NATIONAL EXAMINATIONS

May 2014

04-BS-7 MECHANICS OF FLUIDS

Three (3) hours duration

Notes to Candidates

1. This is a **Closed Book** examination.

2. Exam consists of two Sections. **Section A is Calculative (9 questions)** and **Section B is Analytical (4 questions)**.

3. **Do seven (7) questions from Section A (Calculative) and three (3) questions from Section B (Analytical).** Note that the Analytical Questions do not require detailed calculations but do require full explanations.

4. **Ten (10) questions constitute a complete paper.** (Total 50 marks).

5. **All questions are of equal value.** (Each 5 marks).

6. If doubt exists as to the interpretation of any question, the candidate is urged to submit, with the answer paper, a clear statement of any assumptions made.

7. Candidates may use one of the approved **Casio** or **Sharp** calculators.

8. **Reference information** for particular questions are given on pages 8 to 11. **All pages of questions attempted are to be returned with the Answer Booklet showing diagrams generated or where readings were taken and which data was used. Candidates must write their names on these pages.**

9. **Constants** are given on page 12.

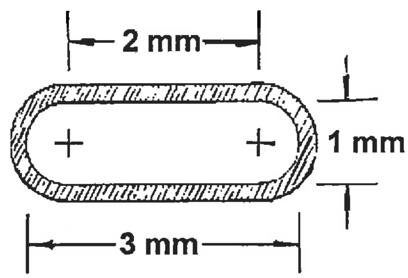
10. **Reference Equations** are given on pages 13 to 16.

SECTION A CALCULATIVE QUESTIONS

Do seven of nine questions. Solutions to these questions must be set out logically with all intermediate answers and units given.

QUESTION 1

A small diameter tube is partially flattened so as to assume the shape shown in the cross-sectional sketch below, that is, with semi-circular and flat sides. Inside dimensions are given. Determine to what height water will rise within this tube, due to capillarity, when it is held vertically and dipped into water.



Surface tension of water = 0.0728 N/m
Contact angle of water with tube = 0°

(5 marks)

QUESTION 2

Refer to the Examination Paper Attachments Page 8 **Manometer Fluids.**

Determine the fluids in each section of each manometer based on the specific gravities of water, glycerine and mercury as given in the General Reference Information on Page 12 of the examination paper. Label the diagram accordingly (air, water, glycerine or mercdury) in the spaces provided. Note that interfaces between different fluids are shown by a change in shading but similar shading does not necessarily mean the same fluid.

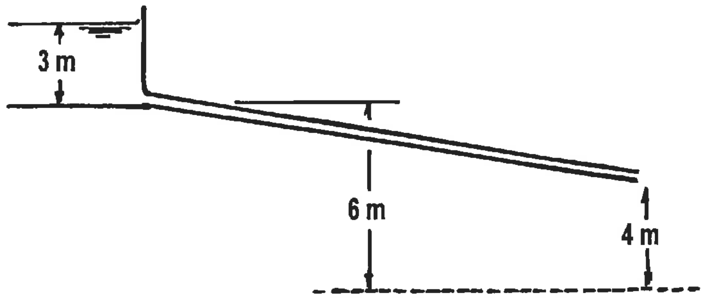
Return the diagram with your answer booklet. *(5 marks)*

QUESTION 3

Water flows in a river. At 9 am the flow past bridge A is 55 m^3/s. At the same instant the flow past bridge B, some distance further downstream, is 45 m^3/s. Determine the rate at which water is accumulating, due to the difference in flow rates, in the river between the two bridges at this instant. If the flows remain the same and if the surface area of the river between the bridges is 1.44 km^2 calculate by how much the level of the river will have risen by 9 pm that night. Assume zero seepage and negligible evaporation.

(5 marks)

QUESTION 4



In an experiment to determine the head loss in a pipe system, one end of a pipe at an elevation of 6 m was connected to a reservoir of water while the other end at an elevation of 4 m was left open to the atmosphere as shown above. The pipe was 50 mm in diameter with a total length of 120 m. The reservoir contained water to a level 3 m above the pipe connection. If the measured flow rate was 0.006 m^3/s determine the total head loss in the system. Assume that the pipe has a smooth entrance with no loss.

