Module 9:
Basics of Pumps and Hydraulics
Instructor Guide

Activities for Unit 1 – Basic Hydraulics

Activity 1.1: Convert 45 psi to feet of head.

Ans: 45 psis x $\frac{1 \text{ ft.}}{0.433 \text{ psi}}$ = **103.8 ft**

Activity 1.2: Determine pressure (in psi) on the wall of a sedimentation basin 2 ft., 5 ft., and 10 feet below the water surface.

Ans: 2 ft. x 0.433 psi/ft. of head = **0.866 psi**

5 ft. x 0.433 psi/ft. of head = **2.165 psi**

10 ft. x 0.433 psi/ft. of head = **4.33 psi**

Activity 1.3: What is upward force on an empty tank caused by a groundwater depth of 8 feet above the tank bottom? The tank is 20 feet by 40 feet.

Ans: Head pushing up on bottom is 8 ft.

Pressure pushing up on bottom is 8 ft. x 0.433 psi/ft. = 3.464 psi (pounds per square inch)

Next, convert to pounds per square feet. Since there are 144 sq. in. in 1 sq. ft., pressure is 3.464 psi x 144 sq. in./sq. ft. = 499 lbs/sq. ft.

Total force is pressure x area

Area of basin bottom is 20 ft. x 40 ft. = 800 sq. ft.

Total force = 499 lbs./sq. ft. x 800 sq. ft. = **399,200 lbs**

Example 1.2: Determine factor to convert cfs to gpm.

Ans: There are 7.48 gallons in one cu. ft.
There are 60 seconds in one minute.
Therefore,

$$\frac{1 \text{ cu. ft.}}{\text{sec.}} \times \frac{7.48 \text{ gal.}}{\text{cu. ft.}} \times \frac{60 \text{ sec.}}{\text{min.}} = \frac{449 \text{ gal.}}{\text{min.}} \text{ (gpm)}$$

Activity 1.4: Determine factor to convert MGD to gpm.

Ans: There are 60 min./hr. x 24 hr./day = 1,440 min./day
Therefore,

$$\frac{1{,}000{,}000 \text{ gal.}}{\text{day}} \times \frac{1 \text{ day}}{1{,}440 \text{ min.}} = \frac{694 \text{ gal.}}{\text{min.}} \text{ (gpm)}$$

Activity 1.5: Determine factor to convert MGD to cfs.

Ans: There are 60 sec./min. x 60 min./hr. x 24 hr. day = 86,400 sec./day
As previously stated, there are 7.48 gallons in 1 cu. ft.
Therefore,

$$\frac{1{,}000{,}000 \text{ gal.}}{\text{day}} \times \frac{1 \text{ day}}{86{,}400 \text{ sec.}} \times \frac{1 \text{ cu. ft.}}{7.48 \text{ gal.}} = \frac{1.547 \text{ cu. ft.}}{\text{sec.}} \text{ (cfs)}$$

Activity 1.6: A rectangular channel 3 ft. wide contains water 2 ft. deep flowing at a velocity of 1.5 fps. What is the flow rate in cfs?

Ans: First determine the Area (A).
Cross sectional area is 3 ft. x 2 ft. = 6 sq. ft.

Using the Continuity Equation (Q = V x A)
Q = 1.5 fps x 6 sq. ft. = 9.0 cfs

Activity 1.7: Flow in an 8-inch pipe is 500 gpm. What is the average velocity?

Ans: First determine the Area (A)

Area of an 8-inch pipe $= \dfrac{\pi \times 8^2}{4}$ sq. in. $\times \dfrac{1 \text{ sq. ft.}}{144 \text{ sq. in.}} = 0.349$ sq. ft.

Flow rate(Q) in cfs = 500 gpm $\times \dfrac{1 \text{ cfs}}{449 \text{ gpm}} = 1.11$ cfs

Re-arrange Continuity Equation to solve for velocity

Q = V x A >> V = Q/A

Therefore, V = 1.11 cfs ÷ 0.349 sq. ft. = 3.18 fps

☑ Examples and Activities for Unit 2 – OPEN CHANNEL (GRAVITY) FLOW

Example 2.1: Use figure 2.2 to calculate **Hydraulic radius.**

- Flow area = 2 ft. x 3 ft. = 6 sq. ft.
- Wetted perimeter = length of sides and bottom in contact with water. For this case:
  (2 x 2 ft.)[sides] + (1 x 3 ft.) [bottom] = 7 ft.
- Hydraulic Radius = 6 sq. ft. ÷ 7 ft. = 0.857 ft.

Example 2.2: Use figure 2.3 to calculate **slope.**

- Slope = 3.0 ft. ÷ 500 ft. = 0.006 ft./ft.

Activity 2.1: What is the flow rate in the channel described in Figures 2.2 and 2.3? Use the Manning Equation to determine V (flow velocity) and the Continuity Equation to determine flow rate.

