National Exams May 2009

07-Mec-B6, Advanced Fluid Mechanics

3 hours duration

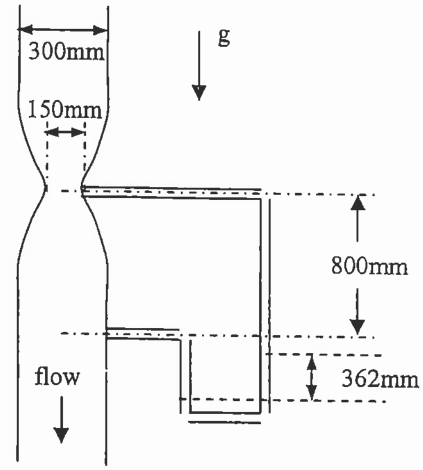
Notes:

1. If doubt exists as to the interpretation of any question the candidate is urged to submit with the answer paper a clear statement of the assumptions made.
2. Candidates may use any non-communicating calculator. The exam is OPEN BOOK.
3. Answer all **3** of the 4 questions in **part A** and any **2** of the 3 question of **part B**. If more questions are attempted, these will be marked in the order presented.
4. Weighting: Part A: 50%; Part B: 50% . Within each section, the questions have equal weighting.

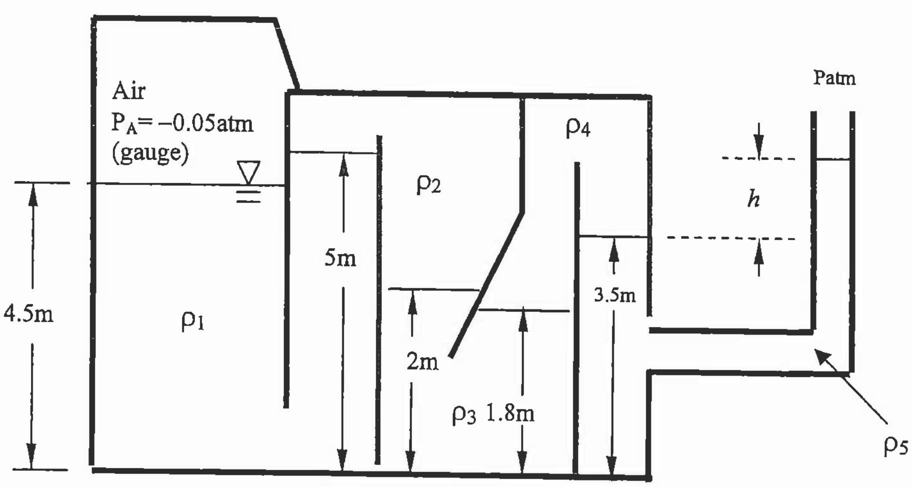
PART A: Answer all 3 of the 4 questions in this section.

Question A1: Water flows in a 30cm-diameter circular pipe vertically down through a *venturi* section as shown in the adjacent figure. The *venture* throat diameter is 15cm.

The pressure differential is measured using manometer tube filled with mercury (specific gravity of 13.6). The deflection of the mercury in the differential gauge is 362mm. Determine the volumetric flow rate of the water. Neglect frictional losses.



Question A2: What is the height of the fluid column, h, as measured from the manometer tube for the conditions shown? The manometer end is open to atmosphere. The fluid densities are given as: ρ_1=1000kg/m^3; ρ_2=680kg/m^3; ρ_3=900kg/m^3; ρ_4=780kg/m^3 and ρ_5=13600kg/m^3.



Question A3: A medical research centre is developing a new heart valve. In order to better understand the hydrodynamic loads on the valve generated by the blood flow (ρ=1100 kg/m^3; μ=1.2×10^{-3} kg/m-s), a consultant engineer is asked to investigate the process. The engineer determines that in order to obtain a good series of observations and measurements, a scale-up model of 5:1 is necessary. The model working fluid is chosen to be Helium (ρ=0.166 kg/m^3; μ=1.94×10^{-5} kg/m-s). If the blood flow rate in a typical heart is 0.1 litres per second and if the valve operates 80 times per minute, what must be the Helium flow rate and the operating frequency of the model valve? If the valve fails after 3.5 years in the laboratory set-up, how long would it be expected to last in actual use inside a human, assuming that the failure is due to hydrodynamic forces?

Question A4: Air (γ=1.4; R=287J/kg-K) flows isentropically through a converging-diverging nozzle of exit area 0.5cm^2. The nozzle is fed from a large plenum chamber, where the stagnation pressure and temperature are 500kPa (abs) and 27°C, respectively. At the exit, the local Mach number is determined to be 2. Determine:

a) The mass flow rate through the nozzle.
b) The temperature and pressure at the exit.
c) The area of the throat.