(5 marks)

QUESTION 5

A pump circulates water against an hydraulic friction head at the rate of 0.125 m^3/s in a closed circuit holding 40 m^3. The net head developed by the pump is 100 m and the pump efficiency is 90 percent. Assuming the pump bearing friction to be negligible and that there is no loss of heat from the system, find the temperature rise in the water in 1 hr.

(5 marks)

QUESTION 6

A jet of water 75 mm in diameter is discharged to atmosphere through a nozzle whose velocity coefficient is 0.96. If the pressure in the pipe is 80 kPa gauge and the pipe diameter is 200 mm and if it is assumed that there is no contraction of the jet, calculate the velocity at the tip of the nozzle. Calculate the rate of discharge.

(5 marks)

QUESTION 7

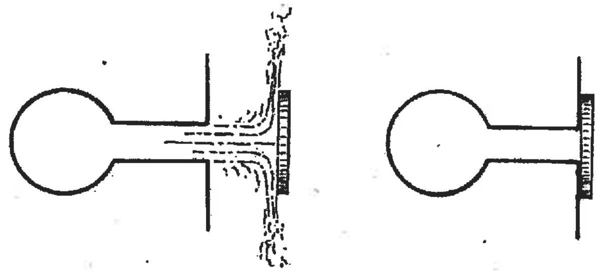


Figure A   Figure B

To ensure proper circulation of water in a swimming pool, water enters through submerged jets and spills into a trough around the sides of the pool. If one holds one's hand or a flat plate perpendicular to the jet and a short distance from the nozzle exit as in Figure A, the force of the jet can be felt. Similarly, by pushing one's hand or a flat plate against the end of the nozzle to stop the flow as in Figure B, the force due to the water pressure in the nozzle can be felt. Are these two forces the same? Consider nozzles 30 mm in diameter and a differential pressure head between the water in the supply pipe and the water in the pool of 2 m head.

(a) Calculate the force due to the jet when the plate is a short distance away from the nozzle (approximately 50 mm).

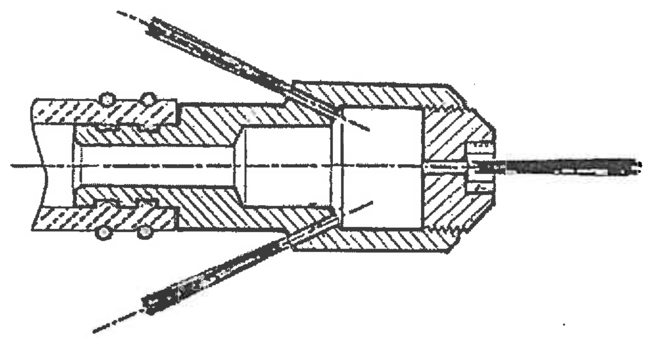
(b) Calculate the force due to the water pressure when the plate is against the nozzle and there is no flow from the nozzle.

Neglect friction effects and turbulence between the jet and the surrounding water.

(5 marks)

QUESTION 8

The nozzle of a drain cleaning device is shown in the sketch below. This is attached to a flexible hose and inserted into the pipe to be cleaned. The single front jet clears debris immediately in front of the hose as it is fed into the drain while the six side jets scour the walls of the drain. All orifices in the nozzle are 2 mm in diameter and the water in the supply pipe is at a pressure of 6 MPa. The angle of the side jets is 26° from the nozzle centre line. Determine the force developed by the nozzle to pull the hose into the drain. Flow velocity in the pipe and nozzle body may be assumed to be low enough to be neglected.



(5 marks)

QUESTION 9

Refer to the Examination Paper Attachments Page 9 **Moody Diagram**

A commercial steel pipe with a roughness of 0.06 mm and a length of 500 m is to convey oil with a density of 800 kg/m^3 and a viscosity of 0.048 Ns/m^2 at a rate of 0.3 m^3/s from a reservoir of surface elevation 190 m to one of surface elevation 120 m. Select a suitable pipe diameter by plotting on the attached Moody Diagram.

Return the diagram with your answer booklet to show your plotting and readings.

Hint: Set up equations of friction factor f and Reynolds number Re in terms of pipe diameter D. Guess two or more values of D within the range of 0.2 m to 0.4 m that will give points on the chart and plot these points. From a line through these points determine the pipe diameter.