Ans: 1. Using **Manning Equation:**

$$V = \frac{1.49}{0.014} \times 0.857^{(2/3)} \times 0.006^{(1/2)} = 7.44 \text{ fps}$$

2. Using **Continuity Equation:**

Q = V x A = 7.44 fps x 6 sq. ft. = **44.6 cfs**

Example 2.3: A 12-inch sewer, laid on a 2% (0.02 ft./ft) slope, is carrying 1,800 gpm. Determine the depth of flow, flow area, and flow velocity for this condition. Use Figure 2.4 to help find the variables for your calculations.

- Calculate full pipe flow using Manning Equation. (Note: Hydraulic radius for a full circular pipe = D/4, where D = pipe diameter in ft.)

$$V = \frac{1.49}{0.014} \times (1.0/4)^{(2/3)} \times 0.02^{(1/2)} = 5.973 \text{ fps}$$

- Convert to gpm

4.69 cfs x 449 gpm/cfs = **2,106 gpm**

- Determine ratio of flow to full pipe flow

1,800 gpm ÷ 2,106 gpm = **0.855**

Find 0.855 on horizontal axis of graph. Go straight up until you intersect curve labeled "Discharge."

Move from that point horizontally and read value off of left vertical axis (in this case 70%). This means the pipe is flowing at a depth of 70% of the pipe diameter.

- Calculate depth of flow:

y = 70% x D = 0.7 x 1.0 ft. = **0.7 ft.**

Starting at the depth ratio on the left axis (in this case 70%), move right until you intersect the line labeled "Area". Move straight down until you intersect the horizontal axis. Read value off of axis (0.75 in this case)

- Calculate flow area:

$$A = \pi \times \frac{1.0^2}{4} \text{ sq. ft.} \times 0.75 = \mathbf{0.589 \text{ sq. ft.}}$$

Starting at depth ratio on left axis (70%), move right until you intersect the curve labeled "Velocity". Move straight down until you intersect the horizontal axis. Read value off axis (1.12 in this case)

- Calculate flow velocity:

5.973 fps (full pipe velocity calculated above) x 1.12 = **6.69 fps**

Activity 2.2: What is the flow (gpm) in a sedimentation basin effluent trough, 20 feet long, with 90-degree V-notch weirs along both sides, if the V-notches are spaced 6-inches apart and the head over the weirs is 1.5 inches?

Ans: Calculate the number of V-notches in the trough:

n = (20 ft. ÷ 0.5 feet per notch) x 2 sides = **80 notches**
Convert head over weir from inches to feet:
1.5 inches ÷ 12 inches/ft. = **0.125 feet**

Calculate the flow using the V-notch weir equation:
$Q = 2.5 \times (0.125)^{(5/2)} \times 80$ notches = **1.105 cfs**

Convert from cfs to gpm:
1.105 cfs x 449 gpm/cfs = **496 gpm**

☑ Exercise for Unit 2 – Open Channel Gravity Flow

1. The two devices used most often to measure open channel flow rate are flumes and weirs .

2. In a steady state open channel flow situation which of the following factors stay the same from the upstream end of the channel to the downstream end of the channel:

   a. _____ shape of the channel
   b. _____ depth of flow
   c. _____ flow velocity
   d. __x__ all of the above

3. The __Manning__ formula is used to estimate friction losses in open channel steady state flows.

4. For most commonly used pipe materials the roughness coefficient (n) can be estimated to be:

   a. _____ zero
   b. _____ 0.010
   c. __x__ 0.014
   d. _____ 0.35

5. Slope is the difference in elevation between upstream and downstream ends of a channel divided by the horizontal length of the channel. Slope is expressed in units of __ft / ft__.

6. Each occurrence of minor losses will contribute approximately __0.2__ to __0.3__ feet of head losses in open channel flow.

7. Weirs should not be used with:

   a. _____ treated wastewater
   b. _____ clean spring water
   c. __x___ untreated waste water
   d. _____ all of the above

☑ Activity and Exercise for Unit 3 – Pressure Flow in Force Mains

Activity 3.1: What would the head and pressure at Point D be?

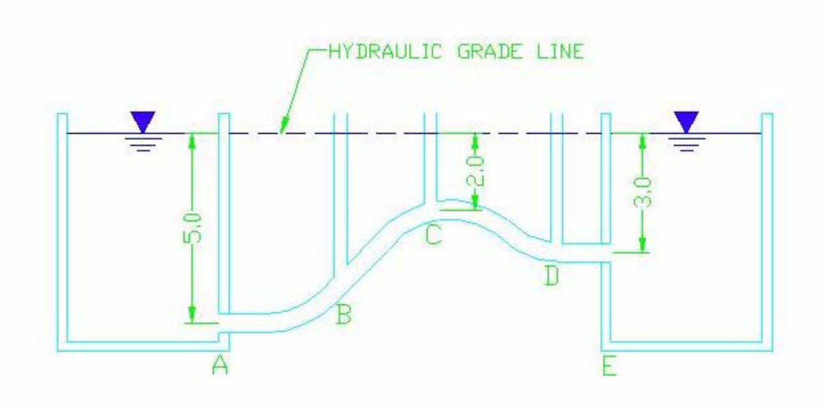

Figure 3.1 Hydraulic grade line

Ans: Head would be 3.0 feet. Pressure would be 3.0 x 0.433 = 1.3 psi

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☑ Exercise for Unit 3 – Pressure Flow in Force Mains