Section B Answer any **2** of the 3 questions in this section.

Question B.1: A jet pump is modelled as shown in the figure below. Pressurized air enters through the centre pipe (inner diameter 2.5cm) at a uniform speed of 3m/s and a pressure of 700kPa. Ambient air (pressure 100kPa) is entrained in the larger pipe (inner diameter of 4.5cm) at a rate of 2.3m/s. The exit pressure is 100kPa. The velocity profile in each section may be assumed uniform. All flow streams are at a temperature of 27°C. The injection pipe thickness can be neglected. For air use R = 287 J/kg-K.

a) Determine the speed of the flow at the exit.
b) If the pipe section downstream of the injection tube has a length of 50cm, what is the average shear stress on the outer tube inner surface?

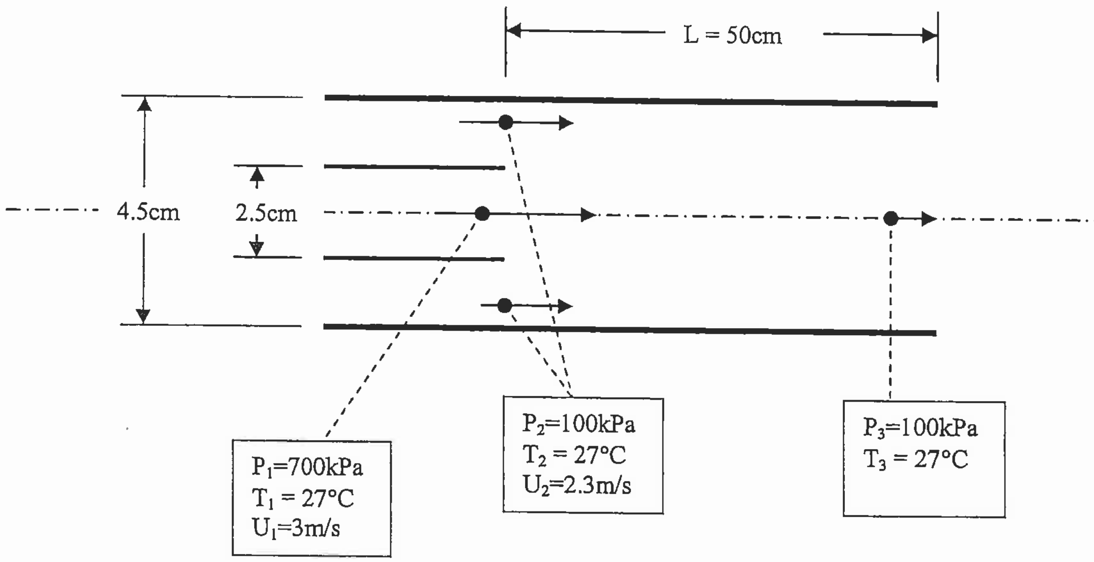


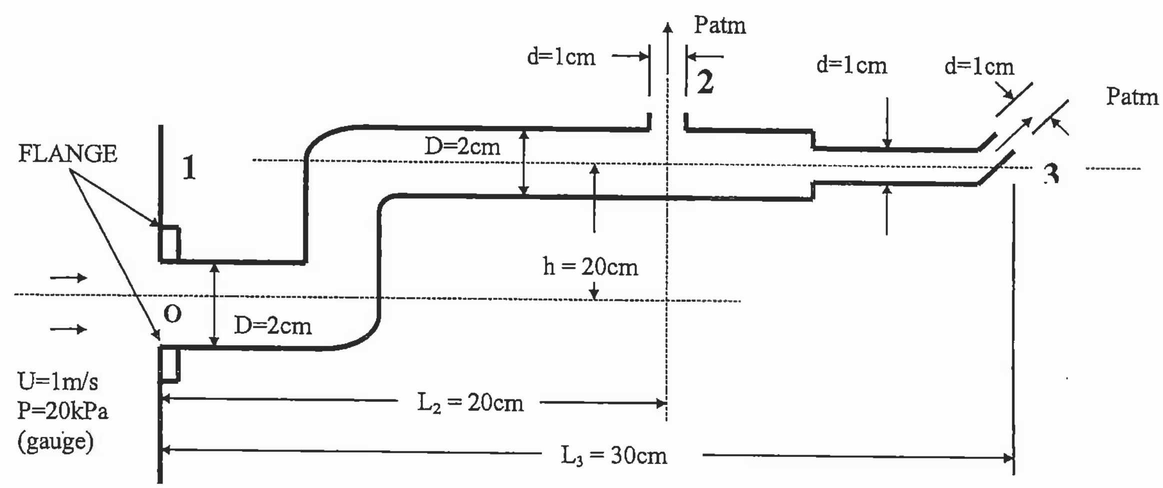
Figure B1: Schematic of jet-pump

Question B.2: A bent pipe is attached to a flange as shown in the figure below. Water (ρ = 1000 kg/m^3) flows from a container at an average speed of 1 m/s. At the flange, the pressure is measured to be 20 kPa (gauge). At the exit points, 2 and 3, the pressure is atmospheric and free jets may be assumed. The pipe effective roughness is given as ε = 0.05mm) Neglecting gravitational effects and assuming uniform velocity profiles inside the pipe, determine:

a) the mass flow rates at the entrance **1** and the exits **2** and **3** (Hint: first approximate the flow rates neglecting major losses).

