WATER DISTRIBUTION SYSTEM MATHEMATICS

OTCO Distribution Workshop

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The Math Basics for this Module

- **Use some formulas**
  - Area = Π • R^2
    - Area = 0.785 X D^2
  - Volume = Area X Height (or depth)
  - Flow rate: Q = A X V or   V = Q/A
  - Detention time = Volume ÷ flow rate
  - HP = (gpm X $Head_{ft}$) ÷ (3960 X Efficiency)
  - Dosage, mg/L = (pounds/MG) ÷ 8.34
  - Amps x Volts = Watts

- **Use some constants**
  - 1 mg/ L = 8.34 lbs/MG   1 day = 1,440 mins
  - 1 ft^3 = 7.48 gals   1 mgd = 694 gpm
  - 1 psi = 2.31 feet head   1 HP = 746 watts
  - 1 inch = 2.54 cm   1 meter = 100 cm
  - 1 gal = 3.785 liters   1 mgd = 1.55 cfs

- **Use the practice of "cancelling units"**
- For example:
  - 25 lbs/MG X (1 mg/L / 8.34 lbs/MG) = 3 mg/L
    - lbs/MG cancels lbs/MG
    - Leaving us with mg/L
- Another example:
  - 3.5 ft^3/sec X (7.48 gals/ft^3) X 60 sec/min = 1,571 gpm
    - Cubic feet cancels cubic feet and seconds cancel seconds, leaving us with gallons per minute

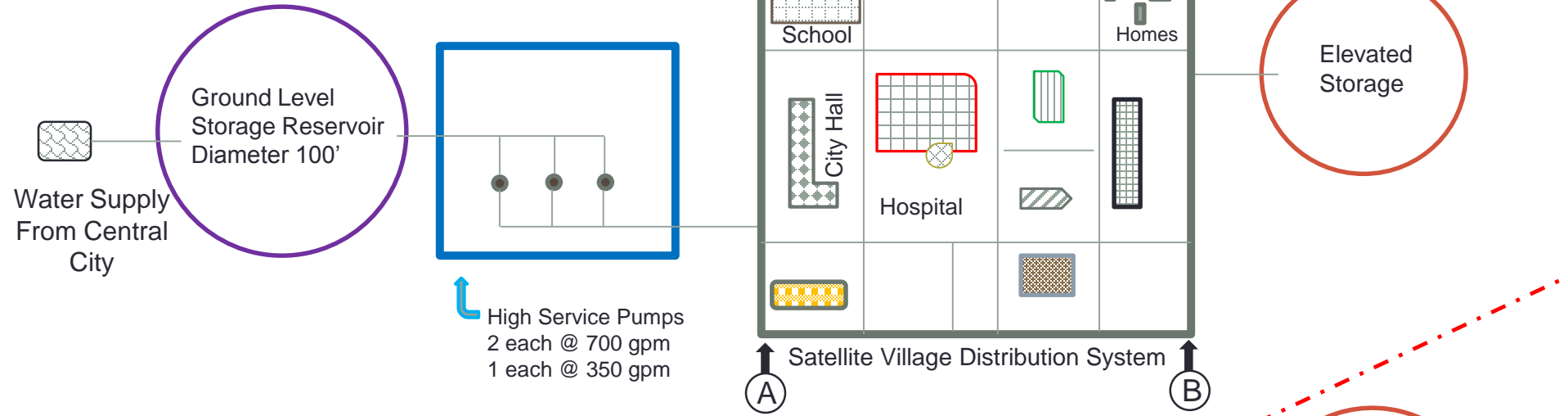- Cancelling means that anything divided by itself always = 1

