

Fluid Mechanics FE Review

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Fluid Mechanics FE Review

These slides contain some notes, thoughts about what to study, and some practice problems. The answers to the problems are given in the last slide.

In the review session, we will be working some of these problems. Feel free to come to the session, or work the problems on your own. I am happy to answer your email questions or those that you bring to the session.

Good luck!

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Fluid Mechanics FE Review

MAJOR TOPICS

Fluid Properties

Fluid Statics

Fluid Dynamics

Fluid Measurements

Dimensional Analysis

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Fluid Mechanics FE Review

It will be very helpful to memorize the following concepts and equations:

- Specific weight, density, and specific gravity
- Hydrostatics pressure equation / manometry
- Force magnitude and location due to hydrostatic pressure for horizontal and vertical plane walls
- Conservation of mass / continuity
- Conservation of energy / Bernoulli and Energy Eqn
- Darcy Eqn
- Relative roughness equation
- Drag equation
- How to use the Moody Diagram

- Most equations and problems taken from Professional Publications, Inc. FERC Review Course Book

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Fluid Mechanics

Properties

Fluids

- Substances in either the liquid or gas phase
- Cannot support shear

FLUID PROPERTIES

DENSITY, ρ

SPECIFIC GRAVITY, $SG = \frac{\rho}{\rho_{H_2O}} = \frac{\gamma}{\gamma_{H_2O}}$

SPECIFIC (UNIT) WT, $\gamma = \rho g$

SURFACE TENSION, $\sigma = \frac{\text{Force}}{\text{Length}}$
 $\sigma = \frac{F}{2L}$ (WIRE FRAME) = $\frac{F}{4\pi r}$ (DU NOUY RING)

VAPOR PRESSURE, P_v ; VISCOSITY, μ ; KINEMATIC VISCOSITY, $\nu = \frac{\mu}{\rho}$
 (ABSOLUTE OR DYNAMIC)

- MAKE SURE YOU USE THE PROPER VALUES ACCORDING TO H_2O TEMPERATURE!

IDEAL GAS LAW: P =pressure ; T =TEMP. ; ρ = DENSITY ; R = GAS CONSTANT

$P_v = \rho_v R T$, $R = \frac{\bar{R}}{MW}$, $\bar{R} = 8.314 \text{ kJ}/(\text{kmol} \cdot \text{K})$; $\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$
 $\rho = \frac{m}{V}$ (volume density) ; \bar{R} Molecular wt.

Make sure you use the ideal gas law when calculating properties for gasses!!

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Fluid Mechanics

Properties

Property	Symbol & Equation	Definition	Etc.
Density	$\rho = \frac{m}{V}$	$\frac{\text{mass}}{\text{volume}}$	
Specific Weight	$\gamma = \rho g$	density x gravity	
Specific Gravity	$SG = \frac{\rho_x}{\rho_{\text{water}}} = \frac{\gamma_x}{\gamma_{\text{water}}}$		
Viscosity	$\mu = \frac{\tau}{du/dy}$	$\frac{\text{shear stress}}{\text{velocity gradient}}$	
Kinematic viscosity	$\nu = \frac{\mu}{\rho}$	$\frac{\text{viscosity}}{\text{density}}$	

Make sure you know the relationship between density, specific weight, and specific gravity!

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Mass & Weight

1. 10.0 L of an incompressible liquid exert a force of 20 N at the earth's surface. What force would 2.3 L of this liquid exert on the surface of the moon? The gravitational acceleration on the surface of the moon is 1.67 m/s^2

- (A) 0.39 N
 (B) 0.78 N
 (C) 3.4 N
 (D) 4.6 N

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Fluid Mechanics – Fluid Properties

Property	Symbol & Equation	Definition	Etc.
Vapor Pressure	p_v	Pressure at which liquid and vapor are in equilibrium	Used to predict cavitation (local pressure < vapor pressure)
Bulk Modulus	$\rho = \frac{m}{V}$	$\frac{\text{mass}}{\text{volume}}$	
Speed of Sound	$c, \text{liquid} = \sqrt{k/\rho}$ $c, \text{gas} = \sqrt{krt}$	Velocity of propagation of a small wave	$k = \text{Bulk modulus}$ $k_{\text{air}} = 1.4$

SPEED OF SOUND

Function of Bulk Modulus (which correlates to compressibility)

For IDEAL GAS:

$$c = \sqrt{kRT} \quad \left(\begin{array}{l} T \text{ must be in } K \text{ or } ^\circ R \\ k = \text{ratio of specific heats} \end{array} \right)$$

MACH NUMBER

$$M = \frac{V}{c} = \frac{\text{object velocity}}{\text{speed of sound}}$$

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Mach Number

2. A jet aircraft is flying at a speed of 1700 km/h. The air temperature is 20 °C. The molecular weight of air is 29 g/mol. What is the Mach number of the aircraft?