b) the forces acting on the flange (magnitude and direction) and

c) the moments produced about the point **O** located at the centre of the entrance.



Additional information:

Loss coefficient at entrance: 0.5

Loss coefficient for sudden contraction: 0.6 (based velocity in small pipe)

Figure B2: Schematic of pipe network.

Question B.3: A closed reservoir is filled with oil of density 800kg/m^3. It has a triangular gate as shown in the figure below. The gate is inclined at 60° to the horizontal and is hinged along the line A-A. A metal sphere (ρ=5500kg/m^3) is suspended through frictionless pulleys and applies a force on the gate at B as shown. The pulley cable at B is vertical. What is the minimum diameter of the sphere to keep the gate closed?

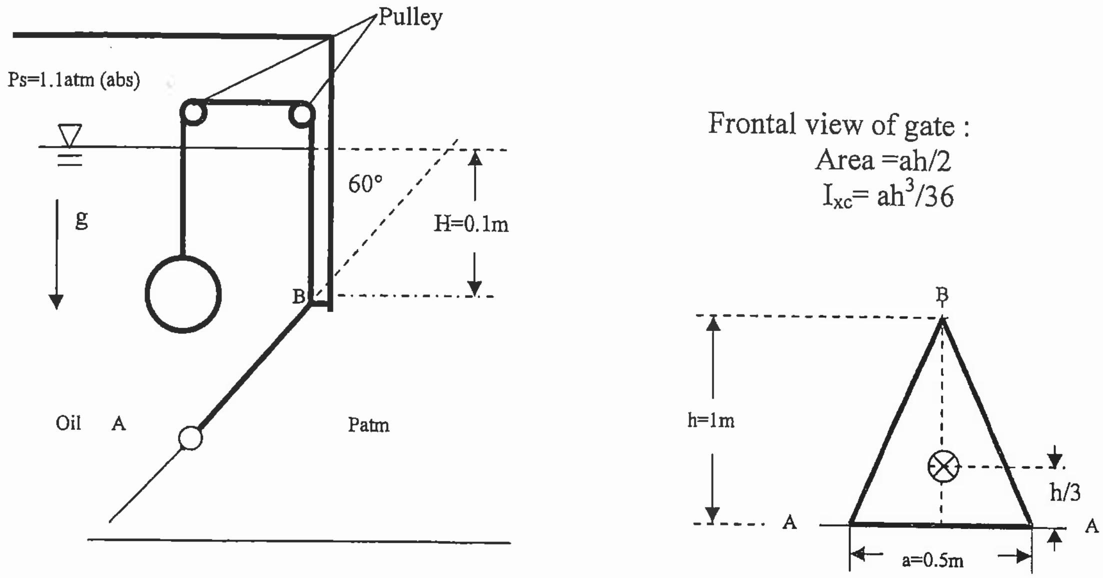


Figure B3: Reservoir with triangular gate.

