American University of Iraq, Sulaimani
Engineering Department
Fluid Mechanics, ENGR 356
Term Exam 1

March 11th/2018, 6:00-8:00pm

Duration 2 hours

Name: ---

Student ID: ---

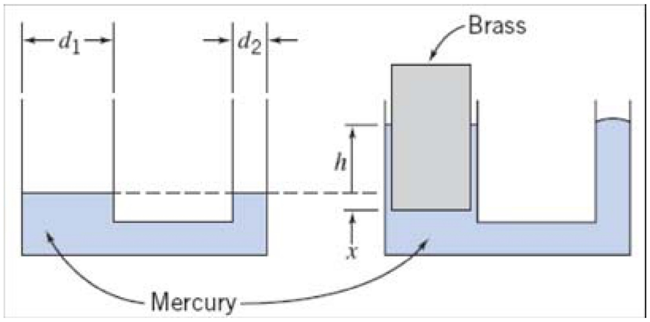
Instructions:

1. **Must do questions 1 - 3**
2. **You are allowed only a basic calculator (not a programmable one)**

3. Clearly state all your knowns, unknowns, assumptions, and include a basic diagram representing your system.

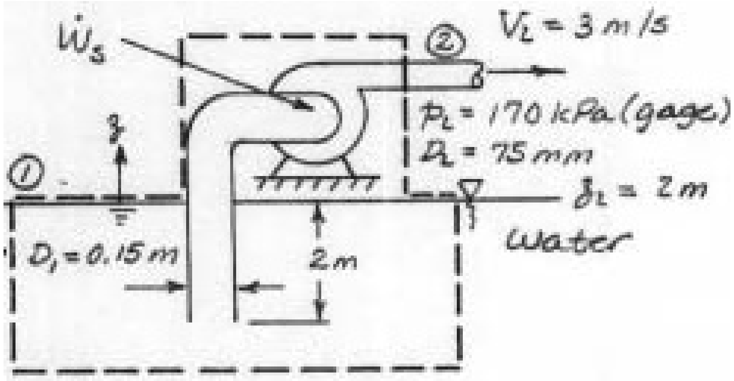
Problem 1 (20 marks)

A container with two circular vertical tubes of diameters d_1 = 39.5mm and d_2 =12.7mm is partially filled with mercury. The equilibrium level of the liquid is shown in the left diagram. A cylindrical object made from solid brass is placed in the larger tube (as shown) so that it floats, as shown in the right diagram. The object is D = 37.5mm in diameter and H = 76.2mm high. Calculate the pressure at the lower surface needed to float the object. Determine the new equilibrium level, h, of the mercury with the brass cylinder place. ($\rho_{water} =$¿ $1000\ \frac{kg}{m^3}$, g = 9.81 m/s^2).



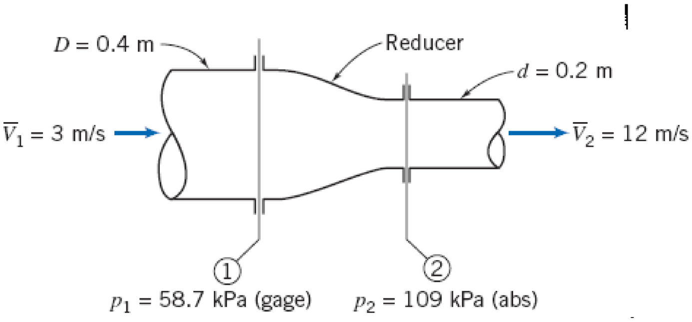
Problem 2 (20 marks)

At steady state conditions, a pump draws water from a reservoir through a 150-mm diameter suction pipe and delivers it to a 75-mm diameter discharge pipe, as shown on the diagram below. The end of the suction pipe is 2 m below the free surface of the reservoir. The pressure gage on the discharge pipe (2 m above the reservoir face) reads 170 kPa. The average speed in the discharge pipe is 3 m/s. If the pump efficiency is 75 percent, determine the power required to drive it. Effects of pressure, motion and gravity in the reservoir (point 1), as well as Shear and other work in the entire system are considered negligible. $\underset{¿}{\rho_{water}} = ¿$ 999 $\frac{kg}{m^3}$ and g = 9.81 m/s^2)