(5 marks)

SECTION B GRAPHICAL AND ANALYTICAL QUESTIONS

<u>Do three of four questions</u>. These questions do not require detailed calculations but complete written explanations must be given to support the answers where desciptive answers are required (Questions 12 and 13).

QUESTION 10

Refer to the Examination Paper Attachments Page 10 **Conical Converging Nozzle.**

Develop a flow net and draw streamlines for water passing through this nozzle and in the resulting jet. The given diagram must be used and the jet must be drawn well beyond the nozzle exit. Assume high velocity and consider inertia effects and the development of a vena contracta at the orifice. Show about 10 streamlines.

Return the diagram with your answer booklet.

(5 marks)

QUESTION 11

Refer to the Examination Paper Attachments Page **11 Orifice with Manometer**

A sharp edged orifice for flow measurement is fitted in a pipe through which a stream of water is flowing. On the given page do the following:

(a) Sketch, in the lower part of the page, the orifice in the pipe leaving space above or below for (b) to be drawn. Show zones of turbulence. (1)

(b) Sketch a mercury manometer connected to the orifice for measuring the flow rate. Show clearly where the manometer is connected to the pipe and where the reading is taken on the manometer. (2)

(c) Sketch, in the upper part of the page, the energy grade line and hydraulic grade line along the pipe over the full extent of the flow disturbance caused by the orifice. (2)

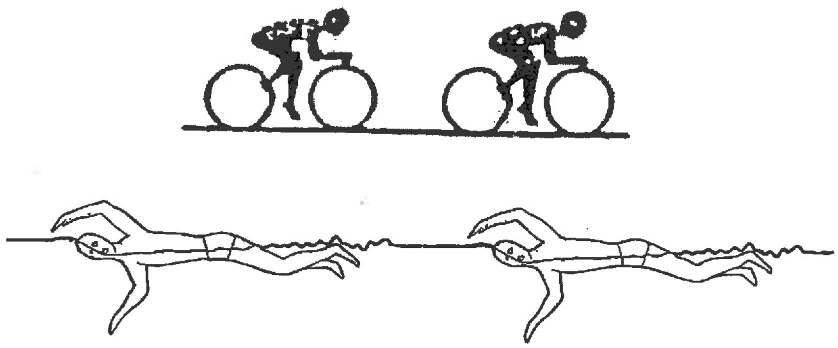
The sketches for (c) must be drawn vertically above the pipe and orifice in (a) so that the energy changes can be directly related to the flow disturbances.

Return the diagram with your answer booklet.

(5 marks)

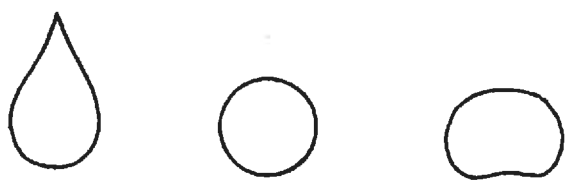
QUESTION 12

Cyclists get some energy advantage by drafting (following closely behind another cyclist). Does the same apply to swimmers who follow closely behind another? By analyzing the forces applicable to cyclists and swimmers determine whether it is advantageous or not for a swimmer to follow closely behind another. Explain your answer fully.



(5 marks)

