Wastewater Treatment Plant Operator Certification Training Instructor Guide

Module 9: Basics of Pumps and Hydraulics

This course includes content developed by the Pennsylvania Department of Environmental Protection (Pa. DEP) in cooperation with the following contractors, subcontractors, or grantees:

The Pennsylvania State Association of Township Supervisors (PSATS)
Gannett Fleming, Inc.
Dering Consulting Group
Penn State Harrisburg Environmental Training Center

A Note to the Instructor

Dear Instructor:

The primary purpose of *Module 9: Basics of Pumps and Hydraulics* is to provide an overview of pumps and hydraulics as they pertain to wastewater plant operation. This module has been designed to be completed in in approximately 3 hours, but the actual course length will depend upon content and/or delivery modifications and results of course dry runs performed by the Pa. DEP-approved sponsor. The number of contact hours of credit assigned to this course is based upon the contact hours approved under the Pa. DEP course approval process. To help you prepare a personal lesson plan, timeframes have been included in the instructor guide at the Unit level and at the Roman numeral level of the topical outline. You may need to adjust these timeframes as necessary to match course content and delivery modifications made by the sponsor. Please make sure that all teaching points are covered and that the course is delivered as approved by Pa. DEP.

Web site URLs and other references are subject to change, and it is the training sponsor's responsibility to keep such references up to date.

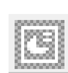
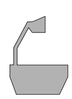
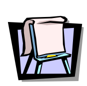
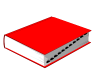
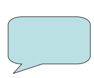
Delivery methods to be used for this course include:

- Lecture
- Small group and full group discussion
- Exercises
- Calculations

To present this module, you will need the following materials:

- One workbook per participant
- *Advance Waste Treatment,* Sacramento Foundation 1998.
- Extra pencils
- Markers
- Laptop (loaded with PowerPoint) and an LCD projector **or** Overheads of presentation and an overhead projector
- Screen
- Flip Chart

Icons to become familiar with include:

Participant Workbook		Instructor Guide	
	Exercise/Activity	Same icons for Participant Workbook apply to the Instructor Guide.	
	Case Study	Ans:	Answer to exercise, case study, discussion, question, etc.
	Discussion Question		PowerPoint Slide
	Calculation(s)		Overhead
	Quiz		Flip Chart
	Key Definition(s)		Suggested "Script"
	Key Point(s)		

Instructor text that is meant to be general instructions for the instructor are designated by being written in script font and enclosed in brackets. For example:

[*Ask participants if they have any questions on how to read the table. Answer any questions participants may have about how to read the table.*]

If your module includes the use of a PowerPoint presentation, below are some helpful controls that you may use within the Slide Show.

PowerPoint Slide Show Controls

You can use the following shortcuts while running your slide show in full-screen mode.

To	**Press**
Advance to the next slide	N, ENTER, or the SPACEBAR (or click the mouse)
Return to the previous slide	P or BACKSPACE
Go to slide <number>	<number>+ENTER
Display a black screen, or return to the slide show from a black screen	B
Display a white screen, or return to the slide show from a white screen	W
Stop or restart an automatic slide show	S
End a slide show	ESC
Return to the first slide	Both mouse buttons for 2 seconds
Change the pointer to a pen	CTRL+P
Change the pen to a pointer	CTRL+A
Hide the pointer and button temporarily	CTRL+H
Hide the pointer and button always	CTRL+L
Display the shortcut menu	SHIFT+F10 (or right-click)
Erase on-screen annotations	E
Go to next hidden slide	H
Set new timings while rehearsing	T
Use original timings while rehearsing	O
Use mouse-click to advance while rehearsing	M

MODULE: 9 - BASICS OF PUMPS AND HYDRAULICS : 180 minutes

Display Slide 1 - Module 9: Basics of Pumps and Hydraulics.

[Welcome participants to "Module 9 – Basics of Pumps and Hydraulics." Indicate the primary purpose of this course is to provide participants with an introduction to basic concepts of hydraulics, flow in open and closed channels, and pump types and applications.]

[Provide a brief overview of the module.]

This module contains three units. On page i, you will see the topical outline for Unit 1 – Basic Hydraulics and Unit 2 – Open Channel (Gravity) Flow. If you turn the page, you will see the topical outline for Unit 3 – Pressure Flow in Force Mains and Unit 4 – Pump Types and Applications.

[Continue to briefly review the outline.]

UNIT 1 – BASIC HYDRAULICS: 25 minutes

Display Slide 2 - Unit 1 – Basic Hydraulics

At the end of this unit, you should be able to:

- Define force, pressure, and head, and use these formulas to solve wastewater treatment plant problems.
- Convert head to pressure and pressure to head.
- Define velocity and flow rate, and use the continuity equation to solve wastewater treatment plant problems.

FORCE, PRESSURE AND HEAD: 15 minutes

Definitions and Units of Measure

We will begin this unit by covering definitions and units of force, pressure, and head. Force, pressure and head are the foundation of the study of hydraulics. Understanding hydraulics will help you understand how water moves through a treatment plant and can help you estimate how much water you should be able to move through your treatment plant.

