

# Wisconsin Wastewater Operators Association

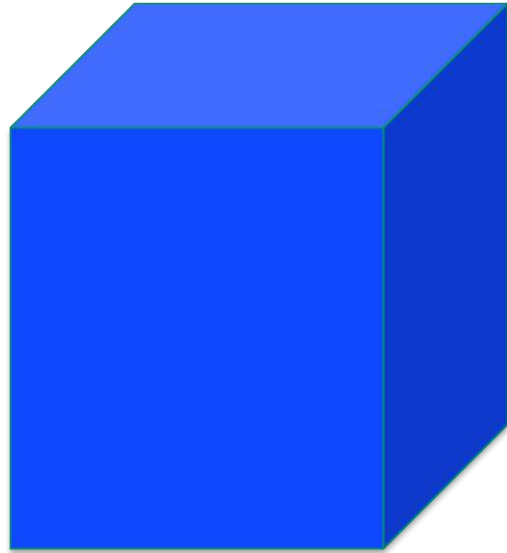
## Submersible Pump Operation

Mike Zelinsky, PE  
June 4, 2020

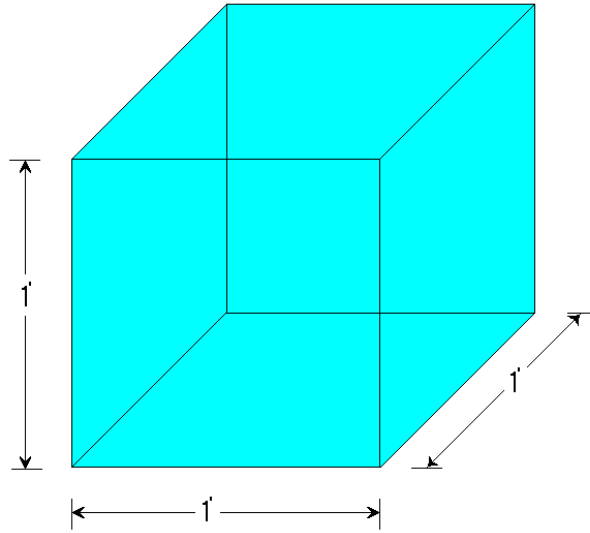
# PUMP OPERATIONAL POINT

TOTAL DYNAMIC HEAD = STATIC HEAD + FRICTION HEAD

# Static Head



# Static Head

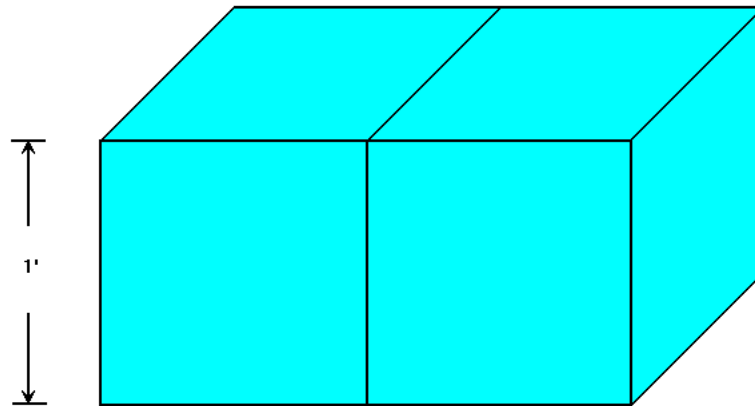


$$\text{PRESSURE} = \frac{\text{FORCE (WEIGHT)}}{\text{AREA}}$$

$$P = \frac{F}{A}$$

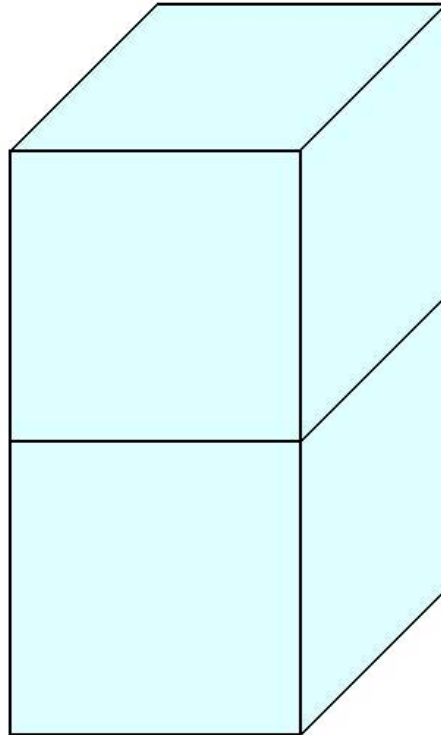
**PRESSURE EXERTED BY  
A COLUMN OF LIQUID**

# Static Head



$$P = \frac{F}{A} \quad \frac{2}{2} = 1$$

# Static Head



← 1 →

$$P = \frac{F}{A} \quad \frac{2}{1} = 2$$

# Static Head

Density of Water = 62.4 lbs/cubic foot

62.4 lbs/cubic foot X 1 foot of water

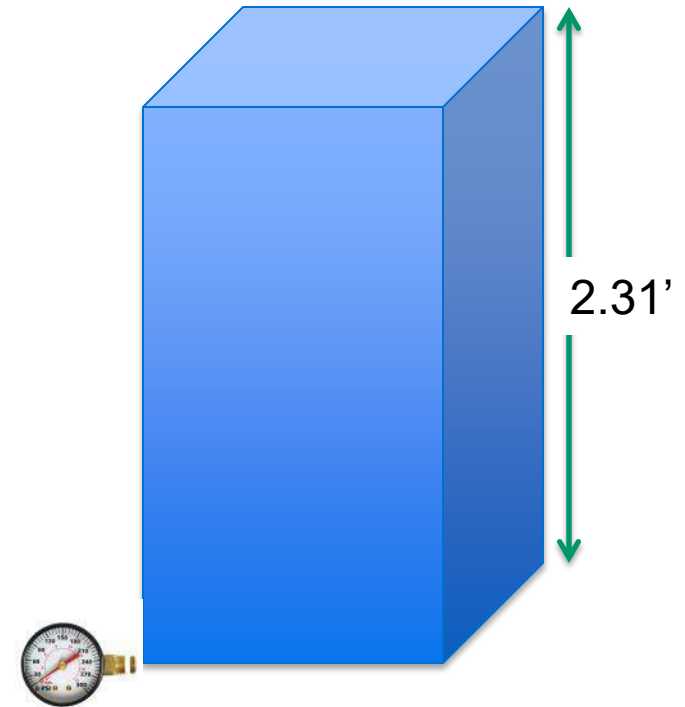
62.4 lbs/square feet X  $\frac{(1 \text{ ft})^2}{(12 \text{ in})^2}$  = .433 PSI

So,

1 foot of water produces a pressure of .433 PSI

Or

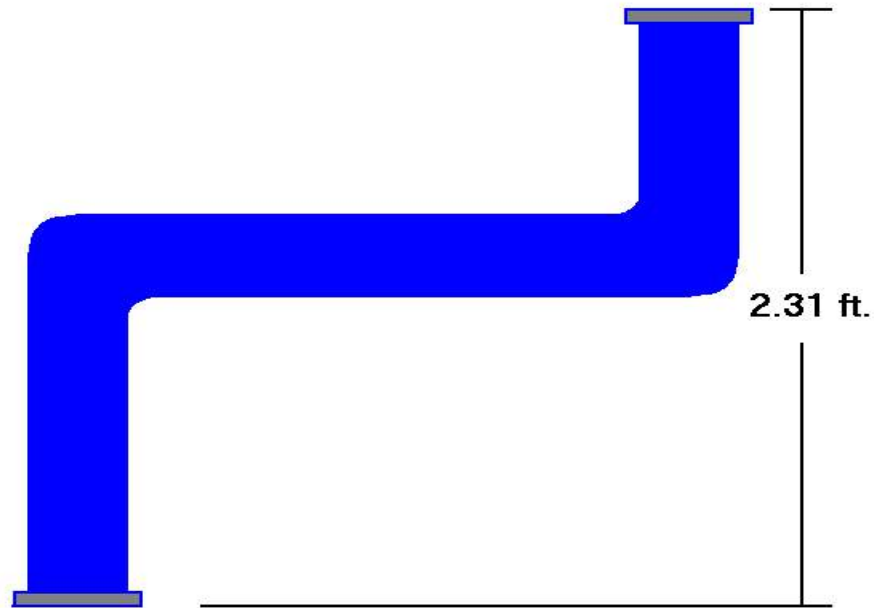
1 PSI = 2.31 feet of liquid



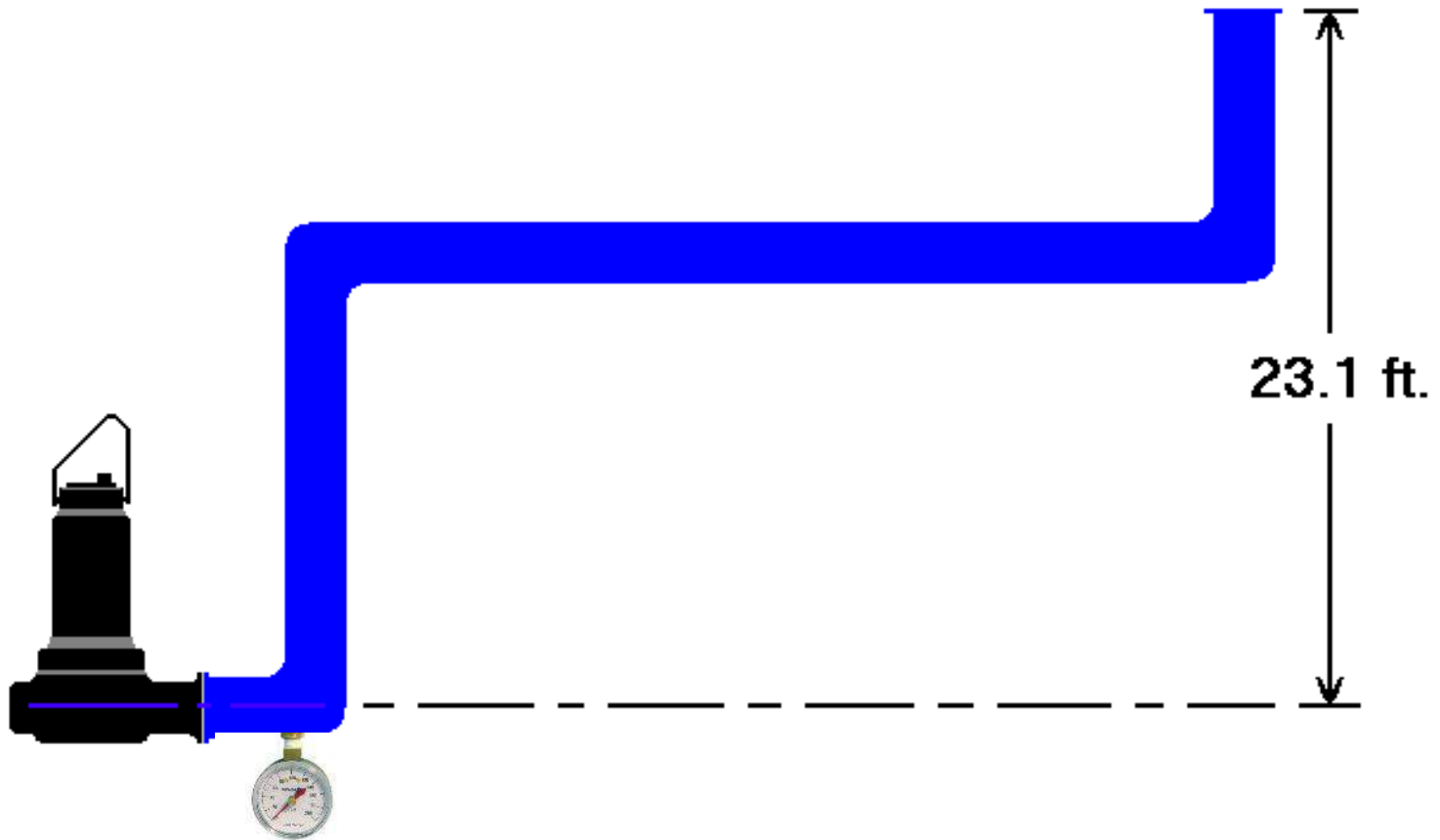
# Static Head



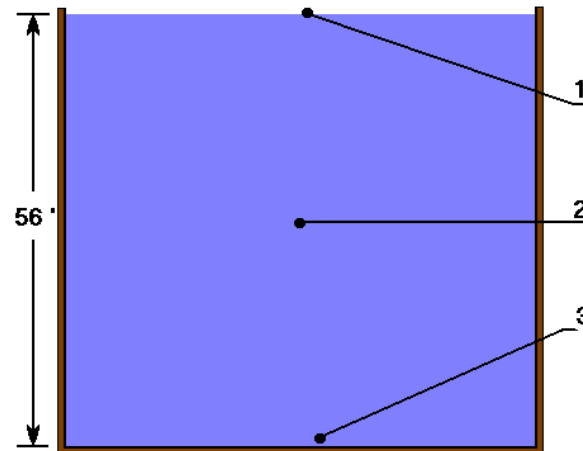
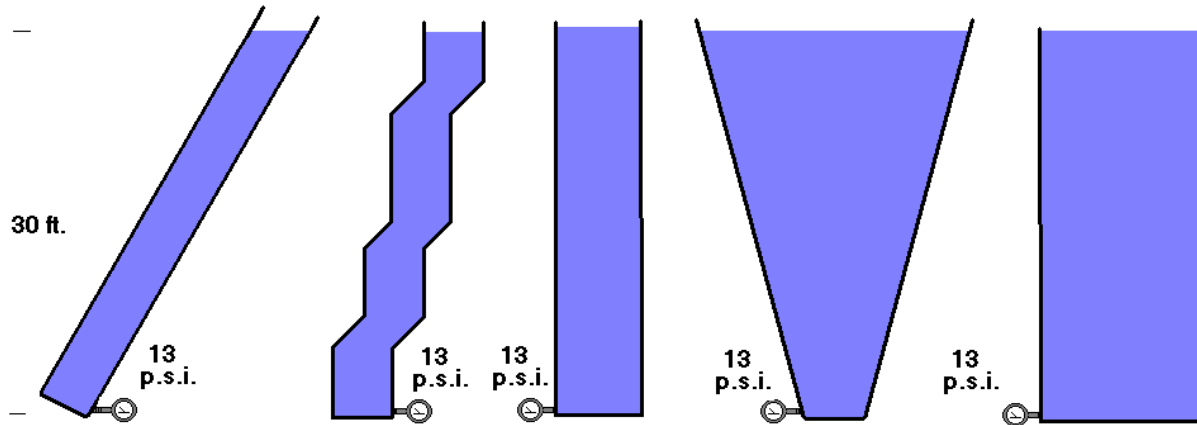
# Static Head