QUESTION 13



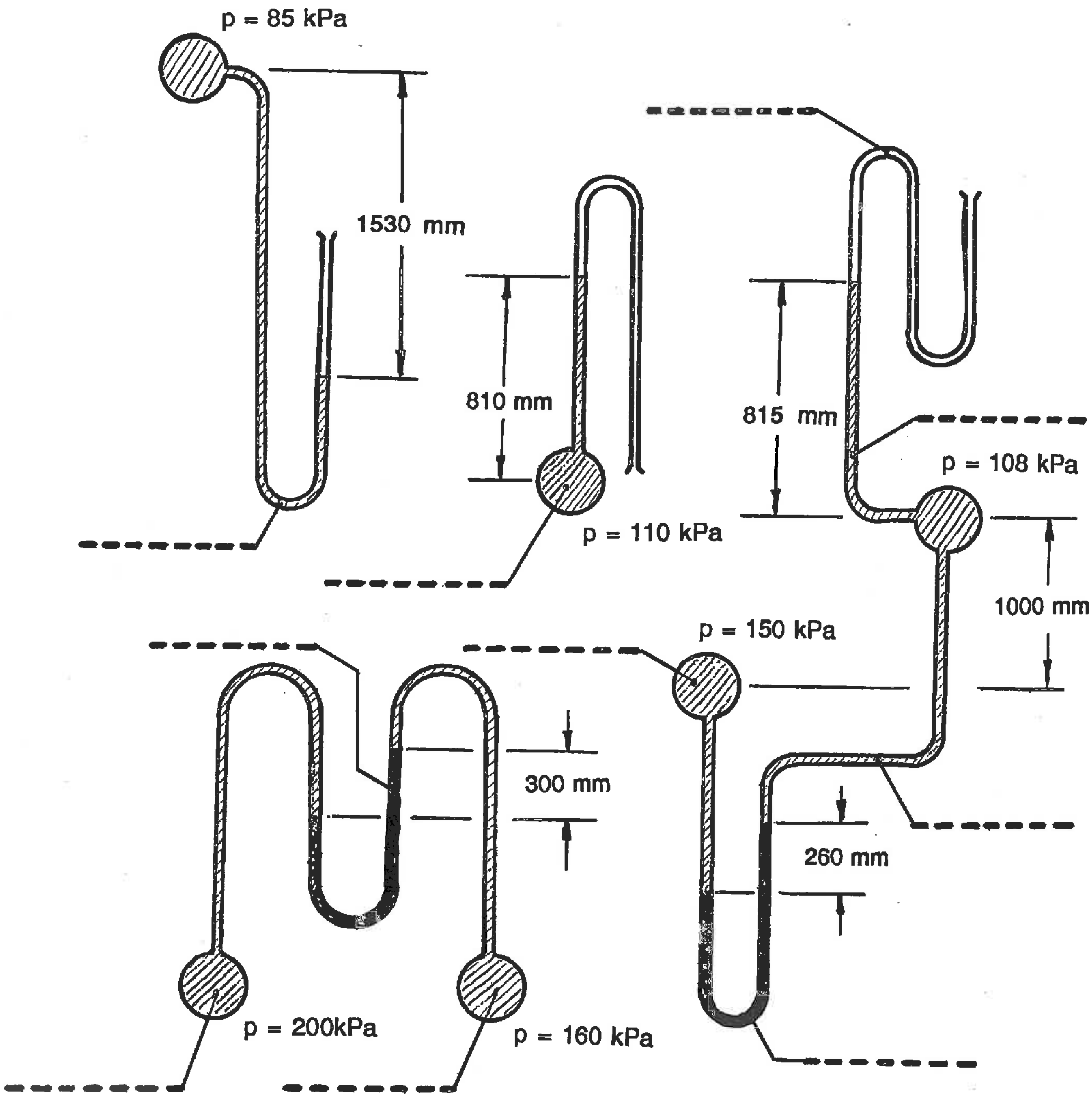
Pointed Prolate   Spherical   Oblate (Flattened)

With reference to the sketches above state what shape a very large rain drop falling through the atmosphere is likely to assume - prolate, spherical or oblate. Explain fully why it would assume the chosen shape and compare this shape with the likely shape of a very small raindrop.

(5 marks)