[Review the definitions for force*,* pressure*, and* head *that appear in the participant workbook. Note for the participants that head is referred to as "ft. of head."]*

Display Slide 3 – One cubic foot of water (Figure 1.1 of participant workbook)

[Use Figure 1.1 to illustrate force, pressure, and head. Indicate the following:

- *Picture a box on a table. The box is 1 foot per side, filled with water. The one cubic foot of water in the box weighs 62.4 lbs. Therefore, the force on the table is equal to 62.4 lbs.*
- *Using this same box, with an area of 1 sq ft on the bottom, the pressure exerted on the table is 62.4 lbs per sq ft.*
- *Using the same box, the distance from the water surface at the top of the box to the table top is 1 foot. Therefore, the head on the table is 1 foot of water or 12-inches of water.*
- *If the box was 2 feet high, the water in the box would weigh 124.8 lbs. The pressure on the table would be 128.4 lbs per sq. ft. The head on the table would be 2 feet.]*

Now let's discuss conversion factors. There are many times that you may have a pressure gage reading available in pounds per square inch (abbreviated psi) and need to know what that is in feet of head. This next discussion will show how pressure and head are related so you can convert a measure of one to an equivalent measure of the other.

Conversion Factors

Re-display Slide 3 - One cubic foot of water (Figure 1.1 of participant workbook)

[Use Example 1.1 and Figure 1.1 to explain how to convert feet of head to psi.]

Record Example 1.1 on the flip chart as you take the class through the example.

[Stress that pressure at any given depth acts the same in ALL *directions—pressure will act on the walls of a vessel as well as the bottom]*

Display Slide 4 - Relationship of pressure and head (Figure 1.2 of participant workbook)

[Ask participants to take a minute to work in pairs [or in small groups] on Problem 1.1. State that once everyone is finished, they will discuss the answer and go over any questions the participants may have.]

Optional: Use flip chart to discuss answers, after class has worked through problems in pairs [or small groups].

Activity 1.1: Convert 45 psi to feet of head.

***[Ans**: 45 psi x* $\dfrac{1 \text{ ft.}}{0.433 \text{ psi}}$ *= 103.8 ft]*

Display Slide 5 - Head and pressure in an open basin (Figure 1.3 of participant workbook)

[Ask participants to get back into their pairs [or small groups] to work on Problem 1.2.]

Optional: Use flip chart to discuss answers, after class has worked through problems in pairs [or small groups].

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]***

Display Slide 6 - Ground water pressure on an empty tank (Figure 1.4 of participant workbook)

[Ask participants to get back into their pairs [or small groups] to work on Problem 1.3.]

Optional: Use flip chart to discuss answers, after class has worked through problems in pairs [or small groups}.

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.]

In the above problem, if the weight of the concrete in the empty basin is less than 399,200 lbs.,(i.e., the basin has been drained for cleaning), the groundwater pressure can lift the basin out of the ground! Anyone work on a plant or construction site where that has happened?

Wastewater treatment plants are usually next to rivers. If the river floods while a basin is empty for cleaning, it will float out of the ground like a boat, causing extensive damage. It is the operator's responsibility to know this can happen and be prepared to refill an empty basin if a flood is anticipated.

[Check to make sure participants who did not have the correct answers for any of the problems now understand how to determine force, pressure, and head and how to convert from one to another.]

Up to this point, our discussion has related to water at rest. The next section pertains to water that is moving.

VELOCITY AND FLOW RATE: <u>10 minutes</u>

Velocity

*[Review the definition of **velocity**.]*

Flow Rate and Continuity Equation

This section relates flow, velocity, and a cross sectional area of a channel. Understanding these principals will help you to determine how much water is moving through various parts of your treatment plant and how much water you should be able to move through your treatment plant.

Display Slide 7 - Flow and velocity in a channel (Figure 1.5 of participant workbook)

[Review the steps on page 1-6, that relate flow, velocity and a cross sectional area of a channel. Use Figure 1.5 to illustrate the process. Point out that the Continuity Equation lets you figure out flow rate, which is one of the most basic equations in hydraulics.]

Do you have any questions or comments so far?

Conversion Factors & Sample Problems

Example 1.2: Determine factor to convert cfs to gpm.

[Use flip chart to work through problem. Go through each step as a class.]

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

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

Now you will find four problems in which you will need to use the continuity equation. Find a partner and take a few minutes to work on the problems, at the end of which we will discuss the answers and any questions you may have.

[Optional: Break class into small groups of 3 to 4 participants to work out problems in workbook.]

[Optional: Use flip chart to discuss answers, after class has worked through the activities in pairs (orsmallgroups).]

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,

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

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,

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

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 $= \frac{\pi \times 8^2}{4}$ *sq. in. x* $\frac{1 \text{ sq. ft.}}{144 \text{ sq. in.}}$ *= 0.349 sq. ft.*

Flow rate(Q) in cfs = 500 gpm x $\frac{1 \text{ cfs}}{449 \text{ gpm}}$ *= 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]

This concludes Unit 1. Did anyone have any questions about the calculations?

[Answer questions that would benefit the whole group. If only one or two people experienced difficulty ask them to see you during the break. Try to make connections to the workbook by indicating where the material was covered.]

[Move on to Unit 2.]

[Have the participants review the key points on this page.]

[This page was intentionally left blank.]

UNIT 2 - OPEN CHANNEL (GRAVITY) FLOW: 55 minutes

Display Slide 8 – Unit 2 – Open Channel (Gravity) Flow

[Review the Learning Objectives.]

At the end of this unit, you should be able to:

- Define open channel steady state flow.
- Name the two sources of energy loss, and describe the methodologies used to estimate energy losses for these sources.
- Describe the two methods of measuring open channel flow rate.

