

Grundfos ECADEMY

Pump hydraulics

Energy losses in pumping



GRUNDFOS 

Possibility in every drop



Energy losses in pumping

- There are two categories of losses in Pumping;
- Hydraulic losses in the pump and pump piping.
- Electrical losses in the motor and associated electrical components.

Hydraulic losses

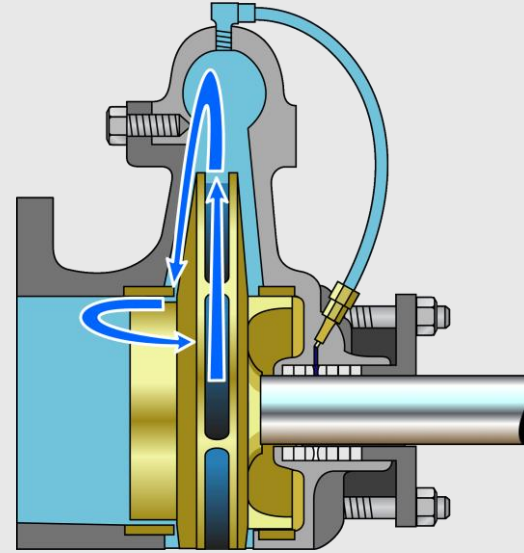
Electrical losses

Hydraulic losses

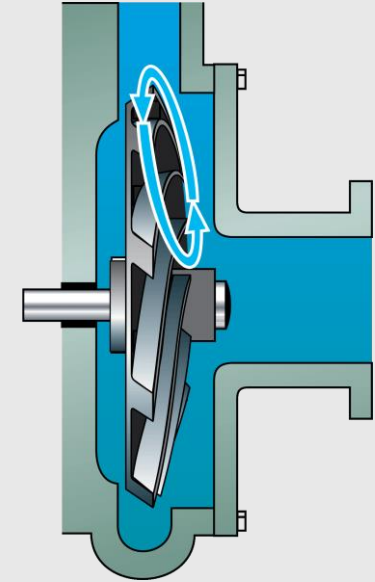
- Entrance losses where the suction piping connects to the volute case
- Friction between the water and the volute case
- Recirculation of water inside the volute case
- Water moving between the high and low pressure zones
- The amount is dependent upon impeller type and condition of the pump

Hydraulic losses

- Here's an example of recirculation losses.
- You can see from the pictures that there will be more recirculation losses in a semi open impeller.



Closed Impeller



Semi-open Impeller



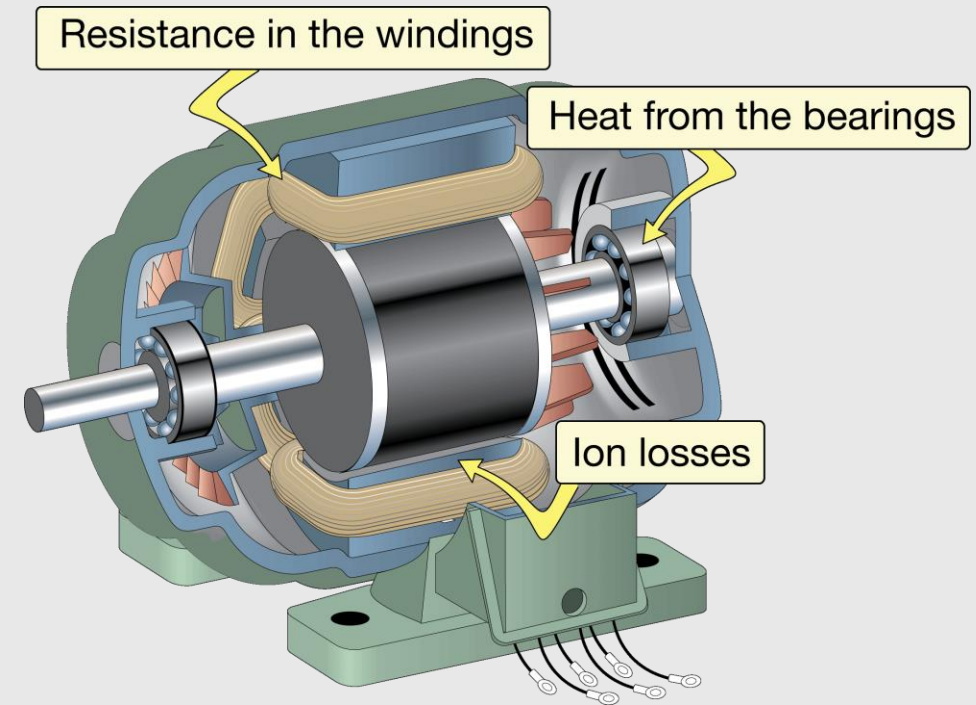
Electrical losses

- In addition to the hydraulic losses we have the electrical losses.
- These electrical losses include
 - Electrical losses in the motor
 - Mechanical losses in the motor
 - Improper load on the motor and thermal protection devices



