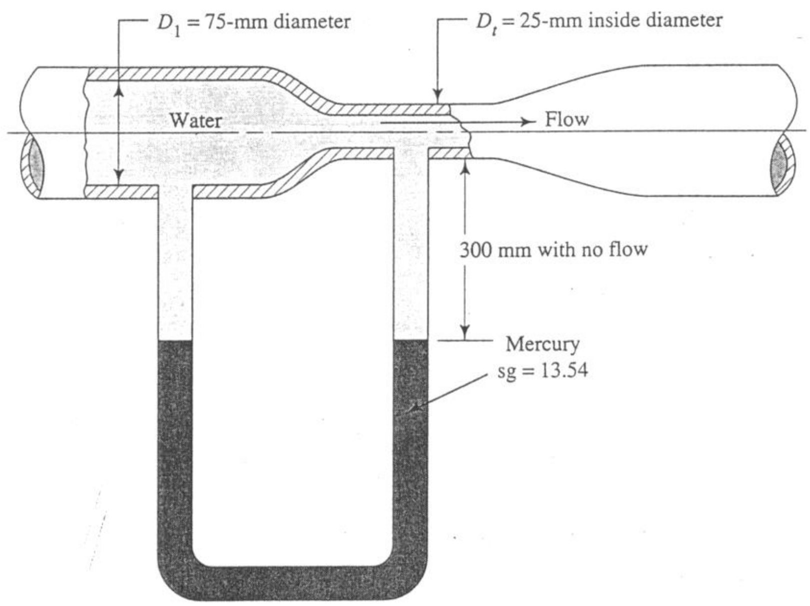
Fluid Mechanics
University of Massachusetts, Lowell – Department of Chemical Engineering
CHEN.3030 – Spring 2017

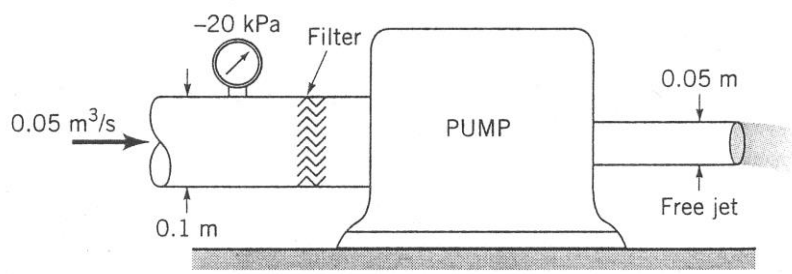
Name:______________________ Student ID: ____________________________

Exam 2; Time: 5:00PM – 7:00PM; Location: Ball Hall 214; Exam type: Open book (Only text book is allowed) without any additional writing or attachment. (Do all five (5) problems, with each problem having equal weight.)

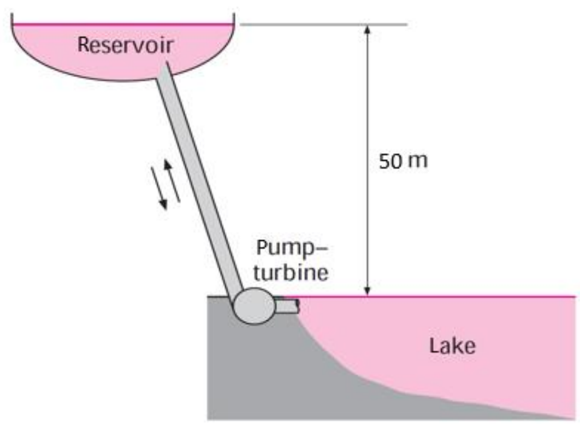
Q1. The Venturi meter shown has a U-tube manometer to measure the velocity of flow. When no flow occurs, the mercury column is balanced and its top is 300 mm below the throat. Compute the volume flow rate (m^3/s) that will cause the Hg to rise to the throat level.