OPEN CHANNEL (GRAVITY) FLOW: 5 minutes

Unit 1 describes water moving in general. In this unit we will talk about water moving in an open channel.

Open Channel (Gravity) Flow

[Review the definition for **open channel** *(gravity)* **flow** *in participant workbook.]*

Steady State Flow

This is the most commonly encountered type of open channel flow in wastewater systems.

[Review the explantion of steady state flow.]

There are factors that can cause energy loss. The next section, Energy Losses, apply to steady state flow.

ENERGY LOSSES: 25 minutes

Basic Principles

[Review Rule No. 1*. Use Figure 2.1 Gravity flow, to illustrate Basic Principles.]*

Display Slide 9 - Gravity flow (Figure 2.1 in participant workbook)

Figure 2.1 demonstrates that water will always flow from a higher elevation (higher potential energy) to a lower elevation.

[Review Potential energy*. Point out that the water level on the left side is higher than the water level on the right side, and has potential energy to move from point A to point B.]*

[Review Energy used*. Point out that in the Figure 2.1 example, the energy used is 3 ft of head.]*

When water moves from the higher elevation to the lower elevation it uses up the potential energy. That energy is basically lost. The higher the flow rate (the more water you're moving) the more energy you lose.

[Review Sources of energy loss*. Point out that there are friction losses and minor losses.]*

We know where energy losses come from, now we will discuss how to quantify them. This will allow you to estimate how much flow you should be able to get through various parts of your treatment plant. Knowing this can help you locate restrictions or obstructions to flow through the plant and identify what parts of the plant may limit the amount of flow you can process.

Friction Losses

The Manning Formula is the formula used to figure out velocity (which can be directly related to flow) while taking into account friction losses. It's important to us because we may need to make adjustments in our treatment of wastewater based on the rate of flow.

[Review Manning Formula*, which appears on page 2-3 in the workbook.]*

*[Point out key concept of **Roughness co-efficient.]***

Display Slide 10 – Hydraulic radius (Figure 2.2 of participant workbook)

*[Review definition of **Hydraulic radius**.]*

Figure 2.2 Hydraulic radius, demonstrates how the channel properties and water depth are used to calculate the Hydraulic radius.

Take participants through example 2.1.

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.

Display Slide 11 - Slope of channel and hydraulic grade line (Figure 2.3 of participant workbook)

*[Review definition of **Slope**.]*

Figure 2.3 demonstrates how to calculate slope.

Take participants through example 2.2.

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

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

Remember, in steady state flow, the slope of the channel bottom and the slope of the water surface are the same.

[Note: Activity 2.1 can be considered an optional activity which can be covered in the class depending on the interest level of the participants about this topic.]

Please turn to page 2-5 in your participant workbook. Problem 2.1 asks you to figure out the flow rate in the channel described in Figures 2.2 and in Figure 2.3, using the Manning Equation and the Continuity equation. Find a partner and take a few minutes to work out the problems, at the end of which we will discuss the answers and any questions you may have.

Optional: Use flip chart to discuss answers, after class has worked through problems in groups.

Optional 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:*

$$Q = V \times A = 7.44 \text{ fps} \times 6 \text{ sq. ft.} = 44.6 \text{ cfs}]$$

Estimating Pipe Capacity

The problems and examples up to this point have been for rectangular channels. Most conduits in a sanitary sewer system are round pipes. When the pipe is only flowing partly full, it is still open channel flow. The surface of the flowing water surface is still open to the atmosphere. Determining flow in a round channel is a little more involved.

You will need to calculate the area of a circular pipe for this section.
The area of a circle is:

$$A = \pi \times \frac{D^2}{4}$$

Where A (area) = Cross sectional area of pipe in sq. ft.
π (pi) = A constant approximately equal to 3.14
D (diameter) = Pipe diameter in ft.

Display Slide 12 - Hydraulic elements in terms of hydraulic for full section (Figure 2.4 of participant workbook)

[Review the Hydraulics elements graph (Figure 2.4) and its definition in participant workbook.]

The Manning Equation is fairly straight forward for a circular pipe flowing full. However, most gravity sewers are circular pipes that are flowing partly full. The Hydraulic Elements graph provides a way to relate what's going on in a partially full pipe (which can be very difficult to calculate) to what would be going on in the same pipe if it were flowing full (which is easier to calculate). Note that the y-axis of the graph is the ratio of the depth of water in the pipe to the diameter of the pipe – a measure of how full the pipe is flowing. The four lines on the graph relate all the "elements" of open channel flow, discharge (or flow), flow velocity, cross-sectional area of the flow, and hydraulic radius, to that depth ratio. The ratio of any one of the four elements to the same element for a full pipe is read off the x-axis. Example 2.3 shows how this is done.

[Participants are to use the Hydraulics elements graph on page 2-8 to plot the numbers as calculated through Example 2.3 below.]

Use flip chart to work out example.

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.

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

[Optional: You may want to prove that the hydraulic radius for a full circular pipe = D/4 is true for any size circular pipe.

Hydraulic Radius = Area/Wetted Perimeter.