Operations

MOR for
April 2015

- Served 4,695 persons

- Used 123 pounds Chlorine

- Electrical Use: $870.00

- Max Day: 0.720 mg

- Avg Day: 0.560 mg

- Tap Free Cl_2 = 0.4 mg/L

- Tap Total Cl_2 = 0.5 mg/L

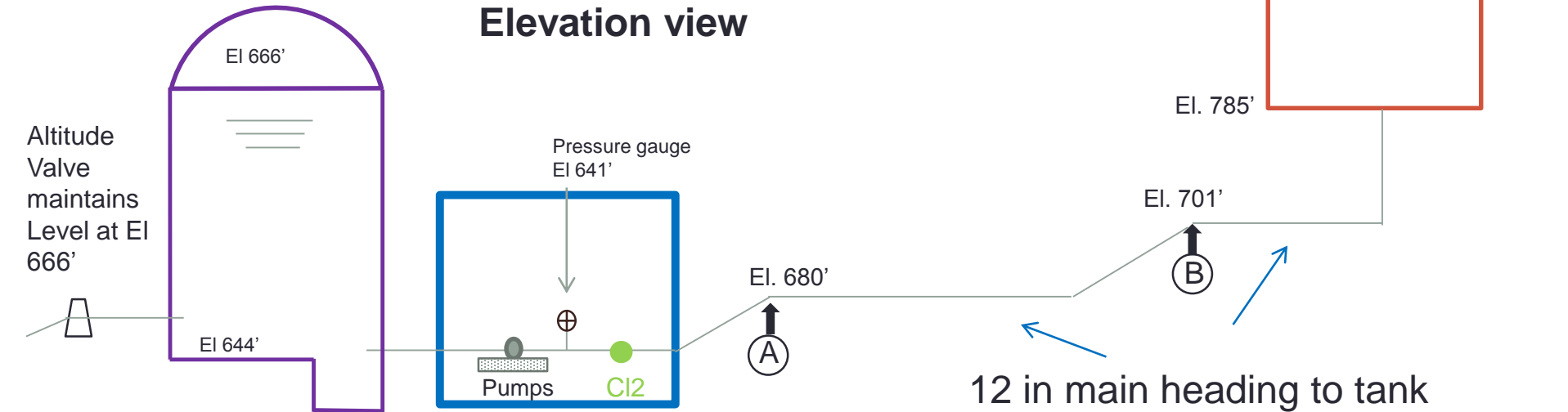 - Dist free and total Cl_2

    - 0.2 and 0.3 mg/L

Design

- The Satellite, OH Village Water System has been designed to serve a population of 5,000 persons with a capacity of 120 gallons per person per day. The planned operation of this system is to run 1 pump at 700 gpm for 15 hours per day to fill the tank. The system is then shut down, and the tank elevation serves the town with pressure in the evening hours. Automatic controls allow for pumps to activate if there is additional need for pressure or flow.

- The Village buys its water from Central City, which has agreed to keep the ground level storage tank filled to an elevation of 666 feet. The Village adds a little chlorine and pumps water from the ground storage through the distribution system grid, and up to an elevated storage tank which it owns.

Plan view

Water Supply From Central City

Ground Level Storage Reservoir Diameter 100'

High Service Pumps
2 each @ 700 gpm
1 each @ 350 gpm

School

Homes

Elevated Storage

City Hall

Hospital

Satellite Village Distribution System

(A)

(B)

Overflow
El. 819'

38'

El. 785'

Elevation view

El 666'

Altitude Valve maintains Level at El 666'

El 644'

Pressure gauge
El 641'

Pumps

Cl2

El. 680'

(A)

El. 701'

(B)

12 in main heading to tank

Question 1

- What is the rate of pumpage in gpm if the high service pumps required 2 hours and 21 minutes to raise the water level in the elevated tank 10 feet, and the system is using 500 gpm?

Remember: Detention Time = Volume ÷ Flow

- 10' of water into tank = 3.14 X 19 X 19 X 10 X 7.48 gal/ft^3 = 84,788 gals
  - Alternately : 0.785 X 38' X 38' X 10' X 7.48 = 84,788 gals
- 2 hours 21 minutes = 141 minutes
- Tank demand: 84,788 gals / 141 minutes = 601 gpm
- But – system demand is 500 gpm
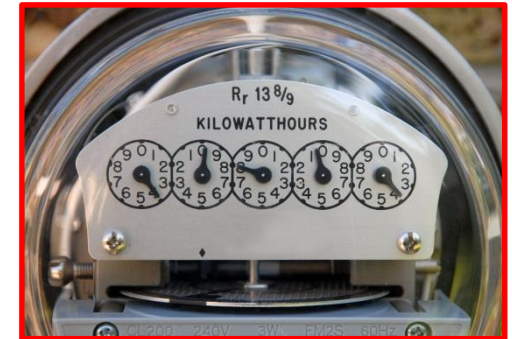- So total demand = 601 gpm + 500 gpm = 1,101 gpm