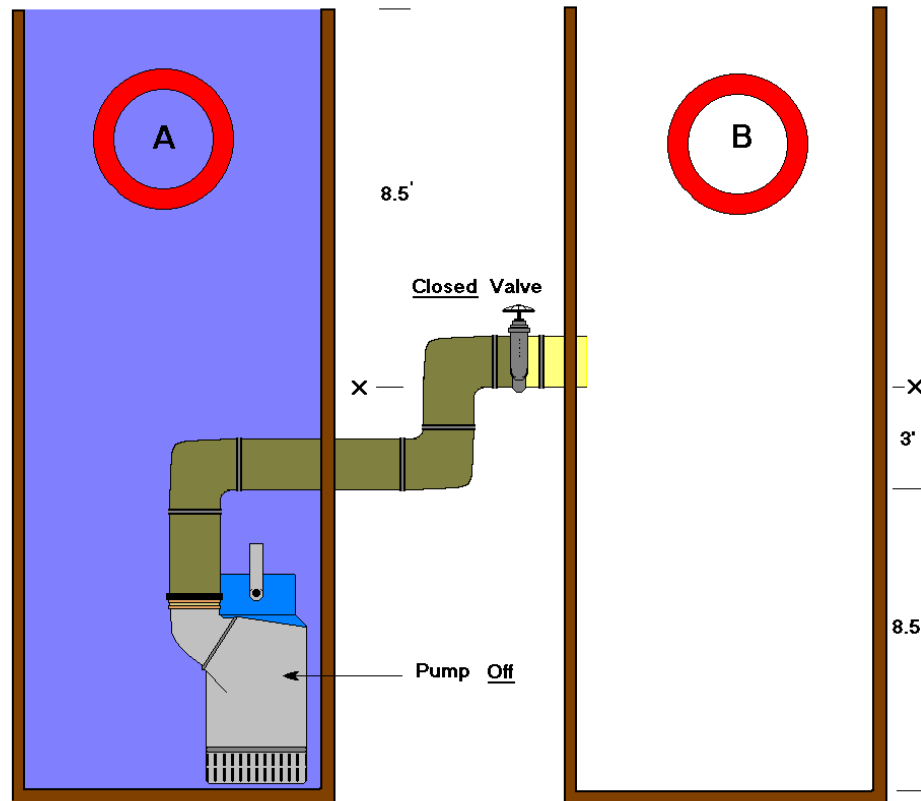
# Static Head



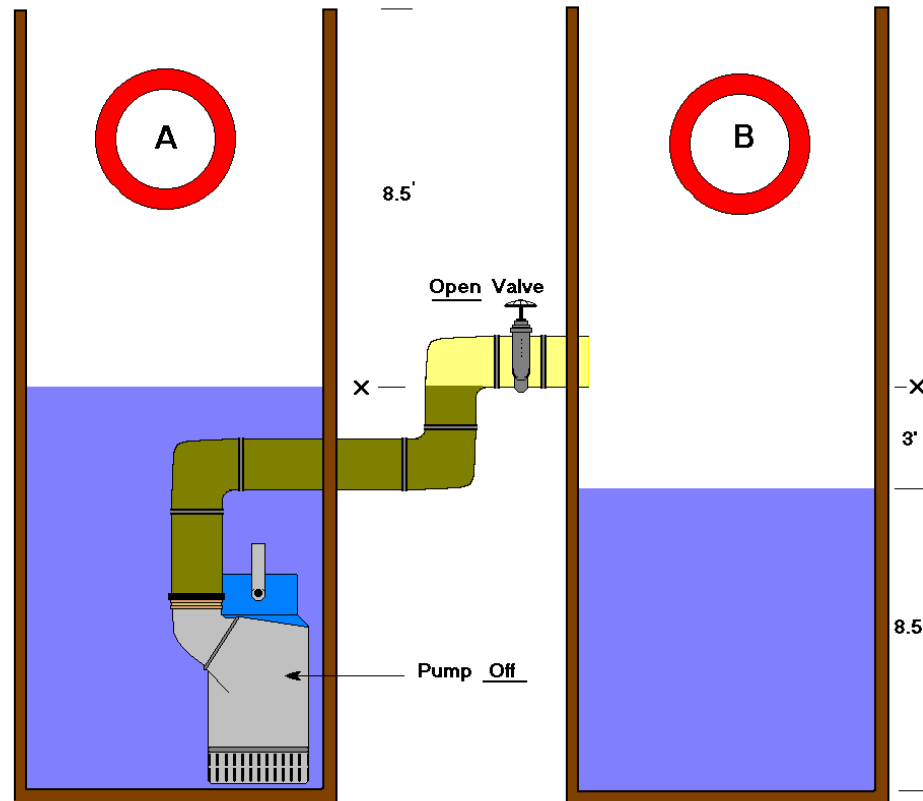
# Static Head



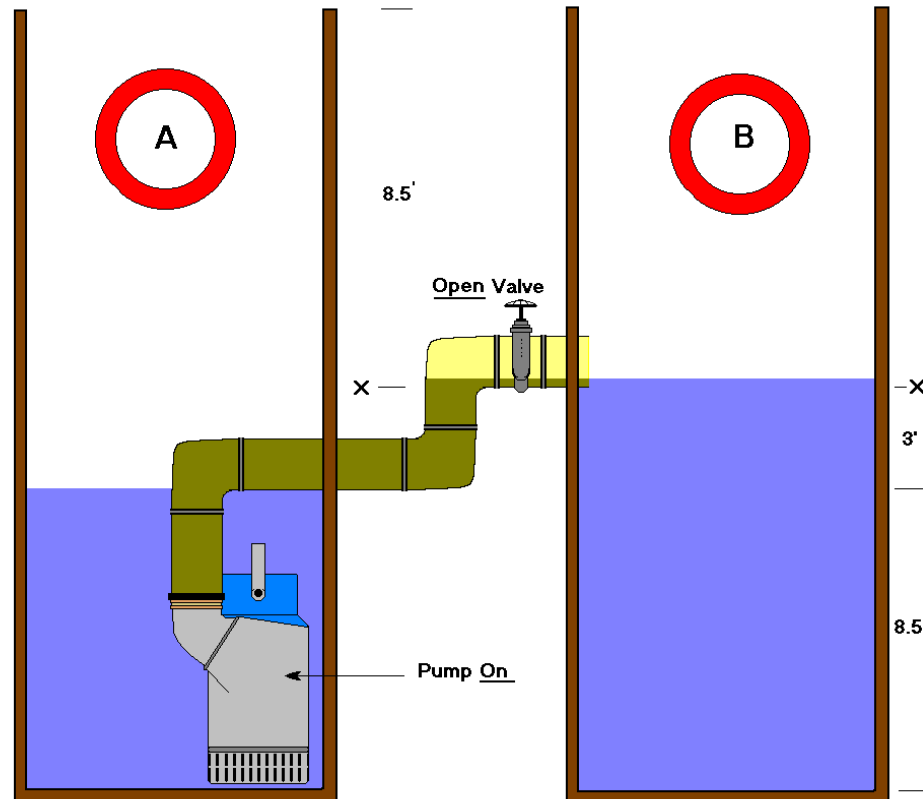
# Static Head



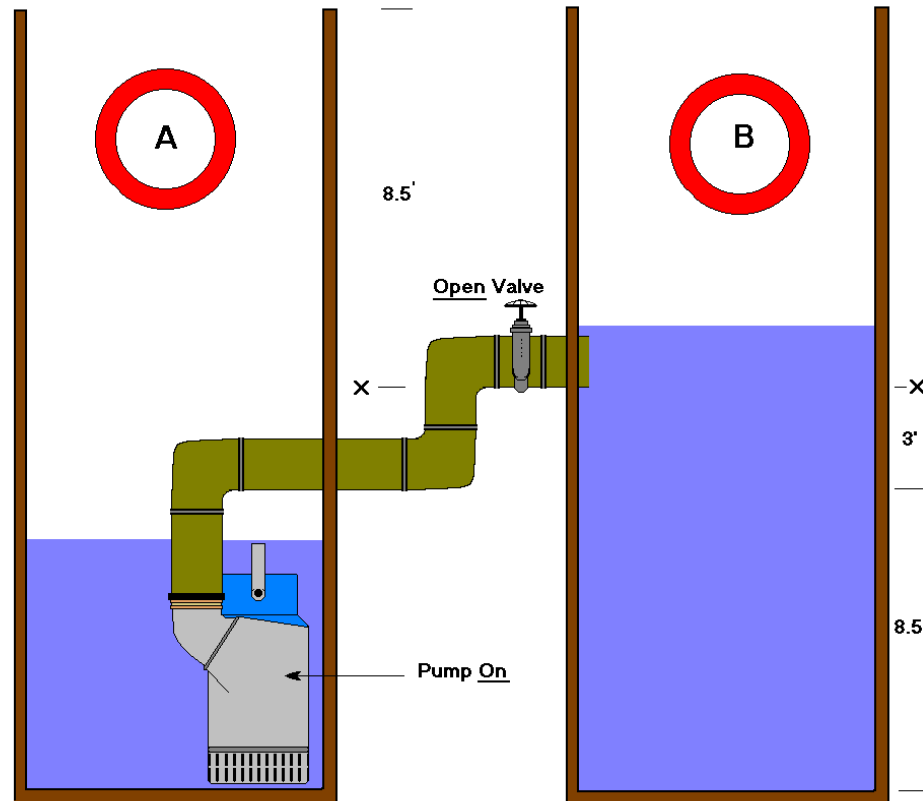
# Static Head



# Static Head

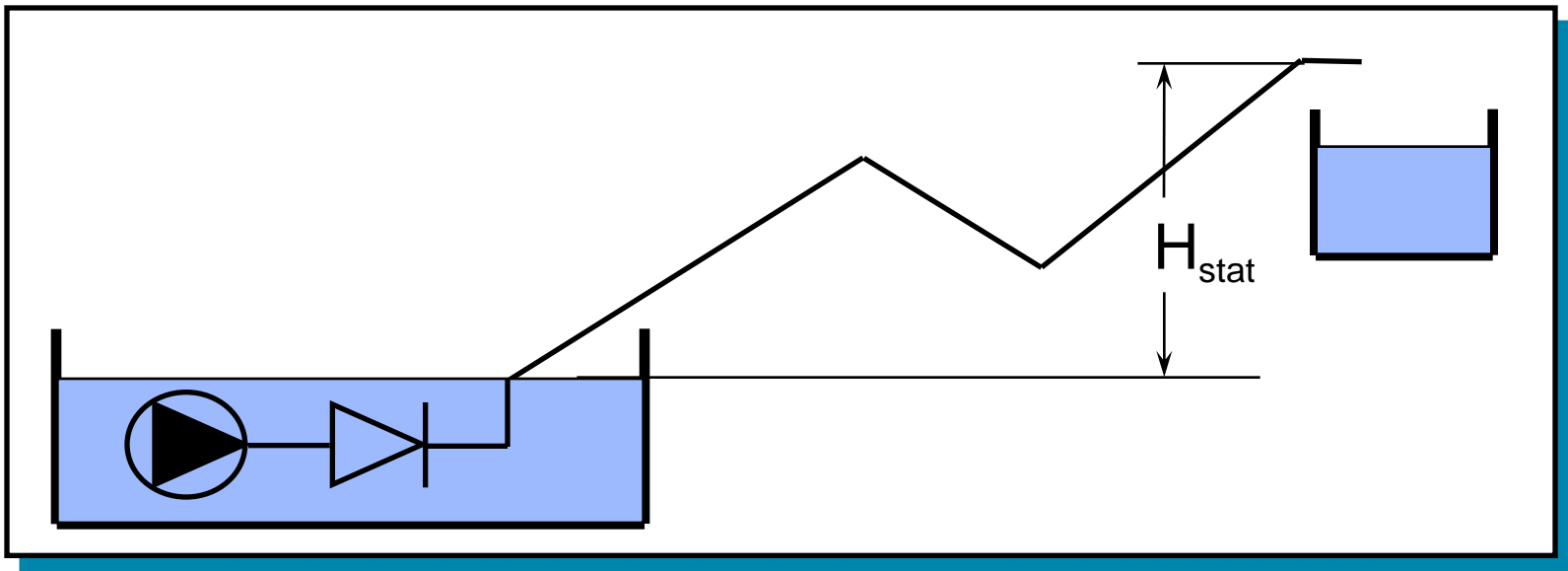


# Static Head



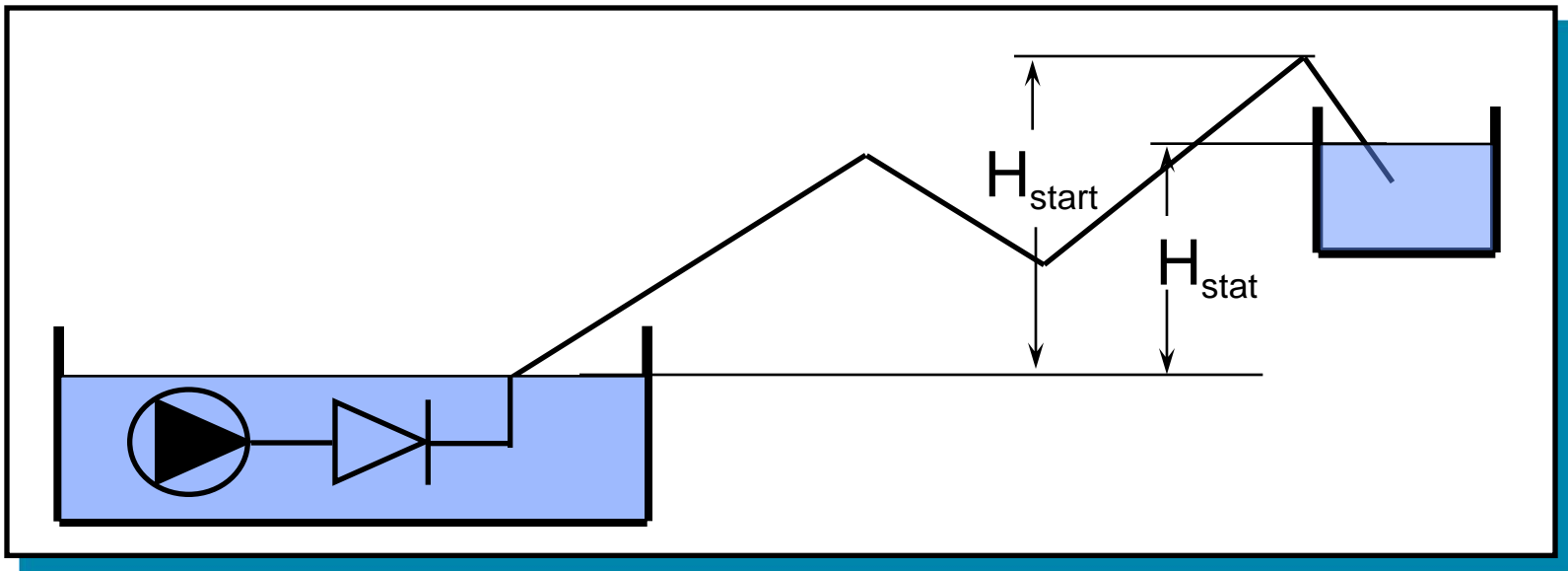
# Static head - open outlet

- Filled pipes - no air pockets
- Static head independent of pipe profile



# Static head - submerged outlet

- Filled pipes - no air pockets
- Static head independent of pipe profile
- $H_{\text{start}}$  = Head needed to start pumping



# Calculating Friction Head

## Darcy-Weisbach

$$H_f = \frac{f * L * V^2}{D * 2 * g}$$

f = friction factor

L= length of piping

V=velocity of flow

D= inside diameter of pipe

g= gravity

## Hazen-Williams

$$H_f = 0.002083 * L * \frac{(100)^{1.85} * \text{GPM}^{1.85}}{(C)^{1.85} * d^{4.3655}}$$

L= length of pipe

GPM= flow through pipe

C= friction factor

d= inside diameter of pipe

# Friction Head Increases with Increasing Flow Rate

## 3-inch

Flow GPM	Velocity ft/sec	Head Loss in ft/100'
40	1.82	.914
45	2.04	1.14
50	2.27	1.38
55	2.50	1.64
60	2.72	1.94
65	2.95	2.24
70	3.18	2.57
75	3.40	2.92
80	3.63	3.30
85	3.86	3.69
90	4.09	4.10
95	4.31	4.53
100	4.54	4.98
110	4.99	5.94
120	5.45	6.98
130	5.90	8.09



# Friction Head Loss Decreases with Increasing Diameter

## Cast Iron Pipe\*

### 3-inch

Flow GPM	Velocity ft/sec	Head Loss in ft/100'
40	1.82	.914
45	2.04	1.14
50	2.27	1.38
55	2.50	1.64
60	2.72	1.94
65	2.95	2.24
70	3.18	2.57
75	3.40	2.92
80	3.63	3.30
85	3.86	3.69
90	4.09	4.10
95	4.31	4.53
100	4.54	4.98
110	4.99	5.94
120	5.45	6.98
130	5.90	8.09
140	6.35	9.28
150	6.81	10.6
160	7.26	11.9
180	8.16	14.8
200	9.08	18.0
220	9.99	21.4

### 4-inch

Flow GPM	Velocity ft/sec	Head Loss in ft/100'
80	2.04	.813
90	2.30	1.01
100	2.55	1.23
110	2.81	1.47
120	3.06	1.72
130	3.32	2.00
140	3.57	2.29
150	3.83	2.61
160	4.08	2.93
170	4.34	3.28
180	4.60	3.64
190	4.86	4.03
200	5.11	4.43
220	5.62	5.28
240	6.13	6.21
260	6.64	7.20
280	7.15	8.25
300	7.66	9.38
320	8.17	10.6
340	8.68	11.8
360	9.19	13.1
380	9.70	14.5

### 6-inch

Flow GPM	Velocity ft/sec	Head Loss in ft/100'
180	2.04	.507
200	2.27	.616
220	2.50	.735
240	2.72	.863
260	2.95	1.00
280	3.18	1.15
300	3.40	1.30
320	3.64	1.47
340	3.86	1.64
360	4.08	1.83
380	4.31	2.02
400	4.55	2.22
450	5.11	2.76
500	5.68	3.36
550	6.25	4.00
600	6.81	4.70
650	7.38	5.45
700	7.95	6.25
750	8.52	7.10
800	9.08	8.00
850	9.65	8.95
900	10.2	9.95

# Friction Loss Increases with a Rougher Pipe Wall

## Smooth Bore Hose

### 2-inch

Flow GPM	Velocity ft/sec	Head Loss in ft/100'
10	1.0	.2
15	1.5	.5
20	2.0	.9
25	2.5	1.4
30	3.1	2.0
35	3.6	2.7
40	4.1	3.5
45	4.6	4.3

### 3-inch

Flow GPM	Velocity ft/sec	Head Loss in ft/100'
30	1.4	.3
35	1.6	.4
40	1.8	.5
45	2.0	.6
50	2.3	.7
60	2.7	1.0
70	3.2	1.3
80	3.6	1.7

## Cast Iron Pipe\*

### 3-inch

Flow GPM	Velocity ft/sec	Head Loss in ft/100'
40	1.82	.914
45	2.04	1.14
50	2.27	1.38