For a circle, Area = $(\pi \times D^2)/4$

Wetted perimeter = the circumference of the circle = $\pi \times D$

Hydraulic Radius = $\dfrac{(\pi \times D^2)}{4} \div (\pi \times D)$

or $\dfrac{(\pi \times D^2)}{4} \times \dfrac{1}{(\pi \times D)}$

which leaves $\dfrac{D}{4}$

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

$$Q = V \times A = 5.973 \text{ fps} \times \pi \times \frac{1.0^2}{4} = 4.69]$$

Continued

- *[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:*

  $A = \pi \times \frac{1.0^2}{4}$ *sq. ft. x 0.75 = 0.589 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)

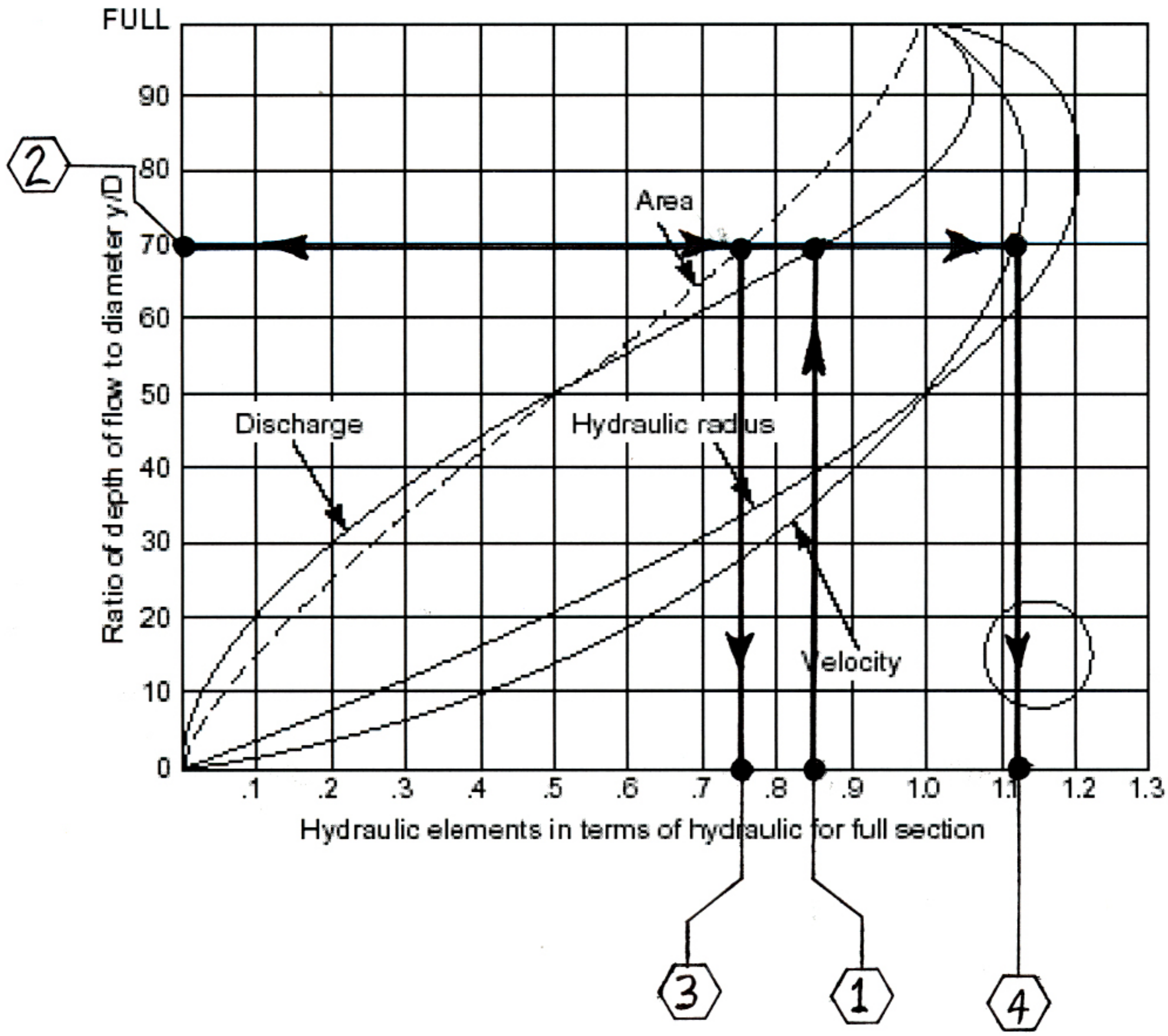
- *Calculate flow velocity:*

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

Ratio of depth of flow to diameter y/D Graph

[Display Slide 13 – Example 2.3 Hydraulics Elements Graph.

Indicate the participants' plotted points for Example 2.3 on the previous page should look like Slide 13.]



1 = Ratio of flow to full pipe flow

2 = Ratio of flow depth to diameter of pipe

3 = Ratio of flow area to full pipe area

4 = Ratio of flow velocity to full pipe flow velocity

Minor Losses

[Review sources of minor losses in participant workbook. Point out that minor losses are in addition to steady state losses. If you have two feet of head available from point A to point B but there's a manhole in between, you need to subtract 0.3 feet for the manhole loss. Only 1.7 feet of head would be available for the steady state losses in the pipe.]

OPEN CHANNEL FLOW MEASUREMENT: <u>20 minutes</u>

Up until now, we've been discussing flow and energy losses in an open channel. The following section describes two ways in which to measure flow in an open channel—Parshall Flume and Weir.

Parshall Flume

Display Slide 14 – Parshall Flume (Figure 2.5 of participant workbook). Note: can also refer to picture of Parshall Flume in Sacramento book 3.4, Vol 1, p. 41.