38'
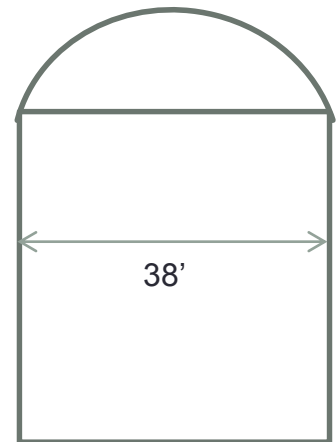
Question 2

- You think your pumps are too costly and inefficient. How many kilowatt-hours/MG were used for pumping if power costs 7.9 cents per KWH? (Assume electrical costs were for pumping only)

- System use and system production figures:
    - $870.00 electricity in the month
    - 0.560 mgd X 30 days/month , or
    - = 16.8 mg for the month

- Therefore: $870.00 / month X (1 month/16.8 MG) = $51.78/MG Electrical costs

- ($58.71 / MG) X (KWH / $0.079) = 655.52 KWH/MG

Question 3

- You think that your lab is a bit off in their chlorine residual determinations. What is the average chlorine dosage in pounds per million gallons and mg/L based on the max April pumpage and average chlorine use?

  Remember: mg/L dosage equals pounds/MG ÷ 8.34

  - 123 pounds used in 30 days
    - 123 lbs / 30 days = 4.1 pounds per day
  - Pumpage averaged 0.720 mgd
  - 4.1 lbs per day / 0.72 mgd = 5.7 lbs/mg
  - 5.7 lbs/mg / 8.34 = 0.68 mg/L

Question 4

- The water supply from Central City is temporarily lost. For what period of time can water be pumped from the ground storage reservoir when the system is operating AS DESIGNED?

Remember: Detention time

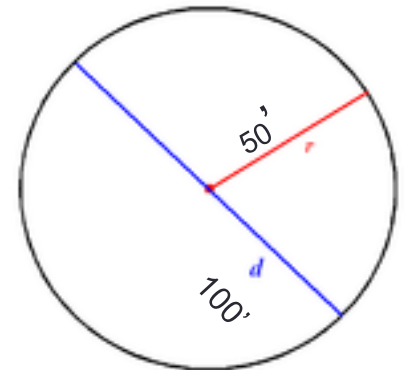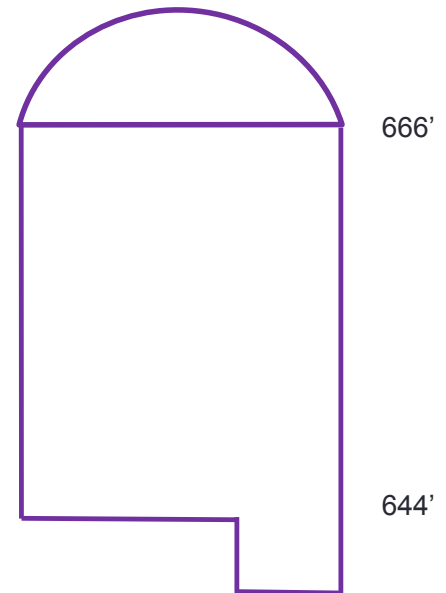Ground storage res = 100 foot diameter, and (666'- 644') = 22'