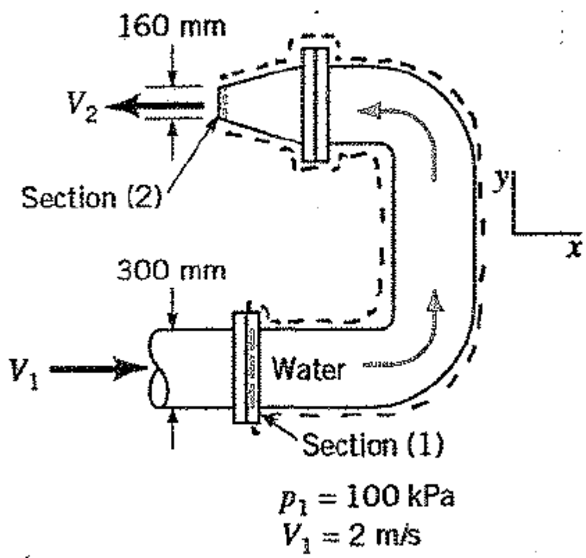
Q2. The pump shown in the diagram adds 20 kW of power to the flowing water. The only major loss in the system is that which occurs across the filter at the inlet of the pump. With the data given, determine the head loss for this filter.



Q3. The demand for electric power is usually much higher during the day than it is at night, and utility companies often sell power at night at much lower prices to encourage consumers to use the available power generation capacity and to avoid building new expensive power plants that will be used only a short time during peak periods. Utilities are also willing to purchase power produced during the day from private parties at a high price. Suppose a utility company is selling electric power for \$0.03/kWh at night and is willing to pay \$0.08/kWh for power produced during the day. To take advantage of this opportunity, an entrepreneur is considering building a large reservoir 50m above the tank level, pumping water from the lake to the reservoir at night using cheap power, and letting the water flow from the reservoir back to the lake during the day, producing power as the pump–motor operates as a turbine– generator during reverse flow. Preliminary analysis shows that a water flow rate of $2 m^3/s$ can be used in either direction, and the irreversible head loss of the piping system is 4m. The combined pump–motor and turbine–generator efficiencies are expected to be 75 percent each. Assuming the system operates for 10 hr each in the pump and turbine modes during a typical day, determine the potential revenue this pump–turbine system can generate per year.



Q4. Determine the magnitude and direction of the anchoring force needed to hold the horizontal elbow and nozzle combination shown in Figure. Atmospheric pressure is 100kPa. The gage pressure at section 1) is 100kPa. At section (2), the water exits to the atmosphere.

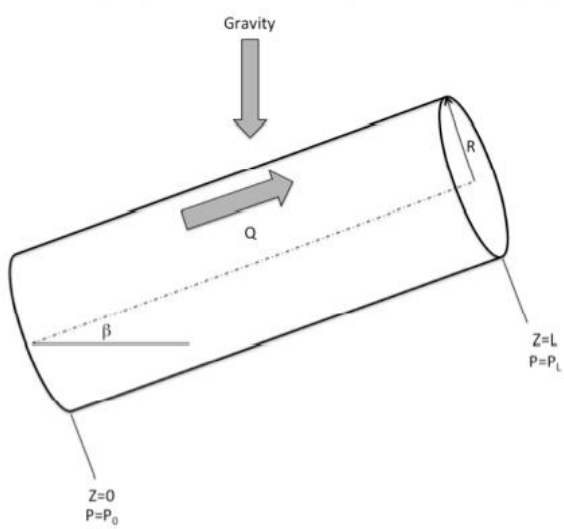


Q5. The engine oil in the pipe shown is driven by the pressure drop established by a pump in the piping system with flow from lower left to upper right. However, when the pump is stopped, the flow is in the opposite direction. The pipe is positively inclined (30^{O}). The engine oil temperature is T=60 °C. The circular pipe has a radius of 5 cm and the pipe length is 200 cm. The viscosity and density of the oil at $T = 60^{o}$C are 72.5×10^{-3}kg/(m·s) and 864 kg/m^3, respectively.