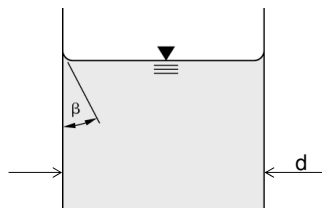
- (A) 0.979
 (B) 1.38
 (C) 1.92
 (D) 5.28

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Fluid Mechanics – Fluid Properties

Property	Symbol & Equation	Definition	Etc.
Surface Tension	$\sigma = \frac{F}{L}$	<i>force</i> <i>length</i>	
Capillary Rise	$h = \frac{4\sigma \cos\beta}{\rho d_{\text{tube}} g}$	<i>Distance a liquid will rise (or fall) in a "tube"</i>	

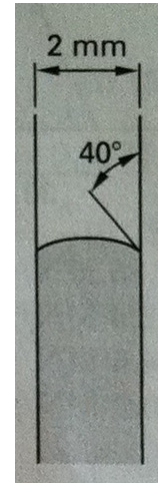


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Surface Tension

3. A 2 mm (inside diameter) glass tube is placed in a container of mercury. An angle of 40° is measured as illustrated. The density and surface tension of mercury are 13550 kg/m^3 and $37.5 \times 10^{-2} \text{ N/m}$, respectively. How high will the mercury rise or be depressed in the tube as a result of capillary action?



- (A) -4.3 mm (depression)
 (B) -1.6 mm (depression)
 (C) 4.2 mm (rise)
 (D) 6.4 mm (rise)

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Fluid Mechanics

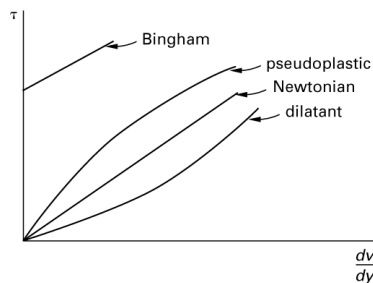
9-1b

Stresses and Viscosity

Shear Stress

- Normal Component: $\tau_n = p = \frac{\text{Force}}{\text{Area}}$
- Tangential Component
 - For a Newtonian fluid: $\tau_t = \mu \frac{dv}{dy}$ ($v = \text{velocity}$)
 - For a pseudoplastic or dilatant fluid: $\tau_t = K \left(\frac{dv}{dy} \right)^n$

Absolute Viscosity = μ = Ratio of shear stress to rate of shear deformation



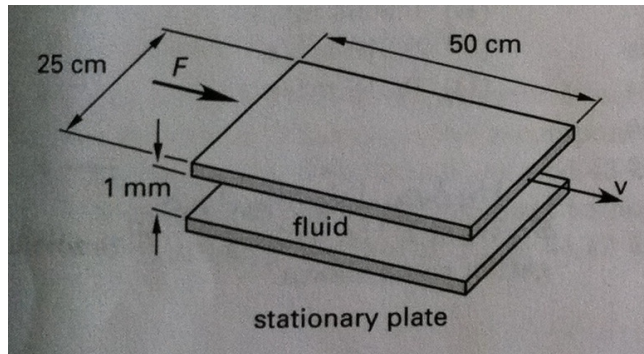
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Viscosity

4. A sliding-plate viscometer is used to measure the viscosity of a Newtonian fluid. A force of 25 N is required to keep the top plate moving at a constant velocity of 5 m/s. What is the viscosity of the fluid?

- (A) 0.005 N-s/m²
 (B) 0.04 N-s/m²
 (C) 0.2 N-s/m²
 (D) 5.0 N-s/m²



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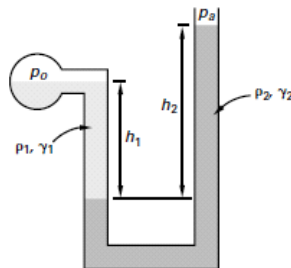
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Fluid Statics

PRESSURE: $P_{\text{absolute}} = P_{\text{gage}} + P_{\text{atmospheric}} = P_{\text{atmospheric}} - P_{\text{vacuum}}$

HYDROSTATIC PRESSURE: $P = \gamma h$ * Pressure is ALWAYS NORMAL to a surface!

MANOMETRY: start w/ P on one end & add or subtract changes in hydrostatic pressure to find P at other end ("TAKE A JOURNEY" through)



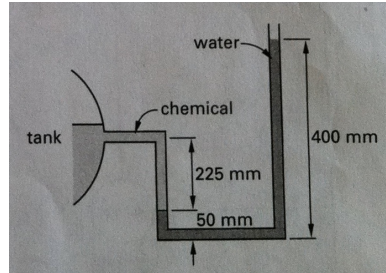
$$p_0 - p_a = \gamma_2 h_2 - \gamma_1 h_1$$

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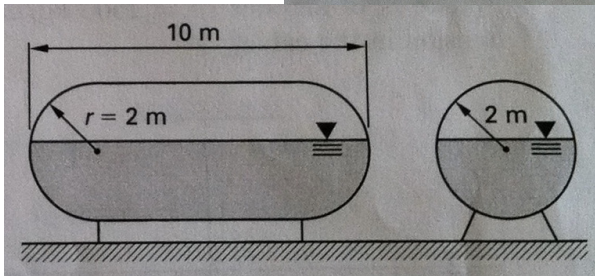
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Manometry

5. An open water manometer is used to measure the pressure in a tank. The tank is half-filled with 50,000 kg of a liquid chemical that is not miscible in water. The manometer tube is filled with liquid chemical. What is the pressure in the tank relative to the atmospheric pressure?



