface is $\sigma = 0.073$ N/m.
   . [36.5 N/m^2]

7. At what minimum speed (in km/hr) would an automobile have to travel for compressibility effects to be important? Assume ambient temperature to be 30^{o}C. [376.8 km/hr]

Additional problems for self-practice

8. A thrust bearing consists of a 10 cm diameter pad rotating on another pad separated by an oil film $\mu = 80$ centipoise by 1.5 mm. Compute the power dissipated in the bearing if it rotates at 100 RPM. [0.00548 Nm, 0.0574 W]

9. Derive an expression for Bulk modulus of an ideal gas under (i) isothermal process, and (ii) isentropic process. [(i) $K = p$ (ii) $K = \gamma p$]

10. Some non-Newtonian fluids behave as a Bingham plastic for which shear stress can be expressed as $\tau = \tau_0 + \mu(du/dr)$. For laminar flow of a Bingham plastic in a horizontal pipe of radius R, the velocity profile is given as $u(r) = (\Delta P/4\mu L)(r^2 - R^2) + (\tau_0/\mu)(r - R)$, where $\Delta P/L$ is the constant pressure drop along the pipe per unit length, μ is the dynamic viscosity, r is the radial distance from the centerline, and τ_0 is the yield stress of Bingham plastic. Determine (a) the shear stress at the pipe wall and (b) the drag force acting on a pipe section of length L as a function or r.
. [$\tau_w = 2\tau_0 + \frac{\Delta P}{2}\frac{R}{L}$; $D = 4\pi\tau_0 Lr + \Delta P \cdot \pi r^2$]

11. The density of seawater at a free surface where the pressure is 98 kPa is approximately 1030 kg/m^3. Taking the bulk modulus of elasticity of seawater to be 2.34×10^9 N/m^2 and expressing variation of pressure with depth z as $dP = \rho g dz$ determine the density and pressure at a depth of 2500 m. Disregard the effect of temperature. Compute pressure at the given depth assuming it to be an incompressible fluid. [$\rho = 1041.3$ kg/m^3; P=25.497 MPa; P=25.261 MPa]

12. Derive a relationship between pressure inside a bubble, and the outside pressure. [$\Delta p = \frac{4\sigma}{R}$]