a) If the pump establishes a $\Delta p = p_0 - p_L$, set up the force balance equation and formally derive and solve the differential equations for shear stress and velocity profiles assuming laminar flow conditions (be sure to specify the proper boundary conditions as part of your derivation). Also formally derive expressions for the average axial velocity and volumetric flowrate.

b) If $\Delta p = p_0 - p_L = 70\ kPa$, compute numerical values for the average axial velocity and volumetric flowrate for this case.

c) After the pump is stopped, the flow is downward from the upper right to lower left. Assuming fully developed steady flow, calculate numerical values for the average axial velocity and volumetric flowrate for this flow situation.



DIMENSION	METRIC	METRIC/ENGLISH
Viscosity, kinematic	$1\ m^2/s = 10^4\ cm^2/s$ $1\ stoke = 1\ cm^2/s = 10^{-4}\ m^2/s$	$1\ m^2/s = 10.764\ ft^2/s = 3.875 \times 10^4\ ft^2/h$ $1\ m^2/s = 10.764\ ft^2/s$
Volume	$1\ m^3 = 1000\ L = 10^6\ cm^3$ (cc)	$1\ m^3 = 6.1024 \times 10^4\ in^3 = 35.315\ ft^3$ $= 264.17$ gal (U.S.) 1 U.S. gallon = $231\ in^3 = 3.7854$ L 1 fl ounce = $29.5735\ cm^3 = 0.0295735$ L 1 U.S. gallon = 128 fl ounces
Volume flow rate	$1\ m^3/s = 60{,}000\ L/min = 10^6\ cm^3/s$	$1\ m^3/s = 15{,}850\ gal/min = 35.315\ ft^3/s$ $= 2118.9\ ft^3/min$ (CFM)

*Exact conversion factor between metric and English units.

Some Physical Constants

PHYSICAL CONSTANT	METRIC	ENGLISH
Standard acceleration of gravity	$g = 9.80665\ m/s^2$	$g = 32.174\ ft/s^2$
Standard atmospheric pressure	$P_{atm} = 1$ atm $= 101.325$ kPa $= 1.01325$ bar $= 760$ mm Hg (0°C) $= 10.3323$ m H_2O (4°C)	$P_{atm} = 1$ atm $= 14.696$ psia $= 2116.2\ lbf/ft^2$ $= 29.9213$ inches Hg (32°F) $= 406.78$ inches H_2O (39.2°F)
Universal gas constant	$R_u = 8.31447\ kJ/kmol \cdot K$ $= 8.31447\ kN \cdot m/kmol \cdot K$	$R_u = 1.9859\ Btu/lbmol \cdot R$ $= 1545.37\ ft \cdot lbf/lbmol \cdot R$