Volume = 3.14 X 50' X 50' X 22' X 7.48 = 1,291,796 gallons

Detention Time = Volume / flow rate

Design flow rate = 5,000 persons X 120 gals/person/Day = 600,000 gal per Day

Detention time = Volume / flow rate

1,291,796 gals ÷ (600,000 gal/Day) = 2.15 Days
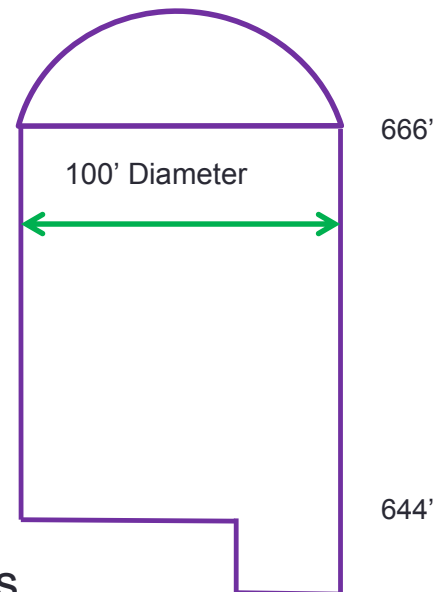
666'

644'

50'

100'

Question 5

- What is the total force against the bottom of the Ground Level Storage Tank in pounds?

Remember: 1 psi = 2.31 feet of head

- Determine the pressure with 22 feet of water in tank

  - 22 feet X 1 psi / 2.31 foot of head = 9.5238 psi

  - 50' X 12"/ft = 600 inches

- Calculate total force:

  - (9.5238 psi) X (3.14 X 600" X 600") = 10,765,713 pounds

666'

100' Diameter

644'

Question 6

- What would be the chlorine demand in mg/L if the chlorine residual is the average total residual reported coming out of the pump station for April?

<p style="text-align:center">Remember: Demand = Dosage − Residual</p>

- Dosage can be calculated by dividing the amount of chlorine used by the pumpage

  - 123 pounds in April ÷ 30 days in April = 4.1 ppd

  - Average day pumpage = 0.56 mgd

  - Dosage = 4.1 ppd ÷ 0.56mgd ÷ 8.34 = 0.87 mg/L

  - Demand = 0.87 mg/L – 0.5 mg/L = 0.37 mg/L Demand

Question 7

- The Village suspects sporadic high pressure from the Central City altitude valve, but the Village pressure gauges are out of service. Central City denies this. The Village foreman finds an old mercury manometer on the shelf and uses it to find the pressure at the incoming line. If the specific gravity of Mercury is 13.6, what is the line pressure?

- 36 inches X 1 ft/ 12 in = 3 feet
- (3' X 13.6) – (3' x 1) = 37.8 ft
- 37.8 ft X 0.433 = 16.4 psi

12 in

Not to scale

Water

36 in

Hg
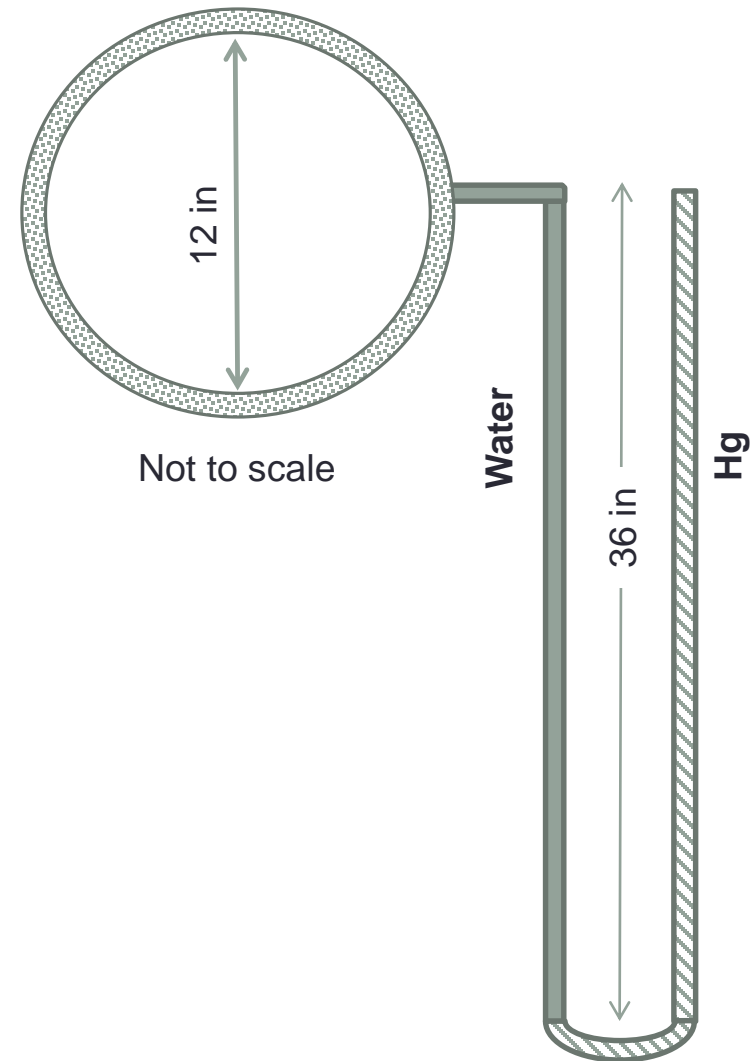
Don't do this at home!

