NATIONAL EXAMINATIONS

Dec 2018

04-BS-7 MECHANICS OF FLUIDS

Three (3) hours duration

Notes to Candidates

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

2. The examination 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. **Read the entire question before commencing** the calculations and **take note of hints or recommendations** given.

8. Either one of the approved **Casio** or **Sharp** calculators may be used.

9. **Reference information** for particular questions is given on pages 8 to 9. **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.**

10. **Constants** are given on page 10.

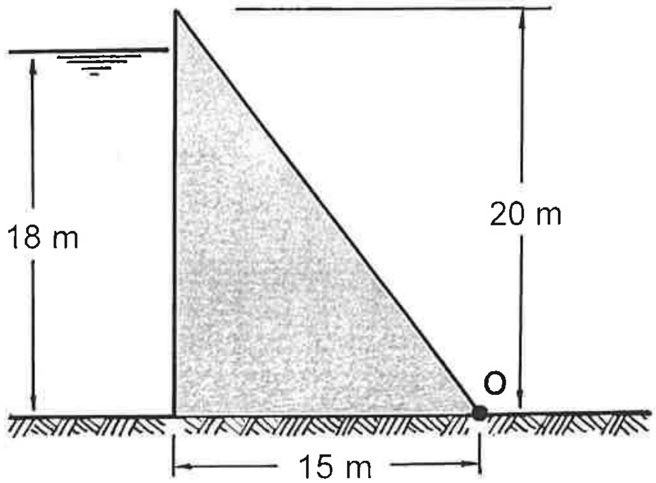
11. **Nomenclature** and **Reference Equations** are given on pages 11 to 14.

SECTION A CALCULATIVE QUESTIONS

Do seven of nine questions. Solutions to these questions must be set out logically with equations and calculation steps shown. All intermediate answers and units must be given.

QUESTION 1

A gravity dam built of concrete has dimensions as shown in the adjoining sketch. It is filled with water to a depth of 18 m. To prevent cracking of the concrete or separation from the bedrock, the resultant force on the structure must pass through the middle third of the base so as to maintain compressive stress everywhere in the concrete and bedrock. By taking moments about the toe of the dam (Point O), determine the point (horizontal distance from Point O) through which the resultant force passes through the base and hence whether the dam is safe or not.



(5 marks)

QUESTION 2

Refer to the Examination Paper Attachments Page 8 **Absolute Viscosity.**

Consider a cylindrical tank 300 mm in diameter and 500 mm in height. Either gasoline (s = 0.716) or lubricating oil (SAE 30 Eastern) at 20°C flows into the tank at a constant rate of 0.20 litre/s. The contents are discharged through a fixed orifice of 10 mm diameter having a discharge coefficient C_d for gasoline of 0.90 and a discharge coefficient C_d for oil of 0.75.

(a) Calculate the equilibrium level of gasoline in the tank.
(b) Calculate the equilibrium level of lubricating oil in the tank.
(c) Comment on any differences or observations arising from (a) and (b) above.
(d) If the temperature is increased to 40°C state how this would affect the results of (a) and (b). Clarify with reasons what parameter might be different and how it would affect the results.

Refer to the attached chart Page 8 **Absolute Viscosity** for viscosities.

(5 marks)

QUESTION 3

Suppose that, in determining the purity of the gold crown belonging to the ruler of Syracuse, Archimedes found that it displaced 0.33 L of water when submerged while an equivalent mass of pure gold displaced 0.22 L of water when submerged. If some gold could have been replaced with silver, what would the purity (% gold) by weight have been. Specific gravity of gold is 19.32 and that of silver is 10.50.

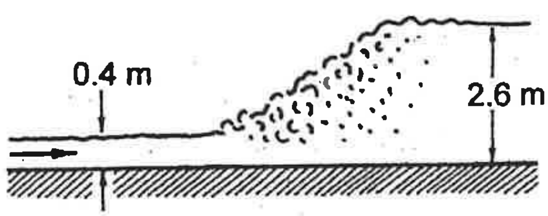
(5 marks)

QUESTION 4

An hydraulic jump forms in a channel in which there is high velocity water flow. The channel is 2.4 m wide and the water depth is 0.4 m before the jump and 2.6 m after the jump.

(a) Determine the force balance in terms of the initial and final flow velocities.

(b) Determine the volume flow rate through the jump (m^3/s).



Hint: Use the momentum and continuity equations.