Commonly Used Properties

PROPERTY	METRIC	ENGLISH
Air at 20°C (68°F) and 1 atm		
Specific gas constant*	$R_{air} = 0.2870\ kJ/kg \cdot K$ $= 287.0\ m^2/s^2 \cdot K$	$R_{air} = 0.06855\ Btu/lbm \cdot R$ $= 53.34\ ft \cdot lbf/lbm \cdot R$ $= 1716\ ft^2/s^2 \cdot R$
Specific heat ratio	$k = c_p/c_v = 1.40$	$k = c_p/c_v = 1.40$
Specific heats	$c_p = 1.007\ kJ/kg \cdot K$ $= 1007\ m^2/s^2 \cdot K$ $c_v = 0.7200\ kJ/kg \cdot K$ $= 720.0\ m^2/s^2 \cdot K$	$c_p = 0.2404\ Btu/lbm \cdot R$ $= 187.1\ ft \cdot lbf/lbm \cdot R$ $= 6019\ ft^2/s^2 \cdot R$ $c_v = 0.1719\ Btu/lbm \cdot R$ $= 133.8\ ft \cdot lbf/lbm \cdot R$ $= 4304\ ft^2/s^2 \cdot R$
Speed of sound	$c = 343.2\ m/s = 1236\ km/h$	$c = 1126\ ft/s = 767.7\ mi/h$
Density	$\rho = 1.204\ kg/m^3$	$\rho = 0.07518\ lbm/ft^3$
Viscosity	$\mu = 1.825 \times 10^{-5}\ kg/m \cdot s$	$\mu = 1.227 \times 10^{-5}\ lbm/ft \cdot s$
Kinematic viscosity	$\nu = 1.516 \times 10^{-5}\ m^2/s$	$\nu = 1.632 \times 10^{-4}\ ft^2/s$
Liquid water at 20°C (68°F) and 1 atm		
Specific heat ($c = c_p = c_v$)	$c = 4.182\ kJ/kg \cdot K$ $= 4182\ m^2/s^2 \cdot K$	$c = 0.9989\ Btu/lbm \cdot R$ $= 777.3\ ft \cdot lbf/lbm \cdot R$ $= 25{,}009\ ft^2/s^2 \cdot R$
Density	$\rho = 998.0\ kg/m^3$	$\rho = 62.30\ lbm/ft^3$
Viscosity	$\mu = 1.002 \times 10^{-3}\ kg/m \cdot s$	$\mu = 6.733 \times 10^{-4}\ lbm/ft \cdot s$
Kinematic viscosity	$\nu = 1.004 \times 10^{-6}\ m^2/s$	$\nu = 1.081 \times 10^{-5}\ ft^2/s$