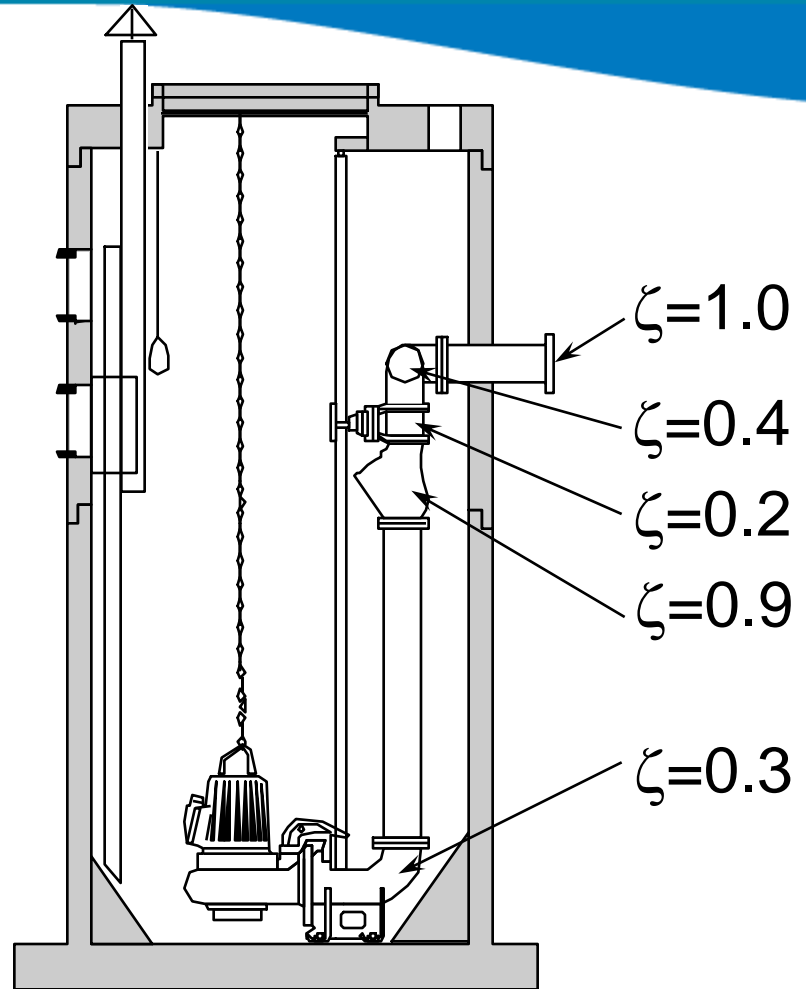
### 4-inch

Flow GPM	Velocity ft/sec	Head Loss in ft/100'
80	2.04	.813
90	2.30	1.01
100	2.55	1.23

# Point losses

- Typical loss coefficients ( $\zeta$ )
- Combination effects

$$H_{\text{pointloss}} = \frac{\sum (\zeta_1 + \zeta_2 + \dots + \zeta_n) \cdot v^2}{2g}$$



# Dynamic head

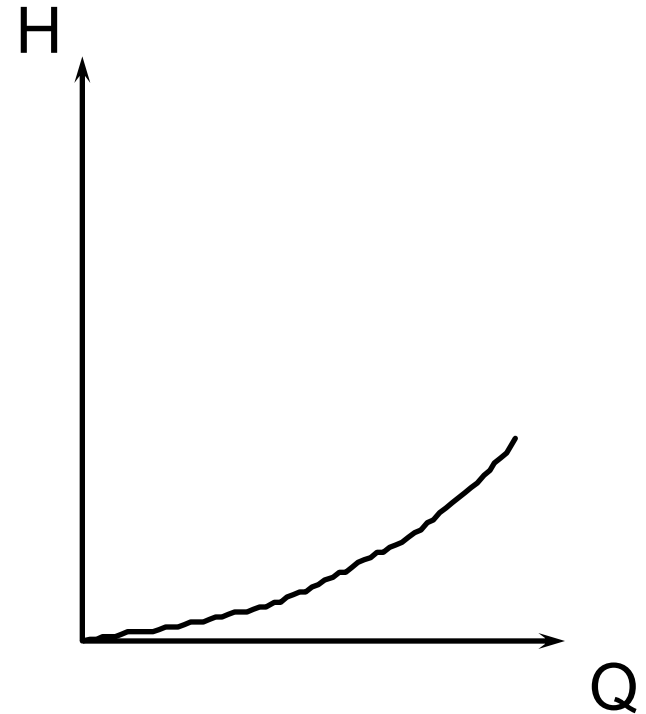
Dynamic head = friction, point losses and fluid velocity

Friction losses  $\sim v^2$

- Friction between pipes and the pumped media
- Proportional to length and friction factor of pipes

Point losses  $\sim v^2$

- Losses associated with sudden disturbances of the flow





# System curve

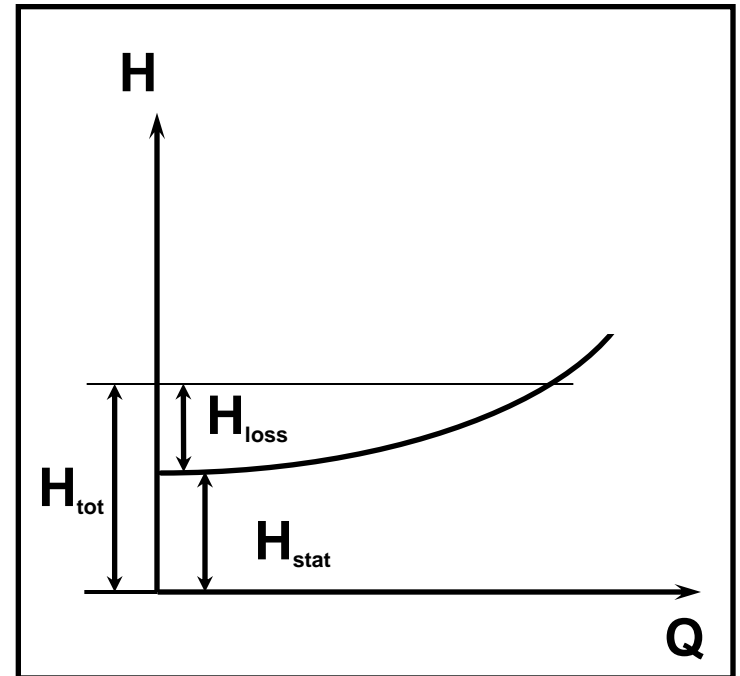
# Total Head

**Total head:**

$$H_{\text{tot}} = H_{\text{stat}} + H_{\text{loss}}$$

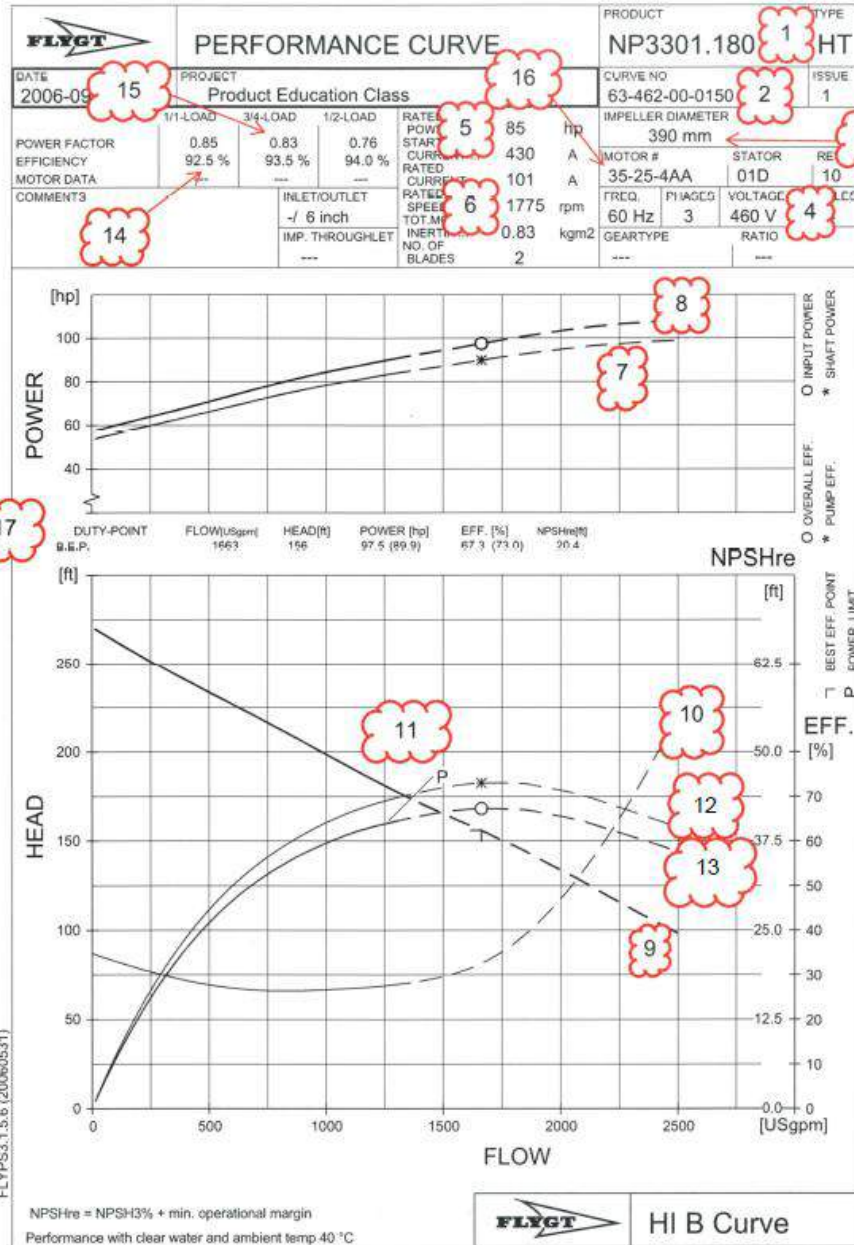
$H_{\text{stat}}$  = static head

$H_{\text{loss}}$  = friction losses + point losses



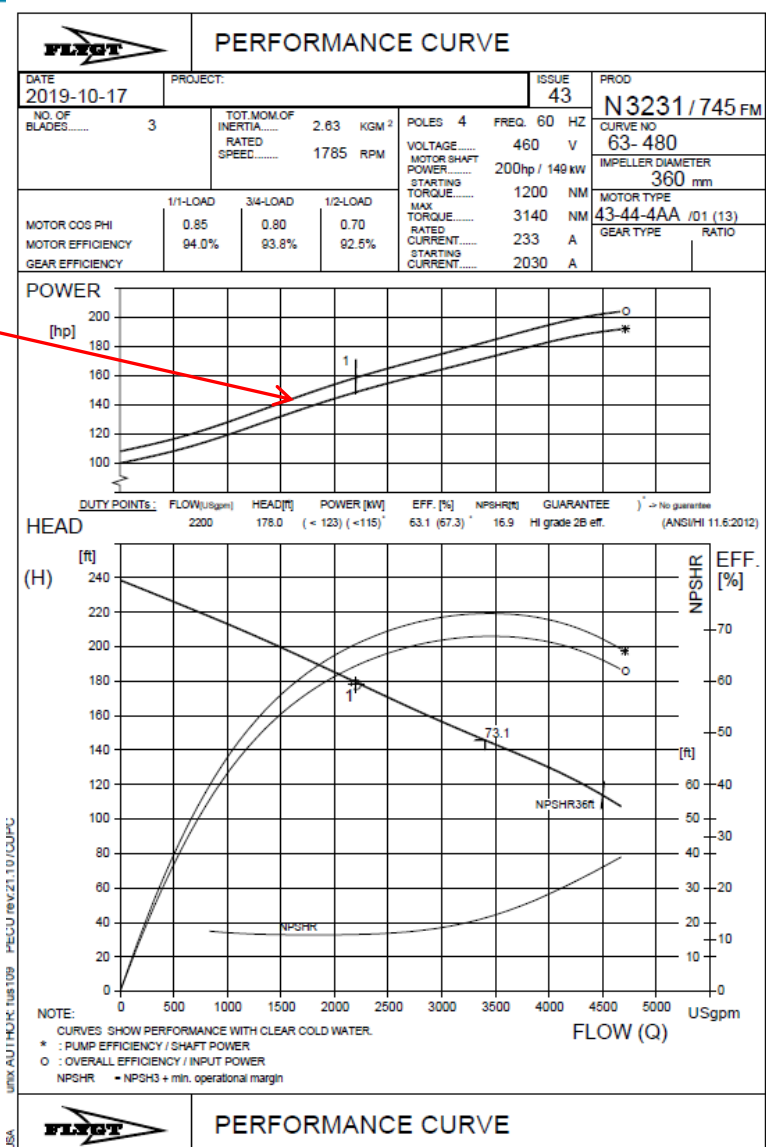
# PUMP CURVE DETAILS

1. Basic Model Number and Type
2. Impeller Code Number
3. Impeller Diameter
4. Voltage Supply
5. Motor HP
6. RPM
7. Brake Horsepower Curve
8. Motor input (KW) curve
9. Capacity (Q)-Head (H) Curve
10. Net Positive Suction head required curve (NPSHR)
11. Power Limit (P)
12. Hydraulic Efficiency
13. Overall Efficiency
14. Motor Efficiency
15. Power Factor
16. Motor #
17. BEP or Duty Point



# Flygt Performance curve

- Input power (P1)
- Shaft power (P2)
- Pump efficiency
- Overall efficiency
- Head
- Flow
- Limitations (Power)
- NPSHR

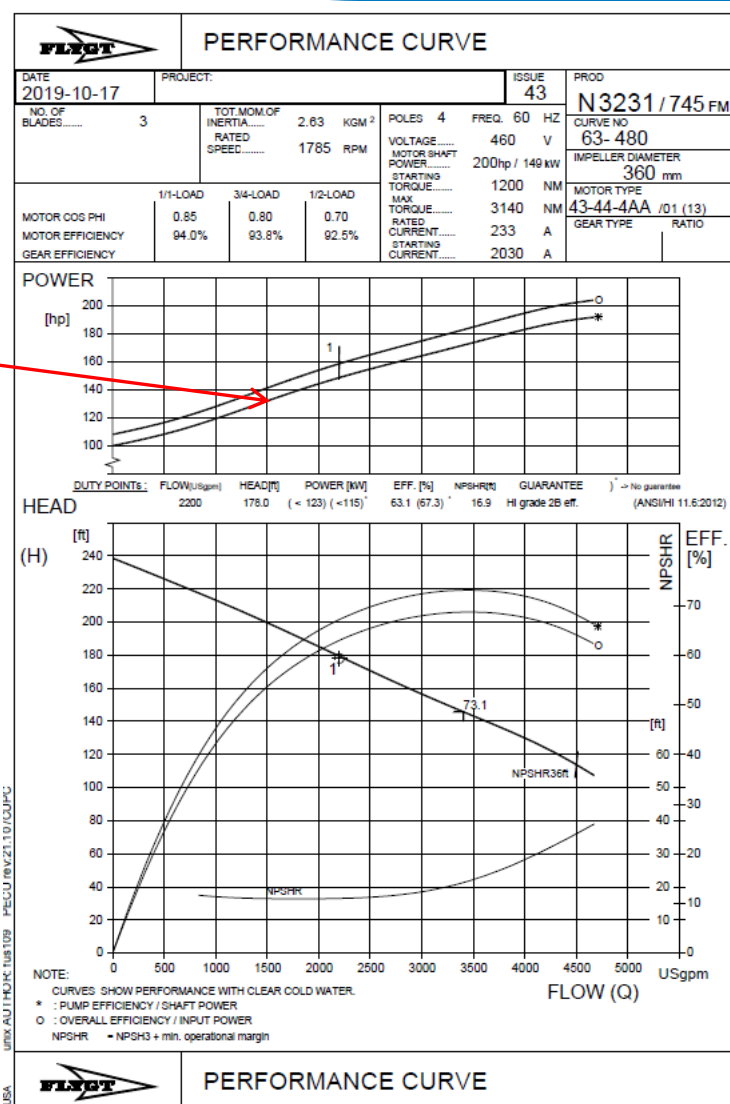


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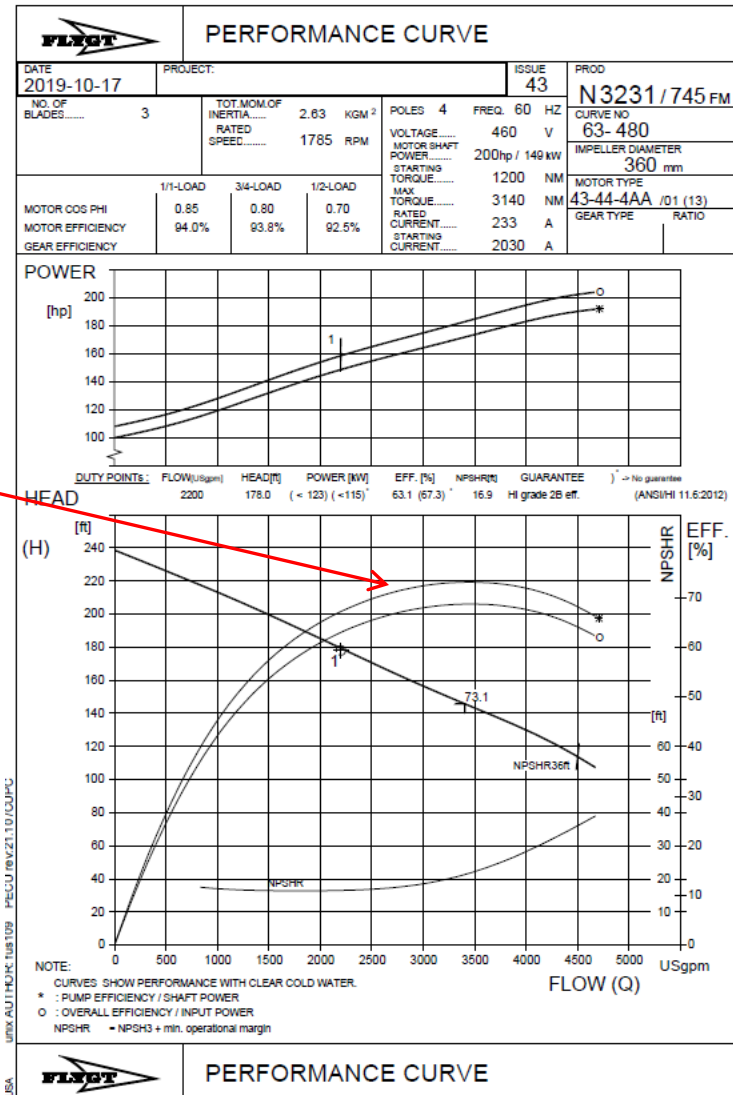
# Flygt Performance curve