Question 8

- You get a low pressure complaint. A flow and pressure test is conducted on the pipe from point A to B on the design sheet. The test conditions are that all side main valves are off and the distance from A to B is 2,000', pressure at A is 55 psi, friction loss is 4.5 ft. per 1,000' of pipe, and flow rate through the pipe is 1 mgd. What is the pressure at B?

  - We must determine pressure loss due to 1) elevation, and 2) due to friction

  - Elevation: point A is at El 680' and point B is at El 701'

    - So 701' – 680' = 21', or (21' X 0.433) = 9 psi lost

  - Friction: we have 2 units of 1,000' @ 4.5' loss for each

    - 4.5' X 2 = 9', or (9' X 0.433) = 3.9 psi

- 55 psi – 9 psi – 3.9 psi = 42.1 psi

Remember: water moving uphill is losing pressure, and faster flowing water means more pressure is lost due to friction

Question 9

- When the elevated tank is one half full and the pumps are shut off, the psi at the high service pump discharge gauge will read what in psi? Ignore use from Village

  - The static pressure – no pumps running – head from elevated tank provides the pressure

    - Pump gauge sits at El 641', and tank El is half the distance from El 819' and El 785', or (819' – 785') = 17'

    - So El 785 + 17 = 802'

    - Gauge pressure is then:

      - 802' – 641' = 161'

      - 161' X 0.433 = 69.7 psi


819'

38'

785'
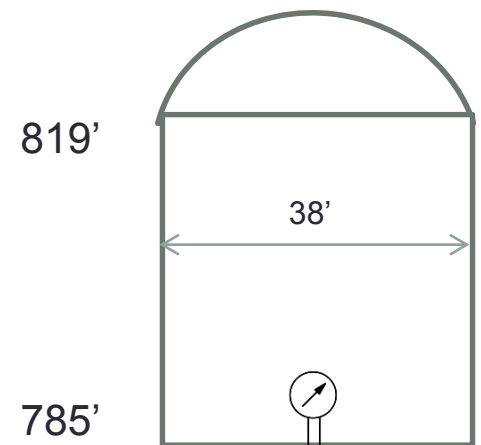
Question 10

- What is the net pressure required to lift water from the pump to the maximum elevation as shown in the design data sheet? Ignore friction
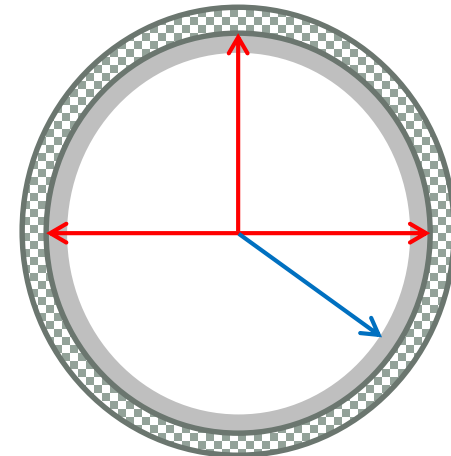
  - Question may be too vague. Depends on what they mean by "net pressure"