- (A) 1.4 kPa
- (B) 1.9 kPa
- (C) 2.4 kPa
- (D) 3.4 kPa



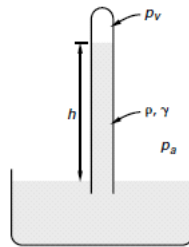
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Fluid Statics

9-2c

Barometer



Atmospheric Pressure

$$p_a - p_v = \rho gh \quad [SI]$$

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Fluid Statics

FORCES ON SUBMERGED SURFACES : FORCES ACT @ CENTER OF PRESSURE

$$F = \text{VOLUME OF PRESSURE PRISM} \quad \text{OR} \quad F = \gamma A z_c \sin \theta$$

$$\text{LOCATION} = \text{CENTROID OF PRESSURE PRISM} \quad \text{OR} \quad y^* = \frac{I_{yz}}{z_c A} ; z^* = \frac{I_{yz}}{z_c A}$$



$$\text{BUOYANCY} : F_{\text{buoyant}} = \gamma_{\text{fluid}} V_{\text{displaced}}$$

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Hydrostatics

6. A 6m x 6m x 6m vented cubical tank is half-filled with water; the remaining space is filled with oil (SG=0.8). What is the total force on one side of the tank?

- (A) 690 kN
- (B) 900 kN
- (C) 950 kN
- (D) 1.0 MN

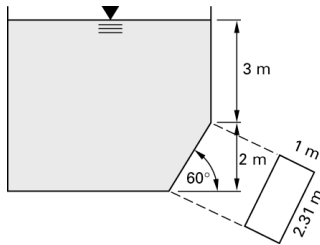
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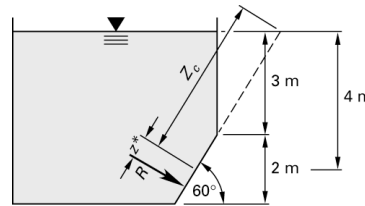
Fluid Statics Examples

9-2f1

Example 1 (FEIM):
The tank shown is filled with water. At what depth does the resultant force act?



The surface under pressure is a rectangle 1 m at the base and 2.31 m tall.



$$A = bh$$

$$I_{y_c} = \frac{b^3 h}{12}$$

$$Z_c = \frac{4 \text{ m}}{\sin 60^\circ} = 4.618 \text{ m}$$

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Fluid Statics Examples

9-2f2

Using the moment of inertia for a rectangle given in the NCEES Handbook,

$$z^* = \frac{I_{y_c}}{AZ_c} = \frac{b^3 h}{12bhZ_c} = \frac{b^2}{12Z_c}$$

$$= \frac{(2.31 \text{ m})^2}{(12)(4.618 \text{ m})} = 0.0963 \text{ m}$$

$$R_{\text{depth}} = (Z_c + z^*) \sin 60^\circ = (4.618 \text{ m} + 0.0963 \text{ m}) \sin 60^\circ = 4.08 \text{ m}$$

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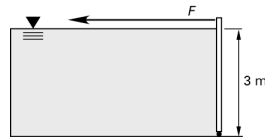
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Fluid Statics Examples

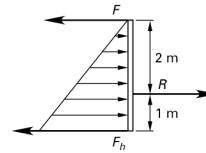
9-2g

Example 2 (FEIM):

The rectangular gate shown is 3 m high and has a frictionless hinge at the bottom. The fluid has a density of 1600 kg/m³. The magnitude of the force F per meter of width to keep the gate closed is most nearly



- (A) 0 kN/m
- (B) 24 kN/m
- (C) 71 kN/m
- (D) 370 kN/m



$$p_{ave} = \rho g z_{ave} = (1600 \frac{\text{kg}}{\text{m}^3})(9.81 \frac{\text{m}}{\text{s}^2})(\frac{1}{2})(3 \text{ m}) = 23544 \text{ Pa}$$

$$\frac{R}{w} = p_{ave} h = (23544 \text{ Pa})(3 \text{ m}) = 70662 \text{ N/m}$$

$$F + F_h = R$$

R is one-third from the bottom (centroid of a triangle from the NCEES Handbook). Taking the moments about R ,

$$2F = F_h$$

$$\frac{F}{w} = \left(\frac{1}{3}\right)\left(\frac{R}{w}\right) = \frac{70,667 \text{ N}}{3} = 23.6 \text{ kN/m}$$

Therefore, (B) is correct.

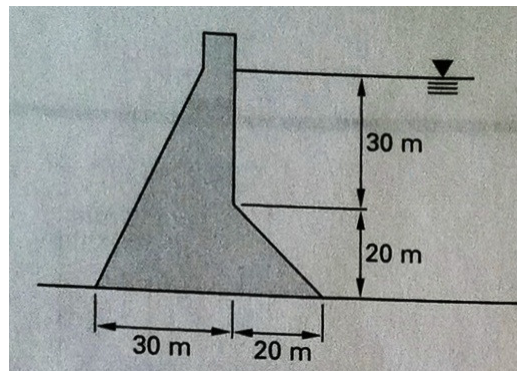
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Hydrostatics

6. A gravity dam has the cross section shown. What is the magnitude of the resultant water force (per meter of width) acting on the face of the dam?