- Input power (P1)
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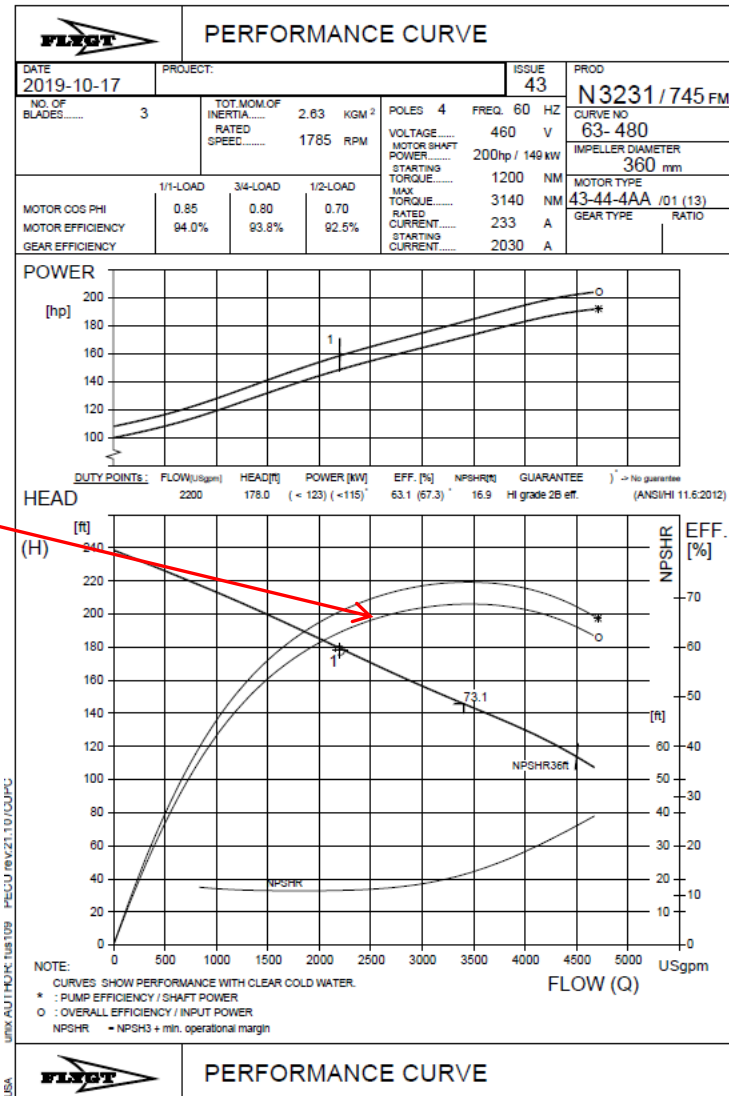
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PERFORMANCE CURVE

# Flygt Performance curve

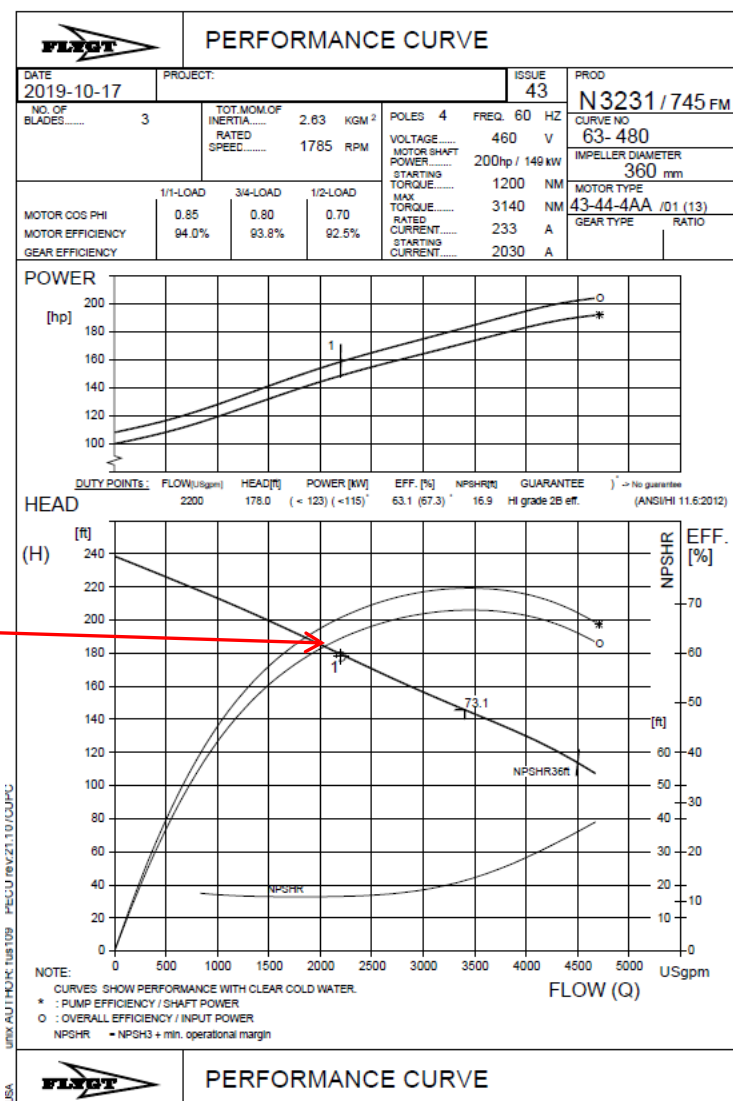
- Input power (P1)
- Shaft power (P2)
- Pump efficiency
- Overall efficiency
- Head
- Flow
- Limitations (Power)
- NPSHR



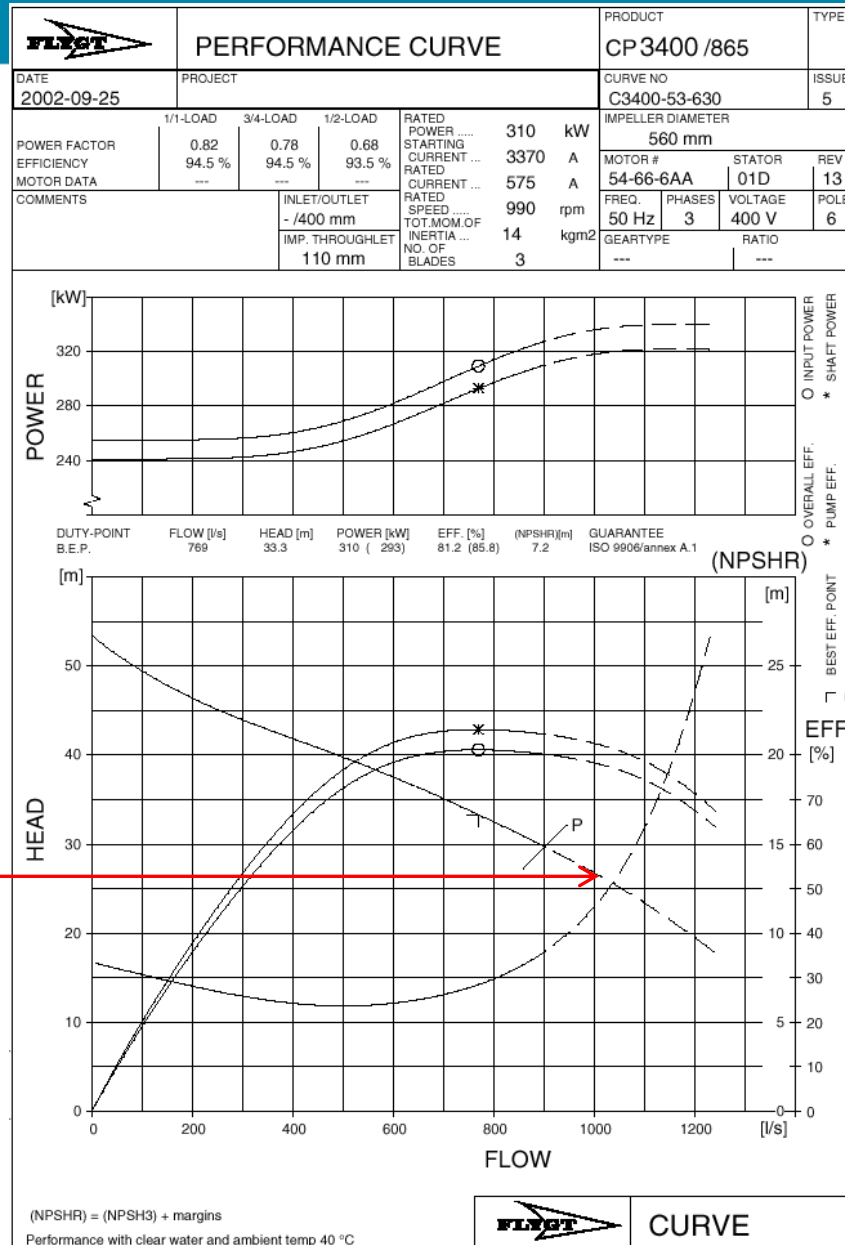
# Flygt Performance curve

- Input power (P1)
- Shaft power (P2)
- Pump efficiency
- Overall efficiency

- Head
- Flow
- Limitations (Power)
- NPSHR



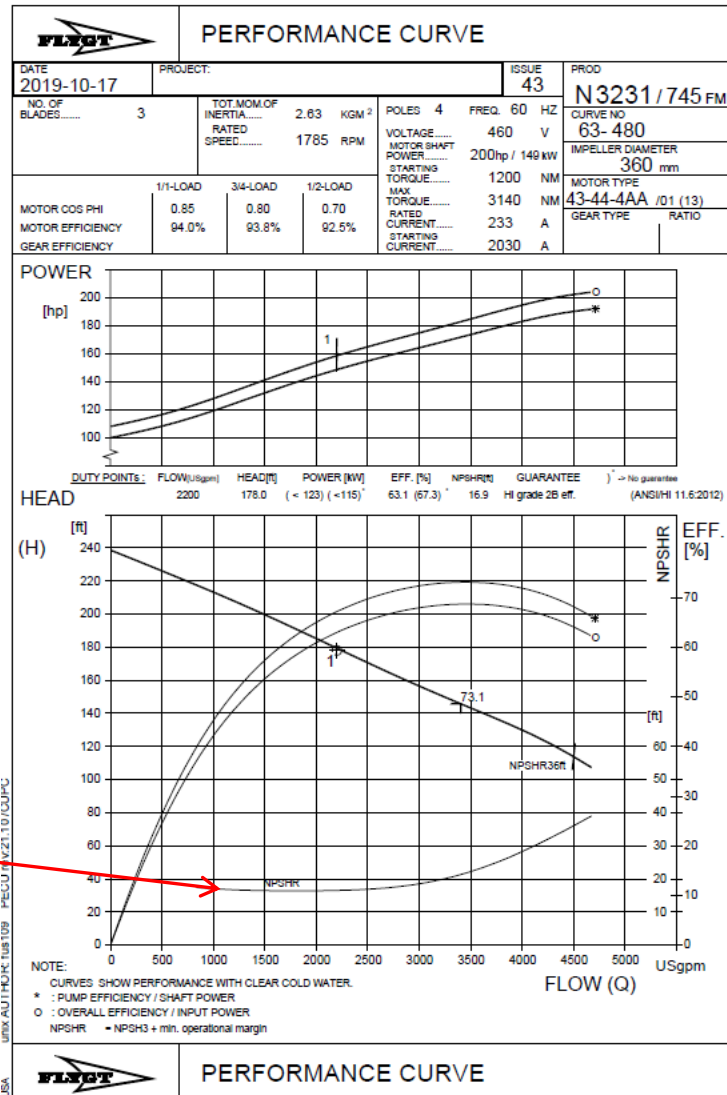
# Flygt Performance curve



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- Shaft power (P2)
- Pump efficiency
- Overall efficiency
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# Flygt Performance curve

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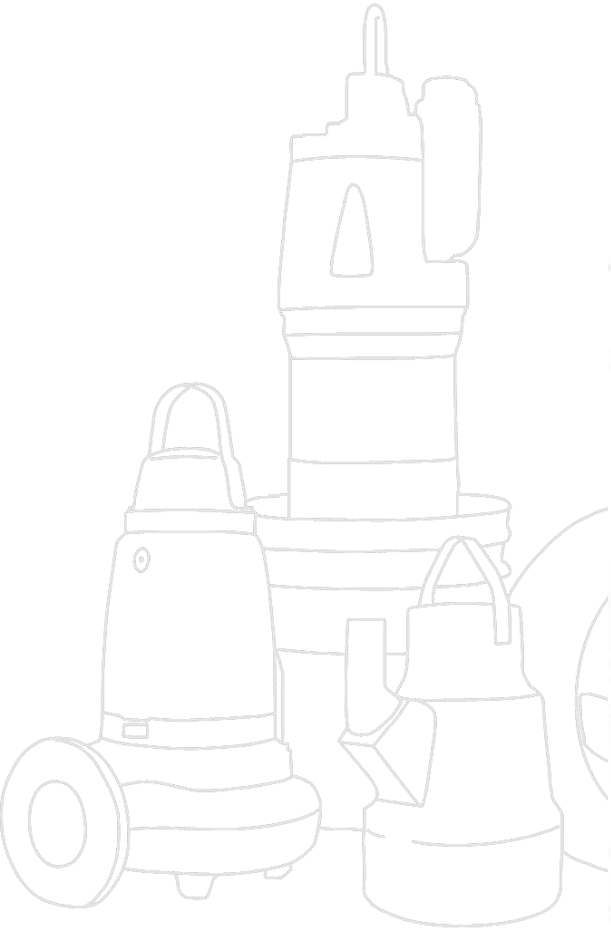
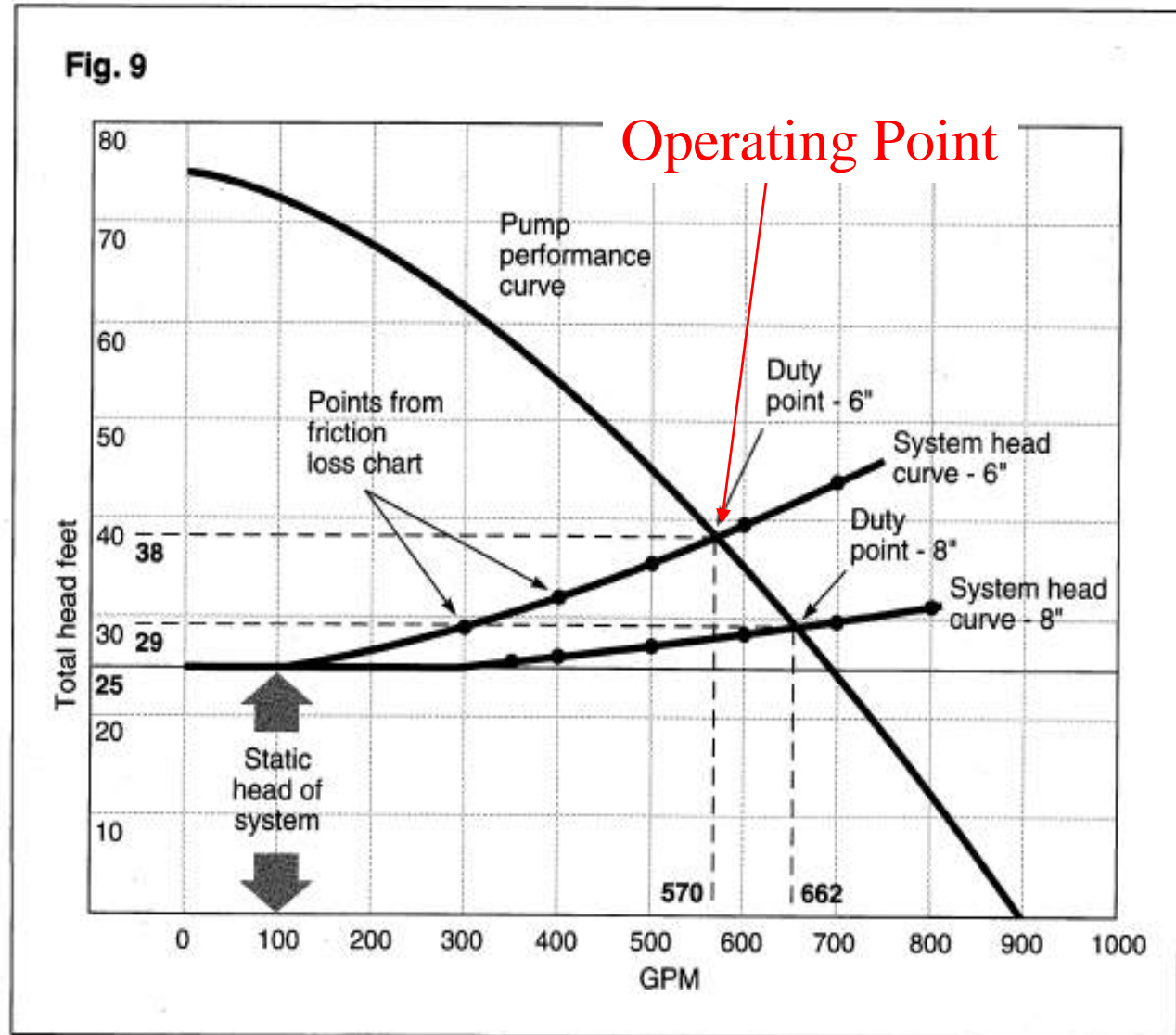