  - Net pressure will be the difference in elevations from the pump to the top of tank, or can mean the difference in elevations from reservoir to tank

    - 819' – 641' = 178' or 77 psi (pump to tank)

    - 819' – 666' = 153' or 66.2 psi

      - (work done from reservoir to tank)
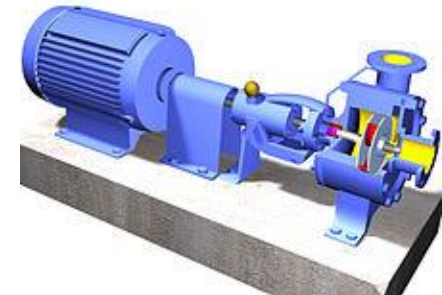
Question 11

- The interior of 300' of the 12 inch pipe is uniformly coated with one inch of scale. How many gallons of water will the pipe contain?

  - New pipe is 12 inch, or 1 foot diameter, 0.5' radius

  - (3.14 X 0.5' X 0.5' X 300' X 7.48) - 1,761.54 gals

    - Or 0.785 X 1' X 1' X 300' X 7.48 = 1,761.54 gals

  - But for 1 inch scale, we have a diameter of 10 inches or a radius of 5 inches (5/12 = 0.4166)

  - - (3.14 X 0.4166' X 0.4166' X 300' X 7.48) = 1,222.9 gallons

    - Or 0.785 X 0.833' X 0.833' X 300' X 7.48 = 1,222.3 gallons

Remember: scale build-up reduces the carrying capacity of mains

D/Radius B4

Radius After

Diameter of new pipe: 12 in so radius is 6 in

Diameter of corroded pipe: 10 in and radius 5 in

Question 12

- How many pounds of 15% hypochlorite will be required to disinfect eight hundred feet of 16 inch pipe with a chlorine dosage of 100 mg/L?

  Remember: Calculate the amount of pure chemical needed first, then you must divide by the percentage of purity

  - Volume of 800' of 16" pipe: V = 3.14 X 0.66' X 0.66' X 800' X 7.48 ≈ 8,185 gals

    - 8,185 gallons / 1,000,000 = 0.008185 MG

  - 100 mg/L X (8.34 lbs/MG / 1 mg/L) X 0.008185 MG = 6.8 pounds Chlorine

  - But we don't have pure chlorine – we have hypo at 15%, so:

  - 6.8 pounds ÷ 0.15 = 45.3 pounds of 15% hypo

    - (FYI – 15% hypo contains 1.25 pounds Cl_2 per gallon, so we would need 45.3 pounds X 1 gal/1.25 pounds = 36.24 gals)

Question 13

- A main break in the Village caused one large and the small HS pumps to operate at capacity during the two hours it took to isolate and shut off the leak. Also, the tank dropped 2.5 feet. Approximately how much water was lost in that period using average system demand numbers?

  - 2 hours of normal use: (560,000 gpd X 2 hours) ÷ (24 hrs / Day) = 46,666 gals
    - 46,666 gals ÷ 120 mins = 389 gpm
  - 2.5' Tank volume = 3.14 X 19' X 19' X 2.5' X 7.48 = 21,197 gals
    - 21,197 gals ÷ 120 mins = 176 gpm = what the tank supplied
  - Pump supplied = 700 gpm + 350 gpm = 1,050 gpm
  - Tank + pump = 176 gpm + 1,050 gpm = 1,226 gpm

 - Lost water = 1,226 gpm – 389 gpm = 837 gpm, and for 120 mins = 100,440 gals lost

Question 14

- What is the overall efficiency of one of the large pumping units if the current usage is 75 amps at 220 volts and the pump output results in a head of 100 feet? (1 HP = 746 watts.)