- (A) 7.85 MN/m
- (B) 12.3 MN/m
- (C) 14.6 MN/m
- (D) 20.2 MN/m



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Buoyancy

Archimedes' Principle and Buoyancy

- The buoyant force on a submerged or floating object is equal to the weight of the displaced fluid.
- A body floating at the interface between two fluids will have buoyant force equal to the weights of both fluids displaced.

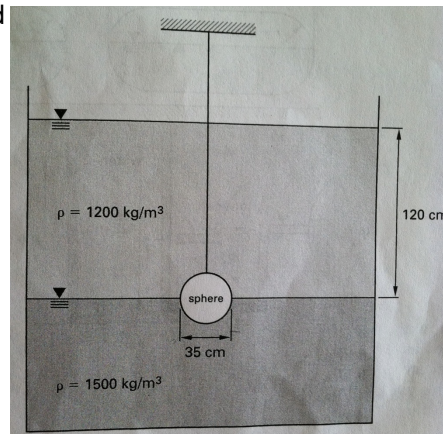
$$F_{\text{buoyant}} = \gamma_{\text{water}} V_{\text{displaced}}$$

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Buoyancy

8. A 35 cm diameter solid sphere ($\rho = 4500 \text{ kg/m}^3$) is suspended by a cable as shown. Half of the sphere is in one fluid ($\rho = 1200 \text{ kg/m}^3$) and the other half of the sphere is in another ($\rho = 1500 \text{ kg/m}^3$). What is the tension in the cable?

- (A) 297 N
 (B) 593 N
 (C) 694 N
 (D) 826 N



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Fluid Dynamics

CONTINUITY: Mass is Conserved $\dot{m}_1 = \dot{m}_2$

$$\rho_1 A_1 v_1 = \rho_2 A_2 v_2$$

$$\rho_1 Q_1 = \rho_2 Q_2$$

For incompressible fluids
(ρ 's constant)

$$Q = A_1 v_1 = A_2 v_2 = \text{Etc.}$$

BERNOULLI EQUATION:
(might be called the field eqn.)

$$\frac{P_1}{\gamma_1} + \frac{v_1^2}{2g} + z_1 = \frac{P_2}{\gamma_2} + \frac{v_2^2}{2g} + z_2 \quad \text{or} \quad \frac{P_1}{\rho_1} + \frac{v_1^2}{2g} + g z_1 = \frac{P_2}{\rho_2} + \frac{v_2^2}{2g} + g z_2$$

↑ units = "HEAD" of liquid

REYNOLD'S NUMBER:
(Newtonian Fluids)

$$Re = \frac{v D \rho}{\mu} = \frac{v D}{\nu}$$

Laminar Flow: $Re \lesssim 2100$

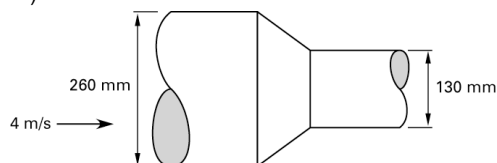
Turbulent Flow: $Re > 4000$

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Continuity Equation Example

9-3c

Example (FEIM):



The speed of an incompressible fluid is 4 m/s entering the 260 mm pipe.

The speed in the 130 mm pipe is most nearly

- (A) 1 m/s
- (B) 2 m/s
- (C) 4 m/s
- (D) 16 m/s

$$A_1 v_1 = A_2 v_2$$

$$A_1 = 4A_2$$

$$\text{so } v_2 = 4v_1 = (4) \left(4 \frac{\text{m}}{\text{s}} \right) = 16 \text{ m/s}$$

Therefore, (D) is correct.

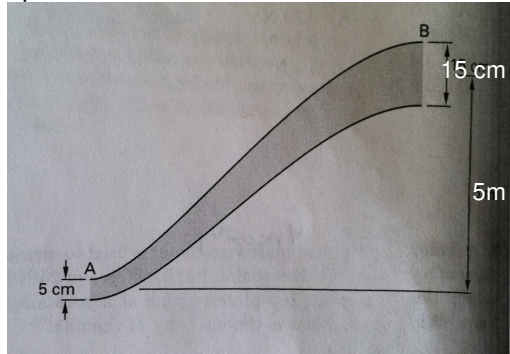
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Bernoulli Equation

9. The diameter of a water pipe gradually changes from 5 cm at point A to 15 cm at point B. Point A is 5 m lower than point B. The pressure is 700 kPa at point A and 664 kPa at point B. Friction between the water and the pipe walls is negligible. What is the rate of discharge at point B?