Electrical losses

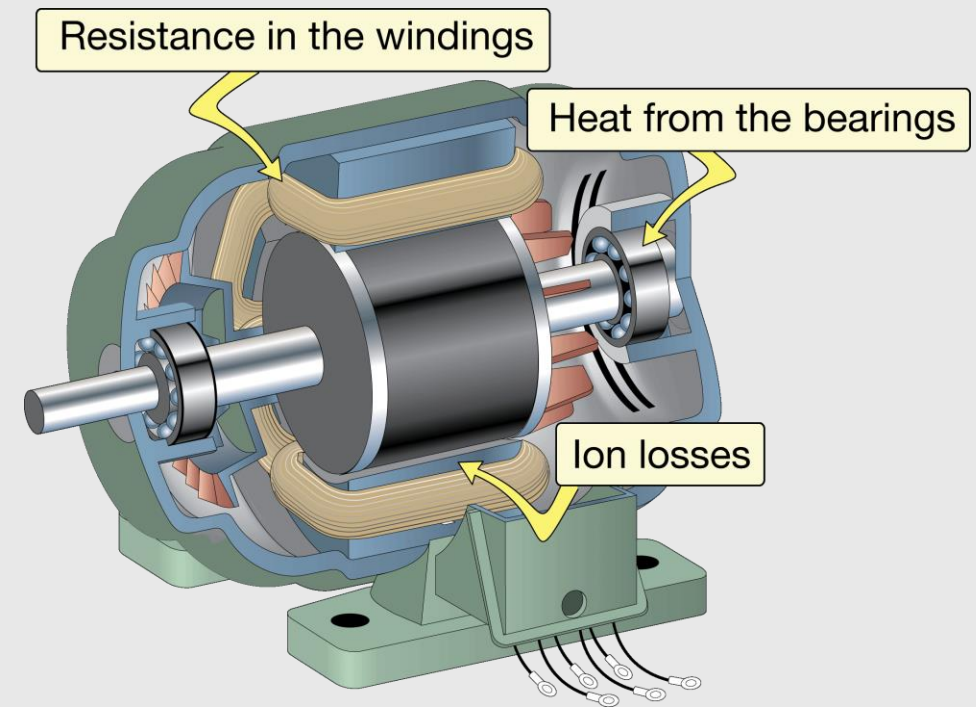
- Motor losses consist of resistance in the windings, heat from the bearings and Ion losses.
- Ion losses (reduction in the strength of the magnetic field in the stator and rotor)
Reduces the transfer of energy between the rotor and stator.