Figure 2.5 shows a plan and section view of a Parshall Flume and shows where the depth is measured to determine flow.

[Review description and advantages of Parshall Flume.]

Does anyone know where a Parshall Flume is normally used? Why?

[Ans: *To measure flow at the head end of a treatment plant. The Operator needs to know how much wastewater is coming into the plant, but since it is untreated at this point, it's loaded with solids]*

Weir

Display Slide 15 – Weir (Figure 2.6 of participant workbook)

Figure 2.6 Weir, shows how head (which is used to determine flow) is measured over a weir.

[Review Weir Advantages/Disadvantages]

[Review definition of ***straight weir****. Use Figure 2.6 to show where head over the weir is measured. Review formula used to calculate flow rate.]*

Use flip chart and the following Example.

The flow over a 5 foot long straight weir (in gpm) if the head above the wier is 9.5 inches can be determined by:

Step 1. Convert inches of head to feet:
= 9.5 in. x (1 ft./12in.)
= 0.792 feet.

Step 2. Use Weir formula to calculate flow rate in cfs:
$Q = 3.33 \times 5 \text{ ft} \times 0.792^{(3/2)}$
$Q = 11.7$ cfs

Step 3. Convert cfs to gpm (using the formula learned in Unit 1)
11.7 cfs x (449 gpm/1cfs)
= 5,250 gpm

Does anyone know where a straight weir might be used? Why?

[Ans: *To measure flow at the effluent end of a treatment plant. The Operator needs to know how much wastewater is being discharged to the receiving stream to meet permitting and reporting requirements. Since the effluent is treated and has very low solids, the "dead zone" upstream of the weir doesn't cause a problem.]*

Display Slide 16 – V-notch weir (Figure 2.7 of participant workbook)

Figure 2.7 shows a front elevation view of a V-notch weir and how the head over the weir is measured.

[Review V-notch weir. Use Figure 2.7 to demonstrate how to calculate flow rate.]

Does anyone know where a V-notch weir might be used? Why?

[Ans: *They're often used along the top edges of the effluent troughs in settling basins. They help spread the flow out over a larger area, which gives the wastewater more time to settle. They can handle a wide range of flow with fairly small changes in head over the weir. This helps keep the water level in the settling basins nearly constant.]*

Problem 2.2 asks you to determine flow (gpm) using the V-notch weir equation. Find a partner and take a few minutes to work out the problem, at the end of which we will discuss the answer and any questions you may have.

Optional: Use flip chart to discuss answers, after class has worked through problems in groups.

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]

[Have the participants review the Key Points on this page.]

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

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UNIT 3 – PRESSURE FLOW IN FORCE MAINS: 50 minutes

Display Slide 17 - Unit 3 – Pressure Flow in Force Mains

At the end of this unit, you should be able to:

- Define hydraulic grade line (HGL).
- Describe how static head and high points/siphons affect flow rate.
- Describe a system head curve.
- Describe how the Venturi Meter and Magnetic Flow Meter measures force main flow.

DEFINITIONS: 5 minutes

Unit 2 describes flow in an open channel. Unit 3 will discuss flow in a closed channel.

Pressure Flow in Force Mains

[Review the definition for **pressure flow in force mains** *in participant workbook.]*

Display Slide 18 – Hydraulic grade line (Figure 3.1 in participant workbook)

[Review definition of **hydraulic grade line**. *]*

[Discuss points in graph as pointed out in participant workbook.]

[Ask participants to review Activity 3.1. Ask for someone to volunteer answer. Use flip chart to record volunteer's answers.]

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

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

Any questions?

Water always "seeks its own level." When it's not moving, the HGL is flat. Let's look at what happens to the HGL when water starts moving.

ENERGY LOSSES: 25 minutes

Basic Principles of Energy Losses

[Review Rule No. 1.]

Display Slide 19 – Hydraulic grade line for flowing pipe (Figure 3.2 in participant workbook)

Figure 3.2 demonstrates gravity flow will always flow from a higher elevation (higher potential energy) to a lower elevation.

[Review Sources of Energy.]

Display Slide 20 – Hydraulic grade line for pump flow (Figure 3.3 in participant workbook)

[Use slide to illustrate static head and pumps as sources of energy.]

Figure 3.3 demonstrates how a pump adds energy to a system and also shows static head and head loss.

[Review Energy Used.]

[Review Sources of Energy Loss. Point out that like in open channel (gravity) flow, there are friction losses and minor losses in pressure flow.]

We know where energy losses come from, now we will discuss how to quantify them.

[Review the information on friction losses.]

Display Slide 21 – Minor Loss "K" factors (Figure 3.4 in participant workbook)

[Review Minor Loss K Factors table. Emphasize that the table is only a small representative sample. Indicate that K-factors for specific valves can be obtained from the valve manufacturer.]

Up until now, the discussion has been about head losses in pressurized pipe. There are other considerations you need to be aware of in closed conduit flow.

OTHER HYDRAULIC CONSIDERATIONS: 10 minutes

[Review key points of ***Static Head*** *and* ***HighPoints/Siphons****.]*

Display Slide 22 – Hydraulic grade line for a siphon (Figure 3.5 in participant workbook)

Figure 3.5 demonstrates a hydraulic grade line for a siphon. If you placed a pressure/vacuum gage at point “C,” you would read a negative 1.0 ft. of head or –0.433 psi. If anything would allow air into the pipe and “break” the vacuum, flow would stop.