(5 marks)

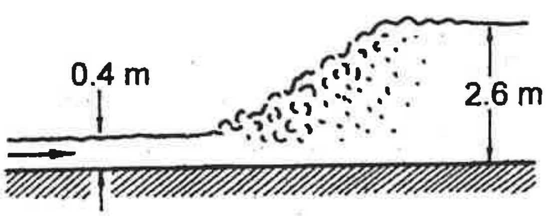
QUESTION 5

An hydraulic jump forms in a channel in which there is high velocity water flow. The channel is 2.4 m wide and the water depth is 0.4 m before the jump and 2.6 m after the jump. The flow rate in the channel is 9.4 m^3/s. Determine the following:

(a) Head loss in the jump (m)

(b) Energy loss in the jump (J/kg)

(c) Power loss in the jump (kW)



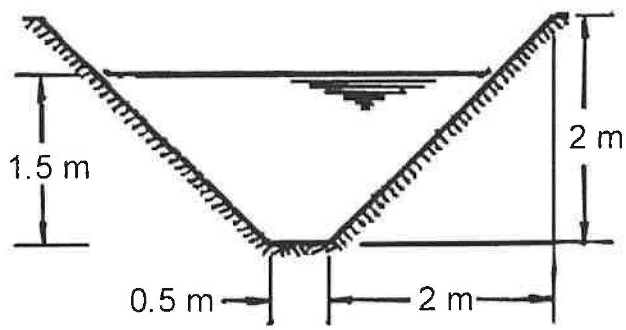
Hint: Use the energy equation.

(5 marks)

QUESTION 6

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

Consider a concrete trapezoidal irrigation canal with cross section as shown that is 4.5 m wide by 2 m deep with 45° sides and 0.5 m wide bottom. Water is required to flow 1.5 m deep at a flow rate of 3 m^3/s. This canal is required to deliver water to a location 8 km from the source. Determine, from general pipe flow relations, the drop in elevation required to maintain the specified flow rate. Assume a roughness of 1 mm for the concrete.



(5 marks)

QUESTION 7

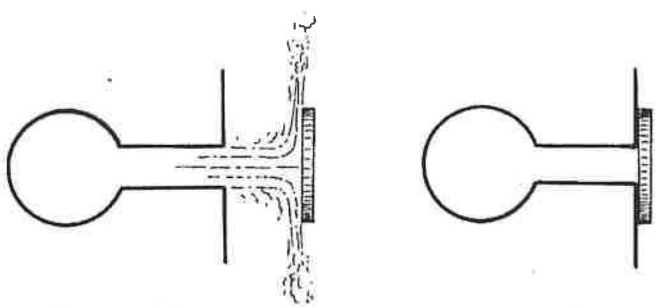


Figure A Figure B

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 also be felt. 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. Are these two forces the same? Justify your answer as follows:

(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.

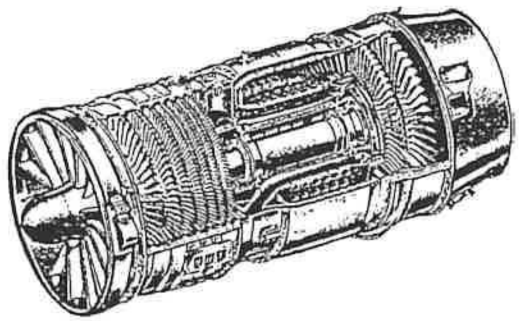
Neglect friction effects and turbulence between the jet and the surrounding water.

(5 marks)

QUESTION 8

The figure alongside shows a typical turbojet aircraft engine. Consider this engine to be operating on the aircraft under the following conditions:

Ambient air pressure	100 kPa
Inlet air temperature	20°C
Exhaust gas temperature	700°C
Exhaust gas velocity	900 m/s
Aircraft velocity	900 km/hr
Exhaust flow area	0.3 m^2



Assume that the exhaust gas pressure is the same as the inlet air pressure. Assume also that the inlet air velocity is equal to the aircraft velocity. Neglect the mass flow of the fuel. Calculate the inlet flow area to give an inlet air velocity equal to the aircraft velocity. Calculate the thrust developed by the engine.