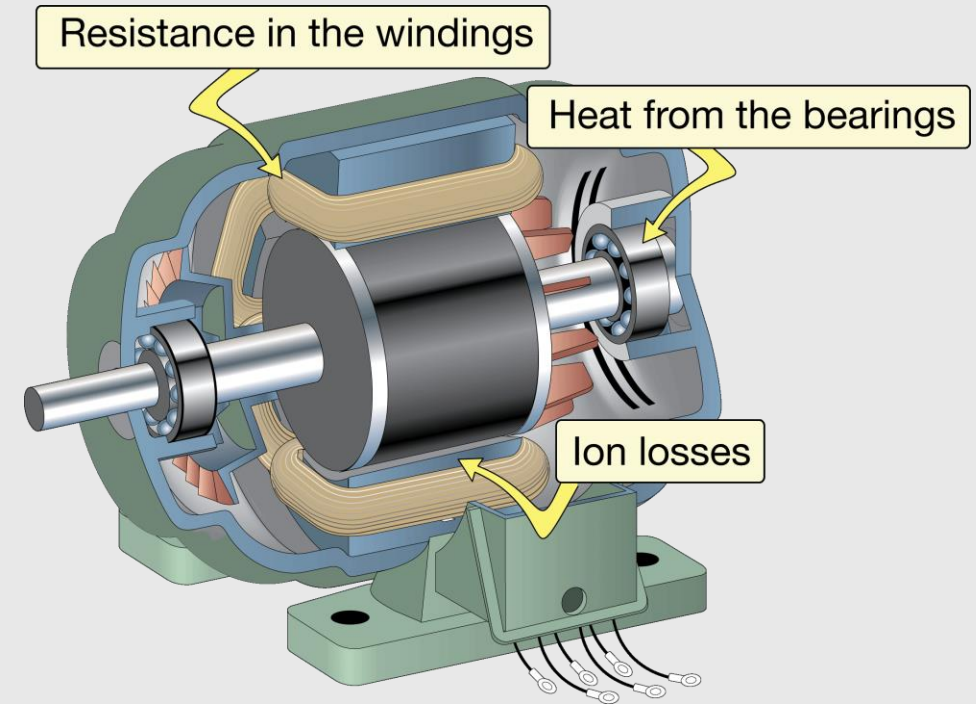
Motor response to load

- BHp is the horsepower delivered on the motor shaft
- A 10 Hp motor will only deliver 10Hp if that is what is required by the pump.
- If the pump only requires 8 Hp then the motor will only deliver 8 Hp.
- Amperage into the motor will then be less than nameplate.
- Nameplate amperage will be met only when the motor is providing nameplate Hp.



Motor size and demand

- Motors are supplied in standard sizes
 - Example - 5, 7.5, 10, etc.
- In the previous example
 - BHp requirement was 7.2.
 - If a 7.5 Hp motor is used; the load would be 96%.
 - If a 10 Hp motor is used, the load would be 72%.
 - In this example the motor efficiency would not change much and could increase a little if the 10 Hp motor was used. The reason being, larger motors have higher electrical efficiencies.



Calculating efficiency

- For our example pump from earlier we can calculate the Overall Efficiency, also known as “Wire to Water” efficiency.
- So 5.05 divided by 8 gives us 0.63 or 63%.
- Is this good or bad?
- The only way to tell is to compare this pump to other pumps that can meet the same requirements.
- When the efficiency of the pump and the efficiency of the motor are known, the overall pumping system efficiency can also be calculated by multiplying the decimal equivalent of the two efficiencies together.
- So 0.70 (the pump efficiency) times 0.90 (the motor efficiency) equals 0.63 or 63%



$$\frac{WHP}{EHP} \times 100$$

= Wire to water efficiency

$$\frac{5.05}{8} \times 100 = 63\%$$

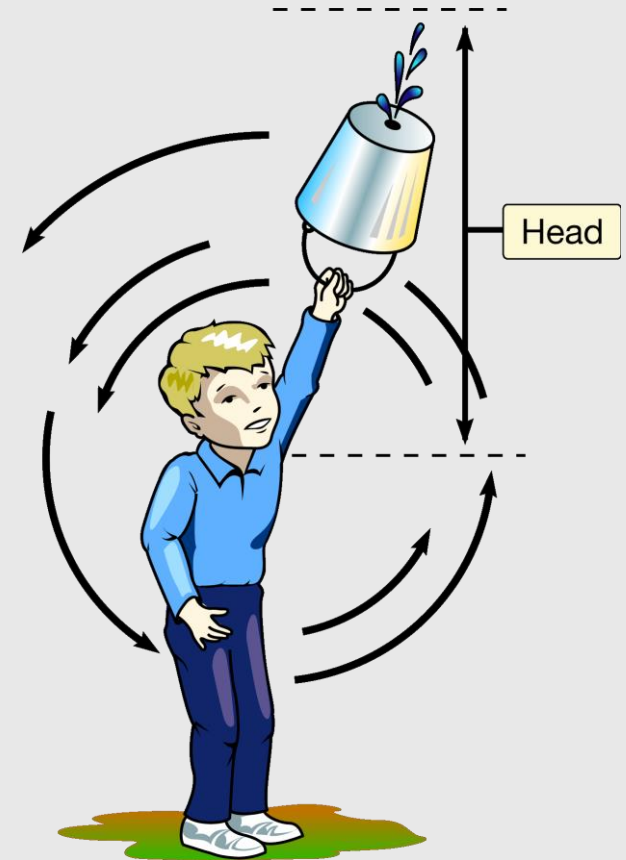
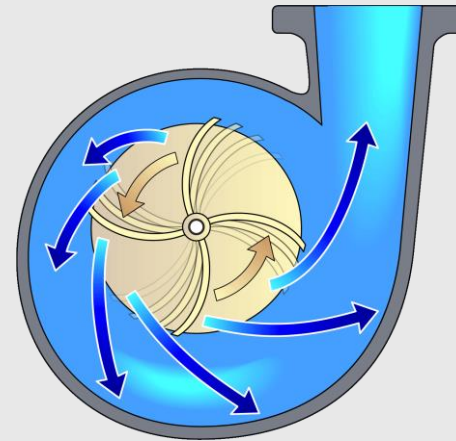
$$0.70 \times 0.90 = 63\%$$