- (A) 0.0035 m³/s
 (B) 0.0064 m³/s
 (C) 0.010 m³/s
 (D) 0.018 m³/s



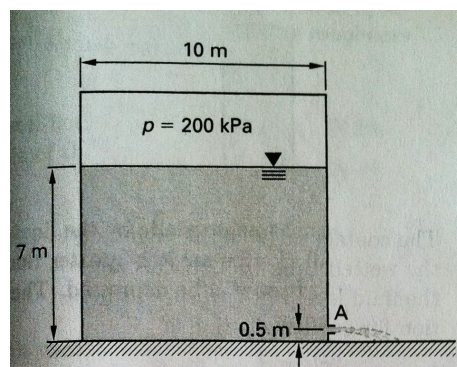
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Bernoulli – Flow from a Jet

10. A liquid with a specific gravity of 0.9 is stored in a pressurized, closed storage tank. The tank is cylindrical with a 10 m diameter. The absolute pressure in the tank above the liquid is 200 kPa. What is the initial velocity of a fluid jet when a 5 cm diameter orifice is opened at point A?

- (A) 11.3 m/s
 (B) 18.0 m/s
 (C) 18.6 m/s
 (D) 23.9 m/s



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Flow in Pipes – Fluid Dynamics and Friction

Steady, Incompressible Flow

ENERGY EQUATION: $\frac{P_1}{\gamma} + \frac{v_1^2}{2g} + z_1 = \frac{P_2}{\gamma} + \frac{v_2^2}{2g} + z_2 + h_f + h_c$ ← loss due to fittings

friction loss → $h_{c, fitting} = C \left(\frac{v^2}{2g} \right)$ ← velocity through fitting

→ $h_f = f \frac{L}{D} \frac{v^2}{2g}$; f is a function of Re and $\frac{\epsilon}{D}$; ϵ = surface roughness

LAMINAR FLOW: $f = \frac{64}{Re}$; $h_f = \frac{32 \mu L v}{\gamma D^2}$

TURBULENT FLOW: use MOODY DIAGRAM to find f

Smooth & hydraulically smooth pipes: $f = \frac{0.316}{Re^{1/4}}$ (for $Re < 100,000$)

Can Also use HAALAND EQN FOR ALL TURBULENT FLOW

$$\frac{1}{\sqrt{f}} = -1.8 \log \left[\frac{6.9}{Re} + \left(\frac{\epsilon/D}{3.7} \right)^{1.11} \right]$$

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Reynolds Number

9-3g

For a Newtonian fluid:

$$Re = \frac{vD\rho}{\mu} \quad [SI]$$

$$Re = \frac{vD}{\nu}$$

D = hydraulic diameter = $4R_H$

ν = kinematic viscosity

μ = dynamic viscosity

For a pseudoplastic or dilatant fluid:

$$Re' = \frac{v^{2-n} D^n \rho}{K \left(\frac{3n+1}{4n} \right)^n 8^{n-1}}$$

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Fluid Dynamics and Friction

11. A steel pipe with an inside diameter of 25 mm is 20 m long and carries water at a rate of 4.5 m³/h. Assuming the specific roughness of the pipe is 0.00005 m, the water has an absolute viscosity of 1.00 x 10⁻³ Pa-s and a density of 1000 kg/m³, what is the friction factor?

- (A) 0.023
 (B) 0.030
 (C) 0.026
 (D) 0.028

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Non-Circular Conduits, Open Channel Flow, and Partially Full Pipes

Hydraulic Radius, $R_H = \frac{\text{area in flow}}{\text{wetted perimeter}}$; Equivalent Diameter, $D_H = 4 R_H$

OPEN CHANNEL : $V = \left(\frac{1}{n}\right) R_H^{2/3} S^{1/2}$ (SI units) $n = \text{Manning's Roughness Coefficient}$
 $V = \left(\frac{1.486}{n}\right) R_H^{2/3} S^{1/2}$ (U.S. units) $S = \text{Slope of channel}$

PARTIALLY FULL PIPES

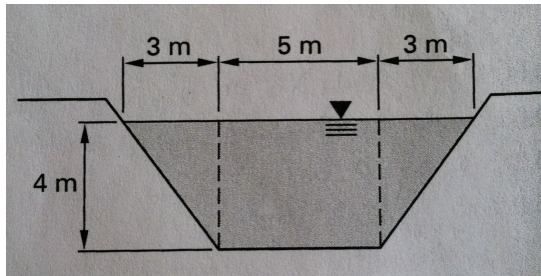
$V = 0.849 C R_H^{0.63} S^{0.54}$ (SI) $C = \text{Hazen-Williams Roughness Coeff.}$
 $V = 1.318 C R_H^{0.63} S^{0.54}$ (U.S.)