Problem 3 (20 marks)

A reducer in a piping system is shown. The internal volume of the reducer is 0.2m^3 and its mass is 25kg. Evaluate the total force that must be provided by the surrounding pipes to support the reducer. The fluid flowing through the reducer is gasoline with specific gravity of 0.72. ρ_{water} =¿ ¿ 1000 $\frac{kg}{m^3}$ and g = 9.81 m/s^2, P_{atm} = 101 kPa)



Useful Equations

Definition of specific gravity:	$SG = \dfrac{\rho}{\rho_{H_2O}}$	**(2.3)**	Page 23
Definition of specific weight:	$\gamma = \dfrac{mg}{\forall} \rightarrow \gamma = \rho g$	**(2.4)**	Page 23
Definition of streamlines (2D):	$\left.\dfrac{dy}{dx}\right)_{\text{streamline}} = \dfrac{v(x, y)}{u(x, y)}$	**(2.8)**	Page 27
Definition of pathlines (2D):	$\left.\dfrac{dx}{dt}\right)_{\text{particle}} = u(x, y, t) \quad \left.\dfrac{dy}{dt}\right)_{\text{particle}} = v(x, y, t)$	**(2.9)**	Page 27
Definition of streaklines (2D):	$x_{\text{streakline}}(t_0) = x(t, x_0, y_0, t_0) \quad y_{\text{streakline}}(t_0) = y(t, x_0, y_0, t_0)$	**(2.10)**	Page 27
Newton's law of viscosity (1D flow):	$\tau_{yx} = \mu \dfrac{du}{dy}$	**(2.15)**	Page 33
Shear stress for a non-Newtonian fluid (1D flow):	$\tau_{yx} = k \left\lvert \dfrac{du}{dy} \right\rvert^{n-1} \dfrac{du}{dy} = \eta \dfrac{du}{dy}$	**(2.17)**	Page 35

Hydrostatic pressure variation:	$\dfrac{dp}{dz} = -\rho g \equiv -\gamma$	**(3.6)**	Page 59
Hydrostatic pressure variation (incompressible fluid):	$p - p_0 = \Delta p = \rho g h$	**(3.7)**	Page 61
Hydrostatic pressure variation (several incompressible fluids):	$\Delta p = g \sum_i \rho_i h_i$	**(3.8)**	Page 65
Hydrostatic force on submerged plane (integral form):	$F_R = \int_A p\, dA$	**(3.10a)**	Page 70
Hydrostatic force on submerged plane:	$F_R = p_c A$	**(3.10b)**	Page 70
Horizontal and vertical hydrostatic forces on curved submerged surface:	$F_H = p_c A$ and $F_V = \rho g \forall$	**(3.15)**	Page 77
Buoyancy force on submerged object:	$F_{\text{buoyancy}} = \rho g \forall$	**(3.16)**	Page 80