[Review the additional points about siphons.]

System Head Curves

[Review definition of system head curves*.]*

Display Slide 23 – Static head, head loss and system head (Figure 3.6 in participant workbook)

[Work class through the system head example.]

The curve is generated by calculating head loss, using an engineering formula called the Hazen Williams equation, at a number of different flows. The head losses are added to the static head to obtain the system head. The system heads are then plotted on a graph with system head on the y-axis and flow on the x-axis.

Display Slide 24 – System head curve (Figure 3.7 in participant workbook)

[Review figure 3.7, and show how the point calculated above falls on the graph (if x axis is 750 gpm, y axis is 26.2 ft.). The system head curve is a "curve" as opposed to a straight line because of the exponent on the slope of the hydraulic grade line "S" in the Hazen Williams equation. The number on the curve tells you how much head you need to move a certain flow through the sysem (or how much flow you can get through the system at a certain head(. It is also used in combination with a pump curve (discussed in Unit 4) to estimate pumping rates.

Review application *of system head curve.*

Additional points to emphasize:

- *A system head curve is for <u>one</u> point in a system. The system head curve at different points will have different shapes.*
- *Changes in system conditions other than flow (i.e. a valve is partially closed or static head changes as a reservoir fills or empties) will change the system shape of the system head curve.]*

FORCE MAIN FLOW MEASUREMENT: <u>5 minutes</u>

Up until now, we've been discussing flow and energy losses in a pressurized pipe. This section discusses how you measure flow in a pressurized pipe using a venturi meter or a magnetic flow meter.

Venturi Meter

Display Slide 25 – Venturi meter (Figure 3.8 in participant workbook)

[Review definition of Venturi Meter *and use slide to illustrate inlet (first third of Figure 3.8); throat (middle third of Figure 3.8), and recovery cone (final third of Figure 3.8).*

Review applications*.]*

Magnetic Flow Meter

[Review definition of Magnetic Flow Meter*.*

Review applications*.]*

[Have the participants review the Key Points for Unit 3 – Pressure Flow in Force Mains.]

☑ 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.

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UNIT 4 – PUMP TYPES AND APPLICATIONS: <u>60 minutes</u>

Display Slide 26 – Unit 4 – Pump Types and Applications

[Review the learning objectives by saying:]

At the end of this unit, you should be able to:

- Define flow, head, horsepower, efficiency, and use them to calculate water horsepower and brake horsepower.
- Describe the basic components of pumps.
- Describe the common types of pumps used in wastewater treatment.
- Estimate the pumping rate from the pump curve.

PUMP BASICS: 20 minutes

We will now discuss pumps and their use in wastewater treatment.

Purpose of Pumps in Wastewater Treatment

Now that we have talked about flow, we will move on to discuss pumps. Pumps serve many purposes in wastewater collection systems and treatment plants, including controlling flow rate in the wastewater system. In addition, pumps supply the energy to "lift" wastewater from lower elevations to higher elevations. They may be used to move wastewater over a hill in a gravity collection system or from one basin to a higher basin in a treatment plant.

[Review the information provided in the participant workbook.]

Flow, Head, Horsepower, and Efficiency

[Review definitions for ***flow*** *and* ***head]***

Display Slide 27 – Pump head (Figure 4.1 in participant workbook)

Figure 4.1 represents the components of pump head. Static head is the difference in elevation between the reservoir on the inlet side and the reservoir on the discharge side of the pump. It represents the head that would be on the pump if no water were flowing (if the system is "static"). The head loss is the energy used by the water flowing through the pipe. The more flow there is, the more head loss there is (remember the Hazen Williams equation from Unit 3). The pump must be able to put enough energy into the system to overcome the static head and the head loss. That total is the "pump head."

[Review definitions of ***water horsepower***, ***brake horsepower***, *and* ***pump efficiency****.]*

Flow, head, water horsepower, brake horsepower, and pump efficiency are all mathematically interrelated. Now we'll discuss the formulas that define the relationships.

Relationships and Calculations

Display Slide 28 – Head and Flow to Water Horsepower

[Review head and flow to water horsepower.]

As you can see, the required horsepower will increase with increases in head or flow. The more water you have to move, the more power it takes. The more head you have to pump against, the more power it takes.

Display Slide 29 – Brake Horsepower to Water Horsepower

[Review brake horsepower to water horsepower.]

Not all the energy that goes into the pump goes to adding head to the water. Some is lost to friction and turbulence inside the pump casing. The motor driving the pump must supply more power than is added to the water. The ratio of the power that actually makes it to the water to the power supplied by the motor is the pump efficiency. The higher the efficiency number, the better, because it means less energy is wasted.

Display Slide 30 – Combination Formula

[Review combination formula, relating head and flow to brake horsepower.]

This formula is just a combination of the previous two relationships that lets you go straight from flow and head to brake horsepower.

[Ask participants to work on Activity 4.1 individually. Indicate they have 3 minutes.]

Work through answer using flip chart to record calculation process.

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]*

Any questions?

A pump, especially a centrifugal pump, will not always operate at the same flow and head. If you increase the head that the pump must work against, it will not deliver as much flow. If you decrease the head the pump must work against, it will deliver more flow. Pump efficiency will also vary with head and flow. Since brake horsepower is related to head, flow, and efficiency, it will also vary. If you plot a graph of head, efficiency, and brake horsepower over a range of flows for a particular pump, you get a Head/Capacity Curve, also called a Performance Curve.