EXAMINATION PAPER ATTACHMENTS

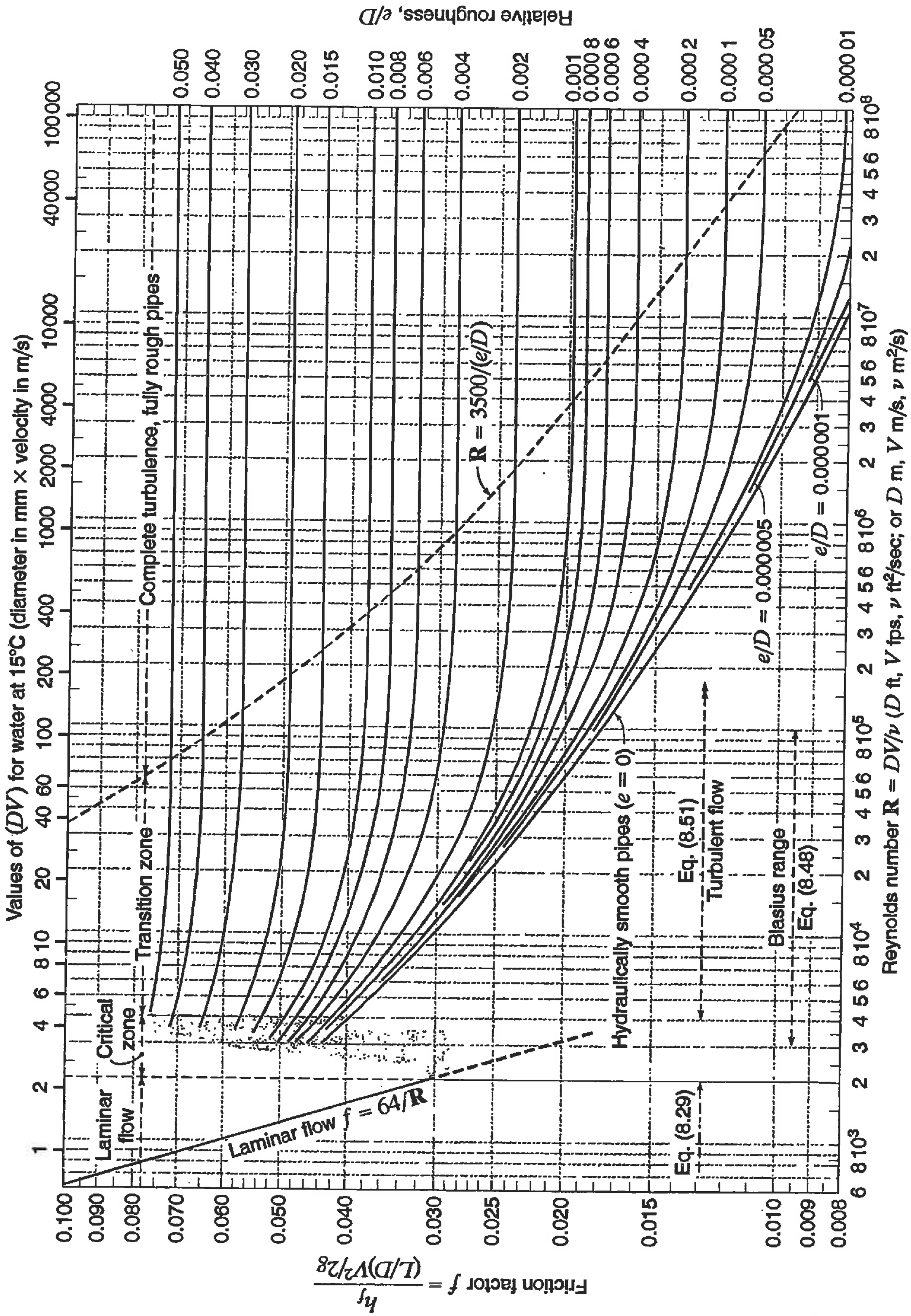
QUESTION 2 MANOMETER FLUIDS **NAME** ....



All pressures in kPa absolute

EXAMINATION PAPER ATTACHMENTS

QUESTION 9 MOODY DIAGRAM **NAME** ....

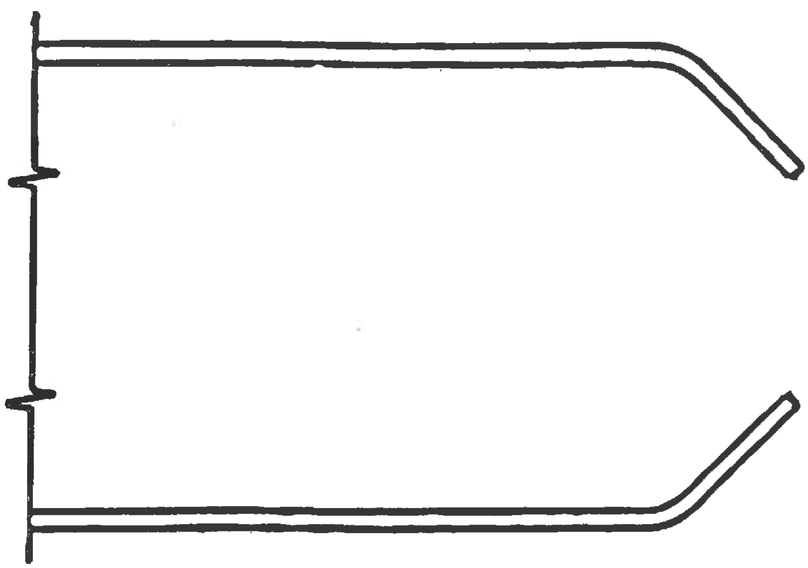


Moody chart for pipe friction factor (Stanton diagram).