Remember: amps X volts = watts; 1,000 watts = 1 KW

- 75 amps X 220 volts = 16,500 watts
  - 16,500 watts ÷ (746 watts / HP) = 22.11 HP
- HP = (gpm X head) ÷ (3,960 X eff)
  - Eff = ((gpm X head) ÷ (HP X 3,960)
  - Eff = (700 gpm X 100') ÷ (22.11 X 3,960) = 0.799, or about 80%
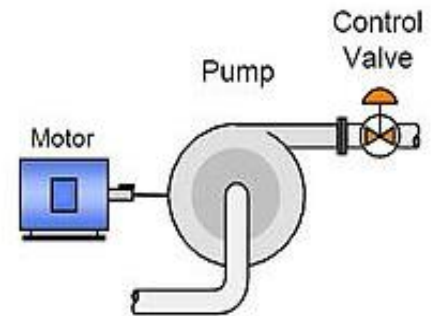
The Remaining Questions

- Do not require use of the design or operating handouts

Question 15

- Water velocity in two 8 inch pipes is 4 feet per second. What size pipe will carry about the same amount of water if the velocity is reduced to 2 feet per second?

  - Area of two 8 inch pipes is (2) X 3.14 X 0.33' X 0.33' = 0.68 ft^2

  - So flow for the 8 inch: Q = A ● V, or 0.68 ft^2 X 4 fps = 2.72 cfs

  - For the unknown pipe: Q = A ● V, and A = Q/V

  - A = 2.72 cfs / 2 fps = 1.36 square feet, and

  - A = Π ● r^2 = 1.36 ft^2, so r^2 = 1.36 ft^2 ÷ 3.14 = 0.433 ft^2 and

  - If R^2 = 0.433, then R = sq root of 0.433 which is 0.658'

    - So – if we have a 0.658 ft radius, then the diameter twice the radius, or 1.31 ft, and

    - 1.31 foot diameter X (12" / foot) = about a 16 inch main

Question 16

- Calculate the velocity in a 24 inch main if the flow through the main is 875 gpm

  - $V = Q_{flow} \div A_{area}$

    - When you calculate velocities using this formula, it is important to get the numerator and denominator in agreement as to units

      - Flow is typically going to be given in gpm or cfs

      - And if area is in square feet we may need to convert

  - $V = 875 \text{ gpm} \div (3.14 \text{ X } 1' \text{ X } 1')$

  - $V = 875 \text{ gpm X } (1ft^3/7.48 \text{ gal}) \div (3.14 \text{ ft}^2)$

  - $V = 37.25$ ft/min

    - 37.25 ft/min ÷ 1 min/ 60 sec = 0.62 ft/sec
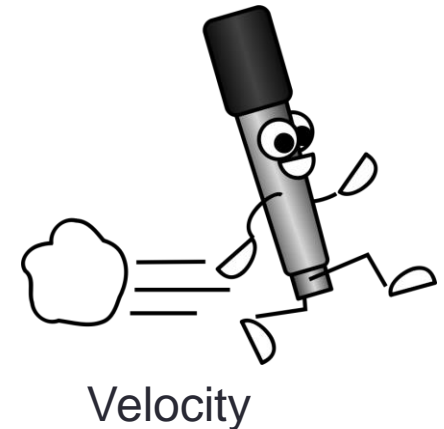
Velocity

Question 17

- What is the velocity, in meters per second (M/sec), in a 42 centimeter diameter pipe if the flow rate through the pipe is 7500 M^3/Day?

- $V = Q_{flow} / A_{area}$
  - Change centimeters to meters and divide by 2 for radius
  - Centimeters ÷ 100 = meters, so 42 centimeters ÷ 100 = 0.42 M
    - 0.42 M ÷ 2 = 0.21 M radius
- $V = 7{,}500\ M^3/\ Day \div (3.14 \times 0.21\ M \times 0.21\ M)$
- $V = (7{,}500\ M \times M \times M / Day) \times (1\ Day/86{,}400\ sec) \div (0.138\ M \times M)$
- $V = 0.63\ M/sec$
- (If interested, 1 M = 39.37 inches, so 39.37 X 0.63 = 24.8 inches, or about 2 fps)

Question 18

- You investigate a customer complaint in which a larger than normal water bill is being disputed. You notice that a utility sink is leaking. The leak fills up a 1 gal container in 1 minute 38 seconds. How much wastage does the leaky faucet produce in April?