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Hydraulic Radius

12. What is the hydraulic radius of the trapezoidal irrigation canal shown?

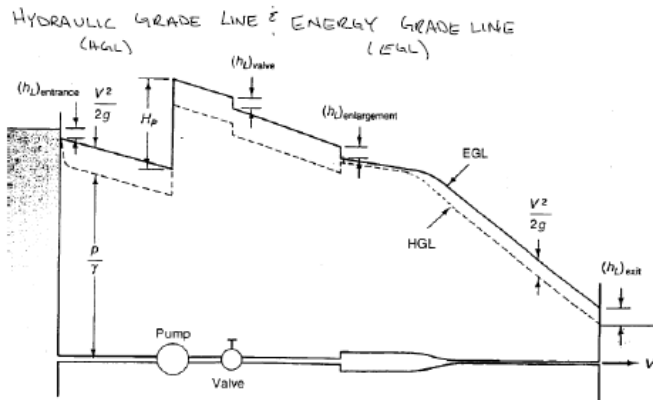
- (A) 1.63 m
- (B) 2.00 m
- (C) 2.13 m
- (D) 4.00 m



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Hydraulic Grade Line and Energy Grade Line Pump Power



NOTE:
 $EGL = HGL + \frac{v^2}{2g}$

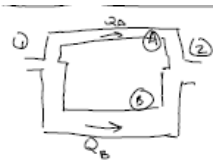
Hydraulic grade line (HGL) and energy grade line (EGL) for a piping system.

PUMP POWER, $P = \dot{W} = \frac{Q \gamma h_p}{\eta}$ $\leftarrow h_p = \text{head added by pump to the fluid}$
 $\eta = \text{pump efficiency}$

Express in watts (1 N·m/s) or horsepower (550 ft·lb/s)

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Multi-path Pipelines



3 MAIN PRINCIPLES

1) Head Loss in each branch is equal: $h_{f,A} = h_{f,B}$

$$f_A \frac{L_A}{D_A} \frac{V_A^2}{2g} = f_B \frac{L_B}{D_B} \frac{V_B^2}{2g}$$

2) Head Loss between the 2 junctions is same as head loss in each branch

3) Mass Must be conserved. Therefore the total flow rate equals the sum of the flow rate in each branch.

$$Q_1 = Q_2 = Q_A + Q_B \quad \text{OR} \quad \frac{\pi}{4} D_1^2 V_1 = \frac{\pi}{4} D_2^2 V_2 = \frac{\pi}{4} D_A^2 V_A + \frac{\pi}{4} D_B^2 V_B$$

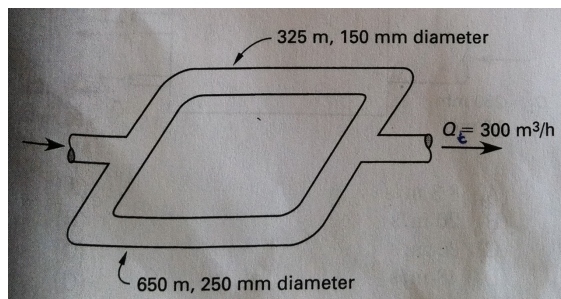
$$\text{THIS SIMPLIFIES TO: } D_1^2 V_1 = D_2^2 V_2 = D_A^2 V_A + D_B^2 V_B$$

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Multi-path pipelines

13. The Darcy friction factor for both of the pipes shown is 0.024. The total flow rate is $300 \text{ m}^3/\text{h}$. What is the flow rate through the 250 mm pipe?

- (A) $0.04 \text{ m}^3/\text{s}$
 (B) $0.05 \text{ m}^3/\text{s}$
 (C) $0.06 \text{ m}^3/\text{s}$
 (D) $0.07 \text{ m}^3/\text{s}$



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Impulse-Momentum

IMPULSE-MOMENTUM

$$\sum F = \rho Q (v_2 - v_1) = \left(\frac{\rho Q}{g}\right) v_{out} - \left(\frac{\rho Q}{g}\right) v_{in}$$

BE SURE TO DRAW FBD!
WATCH YOUR SIGNS!

Be sure to familiarize yourself with how this equation works for bends, enlargements, contractions, jet propulsion, fixed blades, moving blades, and impulse turbines.

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Impulse-Momentum

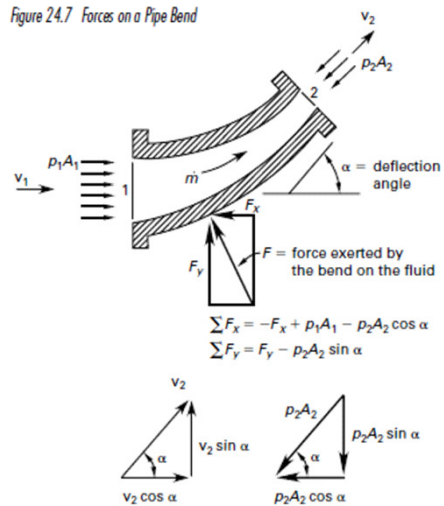
9-6a

$$\sum F = Q_2 \rho_2 v_2 - Q_1 \rho_1 v_1 \quad [SI] \quad 24.38a \quad \text{Figure 24.7 Forces on a Pipe Bend}$$

Pipe Bends, Enlargements, and Contractions

$$-F_x = p_2 A_2 \cos \alpha - p_1 A_1 + Q \rho (v_2 \cos \alpha - v_1) \quad [SI] \quad 24.39a$$

$$F_y = (p_2 A_2 + Q \rho v_2) \sin \alpha + m_{fluid} g \quad [SI] \quad 24.40a$$



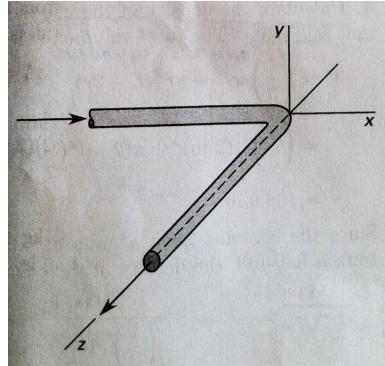
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Impulse-Momentum

14. Water is flowing at 50 m/s through a 15 cm diameter pipe. The pipe makes a 90 degree bend, as shown. What is the reaction on the water in the z-direction at the bend?