(5 marks)

QUESTION 9

An athlete is able to run a 10 km road race in 40 minutes. In an actual race he is subject to wind resistance (due to his own motion) but wishes to train indoors on a treadmill in static air conditions. Calculate at what inclination or degree slope he should set his treadmill to simulate the additional energy expended due to wind resistance in an actual race. Assume the following parameters:

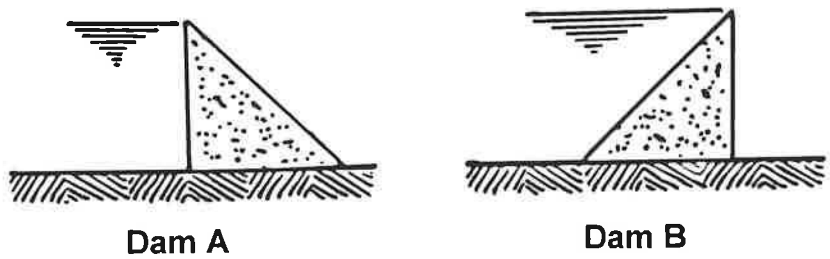
Mass of athlete	90 kg
Effective cross sectional (frontal) area of athlete	0.7 m^2
Drag coefficient of athlete	1.1
Ambient air temperature	20°C

(5 marks)

SECTION B GRAPHICAL AND ANALYTICAL QUESTIONS

***Do three of four questions*. These questions do not require detailed calculations but complete written explanations must be given to support the answers where descriptive answers are required.**

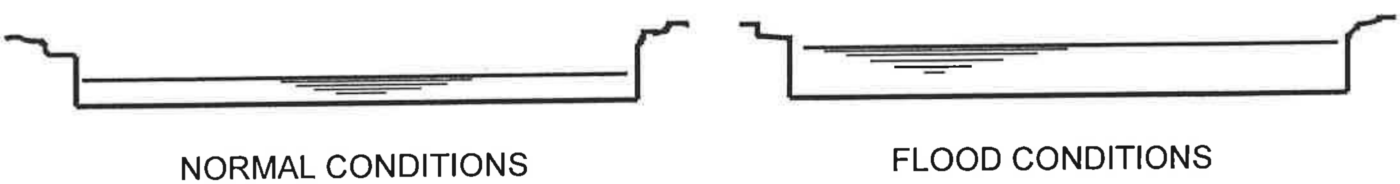
QUESTION 10



Two small triangular dams are built on a firm flat surface as shown above. Assuming that there is no seepage under the wall but that sliding can occur, state which dam - Dam A or Dam B - will be most likely to slide. Explain fully why one will be more likely to slide than the other.

(5 marks)

QUESTION 11



A wide shallow river of uniform depth and constant slope carries water at a certain flow rate. Under flood conditions the water depth is twice (two times) the normal depth. Assume that the river banks are high enough to prevent the river from increasing in width as the level rises.

(a) State whether the velocity under flood conditions will be ***less than / the same as / greater than*** the normal flow velocity.

(b) State whether the flow rate will be ***less than / the same as / between one and two times / two times / greater than two times*** the normal flow rate.

(c) Justify your answers with reference to the applicable theoretical relations.

(5 marks)

QUESTION 12

Consider the aerodynamics of a frisbee. Explain how the air flows over it during forward flight. Explain the effects of its spinning. Clarify how horizontal stability is generally maintained and how lift is created. Show, in sketches of stream lines around the object, how the air flows on top and below the Frisbee, when in flight and when spinning.

(5 marks)