1. Explain the difference between pressure flow in force mains and flow in an open channel.

   Answers may vary somewhat, but in an open channel the top of the channel may be open to the atmosphere or it could be a partially filled pipe with the air above the water level is open to the atmosphere. In pressure flow in force mains, the pipes are completely filled with water and the water is not open to the atmosphere.

2. HGL is the abbreviation for Hydraulic Grade Line.
3. A friction loss in water flow is caused by turbulence along the walls of the pipes.

4. List three examples of things that will cause minor losses:
   a. See Figure 3.4
   b. See Figure 3.4
   c. See Figure 3.4

5. Which of the following devices would normally be expected to have the greatest minor loss?
   a. _____ Butterfly Valve 15 inch
   b. _____ 90 degree bend 12 inch
   c. __X__ Swing Check Valve
   d. _____ Gate Valve

6. The difference in elevation of the HGLs at the ends of a flow system is called Static Head.
7. Explain why a magnetic flow meter is less susceptible to clogging than a venturi meter.
   The magnetic flow meter has an open unobstructed design that will not trap debris or solids.

Activity 4.1: If a pump is operating at 2,200 gpm and 60 feet of head, what is the water horsepower? If the pump efficiency is 71%, what is the brake horsepower?

Ans: *Water Horsepower* $= \frac{2{,}200 \times 60}{3{,}960} = 33.3$ *HP*

Brake Horsepower $= \frac{33.3}{0.71} = 46.9$ *HP*

Activity 4.2: If operating at 60 ft of head, what are flow, efficiency, and brake horsepower?

Ans: Find 60 feet on the y-axis. Move right until you intersect the Head/Flow curve. From this point move straight down until you intersect the x-axis. Read the flow from the x-axis (520 gpm).

From 520 gpm on the x-axis, move straight up until you intersect the efficiency curve. From this point move to the left until you intersect the y-axis. Read the efficiency from the y-axis (73%).

From 520 gpm on the x-axis, move straight up until you intersect the Brake Horsepower curve. From this point move to the right until you intersect the vertical axis. Read the brake horsepower from the right vertical axis (10.8 HP).

Check the numbers read from the graph using the formula on page 4-3 of the participant workbook.

$$\text{Brake Horsepower} = \frac{520 \times 60}{3{,}960 \times 0.73} = 10.8 \text{ HP}$$

Ask the participants if they have done tests on pumps? How did the results compare with the head/capacity curve from the pump manufacturer?

Ans: The numbers often do not match up very well, especially with older pumps. If heads, flows, and/or efficiencies in the field tests are significantly lower than the manufacturer's curve, it indicates that the pump is in need of repair or replacement.

Example 4.1: What is pump efficiency for progressing cavity pump shown in Graphic 9.20 when operating at a flow of 70 gpm and a speed of 1200 rpm?

Equation for relationship between head, flow, efficiency, and horsepower is the same as for centrifugal pumps.

$$BHP = \frac{Q \times H}{3960 \times e}$$

Where: BHP = Brake horsepower
Q = Flow rate in gpm
H = Head in feet
e = Efficiency (expressed as a decimal)

Solving for efficiency:

$$e = \frac{Q \times H}{3960 \times BHP}$$

Reading from pump curve, at flow = 70 gpm, head = 139 feet, and BHP = 4.5.

Therefore:
$e = (70 \times 139)/(3960 \times 4.5) =$ 0.55 or 55%

Example 4.2: What is pump efficiency same pump when operating at a flow of 30 gpm and a speed of 600 rpm?

Reading from pump curve, at flow = 30 gpm, head = 139 feet, and BHP = 2.4

Therefore: e = (30 x 139)/(3960 x 2.4) = 0.44 or 44%

☑ Exercise for Unit 4 – Pump Types and Applications

1. A pump has an efficiency rating of 65%. How much horsepower is actually applied to the water if 100 HP is applied to the shaft of the pump?

   a. _____ 35 HP b. __X__ 65 HP c. _____ 165 HP d. _____ 15.38 HP

2. The impeller in a centrifugal pump can be either open or closed.

   a. __X__ True b. _____ False

3. The system head in a system will decrease as the system flow increases.

   a. _____ True b. __X__ False

4. _Positive_ displacement pumps are usually used to pump water with a very high solids concentration, such as waste sludge.

5. Suction pumps may create small cavities in the flow of water due to pockets of water vapor. The collapse of these cavities is called _cavitation_.