* Independent of pressure or temperature

Conversion Factors

DIMENSION	METRIC	METRIC/ENGLISH
Acceleration	1 m/s^2 = 100 cm/s^2	1 m/s^2 = 3.2808 ft/s^2 1 ft/s^2 = 0.3048* m/s^2
Area	1 m^2 = 10^4 cm^2 = 10^6 mm^2 = 10^{-6} km^2	1 m^2 = 1550 in^2 = 10.764 ft^2 1 ft^2 = 144 in^2 = 0.09290304* m^2
Density	1 g/cm^3 = 1 kg/L = 1000 kg/m^3	1 g/cm^3 = 62.428 lbm/ft^3 = 0.036127 lbm/in^3 1 lbm/in^3 = 1728 lbm/ft^3 1 kg/m^3 = 0.062428 lbm/ft^3
Energy, heat, work, and specific energy	1 kJ = 1000 J = 1000 N · m = 1 kPa · m^3 1 kJ/kg = 1000 m^2/s^2 1 kWh = 3600 kJ	1 kJ = 0.94782 Btu 1 Btu = 1.055056 kJ = 5.40395 psia · ft^3 = 778.169 lbf · ft 1 Btu/lbm = 25,037 ft^2/s^2 = 2.326* kJ/kg 1 kWh = 3412.14 Btu
Force	1 N = 1 kg · m/s^2 = 10^5 dyne 1 kgf = 9.80665 N	1 N = 0.22481 lbf 1 lbf = 32.174 lbm · ft/s^2 = 4.44822 N 1 lbf = 1 slug · ft/s^2
Length	1 m = 100 cm = 1000 mm = 10^6 μm 1 km = 1000 m	1 m = 39.370 in = 3.2808 ft = 1.0926 yd 1 ft = 12 in = 0.3048* m 1 mile = 5280 ft = 1.6093 km 1 in = 2.54* cm
Mass	1 kg = 1000 g 1 metric ton = 1000 kg	1 kg = 2.2046226 lbm 1 lbm = 0.45359237* kg 1 ounce = 28.3495 g 1 slug = 32.174 lbm = 14.5939 kg 1 short ton = 2000 lbm = 907.1847 kg
Power	1 W = 1 J/s 1 kW = 1000 W = 1 kJ/s 1 hp† = 745.7 W	1 kW = 3412.14 Btu/h = 1.341 hp = 737.56 lbf · ft/s 1 hp = 550 lbf · ft/s = 0.7068 Btu/s = 42.41 Btu/min = 2544.5 Btu/h = 0.74570 kW 1 Btu/h = 1.055056 kJ/h
Pressure or stress, and pressure expressed as a head	1 Pa = 1 N/m^2 1 kPa = 10^3 Pa = 10^{-3} MPa 1 atm = 101.325 kPa = 1.01325 bar = 760 mm Hg at 0°C = 1.03323 kgf/cm^2 1 mm Hg = 0.1333 kPa	1 Pa = 1.4504 × 10^{-4} psi = 0.020886 lbf/ft^2 1 psi = 144 lbf/ft^2 = 6.894757 kPa 1 atm = 14.696 psi = 29.92 inches Hg at 30°F 1 inch Hg = 13.60 inches H_2O = 3.387 kPa
Specific heat	1 kJ/kg · °C = 1 kJ/kg · K = 1 J/g · °C	1 Btu/lbm · °F = 4.1868 kJ/kg · °C 1 Btu/lbmol · R = 4.1868 kJ/kmol · K 1 kJ/kg · °C = 0.23885 Btu/lbm · °F = 0.23885 Btu/lbm · R
Specific volume	1 m^3/kg = 1000 L/kg = 1000 cm^3/g	1 m^3/kg = 16.02 ft^3/lbm 1 ft^3/lbm = 0.062428 m^3/kg
Temperature	T(K) = T(°C) + 273.15 ΔT(K) = ΔT(°C)	T(R) = T(°F) + 459.67 = 1.8 T(K) T(°F) = 1.8 T(°C) + 32 ΔT(°F) = ΔT(R) = 1.8* ΔT(K)
Velocity	1 m/s = 3.60 km/h	1 m/s = 3.2808 ft/s = 2.237 mi/h 1 mi/h = 1.46667 ft/s 1 mi/h = 1.6093 km/h
Viscosity, dynamic	1 kg/m · s = 1 N · s/m^2 = 1 Pa · s = 10 poise	1 kg/m · s = 2419.1 lbm/ft · h = 0.020886 lbf · s/ft^2 = 0.67197 lbm/ft · s

Q4.

The control volume shown in the sketch above is used. Application of the y direction component of the linear momentum equation yields

$$R_y = \underline{\underline{0}}$$

Application of the x direction linear momentum equation leads to

$$-u_1 \rho u_1 A_1 - u_2 \rho u_2 A_2 = p_1 A_1 - R_x + p_2 A_2$$

From the conservation of mass equation

$$\dot{m} = \rho u_1 A_1 = \rho u_2 A_2$$

Thus

$$R_x = \rho u_1 A_1 \left(u_1 + u_2\right) + p_1 A_1 + p_2 A_2 = \rho u_1 \frac{\pi D_1^2}{4}\left(u_1 + \frac{D_1^2}{D_2^2} u_1\right) + p_1 \frac{\pi D_1^2}{4} + (0) A_2$$

or

$$R_x = \left(999 \frac{kg}{m^3}\right)\left(2 \frac{m}{s}\right)\frac{\pi}{4}\frac{(300\ mm)^2}{\left(1000 \frac{mm}{m}\right)^2}\left[\left(2 \frac{m}{s}\right) + \frac{(300\ mm)^2}{(160} \left(2 \frac{m}{s}\right)\right]$$

$$+ (100\ kPa)\frac{\pi}{4}\frac{(300\ mm)^2}{\left(1000 \frac{mm}{m}\right)^2}\left(1000 \frac{N}{m^2 \cdot kPa}\right)$$

and

$$R_x = \underline{\underline{8340\ N}}$$