MAJOR LOSSES

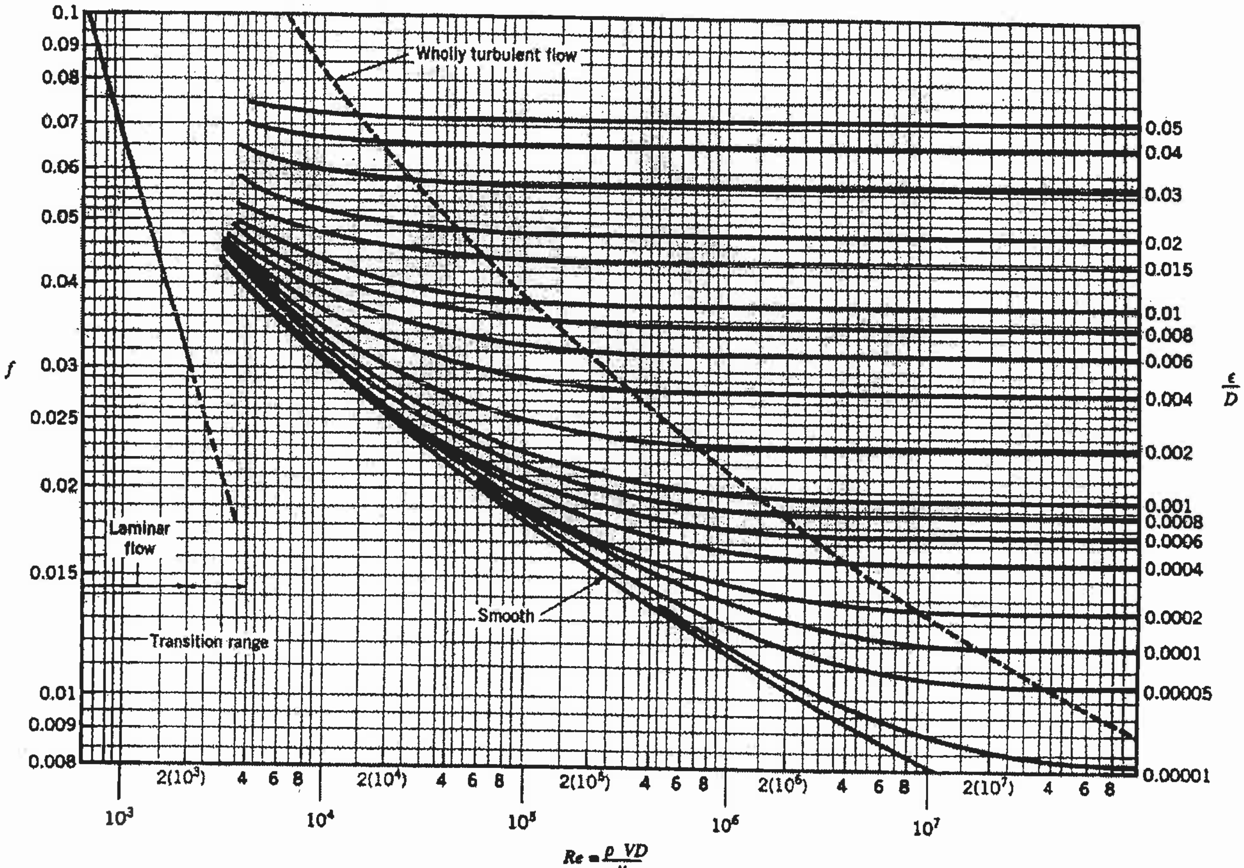
FRICTION COEFFICIENTS:

Colebrook Equation: $$\frac{1}{\sqrt{f}} = -2.0\log_{10}\left[\frac{\varepsilon/D}{3.7} + \frac{2.51}{\mathrm{Re}\sqrt{f}}\right]$$

Laminar Flow Equation: $$f = \frac{64}{\mathrm{Re}} \qquad \mathrm{Re} < 2000$$

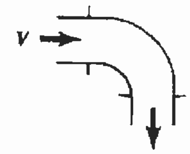
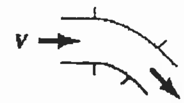
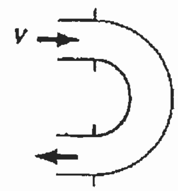
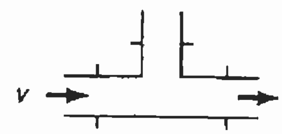
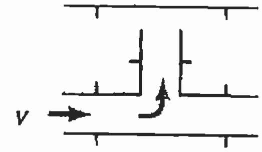
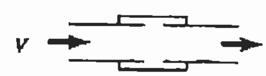
$$\mathrm{Re} = \frac{\rho VD}{\mu} = \frac{VD}{\nu}$$

MOODY CHART for PIPE FRICTION



MINOR LOSSES

Loss Coefficients for Pipe Components $\left(h_L = K_L \frac{V^2}{2g}\right)$

Component	K_L	
a. Elbows		
Regular 90°, flanged	0.3	
Regular 90°, threaded	1.5	
Long radius 90°, flanged	0.2	
Long radius 90°, threaded	0.7	
Long radius 45°, flanged	0.2	
Regular 45°, threaded	0.4	
b. 180° return bends		
180° return bend, flanged	0.2	
180° return bend, threaded	1.5	
c. Tees		
Line flow, flanged	0.2	
Line flow, threaded	0.9	
Branch flow, flanged	1.0	
Branch flow, threaded	2.0	
d. Union, threaded	0.08	
***e. Valves**		
Globe, fully open	10	
Angle, fully open	2	
Gate, fully open	0.15	
Gate, $\frac{1}{4}$ closed	0.26	
Gate, $\frac{1}{2}$ closed	2.1	
Gate, $\frac{3}{4}$ closed	17	
Swing check, forward flow	2	
Swing check, backward flow	∞	
Ball valve, fully open	0.05	
Ball valve, $\frac{1}{3}$ closed	5.5	
Ball valve, $\frac{2}{3}$ closed	210	