EXAMINATION PAPER ATTACHMENTS

NAME ....

QUESTION 10 CONICAL CONVERGING NOZZLE



EXAMINATION PAPER ATTACHMENTS

NAME ....

QUESTION 11 ORIFICE WITH MANOMETER

(c) Sketch Energy Grade Line and Hydraulic Grade Line over full length of pipe

(a) Sketch Pipe with an Orifice (flat plate orifice) inserted for flow measurement

(b) Sketch a Mercury Manometer connected to the pipe to measure the flow

Note that the grade lines in the top drawing must be vertically above and match the conditions created by the orifice meter below.

04-BS-7 MECHANICS OF FLUIDS

GENERAL REFERENCE INFORMATION

CONSTANTS

In engineering calculations a high degree of accuracy is seldom attained due to the neglect of minor influences or the inaccuracy of available data. For consistency in calculations however the following reasonably accurate constants should be used:

Atmospheric Pressure p_o = 100 kPa
Gravitational Acceleration g = 9.81 m/s^2
Specific Gravity of Water = 1.00
Specific Gravity of Glycerine = 1.26
Specific Gravity of Mercury = 13.56
Specific Gravity of Benzene = 0.90
Specific Gravity of Carbon Tetrachloride = 1.59
Density of Water ρ = 1000 kg/m^3
Density of Sea Water ρ = 1025 kg/m^3
Density of Concrete ρ = 2400 kg/m^3
Density of Air ρ = 1.19 kg/m^3 (at 20°C), ρ = 1.21 kg/m^3 (at 15°C)
Absolute Viscosity of Water μ = 1.0 x 10^{-3} Ns/m^2
Absolute Viscosity of Air μ = 1.8 x 10^{-5} Ns/m^2
Surface Tension of Water σ = 0.0728 N/m (at 20°C)
Specific Heat of Water c_p = 4.19 kJ/kg°C
Specific Heat of Air c_p = 1005 J/kg°C
Specific Heat of Air c_p = 718 J/kg°C
Gas Constant for Air R = 287 J/kg°K
Gas Constant for Helium R = 2077 J/kg°K
Gas Constant for Hydrogen R = 4120 J/kg°K

NOMENCLATURE FOR REFERENCE EQUATIONS (SI UNITS)

a	Width	m
A	Flow area, Surface area	m^2
CV	Calorific value	J/kg
c_p	Specific heat at constant pressure	J/kg°C
b	Width	m
D	Diameter	m
E	Energy	J
F	Force	N
g	Gravitational acceleration	m/s^2
h	System head	m
h_L	Head loss	m
H	Pump or turbine head	m
I	Moment of inertia	m^4
k	Ratio of specific heats	
k	Loss coefficient	
K	Constant	
L	Length	m
m	Mass	kg
M	Mass flow rate	kg/s
N	Rotational speed	rev/s
p	Pressure	Pa (N/m^2)
P	Power	W (J/s)
q	Specific heat	J/kg
Q	Flow rate	m^3/s
r	Radius	m
R	Specific gas constant	J/kg K
T	Temperature	K
U	Blade velocity	m/s
v	Specific volume	m^3/kg
V	Velocity	m/s
V	Volume	m^3
w	Specific work	J/kg
W	Work	J
y	Depth	m
z	Elevation	m
η	Efficiency	
μ	Dynamic viscosity	Ns/m^2
ν	Kinematic viscosity	m^2/s
ρ	Density	kg/m^3
σ	Surface tension	N/m
τ	Thrust	N
τ	Shear stress	N/m^2

REFERENCE EQUATIONS

Equation of State

$$p\,v = R\,T$$
$$p = \rho\,RT$$

Universal Gas Law

$$p\,v^n = \text{constant}$$

Compressibility

$$\beta = -\Delta / V\,\Delta p$$

Viscous Force and Viscosity

$$F = \mu\,A\,du/dy$$
$$\mu = \tau / (du/dy)$$
$$\nu = \mu / \rho$$

Capillary Rise and Internal Pressure due to Surface Tension

$$h = (\sigma \cos\theta / \rho\,g) \times (\text{perimeter} / \text{area})$$
$$p = 2\,\sigma / r$$