Pump considerations

- So we've covered pump head and its relation to horsepower so now we can learn more about the pump itself.
- Considerations about the pump include the following:
 - How the impeller develops pressure
 - How a change in impeller diameter or rotational speed (rpm) changes pump performance
 - Affinity Laws
 - Specific speed of the impeller
 - Net positive suction head (NPSH)

How the impeller works

- Probably the easiest way to describe how a centrifugal pump works is to imagine you've got a bucket filled with water and you're twirling it around.
- The faster the pail is circulated the greater the force exerted on the bottom of the pail would be hence, the greater the head and also the greater the flow.



Affinity laws

- The pump affinity laws are used to predict how changes in impeller diameter will impact
 - Flow
 - Head
 - Horsepower and
 - Motor current.



Affinity laws formulas

Changes in impeller diameter and speed impact flow, head and power.

- We'll start with flow (Q);
- The flow will change linearly with the change in diameter.
- Similarly, the flow will change linearly with a change in speed.
- So with a 10% increase in either speed or diameter, the flow will increase by the same percentage, 10%

$$Q_2 = Q_1 \times \left[\frac{D_2}{D_1} \right]$$

$$Q_2 = Q_1 \times \left[\frac{\text{rpm}_2}{\text{rpm}_1} \right]$$



Affinity laws formulas

Changes in impeller diameter and speed impact flow, head and power.

- Next we have head (H).
- The head will change with the square of the impeller diameter.
- The head will also change as a square of the speed.
- So a 10% reduction in diameter or speed will result in a 19% reduction in head.

$$H_2 = H_1 \times \left[\frac{D_2}{D_1} \right]^2$$

$$H_2 = H_1 \times \left[\frac{\text{rpm}_2}{\text{rpm}_1} \right]^2$$

Affinity laws formulas

Changes in impeller diameter and speed impact flow, head and power.

- And then we have Brake Horsepower (BHp).
- Brake Horsepower will change with the cube of the impeller diameter
- And with the cube of the speed.
- A 10% reduction in diameter or speed will result in a 27.1% reduction in Brake Horsepower.
- This is why the use of variable speed drives is becoming so popular as this translates to energy savings.

$$BHp_2 = BHp_1 \times \left[\frac{D_2}{D_1} \right]^3$$

$$BHp_2 = BHp_1 \times \left[\frac{rpm_2}{rpm_1} \right]^3$$





Affinity laws formulas

- The formulas can be reduced by calculating a factor based on the changes in speed or diameter. The factor is used in place of the division of diameters and/or rpm.
- And so the new conditions divided by the old condition gives us our Factor F.

$$BHp_2 = BHp_1 \times \left[\frac{rpm_2}{rpm_1} \right]^3$$

$$\frac{\text{New condition}}{\text{Old condition}} = \text{Factor F}$$

Affinity laws example

- What would be the impact on flow, head and Brake horsepower if an 8 inch diameter impeller were changed to a 10 inch diameter impeller?
 - The Current conditions with the 8 inch Impeller are as follows:
 - Q1 is equal to 200 gpm
 - H1 is equal to 100 feet of TDH
 - BHp1 is equal to 7.2 Brake horsepower

Knowledge check #2

- What would be the impact on flow, head and BHp if a pump were to reduce its speed from 3500 rpm down to 3100 rpm?
 - Current conditions at 3500 rpm
 - $Q_1 = 200$ gpm
 - $H_1 = 100$ feet of TDH
 - $BHp_1 = 7.2$ BHp