**Duty point**



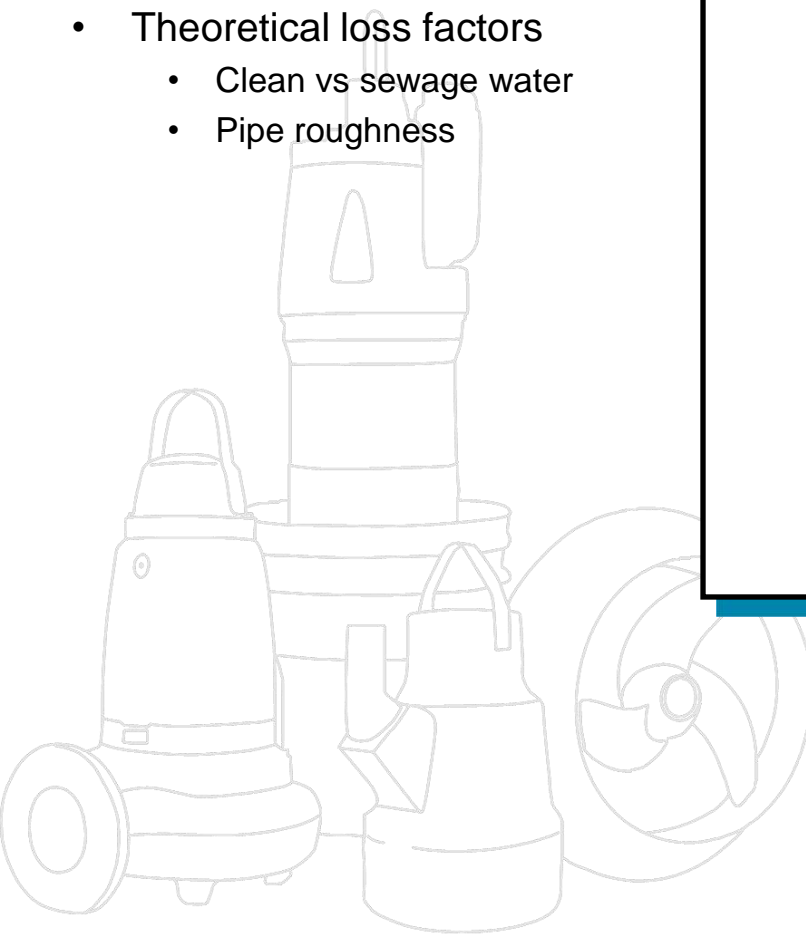
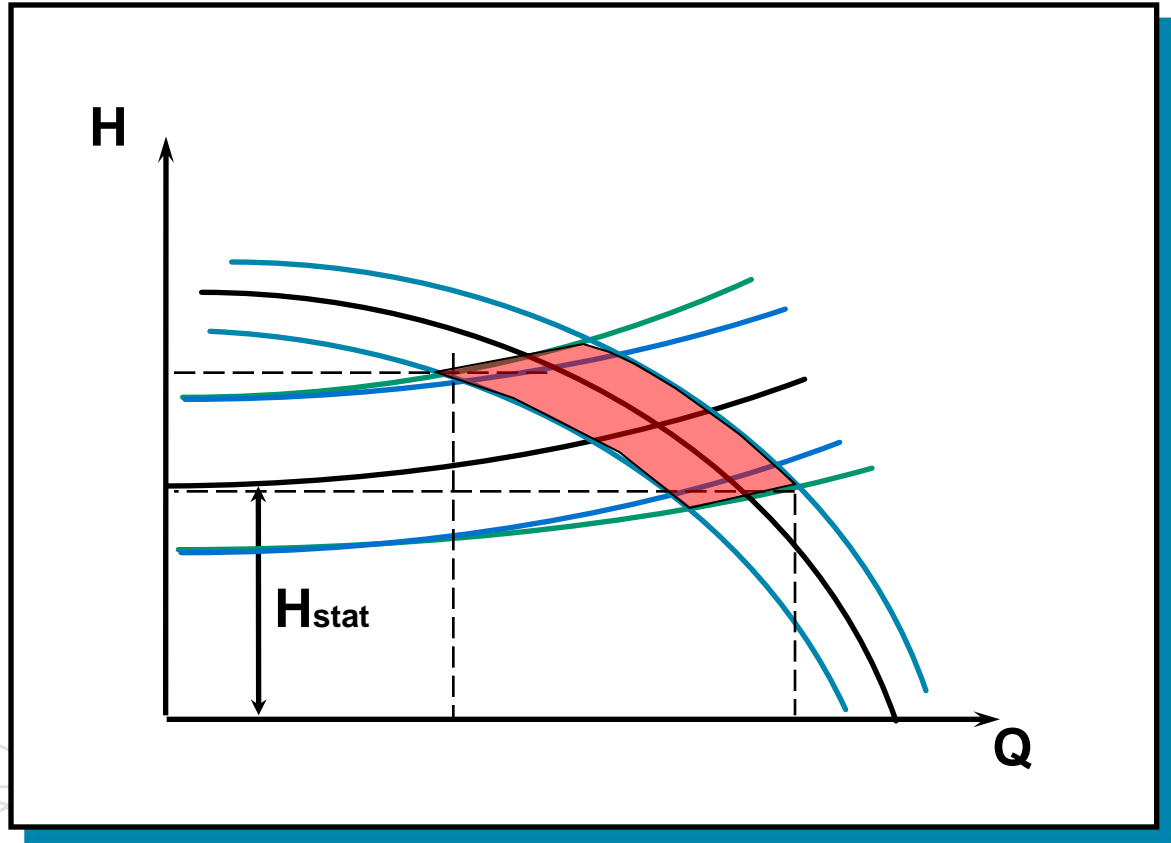
# System Head Curves

A system head curve shows the loss in a system over and above the static head of the system.



# Uncertainty in duty point

- Factory tolerances
- Water levels
- Theoretical loss factors
  - Clean vs sewage water
  - Pipe roughness



# The use of gauges to Determine Pump Performance

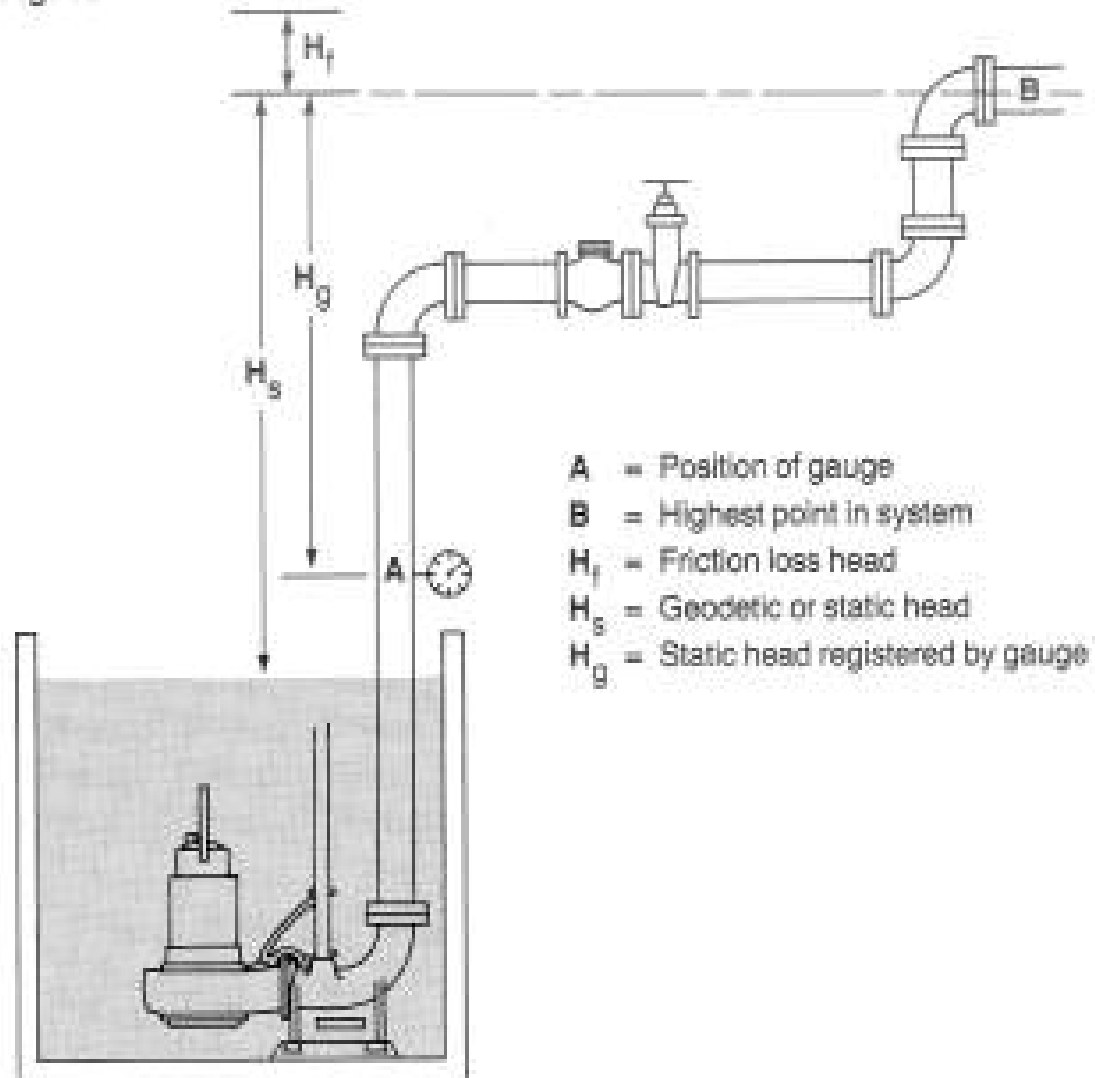
To find the total dynamic head of the system, the following must be added to the gauge reading:

1. Difference in elevation from the surface of the liquid being pumped to the center line of the gauge. (In most cases, this is an ever changing value due to draw-down.)
2. The friction losses from the pump outlet to the center line of the gauge. (This also is an everchanging value due to draw-down, and can be computed by the use of system head curves.)
3. The velocity head at point of gauge installation.

With the throttling valve full open and the pump operating, the gauge at point A will record:

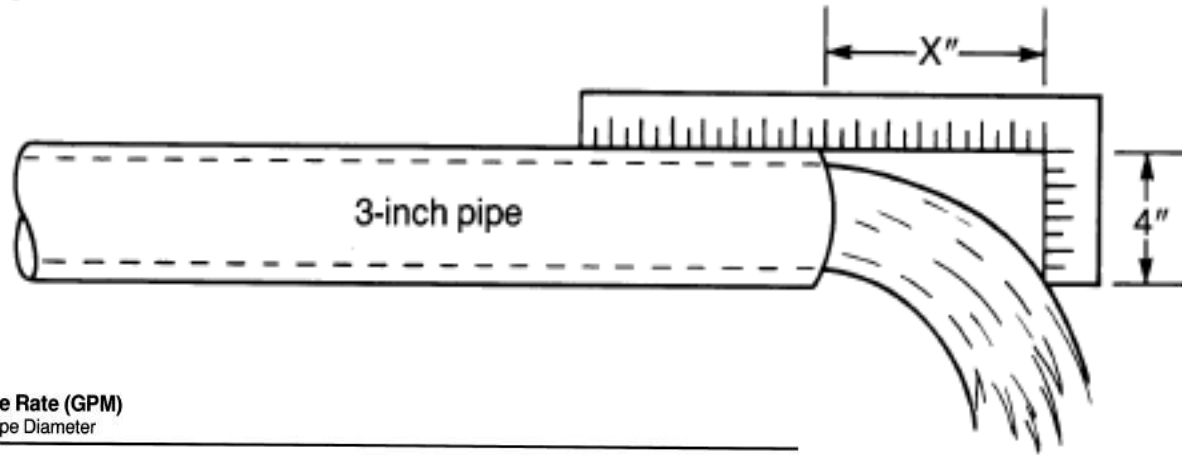
1. The difference in elevation between the center line of the gauge and point B, the highest point in the system. ( $H_g$ )
2. Friction losses in piping, fittings, etc. from the gauge to point B.

Fig. 18



# Estimating Flows

**Fig. 1**



**Discharge Rate (GPM)**  
Nominal Pipe Diameter

Horiz. Dist. "X" (Inches)	1"	1 1/4"	1 1/2"	2"	2 1/2"	3"	4"	5"	6"	8"	10"	12"
4	5.7	9.8	13.3	22.0	31.3	48.5	83.5					
5	7.1	12.2	16.6	27.5	39.0	61.0	104	163				
6	8.5	14.7	20.0	33.0	47.0	73.0	125	195	285			
7	10.0	17.1	23.2	38.5	55.0	85.0	145	228	334	580		
8	11.3	19.6	26.5	44.0	62.5	97.5	166	260	380	665	1060	
9	12.8	22.0	29.8	49.5	70.0	110	187	293	430	750	1190	1660
10	14.2	24.5	33.2	55.5	78.2	122	208	326	476	830	1330	1850
11	15.6	27.0	36.5	60.5	86	134	229	360	525	915	1460	2200
12	17.0	29.0	40.0	66.0	94	146	250	390	570	1000	1600	2200
13	18.5	31.5	43.0	71.5	102	158	270	425	620	1080	1730	2400
14	20.0	34.0	46.5	77.0	109	170	292	456	670	1160	1860	2590
15	21.3	36.3	50.0	82.5	117	183	312	490	710	1250	2000	2780
16	22.7	39.0	53.0	88	125	196	334	520	760	1330	2120	2960
17		41.5	56.5	93	133	207	355	550	810	1410	2260	3140
18			60.0	99	144	220	375	590	860	1500	2390	3330
19				110	148	232	395	620	910	1580	2520	3500
20					156	244	415	650	950	1660	2660	3700
21						256	435	685	1000	1750	2800	
22							460	720	1050	1830	2920	
23								750	1100	1910	3060	
24									1140	2000	3200	

# Pump Draw Down Test for Estimating Flow



## Operation Matters

Kentucky Department for Environmental Protection

To collect the data, you will need to know the size of the lift station (diameter in feet or length, width and depth), design size and rated capacity of the pump, influent rate with no pump running and rise rate with one pump running.

How do I find this data? For the size requirement, you should check the as-built plans to determine the diameter or length, width and depth of the lift station. What about the influent rate? Does it change all the time? You have to measure the influent rate with a rod or pipe marked in feet and inches to determine the cubic footage over a set time period. So with your marked rod, a stopwatch and the pump turned off measure the water rise in a set time to determine the cubic feet per minute and multiply it times 7.48 gal/ft<sup>3</sup> to get gallons per minute influent. Next, turn the pump on and measure the rise in water over a set period with the pump in operation. This is the rise rate with the pump running. Calculate the cubic feet per minute and gallons per minute, and then subtract the influent rate from the rise rate and determine the gallons per minute pump rate.

To determine the efficiency of the pump, divide the pump rate in gallons per minute by the rated capacity of the pump in gallons per minute and multiply that times 100 to get a percentage of efficiency.

# Pump Draw Down Test for Estimating Flow



## Operation Matters

Kentucky Department for Environmental Protection

The following is an example:

You want to check the flow rate of a pump in a lift station rated at 250 gpm to determine its efficiency as compared to its rated capacity. The lift station has a diameter of 10 feet and a depth of 25 feet. The influent flow to the lift station rises, with no pump running, at a rate of 8 feet in 10 minutes and with the pump running, the rise rate is 5 feet in 10 minutes.

- What is the influent rate in gpm?
- What is the rise rate with a pump running in gpm?
- What is the pump rate in gpm?