- (A) -44 kN
 (B) -33 kN
 (C) 14 kN
 (D) 44 kN



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Flow and Pressure Measurement

PITOT TUBE - USED TO MEASURE FLOW VELOCITY $v = \sqrt{\frac{2(p_0 - p_s)}{\rho}} = \sqrt{\frac{2g(p_0 - p_s)}{\gamma}}$

p_0 = static pressure ; p_s = stagnation pressure

VENTURI & ORIFICE METERS
 (see sketches in Ref. Book
 for variable descriptions)

Venturi
 $Q = \left(\frac{C_v A_2}{\sqrt{1 - \left(\frac{A_2}{A_1}\right)^2}} \right) \sqrt{2 \left(\frac{p_1}{\rho} + g z_1 - \frac{p_2}{\rho} - g z_2 \right)}$ (S.I.)

$Q = \left(\frac{C_v A_2}{\sqrt{1 - \left(\frac{A_2}{A_1}\right)^2}} \right) \sqrt{2g \left(\frac{p_1}{\gamma} + z_1 - \frac{p_2}{\gamma} - z_2 \right)}$ (U.S.)

Orifices

$Q = CA \sqrt{2g \left(\frac{p}{\gamma} + z_1 - \frac{p}{\gamma} - z_2 \right)}$ (U.S.)

$Q = CA \sqrt{2 \left(\frac{p}{\rho} + g z_1 - \frac{p}{\rho} - g z_2 \right)}$ (S.I.)

Submerged Orifices

$Q = CA \sqrt{2g(h_1 - h_2)}$

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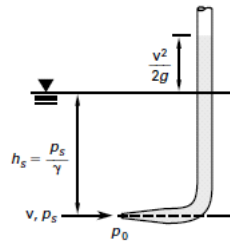
Fluid Mechanics

9-10a

Fluid Measurements

Pitot Tube – measures flow velocity

Figure 25.1 Pitot Tube



- The static pressure of the fluid at the depth of the pitot tube (p_0) must be known. For incompressible fluids and compressible fluids with $M \leq 0.3$,

$$v = \sqrt{\frac{2(p_0 - p_s)}{\rho}} \quad [\text{SI}] \quad 25.11a$$

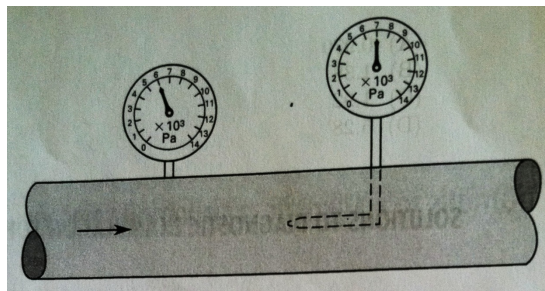
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Flow and Pressure Measurement

15. The density of air flowing in a duct is 1.15 kg/m^3 . A pitot tube is placed in the duct as shown. The static pressure in the duct is measured with a wall tap and pressure gage. Use the gage readings to determine the velocity of the air.

- (A) 42 m/s
 (B) 102 m/s
 (C) 110 m/s
 (D) 150 m/s



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Fluid Mechanics

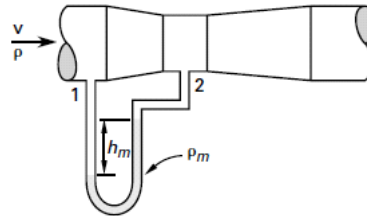
9-10c

Fluid Measurements

Venturi Meters – measures the flow rate in a pipe system

- The changes in pressure and elevation determine the flow rate. In this diagram, $z_1 = z_2$, so there is no change in height.

Figure 25.2 Venturi Meter with Differential Manometer



$$Q = \left(\frac{C_v A_2}{\sqrt{1 - \left(\frac{A_2}{A_1}\right)^2}} \right) \sqrt{2g \left(\frac{p_1}{\gamma} + z_1 - \frac{p_2}{\gamma} - z_2 \right)}$$

[U.S.] 25.14b

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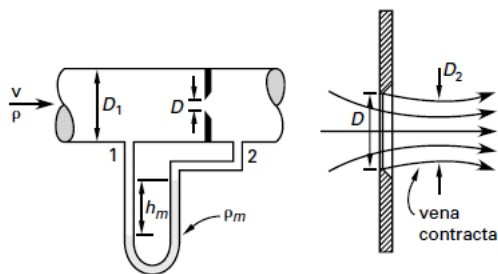
Fluid Mechanics

