Process Fluid Mechanics (CL254) – Semester II, 2020-2021

Department of Chemical Engineering, Indian Institute of Technology - Bombay

Weightage: 20%	**End Semester Examination - Part 2**	April 27, 2021 10:15-11:45 a.m.
Max. marks: 40	*Open Book*	*Duration: 90 min.*

1. (12 marks) **Creeping flow.** Fluid slowly seeps out as it flows through a hollow fibre membrane as shown below. Assume the flow in the system to be steady, axisymmetric and to vary slowly with length. Also assume $v_\theta = 0$, $v_r \approx 0$ and $\partial^2 v_z/\partial z^2 \approx 0$. The radial flow out of the tube is given by

$$v_r(R, z) = K(P(z) - P_a)$$

where K is a constant, P is pressure inside the tube and P_a is the ambient pressure. The pressure at the inlet is P_0 and gravitational forces are negligible.

   (a) Show that the z momentum balance equation reduces to

$$0 = -\frac{\partial P}{\partial z} + \frac{\mu}{r}\frac{\partial}{\partial r}\left(r\frac{\partial v_z}{\partial r}\right),$$

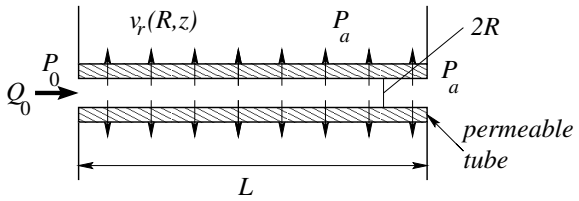
   and obtain the velocity profile $v_z(r)$ in terms of the pressure gradient. (5)

   (b) Obtain the volumetric flow rate in the tube ($Q(z)$) in terms of the pressure gradient.(4)

   (c) Using an overall volume balance given by

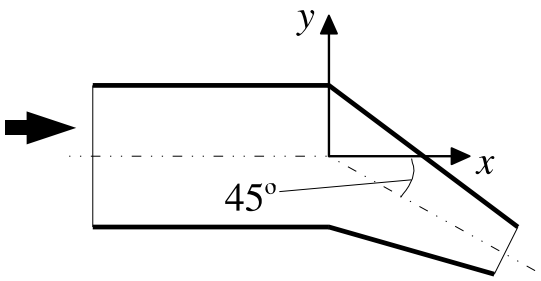
$$Q(z) = Q_0 - 2\pi R \int_0^z v_r(R, z)dz,$$

   obtain an equation for the variation of pressure with length in the tube (do not solve). (3)



2. (12 marks) **Forces on a nozzle.** Water (density 1000 kg/m^3, viscosity 1 mPa s) flows in a nozzle, as shown below, under turbulent conditions. The inlet cross-sectional area is 10 cm^2 and the outlet cross-sectional area is 4 cm^2. The inlet average velocity is 2 m/s and the exit pressure is atmospheric (100 kPa). Plug flow may be assumed in the nozzle and gravity may be neglected. The friction loss factor for the system is $e_v = 0.4$.

[1]D. V. Khakhar



(a) Obtain the nozzle inlet pressure. (6)

(b) Find the components of the force acting on the nozzle. (6)

3. (15 marks) **Piping system analysis.** 0.01 m^3/s of water are to be pumped through a smooth pipe of length 250 m to a tank 12 m above the level of the reservoir. The pipeline has four 90° rounded elbows, three gate valves and one globe valve.

   (a) Calculate the pressure drop for the pipeline assuming the inner diameter equal to the optimum diameter. (6)

   (b) For a centrifugal pump with characteristic curves given below, choose the operating RPM. (5)

   (c) Calculate the power requirement for pumping. (4)

   Data:

μ	10^{-3} Pa s = 1 cP
ρ	10^3 kg m^{-3}

Fitting	L_{eq}/D
90^o rounded elbow	30
Gate valve	13
Globe valve	340

   Friction factor for smooth pipes:

$$f = 0.0791 Re^{-1/4}$$

   Economic pipe diameter:

$$D_{opt} = 33.65 Q^{0.482} \rho^{0.142} \mu^{0.0272}$$

   (units : D_{opt}[cm], Q[m^3/s], ρ[kg/m^3], μ[cP]).

   To convert from gallons to m^3 multiply by 3.785×10^{-3}

   To convert from ft to m multiply by 0.3048

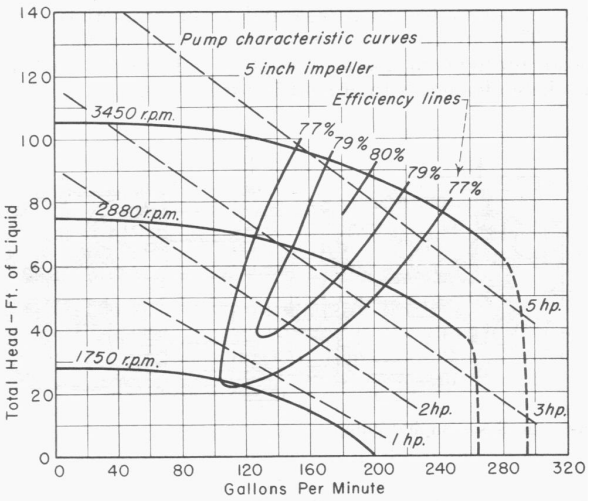


FIG. 6-8. Characteristic curve of centrifugal pump at various speeds.

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