Affinity laws formulas

- The proposed 10 inch diameter impeller is our New Condition and the 8 inch impeller is the Old Condition. So our factor (F) is 10 divided by 8 which is 1.25
- For the new Flow, Q2 we simply multiply the old flow by the factor 1.25 and we get 250 gpm.
- For the new Head, H2 we need to multiply old head times the factor squared and we get 156 feet.
- And the new Brake Horsepower, BHp2 we need to multiply the old Brake Horsepower by the factor cubed which gives us 14 BHp


$$\frac{10 \text{ inches}}{8 \text{ inches}} = 1.25$$

$$Q_2 = Q_1 \times F = 200 \text{ gpm} \times 1.25 = 250 \text{ gpm}$$

$$H_2 = H_1 \times F^2 = 100 \text{ ft} \times 1.25^2 = 156 \text{ ft}$$

$$\text{BHp}_2 = \text{BHp}_1 \times F^3 = 7.2 \text{ BHp} \times 1.25^3 = 14 \text{ BHp}$$

Affinity laws example

- What impact does this have on the motor?
- The biggest impact will be on Brake Horsepower as it jumps from 7.2 to 14, nearly double the original.
- The current draw will increase as approximately the same ratio.
- The new motor will need to be either 15 or 20 horsepower, depending on the actual pump performance range.

Affinity laws formulas

- The new condition is 3100 rpm, the old condition is 3500 rpm. So our factor is 3100 divided by 3500 which is 0.886
- For the new Flow, Q2 we simply multiply the old flow by the factor 0.886 and we get 177 gpm.
- For the new Head, H2 we need to multiply old head times the factor squared and we get 78.4 feet.
- And the new Brake Horsepower, BHp2 we need to multiply the old Brake Horsepower by the factor cubed which gives us 5.0 Brake horsepower.


$$\frac{3,100 \text{ rpm}}{3,500 \text{ rpm}} = 0.886$$

$$Q_2 = Q_1 \times F = 200 \text{ gpm} \times 0.886 = 177 \text{ gpm}$$

$$H_2 = H_1 \times F^2 = 100 \text{ ft} \times 0.886^2 = 78.4 \text{ ft}$$

$$\text{BHp}_2 = \text{BHp}_1 \times F^3 = 7.2 \text{ BHp} \times 0.886^3 = 5 \text{ BHp}$$



Atmospheric pressure

- Now that we've covered how the pump works, horsepower requirements and impeller and speed relationships we need to look at what a pump needs in terms of proper suction conditions.
- We'll start off with Atmospheric Pressure which is made up of gases, namely Oxygen, Nitrogen, Carbon dioxide and a few other trace elements.
- The Atmosphere has mass, meaning it has weight and takes up space and is held to the Earth by gravity.





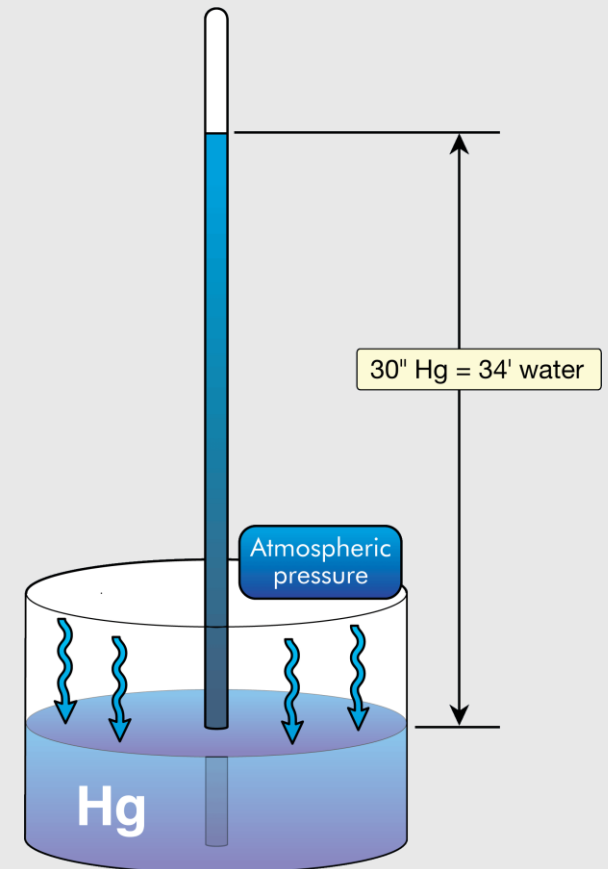
$$30'' \text{ Hg} \times 13.55 = 406.5'' \text{ H}_2\text{O} = 34 \text{ ft}$$