  - Convert 1 min 38 sec to the decimal equivalent

    - 38 sec ÷ 1 min/60 sec = 0.63 min, so total time is 1.63 minutes

  - Flow rate, gpm = Vol / time

    - Flow rate = 1 gal ÷ 1.63 min = 0.613 gal / min

    - 0.613 gpm X 1,440 min/Day X 30 Day/month

      - 26,481.6 gallons lost during the month

Question 19

- You need to take a sample in the system to determine the amount of Cl_2 residual in the area. The only place available to sample is a single-family residence with a meter in the basement near the street-side wall. A sink is right there. How long will it take to flush the ¾ inch service line at 0.5 gpm if it is 30 feet long?

  - Convert the pipe diameter to feet:
    - ¾ inch is 0.75 inches and 0.75 inches ÷ 12 inches / foot = 0.0625 ft
  - Flush time = (0.785 X (0.0625 feet X 0.0625 feet) X 30' X 7.48 gal/ft³) ÷ ½ gal/min
    - Flush time = 0.688 ÷ 0.5 = 1.37 minutes or 1 min 22 sec

Question 20 (info for Question 21)

- Horsepower problems – explaining water HP, brake HP, and motor HP

Horsepower lost here due to slippage and friction of shaft and other pump inefficiencies

Horsepower lost here in the conversion of electrical energy to mechanical energy and other motor inefficiencies

whp

bhp

mhp
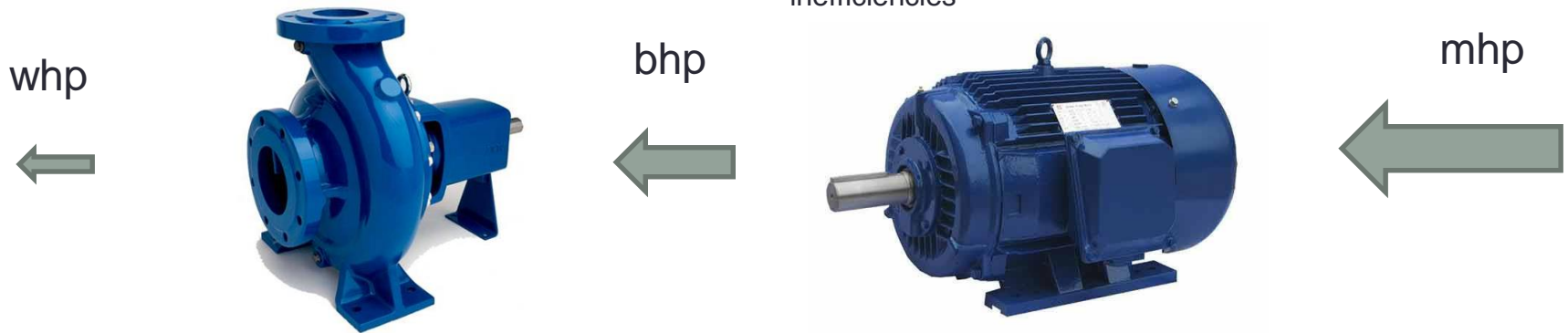
Example: if 12 horsepower is supplied to motor (MHP), what is the BHP and WHP if the motor is 90% efficient and the pump is 85% efficient?

BHP = 90% of the MHP = 0.9 X 12 MHP = 10.8 BHP
WHP = 85% of the BHP = 0.85 X 10.8 BHP = 9.2 WHP

Question 21

- It takes 28 horsepower for a particular pumping application. If the pump efficiency is 75%, and the motor efficiency is 85%, what horsepower must be supplied to the motor?

Remember – they are asking for MHP

- BHP = WHP ÷ pump efficiency

  - 28 horsepower ÷ 75% = 28/0.75 = 37.3 HP

- MHP = BHP ÷ motor efficiency

  - 37.3 horsepower ÷ 85% = 37.3 / 0.85 = 43.9 HP