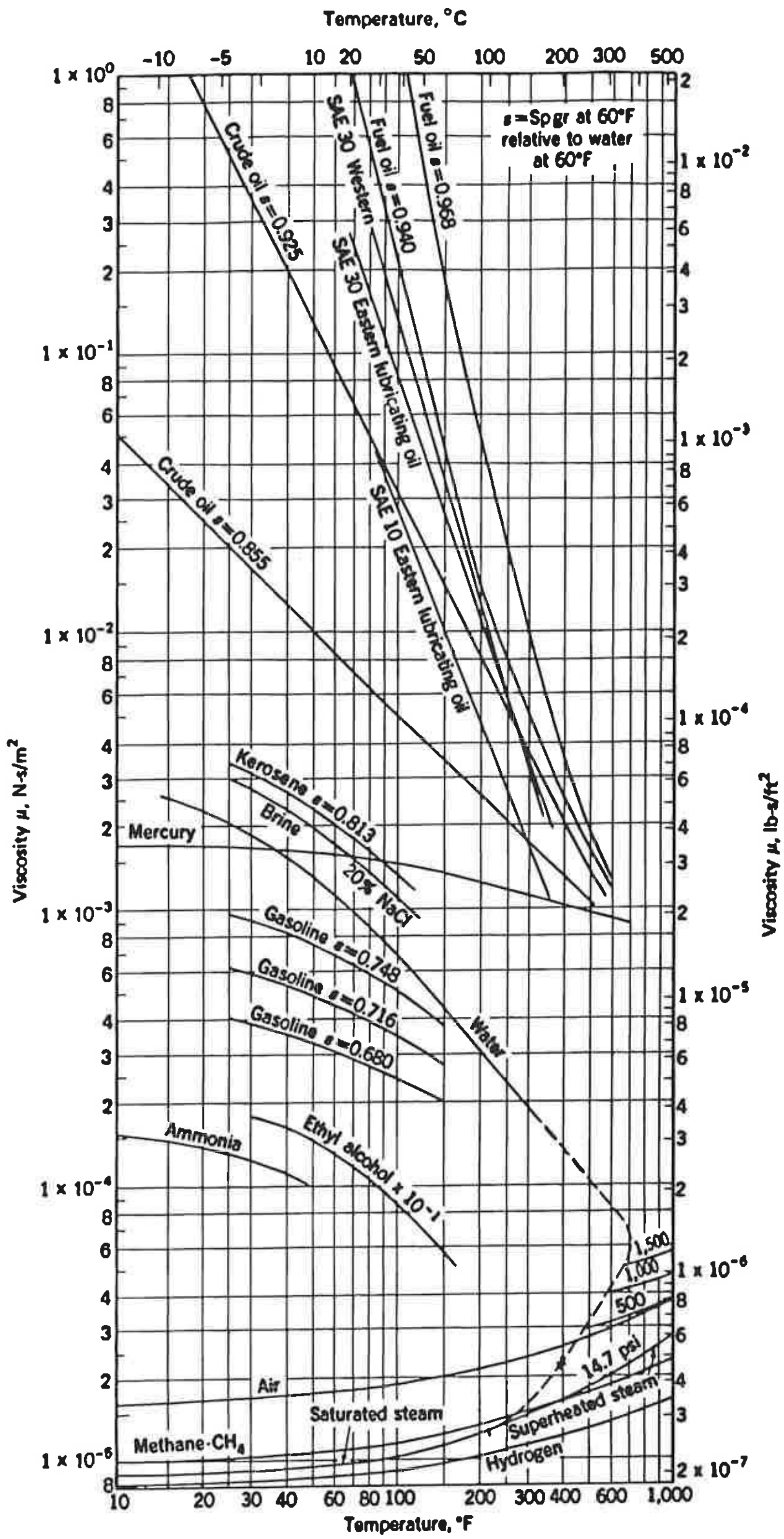
QUESTION 13

When a regular playing card is held vertically and dropped, it descends in an irregular tumbling fashion and veers to the side. However, when it is held horizontally and released from a perfectly horizontal position, it falls straight down with perhaps a slight oscillation. A small deviation from horizontal seems to be self correcting leading to a stable condition while falling. Sketch the stream lines around a horizontal card while falling and show how the stream lines would change when it is tilted slightly. From the change in stream line pattern, deduce the change in pressure which promotes stability.

(5 marks)