- a. Influent rate gpm with no pump running

$$\begin{aligned} & 0.785 \times 10 \text{ ft} \times 10 \text{ ft} \times 8 \text{ ft} \times 7.48 \text{ gal/ft}^3 \\ & = \\ & 4697.4 \text{ gal} \\ & = \\ & \frac{4697.4 \text{ gal}}{10 \text{ min}} \\ & = \\ & 469.74 \text{ gpm influent with no pump running} \end{aligned}$$

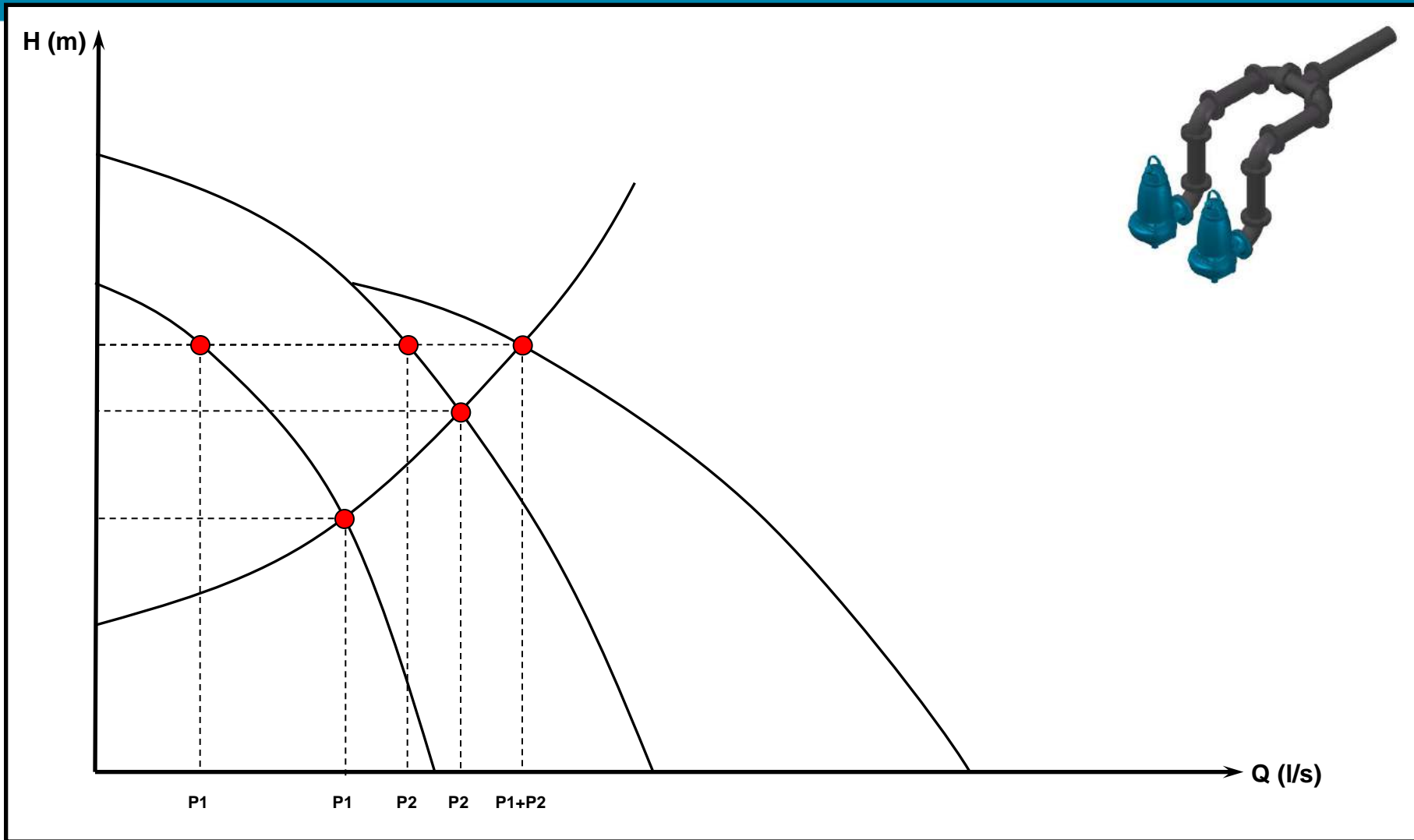
- b. Rise rate gpm with pump running

$$\begin{aligned} & 0.785 \times 10 \text{ ft} \times 10 \text{ ft} \times 5 \text{ ft} \times 7.48 \text{ gal/ft}^3 \\ & = \\ & 2935.9 \text{ gal} \\ & = \\ & \frac{2935.9 \text{ gal}}{10 \text{ min}} \\ & = \\ & 293.5 \text{ gpm rise rate with pump running} \end{aligned}$$

- c. Pump rate = gpm influent with no pump running – gpm rise rate with pump running

$$\begin{aligned} & = \\ & 469.74 \text{ gpm} - 293.5 \text{ gpm} \\ & = \\ & 176.24 \text{ gpm pump rate} \end{aligned}$$

# Parallel pumps





**NPSH- Net Positive Suction Head**

# NPSH- Net Positive Suction Head

## Cavitation

- Pressure drops locally at the inlet to the impeller blade channel.
- Low pressure bubble will form if the pressure falls below the vapor pressure of the liquid.
- The bubbles will implode when the pressure increases.

# NPSH- Net Positive Suction Head

- $NPSH_{req}$  Required pressure at pump inlet to avoid cavitation
- $NPSH_{available}$  Available pressure at the inlet
- $NPSH_{available} > NPSH_{req}$

# NPSH curve

$$NPSH_{avail} = H_{atm} - H_{vap} + S$$

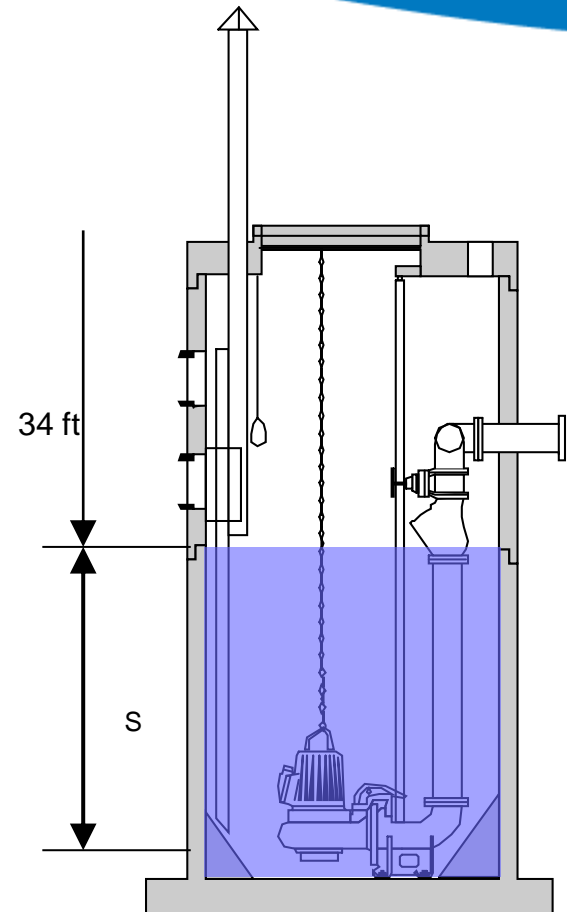
Where :

$H_{atm}$  = Absolute atmospheric pressure [m]

$H_{vap}$  = Absolute vapour pressure [m]

$S$  = Pump submergence

At sea level, we say atmospheric pressure is 1 atmosphere (this is equal to 14.7 psi).

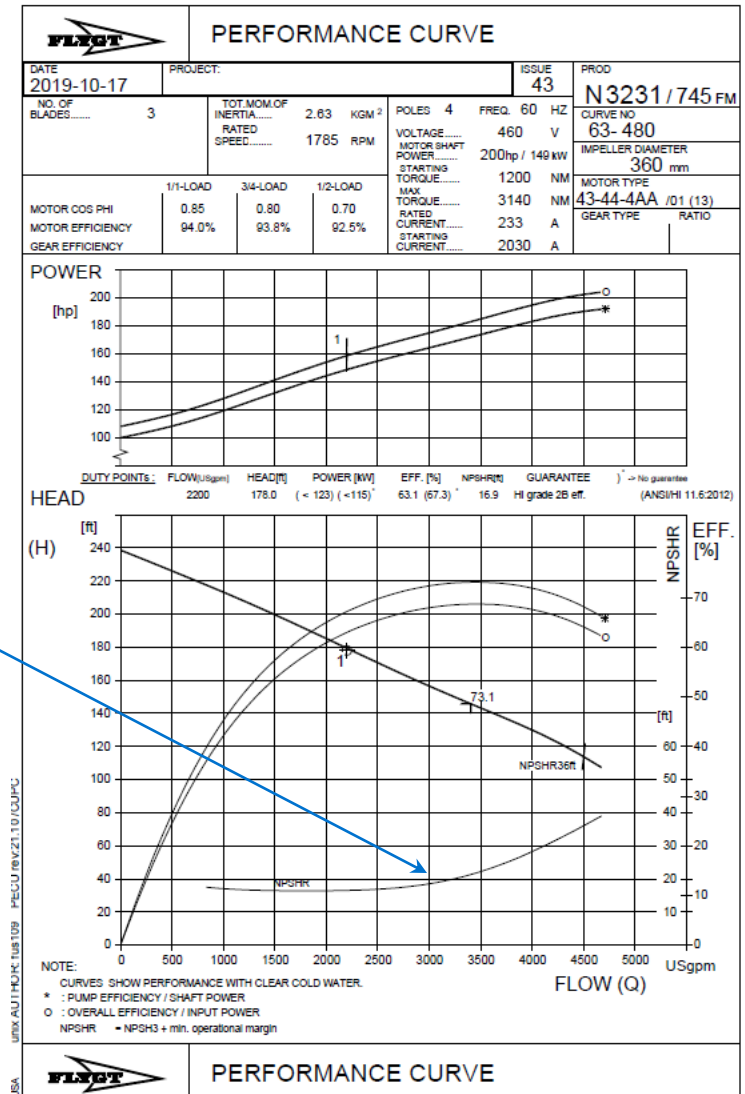


# NPSH curve

- NPSH3 absolut pressure resulting in a 3% drop on discharged head
- $NPSHR = NPSH3 + \text{margin}$
- Flygt NPSH curves show NPSHR

Read more in the Engineering Paper on OASIS: "**Net Positive Suction Head (NPSH) Terms & Applications**"

<http://oasis.xyleminc.com/en-us/Home/engineering-expertise/transport/Engineering-material-broshures-presentations/Pages/default.aspx>



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USA



PERFORMANCE CURVE

# Cavitation

- Cavitation erosion
- Noise (Crackling sound)
- Over time, reduced performance



**Erosion on pressure side**

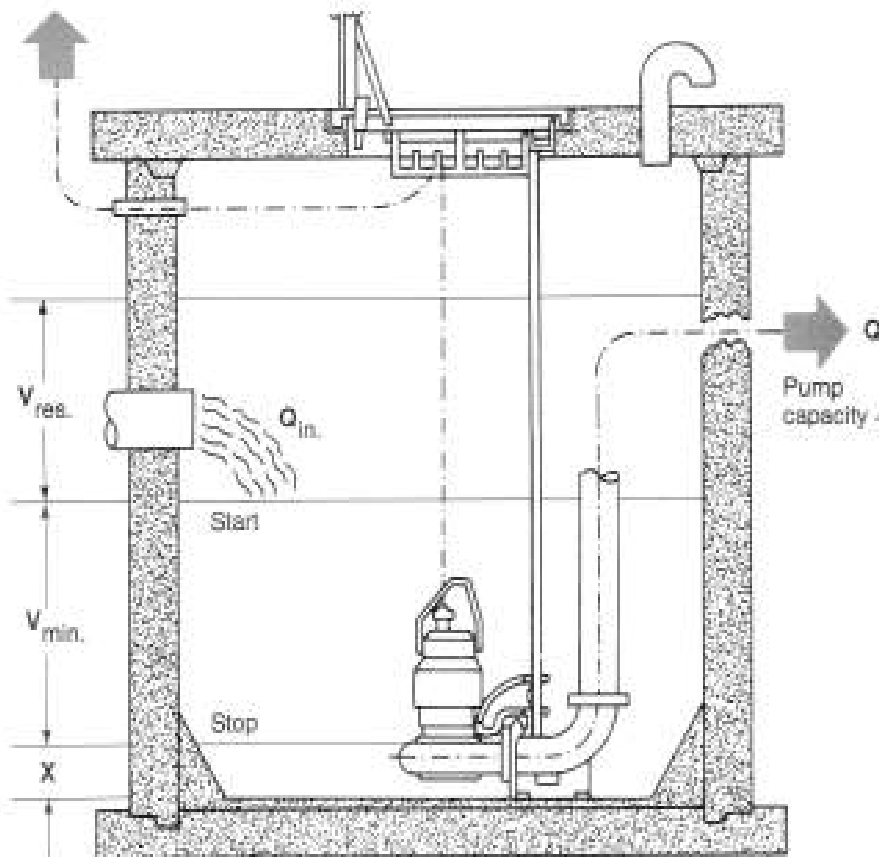


**Erosion on suction side**



# Minimum Retention Volume

Fig. 17 Determining Depth of Lift Station



$$V_{min.} = \frac{T_{min.} \times Q}{4}$$

Where:

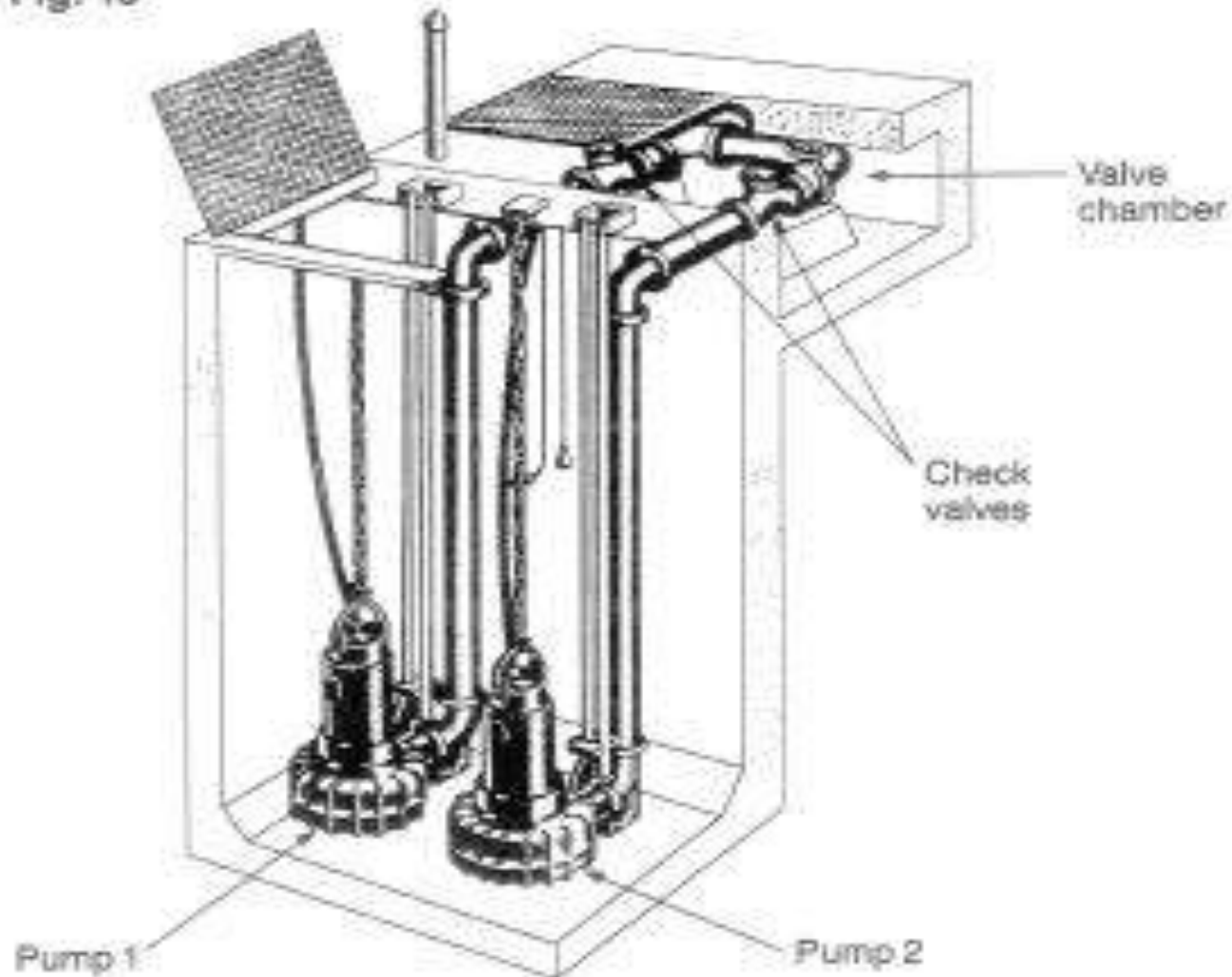
$V_{min.}$  = The minimum effective sump volume in gallons. The effective sump volume is the volume between the start and stop levels in the station. The stop level is normally at the top of the volute. The start level should be somewhere below in the inflow pipe to prevent possible sedimentation in the inflow piping system.

$T_{min.}$  = The minimum cycle time in minutes. The minimum cycle time is 6 minutes and is the sum of the time it takes to fill the sump volume and the time to draw-down to the stop level. This minimum cycle time is achieved when the pump capacity ( $Q$ ) is two times the inflow  $Q_{in}$ .

$Q$  = Pump capacity in GPM.