$$34 \text{ ft} \times 0.433 \text{ psi/ft} = 14.7 \text{ psi}$$

$$30'' \text{ Hg} = 34\text{ft of water} \\ \text{or } 14.7 \text{ psi}$$

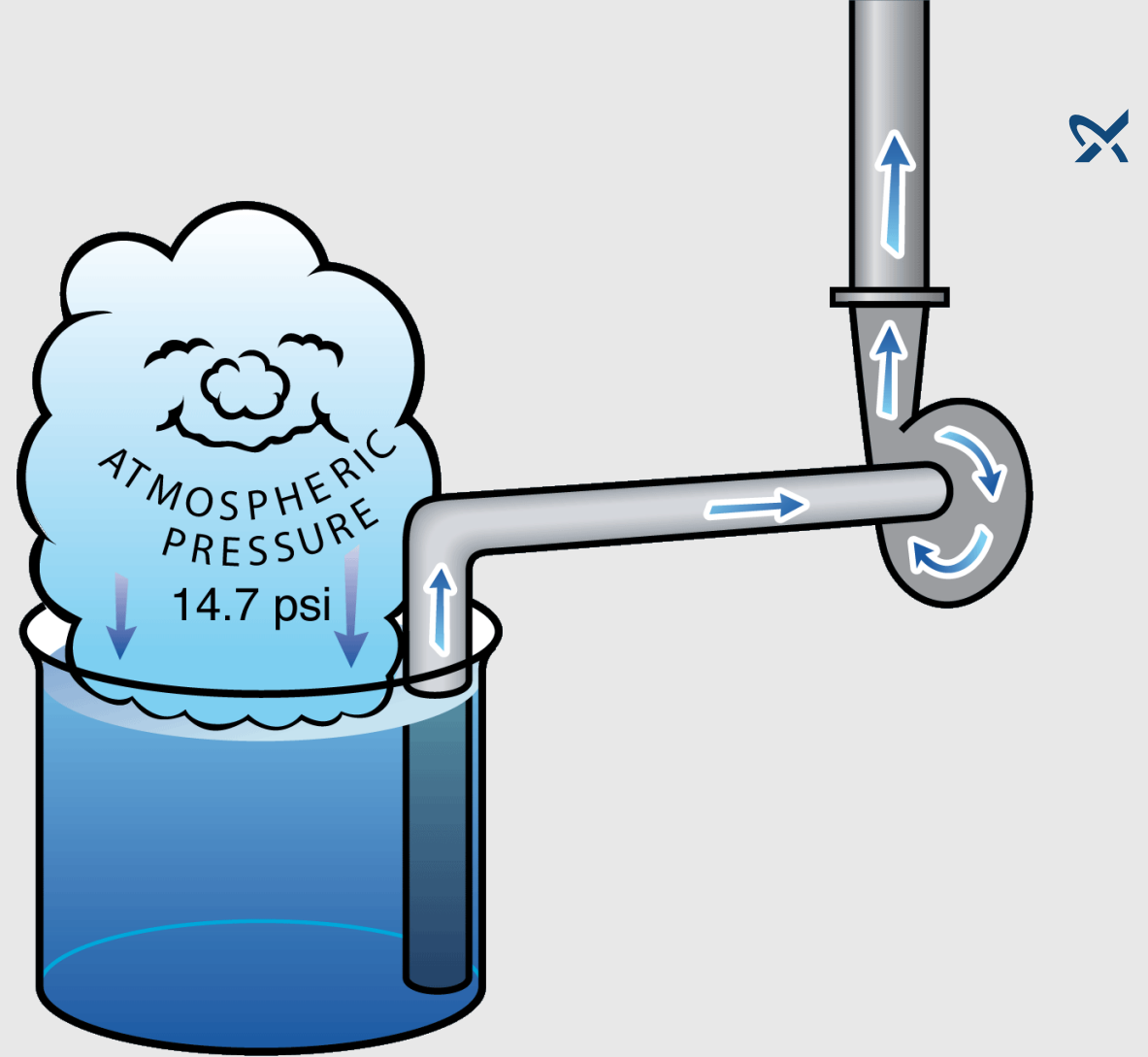
Impact of gravity

- Since the atmosphere has weight it can be measured.
- The weight of a one inch column of mercury 30 inches tall is the same as a one inch column of water 406.5" tall which is 34 feet.
- So if you convert 34 feet to psi you get 14.7.
- The weight of the atmosphere is 30 inches of Mercury or 34 feet of water or 14.7 psi.