Continuity (mass conservation), incompressible fluid:	$\int_{\mathrm{CS}} \vec{V} \cdot d\vec{A} = 0$	(4.13a)	Page 90
Continuity (mass conservation), incompressible fluid, uniform flow:	$\sum_{\mathrm{CS}} \vec{V} \cdot \vec{A} = 0$	(4.13b)	Page 90
Continuity (mass conservation), steady flow:	$\int_{\mathrm{CS}} \rho \vec{V} \cdot d\vec{A} = 0$	(4.15a)	Page 90
Continuity (mass conservation), steady flow, uniform flow:	$\sum_{\mathrm{CS}} \rho \vec{V} \cdot \vec{A} = 0$	(4.15b)	Page 90
Momentum (Newton's second law):	$\vec{F} = \vec{F}_S + \vec{F}_B = \frac{\partial}{\partial t}\int_{\mathrm{CV}} \vec{V}\,\rho\, d\forall + \int_{\mathrm{CS}} \vec{V}\,\rho \vec{V} \cdot d\vec{A}$	(4.17a)	Page 95
Momentum (Newton's second law), uniform flow:	$\vec{F} = \vec{F}_S + \vec{F}_B = \frac{\partial}{\partial t}\int_{\mathrm{CV}} \vec{V}\,\rho\, d\forall + \sum_{\mathrm{CS}} \vec{V} \rho \vec{V} \cdot \vec{A}$	(4.17b)	Page 95
Momentum (Newton's second law), scalar components:	$F_x = F_{S_x} + F_{B_x} = \frac{\partial}{\partial t}\int_{\mathrm{CV}} u\,\rho\, d\forall + \int_{\mathrm{CS}} u\,\rho \vec{V} \cdot d\vec{A}$ $F_y = F_{S_y} + F_{B_y} = \frac{\partial}{\partial t}\int_{\mathrm{CV}} \upsilon\,\rho\, d\forall + \int_{\mathrm{CS}} \upsilon\,\rho \vec{V} \cdot d\vec{A}$ $F_z = F_{S_z} + F_{B_z} = \frac{\partial}{\partial t}\int_{\mathrm{CV}} w\,\rho\, d\forall + \int_{\mathrm{CS}} w\,\rho \vec{V} \cdot d\vec{A}$	(4.18a) (4.18b) (4.18c)	Page 96
Momentum (Newton's second law), uniform flow, scalar components:	$F_x = F_{S_x} + F_{B_x} = \frac{\partial}{\partial t}\int_{\mathrm{CV}} u\,\rho\, d\forall + \sum_{\mathrm{CS}} u\,\rho \vec{V} \cdot \vec{A}$ $F_y = F_{S_y} + F_{B_y} = \frac{\partial}{\partial t}\int_{\mathrm{CV}} \upsilon\rho\, d\forall + \sum_{\mathrm{CS}} \upsilon\,\rho \vec{V} \cdot \vec{A}$ $F_z = F_{S_z} + F_{B_z} = \frac{\partial}{\partial t}\int_{\mathrm{CV}} w\,\rho\, d\forall + \sum_{\mathrm{CS}} w\,\rho \vec{V} \cdot \vec{A}$	(4.18d) (4.18e) (4.18f)	Page 96
Bernoulli equation (steady, incompressible, frictionless, flow along a streamline):	$\frac{p}{\rho} + \frac{V^2}{2} + gz = \text{constant}$	(4.24)	Page 107
Momentum (Newton's second law), inertial control volume (stationary or constant speed):	$\vec{F} = \vec{F}_S + \vec{F}_B = \frac{\partial}{\partial t}\int_{\mathrm{CV}} \vec{V}_{xyz}\,\rho\, d\forall + \int_{\mathrm{CS}} \vec{V}_{xyz}\,\rho\, \vec{V}_{xyz} \cdot d\vec{A}$	(4.26)	Page 109
Momentum (Newton's second law), rectilinear acceleration of control volume:	$\vec{F_S} + \vec{F_B} - \int_{\mathrm{CV}} \vec{a}_{rf}\,\rho\, d\forall = \frac{\partial}{\partial t}\int_{\mathrm{CV}} \vec{V}_{xyz}\,\rho\, d\forall \int_{\mathrm{CS}} \vec{V}_{xyz}\,\rho \vec{V}_{xyz} \cdot d\vec{A}$	(4.33)	Page 112
Angular-momentum principle:	$\vec{r} \times \vec{F}_s + \int_{\mathrm{CV}} \vec{r} \times \vec{g}\,\rho\, d\forall + \vec{T}_{\mathrm{shaft}} = \frac{\partial}{\partial t}\int_{\mathrm{CV}} \vec{r} \times \vec{V}\,\rho\, d\forall + \int_{\mathrm{CS}} \vec{r} \times \vec{V}\,\rho \vec{V} \cdot d\vec{A}$	(4.46)	Page 118
First law of thermodynamics:	$\dot{Q} - \dot{W}_s - \dot{W}_{\mathrm{shear}} - \dot{W}_{\mathrm{other}}$ $= \frac{\partial}{\partial t}\int_{\mathrm{CV}} e\,\rho\, d\forall + \int_{\mathrm{CS}} \left(u + p\upsilon + \frac{V^2}{2} + gz\right) \rho \vec{V} \cdot d\vec{A}$	(4.56)	Page 124
Second law of thermodynamics:	$\frac{\partial}{\partial t}\int_{\mathrm{CV}} s\,\rho\, d\forall + \int_{\mathrm{CS}} s\,\rho \vec{V} \cdot d\vec{A} \geq \int_{\mathrm{CS}} \frac{1}{T}(\dot{Q}A)dA$	(4.58)	Page 127