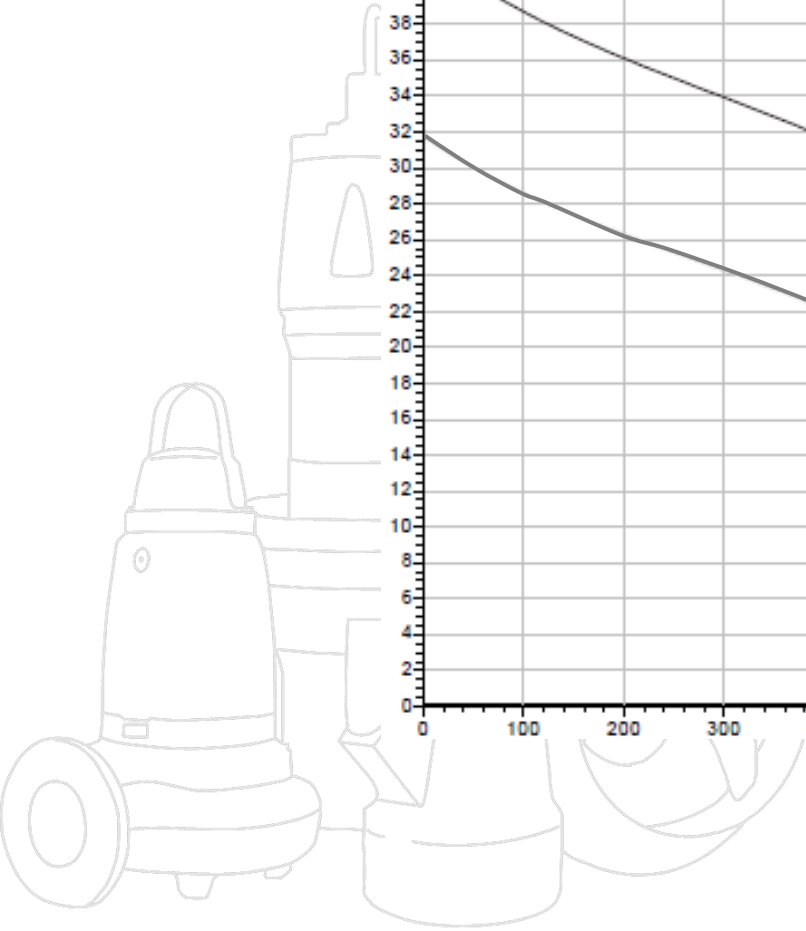
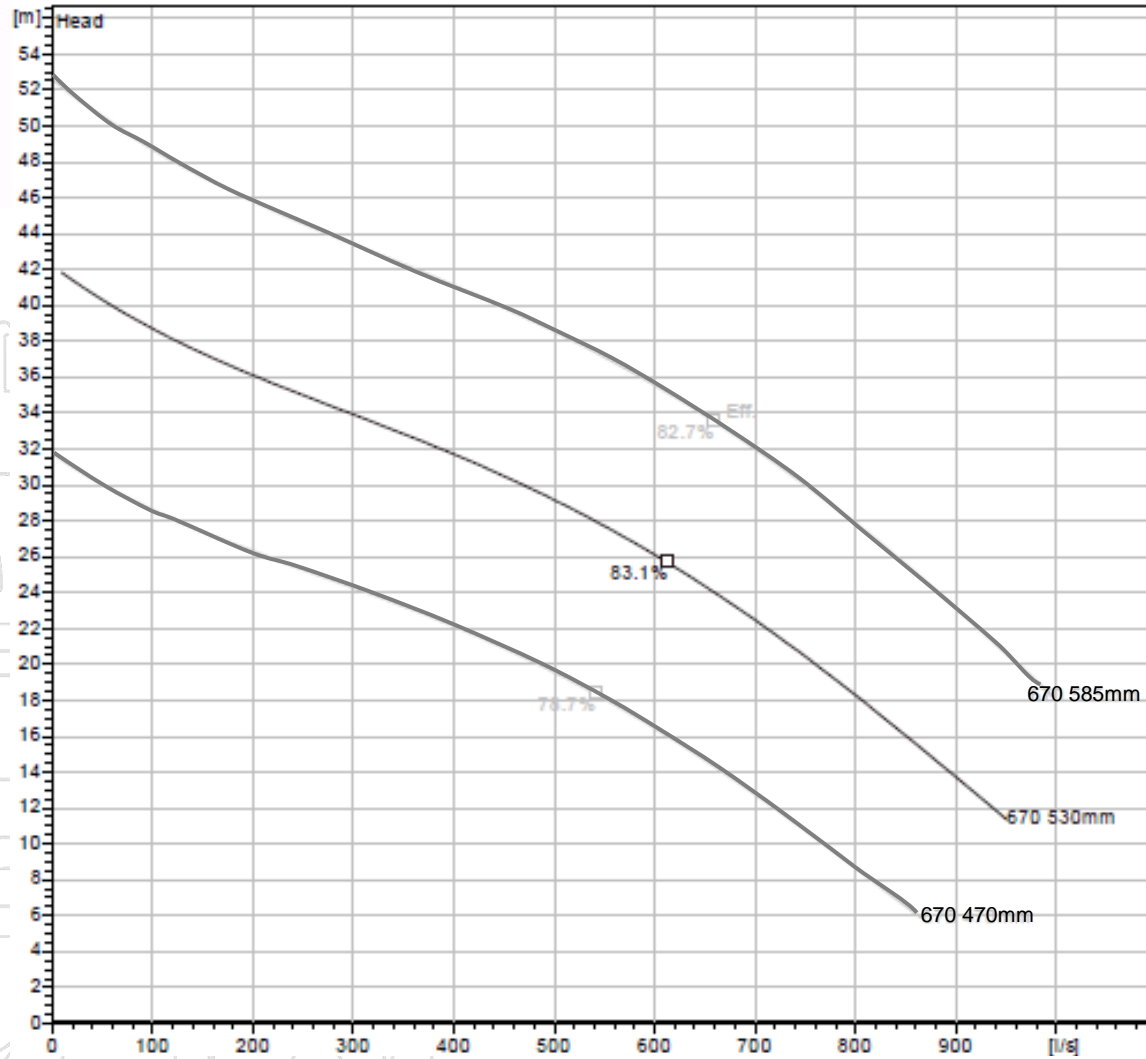
# CHECK VALVE MAINTENANCE

Fig. 15



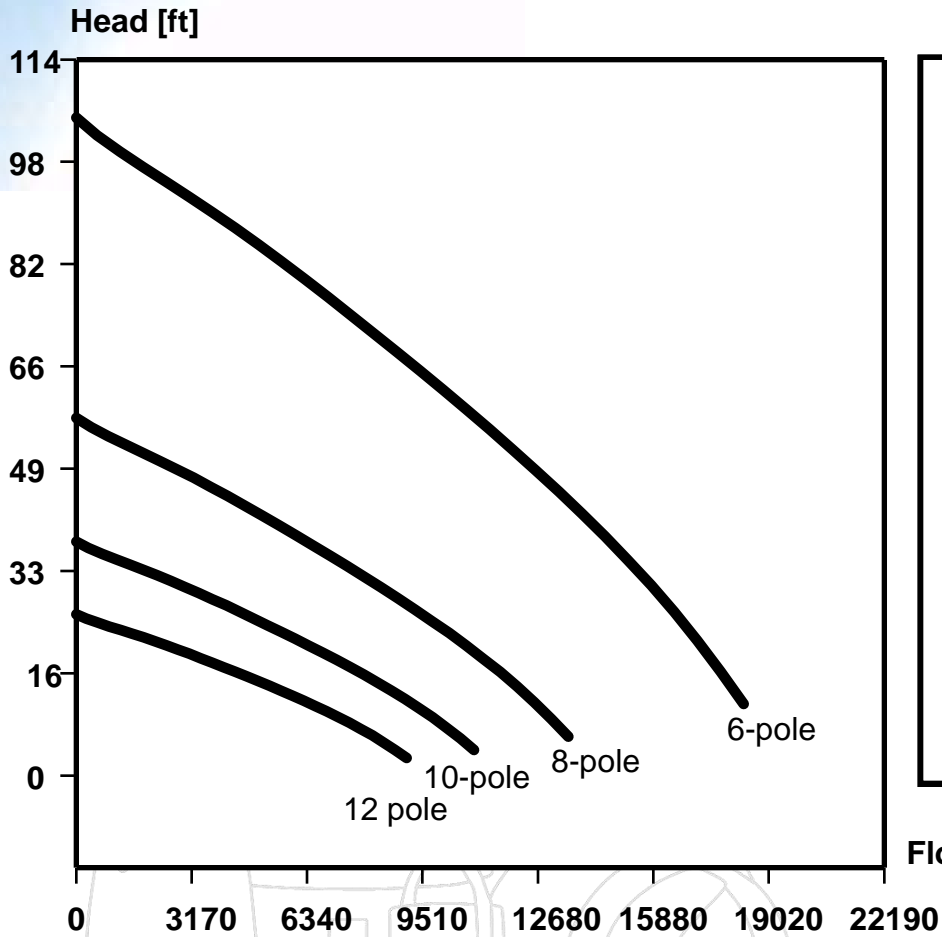


# Changing impeller diameter





# Changing pole number



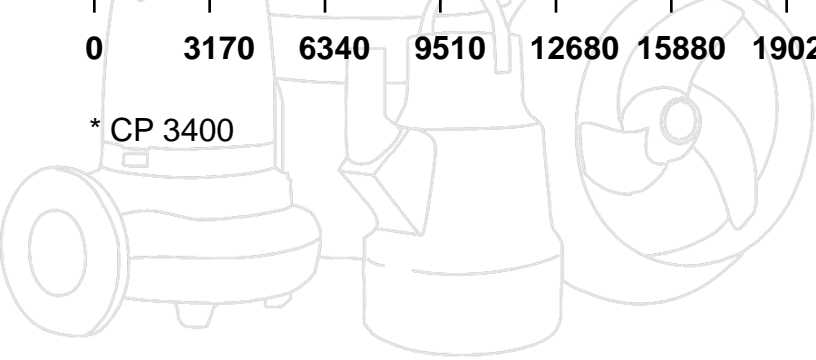
### Synchronous speed:

60 Hz:  $n = 7200 / \text{\# of poles}$        $n = 120 \bullet \frac{\text{frequency}}{\text{pole\#}}$

60 Hz Pole #	rpm
12	600
10	720
8	900
6	1200
4	1800

Flow [gpm]

\* CP 3400



# AFFINITY LAWS

1. Capacity varies directly with speed or diameter changes.

$$GPM_2 = GPM_1 \times \frac{RPM_2}{RPM_1} \text{ or } GPM_2 = GPM_1 \times \frac{d_2}{d_1}$$

2. Total head varies as the square of the speed or diameter.

$$H_2 = H_1 \times \left(\frac{RPM_2}{RPM_1}\right)^2 \text{ or } H_2 = H_1 \times \left(\frac{d_2}{d_1}\right)^2$$

3. Brake horsepower varies as the cube of the speed or diameter.

$$BHP_2 = BHP_1 \times \left(\frac{RPM_2}{RPM_1}\right)^3 \text{ or } BHP_2 = BHP_1 \times \left(\frac{d_2}{d_1}\right)^3$$

## Example using the affinity law formulas:

Original pump capacity is 400 GPM, Head is 200', BHP is 34, Impeller diameter is 6" and the speed is 3450 RPM.

Decrease the speed to 1750 RPM:

Capacity:

$$400 \times \frac{1750}{3450} = 400 \times .507 = 202.8 \text{ GPM}$$

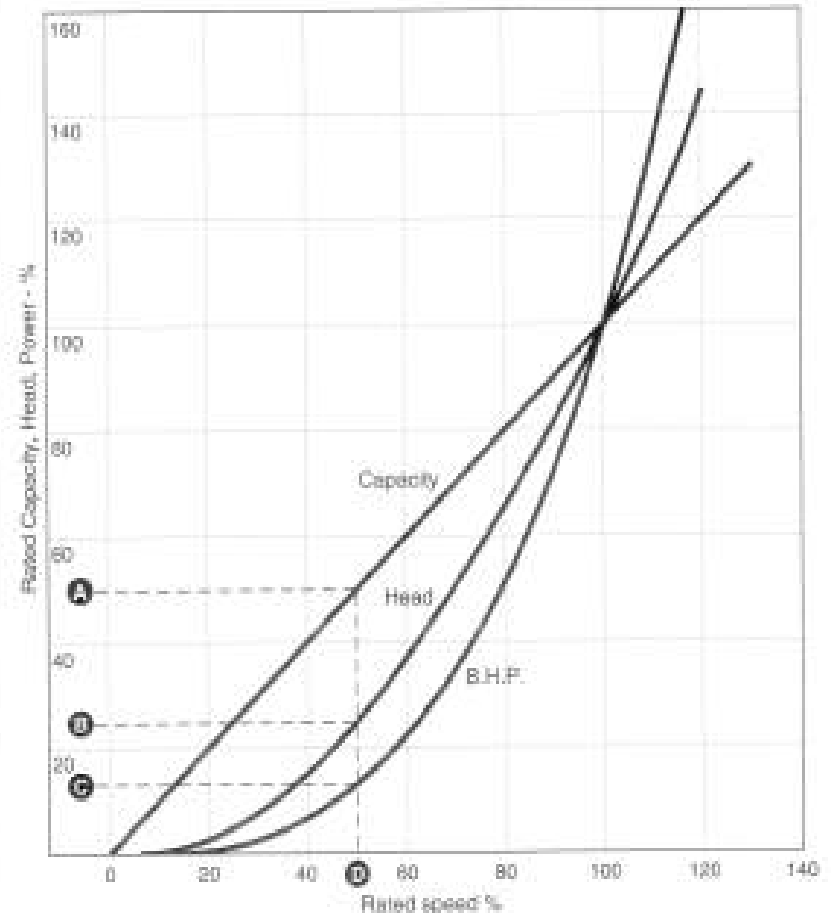
Head:

$$200 \times \left(\frac{1750}{3450}\right)^2 = 200 \times .257 = 51.4 \text{ ft}$$

BHP:

$$34 \times \left(\frac{1750}{3450}\right)^3 = 34 \times .130 = 4.42 \text{ HP}$$

Fig. 19



- A Capacity is reduced to 50%
- B Head (PSI) is reduced to 25%
- C Brake HP is reduced to 12.5%
- D Speed is reduced to approx. 50% (from 3450 RPM to 1750 RPM)

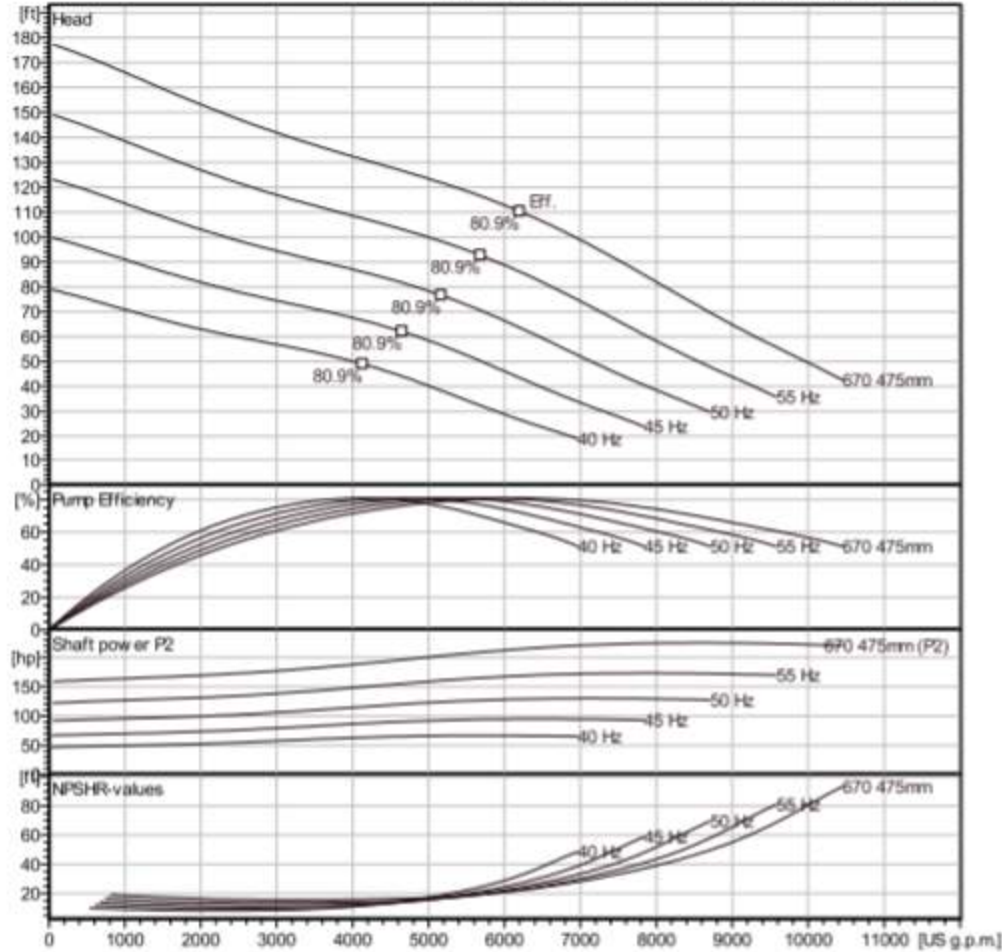
# Flow control with VFD (changing frequency)

NP 3306/765 3~ 670

Duty Analysis



Curves according to: Water, pure [100%]; 39.2°F; 62.42lb/hr; 1.5891E-5ft³/s



# Acceptable Operating Range vs Preferred Operating Range (AOR & POR)

## Defining AOR and POR

POR defines the range where pump flow is well controlled, i.e. uniform and free from separation. The POR for any pump is the more restrictive operating region. According to ANSI/HI standard 9.6.3, the POR for most centrifugal pumps is the range of flow between 70% and 120% of the flow at BEP. For vertical (axial flow) pumps with specific speeds greater than 4500 (US units), the POR is more narrow, 80% to 115% of flow at BEP. The POR is smaller for these types of pumps due to their sensitivity to adverse hydraulic conditions. Operation within POR will ensure that the pump will have its intended service life and will operate as smoothly as possible.