The atmosphere as an energy source

- This is the source used to push water into eye of the impeller when a pump is in a suction lift condition.



The atmosphere as an energy source

- The table here shows how the atmospheric pressure changes based on elevation.
- Remember that at seal level we have 14.7 psi but with increasing elevation comes decreased atmospheric pressure.

Variations in Atmospheric Pressure With Altitude		
Altitude Above sea level (ft)	Pressure (psi)	Head (feet)
-0-	14.7	33.9
1,000	14.2	32.8
2,000	13.7	31.6
3,000	13.2	30.5
4,000	12.7	29.3
5,000	12.2	28.2
5,280	12.1	27.9
6,000	11.8	27.3
7,000	11.3	26.1
8,000	10.9	25.2
9,000	10.5	24.2
10,000	10.1	23.3



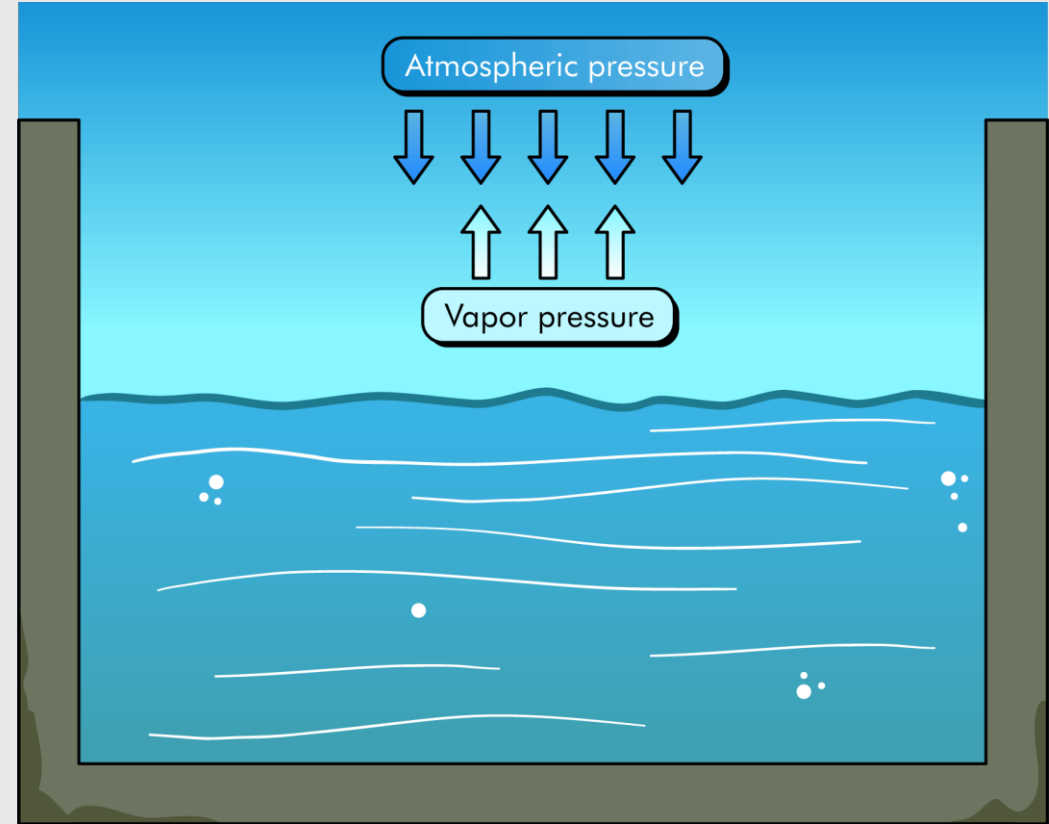
Vapor pressure

- Another factor that can impact pump inlet conditions is Vapor Pressure.
- The Vapor pressure is the pressure at which a liquid can exist in equilibrium with its vapor.
- To understand Vapor Pressure we have to look at the Properties of Liquids
- Liquids contains molecules of gas
- These molecules are close together at the surface which creates surface tension
- The rate of movement of these molecules is dependent on temperature
- Molecules can escape the surface
- When the escape the surface they form vapor