Conversion Factors

Mass and Density

1 kg = 2.2046 lb
1 g/cm^3 = 10^3 kg/m^3
1 g/cm^3 = 62.428 lb/ft^3
1 lb = 0.4536 kg
1 lb/ft^3 = 0.016018 g/cm^3
1 lb/ft^3 = 16.018 kg/m^3

Length

1 cm = 0.3937 in.
1 m = 3.2808 ft
1 in. = 2.54 cm
1 ft = 0.3048 m

Velocity

1 km/h = 0.62137 mile/h
1 mile/h = 1.6093 km/h

Volume

1 cm^3 = 0.061024 in.^{3}
1 m^3 = 35.315 ft^3
1 L = 10^{-3} m^3
1 L = 0.0353 ft^3
1 in.^{3} = 16.387 cm^3
1 ft^3 = 0.028317 m^3
1 gal = 0.13368 ft^3
1 gal = 3.7854×10^{-3} m^3

Force

1 N = 1 kg · m/s^2
1 N = 0.22481 lbf
1 lbf = 32.174 lb · ft/s^2
1 lbf = 4.4482 N

Pressure

1 Pa = 1 N/m^2
= 1.4504×10^{-4} lbf/in.^{2}
1 bar = 10^5 N/m^2
1 atm = 1.01325 bar
1 lbf/in.^{2} = 6894.8 Pa
1 lbf/in.^{2} = 144 lbf/ft^2
1 atm = 14.696 lbf/in.^{2}

Energy and Specific Energy

1 J = 1 N · m = 0.73756 ft · lbf
1 kJ = 737.56 ft · lbf
1 kJ = 0.9478 Btu
1 kJ/kg = 0.42992 Btu/lb
1 ft · lbf = 1.35582 J
1 Btu = 778.17 ft · lbf
1 Btu = 1.0551 kJ
1 Btu/lb = 2.326 kJ/kg
1 kcal = 4.1868 kJ

Energy Transfer Rate

1 W = 1 J/s = 3.413 Btu/h
1 kW = 1.341 hp
1 Btu/h = 0.293 W
1 hp = 2545 Btu/h
1 hp = 550 ft · lbf/s
1 hp = 0.7457 kW

Specific Heat

1 kJ/kg · K = 0.238846 Btu/lb · °R
1 kcal/kg · K = 1 Btu/lb · °R
1 Btu/h · °R = 4.1868 kJ/kg · K

Others

1 ton of refrigeration = 200 Btu/min = 211 kJ/min
1 volt = 1 watt per ampere

Constants

Universal Gas Constant

$$\overline{R} = \begin{cases} 8.314 \text{ kJ/kmol} \cdot \text{K} \\ 1545 \text{ ft} \cdot \text{lbf/lbmol} \cdot {}^\circ\text{R} \\ 1.986 \text{ Btu/lbmol} \cdot {}^\circ\text{R} \end{cases}$$

Standard Acceleration of Gravity

$$g = \begin{cases} 9.80665 \text{ m/s}^2 \\ 32.174 \text{ ft/s}^2 \end{cases}$$

Standard Atmospheric Pressure

$$1 \text{ atm} = \begin{cases} 1.01325 \text{ bar} \\ 14.696 \text{ lbf/in.}^2 \\ 760 \text{ mm Hg} = 29.92 \text{ in. Hg} \end{cases}$$

Temperature Relations

$T(°\text{R}) = 1.8\,T(\text{K})$
$T(°\text{C}) = T(\text{K}) - 273.15$
$T(°\text{F}) = T(°\text{R}) - 459.67$