EXAMINATION PAPER ATTACHMENTS

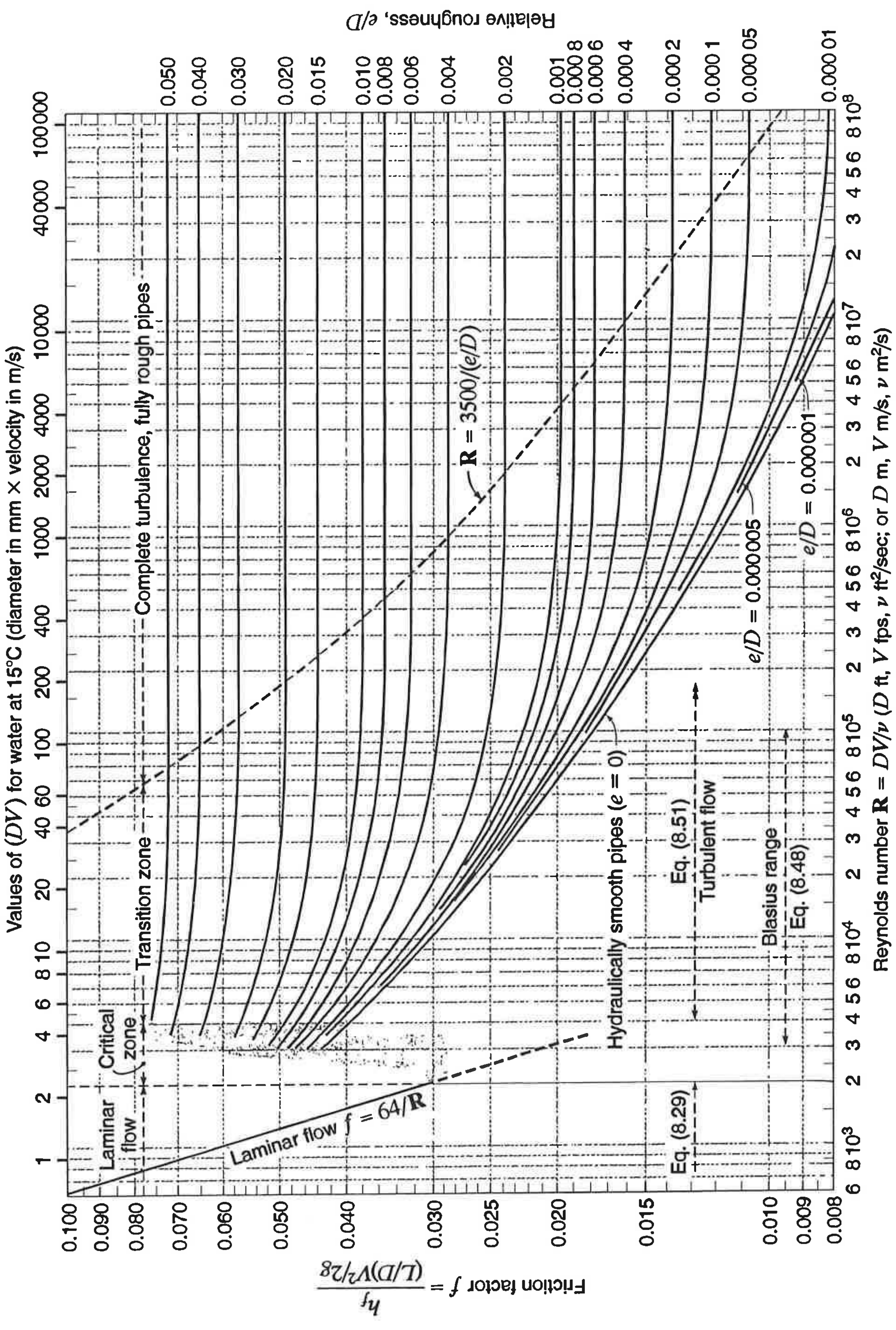
QUESTION 2 ABSOLUTE VISCOSITY **NAME** ....



Absolute viscosity μ of fluids.

EXAMINATION PAPER ATTACHMENTS

QUESTION 6 MOODY DIAGRAM **NAME** ....



Moody chart for pipe friction factor (Stanton diagram).

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 Gasoline ρ = 750 kg/m^3
Density of Aluminum ρ = 2700 kg/m^3
Density of Steel ρ = 7780 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_v = 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: $I_c = \pi\,D^4 / 64$

Surface Area of Solids

Sphere: $A = \pi\,D^2$

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

Closed Conduit: $F_R = p_1 A_1 - p_2 A_2 - M (V_2 - V_1)$
Open Channel: $F_R = p_1 A_1 - p_2 A_2 - M (V_2 - V_1)$
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: $P = ½ \rho Q V^2$
Moving Blades: $P = M \Delta V U$

Aircraft Propulsion

$F_{thrust} = M (V_{jet} - V_{aircraft})$
$P_{thrust} = M (V_{jet} - V_{aircraft}) V_{aircraft}$
$E_{jet} = ½ (V_{jet}^2 - V_{aircraft}^2)$

$P_{jet} = \frac{1}{2} M (V_{jet}^2 - V_{aircraft}^2)$
$E_{fuel} = CV_{fuel}$
$P_{fuel} = M_{fuel} CV_{fuel}$
$\eta_{thermal} = P_{jet} / P_{fuel}$
$\eta_{propulsion} = P_{thrust} / P_{jet} = 2 V_{aircraft} / (V_{jet} + V_{aircraft})$
$\eta_{overall} = \eta_{thermal} \times \eta_{propulsion}$

Wind Power

$P_{total} = \frac{1}{2} \rho A_T V_1^3$
$P_{max} = 8/27 \rho A_T V_1^3$
$H_{max} = P_{max} / P_{total} = 16/27$

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: $F_f = C_f \frac{1}{2} \rho V^2 B L \quad (B = \pi D)$
Pressure Drag: $F_p = C_p \frac{1}{2} \rho V^2 A$
Total Drag: $F_D = C_D \frac{1}{2} \rho V^2 \mathbf{A}$

Aircraft Wing: $F_L = C_L \frac{1}{2} \rho V^2 A_{wing}$
Aircraft Wing: $F_D = C_D \frac{1}{2} \rho V^2 A_{wing}$

Karmen Vortex Frequency

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