Head/Capacity Curves

Display Slide 31 – Head capacity curve (Figure 4.2 in workbook)

[Review Figure 4.2, head capacity curve.

Go over example in the middle of page 4-4 of participant workbook.]

[Have the participants work through Activity 4.2 on their own or in small groups. Then work through the answer on the flip chart.]

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.

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

Head, flow, and horsepower can all be measured in the field. These measurements can be used to calculate pump efficiency.

[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.]*

Any questions?

The discussion to this point has covered the performance of centrifugal pumps. Since you will be operating and maintaining the pumps, it is important to be familiar with their components. We will now talk about the basic components that are common to all centrifugal pumps.

CENTRIFUGAL PUMPS: 20 minutes

Basic Components

[Instructor can refer class to, Advance Waste Treatment, Chapter 15: Maintenance pages 353 thru 359, "Let's Build a Pump" when going through this section.]

[Review list of basic components of centrifugal pumps, on page 4-5 of participant workbook.]

Any questions?

[Emphasize the items related to proper pump installation and operations are in Advance Waste Treatment, Chapter 15: Maintenance page 359, "Let's Build a Pump."]

The basic components outlined here are common to all centrifugal pumps. Now we'll look at three different types of pumps, two configurations of impellers, and review what they're used for.

Types and Application

*[Review **Split Case** pump section, on page 4-5 of participant workbook*

Split case pumps are generally used to pump relatively clear water. Large solids in the water can clog the impeller. Split case pumps are generally heavy duty pumps and are very durable. The fact that the flow enters both sides of the impeller and the shaft is supported by bearings at both ends helps balance all the forces on the pump components and helps reduce vibration and wear. The "split" case makes it simpler to tear down the pump for inspection or repair.

Inform participants that additional information can be found on pages 353 thru 359 in Advance Wastewater Treatment, Chapter 15: Maintenance, "Let's Build a Pump." The pump shown in "Let's Build A Pump" is a split case pump.]

Display Slide 32 – End suction pump (Figure 4.3 in participant workbook)

[Review End Suction pump section, on top of page 4-6 of participant workbook, referring to Figure 4.3.]

End suction pumps are available in either frame mounted, where the pump and motor are separate units mounted on a common base plate (like the split case pump), or, close coupled, where the pump and impeller are mounted directly on an extension of the motor shaft with no coupling. This arrangement of end suction pump is more compact than a split case pump. End suction pumps can also be used to pump water containing solids if you use the right type of impeller. [That will be covered in the discussion of open and closed impellers on page 4-8 of the participant workbook.]

*[Review **Vertical Turbine** pump section, on page 4-7of participant workbook.]*

A vertical turbine pump has the same basic configuration as the propeller pump shown in Figure 15.7 on page 365 of Sacramento Volume II. The main difference is that instead of the propeller, there is a pump casing or "bowl" with an impeller. The advantage of a vertical turbine pump is that the pump bowl can be submerged while the motor is kept above water. The line shaft can be lubricated by the water being pumped, or it can be enclosed in a separate housing and lubricated by a separate oil or water source. The line shaft in Figure 15.7 is the latter type. The enclosed line shaft must be used if there are a lot of solids in the water. Vertical pumps are often used for high head applications since they can be built with multiple bowls (called stages). Each additional bowl adds more head to the water.

Display Slide 33 – Closed and open impellers (Figure 4.4 in participant workbook)

*[Review **Open and Closed Impellers** section, on page 4-8 of participant workbook, referring to Figure 4.4.]*

Any questions?

Pump Curve Characteristics

[Review pump curve characteristics section, on page 4-9 of participant workbook.]

We learned what a pump curve is and what it means back on page 4-4 of the workbook. Knowing the general characteristics of curves for the pumps you are using can help troubleshoot pumping operations. If you have a situation where the flow rate varies over a wide range but the head required doesn't vary much, a pump with a "flat" curve is better. A pump with a "steep" curve may not be able to supply enough head at high flows and may need to be throttled excessively at low flows (which wastes energy). If you have a situation where flow is fairly constant but head varies widely, a pump with a "steep" curve is better. If you're having trouble controlling flow or if your pumps are running inefficiently, the curve may tell you that you have the wrong pump for the job.

Estimating Pumping Rate From Pump Curve

Display Slide 34 – Estimating pumping rate (Figure 4.5 in participant workbook)

[Review section on estimating pumping rate from pump curve, referring to Figure 4.5.

Note that changes in a systems static head will shift the system head curve up or down on the graph. That will change the point where the pump curve intersects the system head curve and where the pump will operate.]

Pumps Operating In Parallel

[Review section on pumps operating in parallel.]

Suction Lift and Cavitation

[Review section on ***suction lift*** *and* ***cavitation****.]*

A centrifugal pump uses the centrifugal force of a spinning impeller or "paddlewheel" to add energy to the water. Next we'll discuss another class of pumps where the moving part or parts of the pump physically displace a volume of water.

POSITIVE DISPLACEMENT PUMPS: 20 minutes

General Description

[Review section in participant workbook.]

Types

Reciprocating (plunger)

[Indicate that reciprocating (plunger) *is one type of positive displacement pump.*

Review reciprocating (plunger) section from participant workbook.]

Display Slide 35 – Reciprocating pump (Figure 4.6 in participant workbook)

[Review Figure 4.6.]