Pressure at a Point

$$p = \rho\,g\,h$$

Forces on Plane Areas and Centre of Pressure

$$F = \rho\,g\,y_c\,A$$
$$y_p = y_c + I_c / y_c\,A$$

Moments of Inertia

Rectangle: $I_c = b\,h^3 / 12$
Triangle: $I_c = b\,h^3 / 36$
Circle: $I_c = \pi\,D^4 / 64$

Volumes of Solids

Sphere: $V = \pi D^3 / 6$
Cone: $V = \pi D^2 h / 12$
Spherical Segment: $V = (3 a^2 + 3 b^2 + 4 h^2) \pi h / 2 g$

Continuity Equation

$$\rho_1 V_1 A_1 = \rho_2 V_2 A_2 = M$$

General Energy Equation

$$p_1 / \rho_1 g + z_1 + V_1^2 / 2 g + q_{in} / g + w_{in} / g$$
$$= p_2 / \rho_2 g + z_2 + V_2^2 / 2 g + h_L + q_{out} / g + w_{out} / g$$

Bernoulli Equation

$$p_1 / \rho g + z_1 + V_1^2 / 2 g = p_2 / \rho g + z_2 + V_2^2 / 2 g$$

Momentum Equation

Conduit: $F_R = p_1 A - p_2 A - M (V_2 - V_1)$
Free Jet: $F_R = - \rho Q (V_2 - V_1)$

Flow Measurement

Venturi Tube: $Q = [C A_2 / \{1 - (D_2 / D_1)^4\}^{1/2}][2 g \Delta h]^{1/2}$
Flow Nozzle: $Q = K A_2 [2 g \Delta h]^{1/2}$
Orifice Meter: $Q = K A_o [2 g \Delta h]^{1/2}$

Flow over Weirs

Rectangular Weir: $Q = C_d (2 / 3) [2 g]^{1/2} L H^{3/2}$

Power

Turbomachine: $P = \rho g Q H$
Free Jet: $P = \frac{1}{2} \rho Q V^2$
Moving Blades: $P = M \Delta V U$

Aircraft Propulsion

$F_{thrust} = M (V_{jet} - V_{aircraft})$
$P_{thrust} = M (V_{jet} - V_{aircraft}) V_{aircraft}$
$E_{jet} = \frac{1}{2} (V_{jet}^2 - V_{aircraft}^2)$
$P_{jet} = \frac{1}{2} M (V_{jet}^2 - V_{aircraft}^2)$

$E_{fuel} = CV_{fuel}$
$P_{fuel} = M_{fuel}\, CV_{fuel}$
$\eta_{thermal} = P_{jet} / P_{fuel}$
$\eta_{propulsion} = P_{thrust} / P_{jet} = 2\, V_{aircraft} / (V_{jet} + V_{aircraft})$
$\eta_{overall} = \eta_{thermal} \times \eta_{propulsion}$

Wind Power

$P_{total} = ½\, \rho\, A_T\, V_1^3$
$P_{max} = 8/27\, \rho\, A_T\, V_1^3$
$H_{max} = P_{max} / P_{total} = 16/27$

Reynolds Number

$Re = d\, V\, \rho / \mu$

Flow in Pipes

$h_L = f\, (L / D)\, (V^2 / 2\, g)$
$D_e = 4$ (flow area) / (wetted perimeter)
$D = D_e$ for non-circular pipes
$L = L_{total} + L_e$ for non-linear pipes
$(L / D) = 35\, k$ for $Re \sim 10^4$

Drag on Immersed Bodies

Friction Drag: $F_f = C_f\, ½\, \rho\, V^2\, B\, L \quad (B = \pi\, D)$
Pressure Drag: $F_p = C_p\, ½\, \rho\, V^2\, A$
Total Drag: $F_D = C_D\, ½\, \rho\, V^2\, A$

Aircraft Wing: $F_L = C_L\, ½\, \rho\, V^2\, A_{wing}$
Aircraft Wing: $F_D = C_D\, ½\, \rho\, V^2\, A_{wing}$

Karmen Vortex Frequency

$f \approx 0.20\, (V / D)\, (1 - 20 / Re)$