AOR defines a wider operating range and is the range of flow where pump operating life is not significantly reduced, as determined by the pump manufacturer. There is a greater risk of adverse conditions in this region, such as increased shaft loading, noise and vibration. As a result, the life of a pump operating in this region is expected to be slightly lower than that of a similar pump operating within the POR. However, the pump manufacturer takes the responsibility to define this region in such a manner as to provide an operating life that is satisfactory to both manufacturer and customer alike. Xylem-Flygt defines the AOR for the majority of their submersible centrifugal wastewater pumps to be between 50% and 125% of flow at BEP.

# Acceptable Operating Range vs Preferred Operating Range (AOR & POR)

Once the operating flow and BEP flow are determined, the operating flow is divided by the flow at BEP and multiplied by 100 to obtain a percentage of BEP flow (1).

$$(1) \quad Q_{OP} / Q_{BEP} \times 100 = \% \text{ BEP flow}$$

Where:

$Q_{OP}$  = flow at operating point

$Q_{BEP}$  = flow at pump best efficiency

The % BEP flow is then compared to the limits defined previously for AOR and POR. If % BEP flow is greater than 50% but less than 125%, the pump will be operating within the AOR. If % BEP flow is greater than 70% but less than 120%, the pump will be operating within the POR. These relationships are summarized in equations (2) and (3).

$$(2) \quad AOR_{LL} < \% \text{ BEP flow} < AOR_{UL}$$

$$(3) \quad POR_{LL} < \% \text{ BEP flow} < POR_{UL}$$

$AOR_{LL}$  = lower limit of allowable operation to remain within AOR (50%)

$AOR_{UL}$  = upper limit of allowable operation to remain within AOR (125%)

$POR_{LL}$  = lower limit of allowable operation to remain within POR (70%)

$POR_{UL}$  = upper limit of allowable operation to remain within POR (120%)

# Acceptable Operating Range vs Preferred Operating Range (AOR & POR)

Relative Radial Load vs Pump Flow

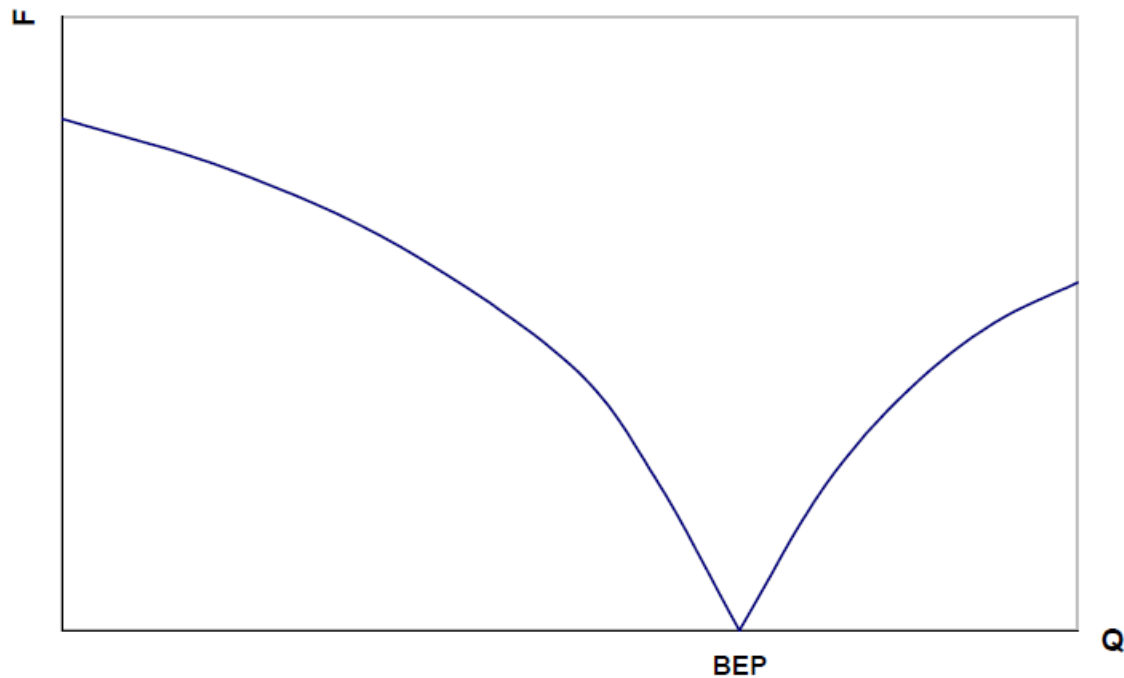


Figure 1. Relative radial load (F) as a function of pump flow (Q) for radial flow impellers

# Acceptable Operating Range vs Preferred Operating Range (AOR & POR)

Relative Radial Load vs Pump Flow

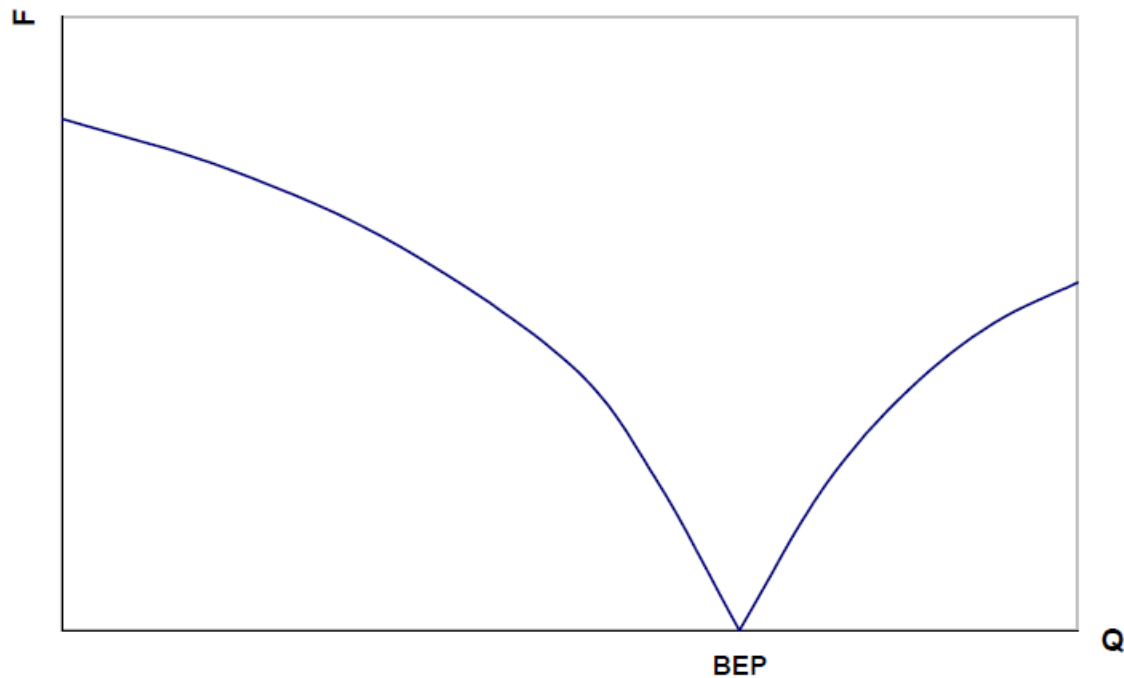
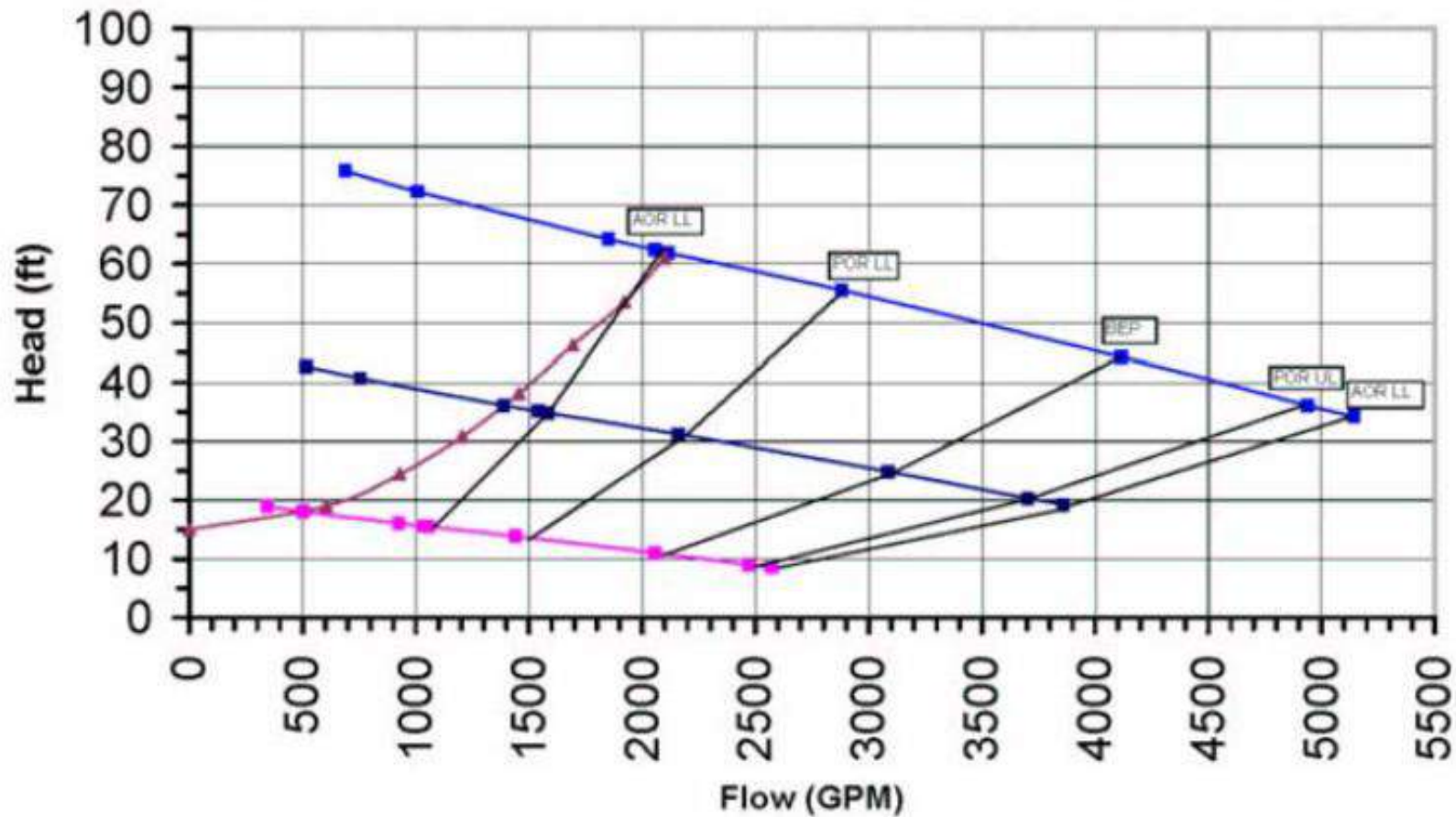
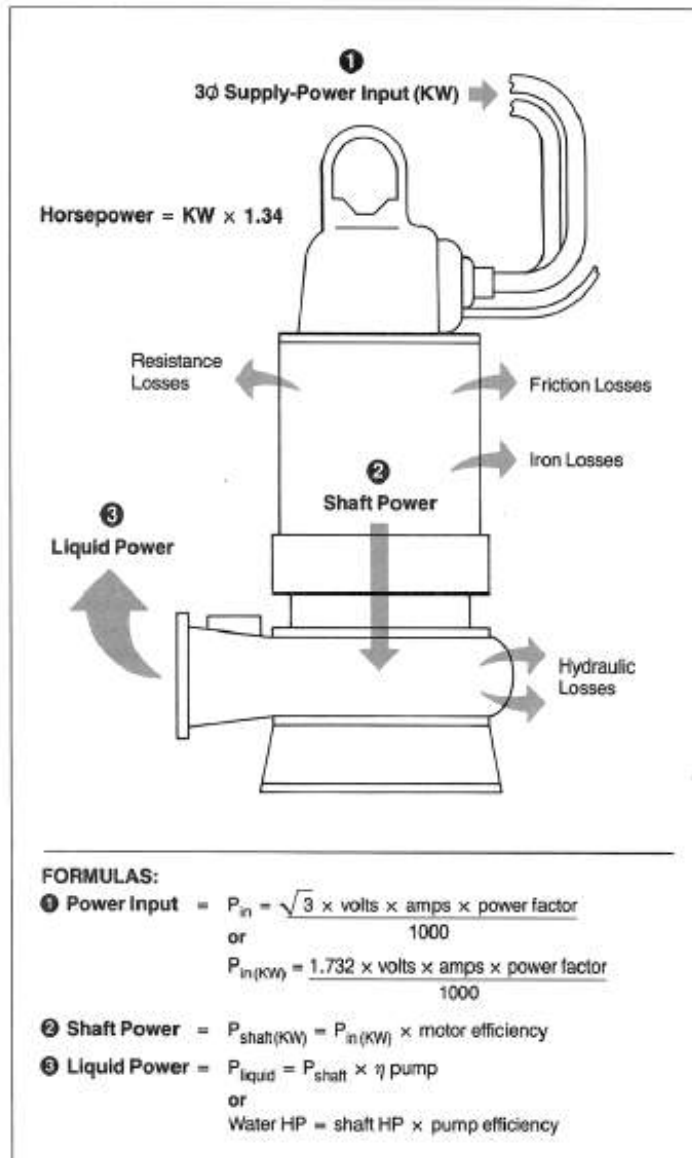


Figure 1. Relative radial load (F) as a function of pump flow (Q) for radial flow impellers

# Acceptable Operating Range vs Preferred Operating Range (AOR & POR)



# Understanding Pump Power & Efficiency

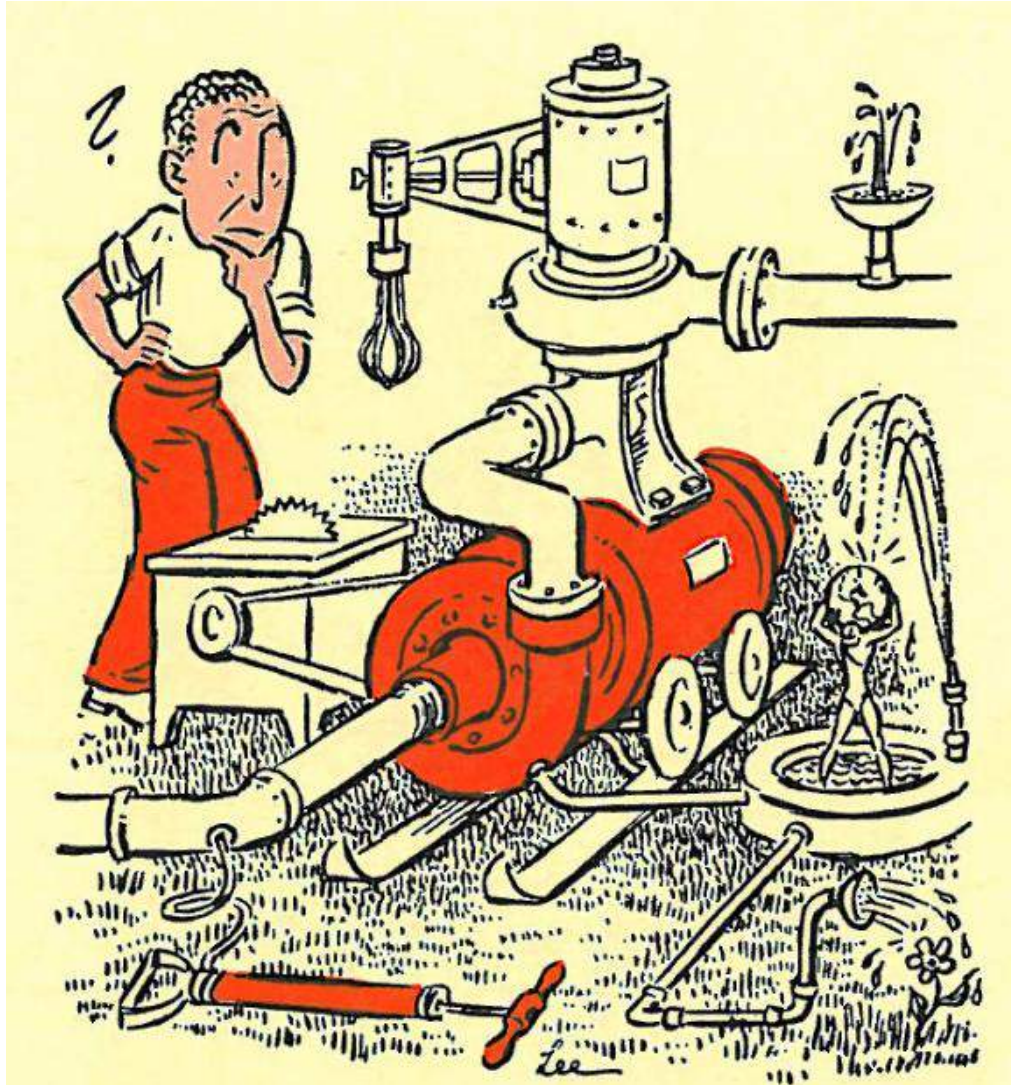


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$$\text{KW input at duty point} = \frac{\text{GPM} \times \text{head in ft}}{3960 \times \text{pump eff.}} \times \frac{.746}{\text{Motor eff.}} \times \text{SG}$$


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# Questions??



# The End – Thank you!

Submersible Pump Operation & Maintenance  
Virtual Operator Training ~ June 4, 2020

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