Plunger pumps are usually used for flow with a lot of solids, such as liquid sludge. Sludge would stick and clog on the spinning impeller of a centrifugal pump. The piston on the plunger pump applies as much force as needed (or at least as much as the motor can provide) to keep the sludge moving. They're often used on primary clarifier sludge or thickened sludge.

NOTE: Reciprocating pumps must NEVER be run against a closed discharge valve. The pump is trying to displace the volume in the chamber. If there is a closed valve on the discharge, the water has nowhere to go. Something will give. The motor may stall (and overheat), the connecting rod or piston may break, or the chamber may crack.

Display Slide 36 – Reciprocating pump components (Figure 4.7 in participant workbook)

[Review Figure 4.7.]

Some of the major components and their functions include:

- Suction check ball and valve seat: This ball lifts off its seat when the plunger draws upward to let water into the pump chamber. The ball drops back onto the seat to keep water from going back into the suction pipe when the plunger pushes down on the discharge stroke.

- Plunger: Pulls water into the pump chamber and then pushes it out the discharge as it moves up and down.

- Packing and stuffing box: Packing seals between the plunger and pump chamber to keep water from leaking out. The stuffing box holds the packing.

- Eccentric and connecting rod: The eccentric converts the rotary motion of the motor into a back and forth motion. The connecting rod transfers the back and forth motion to the plunger.

- Discharge check ball and valve seat: This ball drops onto its seat to prevent water from the discharge side from coming back into the pump chamber when the plunger draws upward. It lifts off its seat when the plunger pushes downward to let the water out of the pump chamber.

- Air chamber: Provides and air cushion to help even out the pulsing flow caused by the up and down motion of the plunger.

- Motor: Provides the power needed to drive the pump.

Progressing Cavity

[State that progressive cavity pump is another type of positive displacement pump.]

Display Slide 37 – Progressing cavity pump (Figure 4.8 in participant workbook)

[Describe function of major components.]

Some of the major components and their functions include:

- Rotor: Turns to move the “cavity” along the stator, which forces water (or sludge) to move from the inlet to the discharge.
- Stator: Provides the spiral groove that meshes with the stator to form the “cavity”
- Packing: Prevents water from leaking out around the pump shaft.
- Packing Gland: Holds the packing in place.
- A motor (not shown in the picture) would be attached to the pump shaft (right side of the picture) by a coupling to power the rotor.

Progressive cavity pumps are also good for pumping heavy sludge. They will move very viscous material with the consistency of syrup or even soft paste like thickened sludge. They are not as suitable for primary clarifier sludge, which may have a lot of grit which will wear the rotor and stator.

Display Slide 38 – Pumping principle for progressing cavity pump (Figure 4.9 in participant workbook)

[Indicate that Figure 4.9 shows how the cavities at the bottom of the stator get displaced to the cavity at the top of the stator as the rotor rotates through 180 degrees.]

NOTE: Progressing cavity pumps must NEVER be run dry or against a closed discharge valve. The reasons a progressing cavity pump should not be run against a closed valve are basically the same as for a reciprocating pump. A progressing cavity pump needs the pumped fluid for lubrication between the rotor (which is usually stainless steel) and stator (which is usually rubber). Running dry can ruin the stator in a matter of minutes.

Pneumatic Ejector

The last type of positive displacement pump we will discuss is a pneumatic ejector pump.

Display Slide 39 – Pneumatic ejector (Figure 4.10 in participant workbook)

[Review pneumatic ejector section in participant workbook. Incorporate the following:]

Some of the major components and their functions include:

- Receiver tank: Accepts the wastewater flow from the low level manhole.
- Inlet check valve: Serves the same function as the inlet check ball on the plunger pump. Opens to let water in when the receiver tank is empty. Closes when the receiver tank is discharging to keep water from going back into the low level manhole.
- Discharge check valve: Serves the same function as the discharge check ball on the plunger pump. Keeps water from the discharge pipe from coming back into the receiver tank while it's filling from the low level manhole. Opens to let water flow into the discharge pipe when the receiver tank is full and air pressure is applied.
- Inlet and discharge gate valves: Allows the receiver tank to be isolated for maintenance or repair.
- Air compressor: Supplies the air pressure used to force the water into the discharge pipe.
- Control air slide valves: Controls the flow and pressure of air going to the receiver tank.

Pneumatic ejectors are usually used on raw sewage. Because they're very simple and reliable, they're often used at remote lift stations.

Any questions?

Pump Curve Characteristics

The same relationships of head, flow, efficiency and horsepower used for centrifugal pumps also hold true for positive displacement pumps.

[Review pump curve characteristics of participant workbook.]

Display Slide 37 – Sample pump curve (Figure 4.11 in participant workbook)

[Review Figure 4.11, and go over example.]

Pump Efficiency and Horsepower

[Review the pump efficiency and horsepower section of participant workbook.]

Let's work out some examples together as a class.

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 x 139)/(3960 x 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%

[Have the participants review the Key Points for Unit 4 – Pump Types and Applications.]

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_.

This concludes the formal instruction for Module 9: Basics of Pumps and Hydraulics. As a treatment plant operator it is important for you to understand basic hydraulics, how water flows, and basic pump operation. Does anyone have any questions?

[Thank attendees for their participation. Offer words of positive encouragement. Remind participants that both the participant workbook from this class and the Advance Waste Treatment textbook, will serve as good references in preparation for the state test.]