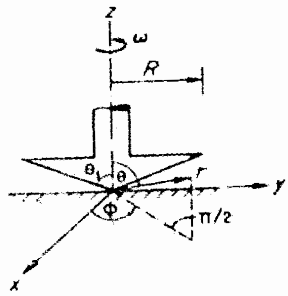
Extra

Department of Chemical Engineering, IIT Kharagpur
Mid-Semester Examination, 2014
Transport Phenomena (CH30012)
Open Book Examination

Only the following two textbooks are allowed – i) Fox & McDonald and ii) Bird Stewart & Lightfoot
Photocopies of text books and class notes are not allowed

1. A cone and plate viscometer consists of a cone rotating at a constant angular velocity ω over a stationary plate. Liquid fills the gap between the cone and plate and the torque required to keep the plate stationary is measured through the deflection of a tensional spring. Simplify the Navier-Stokes equation assuming that flow is laminar and tangential (i.e., only $v_\phi \neq 0$), and that the intertial and gravity terms are negligible. Assuming $v_\phi = r f(\theta)$, show that $f(\theta)$ must satisfy



$$f'' + f'cot\theta + f\left(2 - \frac{1}{sin^2\theta}\right) = 0$$

If the cone angle $[\pi/2 - \theta_1]$ is small, the velocity V_ϕ may be fairly well approximated as linear in the vertical direction. Compute the torque on the lower plate in terms of μ, R, ω, and θ_1. If R=5cm, θ_1=89°, torque=5×10^{-3} Nm, ω = 2rpm, determine the viscosity of the liquid. **5+5=10**

2. Terminal velocity is attained when the drag force becomes equal to the net weight or buoyant force. In modeling this phenomenon, including the unsteady part of the motion of a solid sphere in a stationary fluid, the following forces are of interest

i) net gravity force	~	$(\rho_s - \rho_f) L^3 g$
ii) viscous force	~	μLV
iii) inertia of fluid (convective)	~	$\rho_f L^2 V^2$
iv) inertia of fluid (unsteady)	~	$\rho_f L^3 V/t$
v) inertia of sphere	~	$\rho_f L^3 V/t$

Estimating the forces on a per unit volume basis, demonstrate that the unsteady terms for the fluid are unimportant at times greater than $\rho_f D^2/\mu$ where D is the diameter of the sphere. Also show that the motion of the solid particle cannot be assumed to be steady for times less than $\rho_s D^2/\mu$. For a glass (ρ = 2226 kg/m^3) sphere of diameter 1mm settling in water ($\mu = 10^{-3}$ kg/m.s), estimate these two characteristic times and explain their physical significances. **2x3 + 1 = 7**

A small solid sphere of density equal to 2600 kg/m^{3}and diameter 53×10^{-6} m starts to fall in water with zero velocity. Assuming that Re < 1 throughout its trajectory and the flow to be quasi-steady, obtain the position of the sphere and its velocity as a function of time. Estimate the time taken and the distance travelled by the sphere to attain 99 percent of its terminal velocity. Check whether your results are consistent with the conditions for neglecting the unsteady portion of the trajectory. **2+2+2+1 = 7**

3. A specific test section of a large duct has a cross section of 0.3m x 0.3m and is 0.6m long. Air (ρ = 1.23 kg/m^3) flows through this section with a velocity of 24.4 m/s at the beginning of the section. Turbulent boundary layers form at all sides of the duct with a thickness equal to 20.3 mm at location 1 (entry) and 30.5 mm at the exit of the duct. The boundary layer velocity profiles can be expressed by the 1/7th power law profile. Evaluate the freestream velocity at the exit of this section and the change in static pressure over the length of the duct. **6**