9-10e

Fluid Measurements

Orifices

Figure 25.3 Orifice Meter with Differential Manometer



(a) orifice meter

(b) orifice plate

$$Q = C A \sqrt{2g \left(\frac{p_1}{\gamma} + z_1 - \frac{p_2}{\gamma} - z_2 \right)}$$

[U.S.] 25.17b

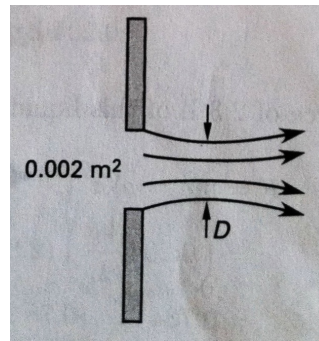
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Orifice Flow

16. Water flows out of a tank at 12.5 m/s from an orifice located 9m below the surface. The cross-sectional area of the orifice is 0.002 m², and the coefficient of discharge is 0.85. What is the diameter D, at the vena contracta?

- (A) 4.2 cm
 (B) 4.5 cm
 (C) 4.7 cm
 (D) 4.8 cm



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Similitude

Geometric Similarity : Model is true to length, area & volume

Kinematic Similarity : Flow Regimes of model & prototype are the same

Dynamic Similarity : Ratios of all types of forces are equal for model & prototype

Met if following simultaneous equations are satisfied for model & prototype

$$\left[\frac{\rho v^2}{P} \right]_m = \left[\frac{\rho v^2}{P} \right]_p ; Re_m = Re_p ; Fr_m = Fr_p ; Ca_m = Ca_p ; We_p = We_m$$

$$Re = \frac{v \rho l}{\mu} ; Fr = \frac{v^2}{g l} ; Ca = \frac{\rho v^2}{E} ; We = \frac{\rho l v^2}{\sigma}$$

\uparrow modulus of elasticity \uparrow surface tension

In other words... Dimensionless parameters must be equal between the model and prototype
 (Each dimensionless parameter is a ratio of different types of forces being exerted on the fluid)

For example:

For completely submerged models/prototypes and pipe flow, the Reynolds numbers must be equal

For Weirs, dams, ships, and open channels, the Froude numbers must be equal

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Similitude – Dimensionless Parameters

Reynolds number = $\frac{\text{inertial force}}{\text{viscous force}}$	$Re = \frac{V\ell\rho}{\mu}$
Froude number = $\frac{\text{inertial force}}{\text{gravity force}}$	$Fr = \frac{V^2}{\ell g}$
Mach number = $\frac{\text{inertial force}}{\text{compressibility force}}$	$M = \frac{V}{c}$
Weber number = $\frac{\text{inertial force}}{\text{surface tension force}}$	$We = \frac{V^2\ell\rho}{\sigma}$
Strouhal number = $\frac{\text{centrifugal force}}{\text{inertial force}}$	$St = \frac{\ell\omega}{V}$
Pressure coefficient = $\frac{\text{pressure force}}{\text{inertial force}}$	$C_p = \frac{\Delta p}{\frac{1}{2}\rho V^2}$
Drag coefficient = $\frac{\text{drag force}}{\text{inertial force}}$	$C_D = \frac{\text{drag}}{\frac{1}{2}\rho V^2 A}$

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Similitude

17. A nuclear submarine is capable of a top underwater speed of 65 km/h. How fast would a 1/20 scale model of the submarine have to be moved through a testing pool filled with seawater for the forces on the submarine and model to be dimensionally similar?

- (A) 0.90 m/s
- (B) 18 m/s
- (C) 180 m/s
- (D) 360 m/s

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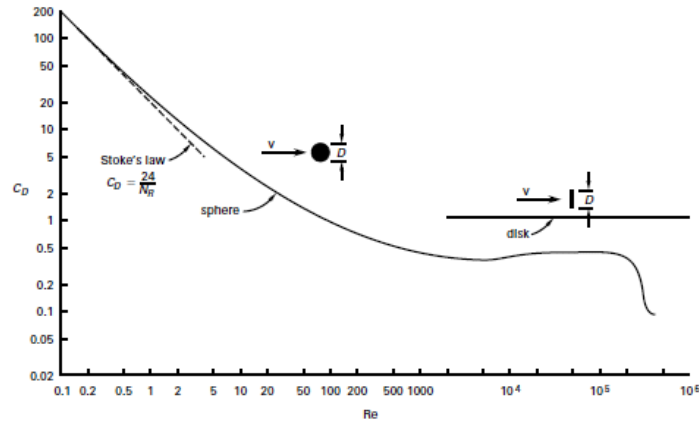
Drag

$F_D = \frac{1}{2} C_D A \rho v^2$; For Laminar Flow, $F_D = \frac{24}{Re}$ (For $Re < 0.1$)

Typically these problems will be "plug and chug"

Drag Coefficients for Spheres and Circular Flat Disks

Figure 24.14 Drag Coefficients for Spheres and Circular Flat Disks



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ANSWERS!!

1. B
2. B
3. A
4. B
5. A
6. B
7. C
8. C
9. C
10. C
11. C
12. C
13. C
14. D
15. A
16. D
17. D

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