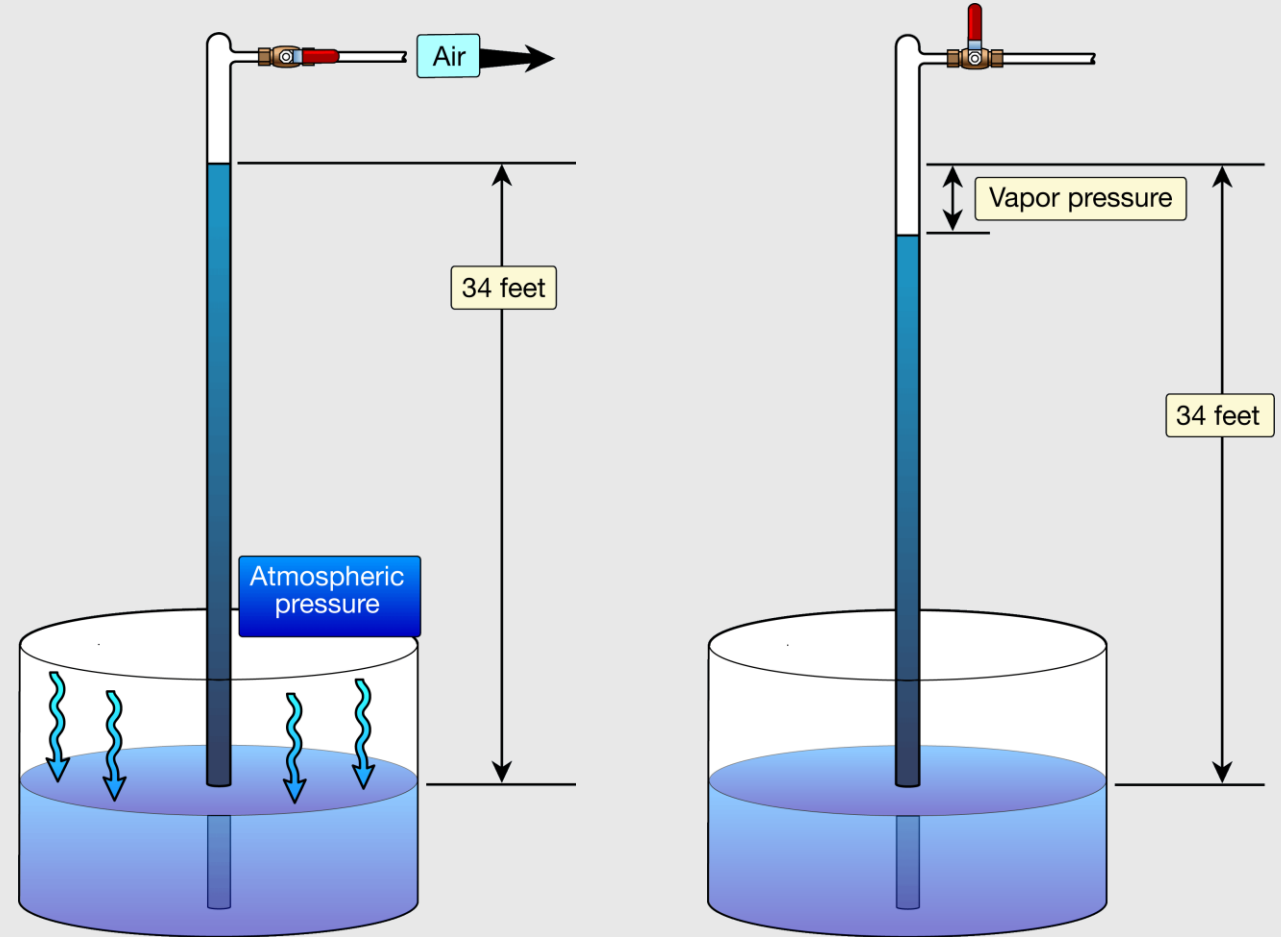
Vapor pressure

- Atmospheric pressure will help keep vapor from forming at the surface until the temperature gets too high.



Vapor pressure

- The column of water on the left is held at exactly 34 feet in length via a vacuum pump.
- When the vacuum pump is switched off, if the column of water stays put, then there's zero effect on the column due to the water temperature.
- If the column of water drops, the difference in height is a function of the water temperature.





Vapor pressure

- Shown here is the relationship between temperature and vapor pressure.
- The vapor pressure increases with temperature and you can see at 212 degrees F, the vapor pressure is equal to the atmosphere pressure at seal level which means they cancel each other out.

Variations in Vapor Pressure with Temperature	
Temp (° F)	Vapor Pressure in feet
32	0.204
59	0.565
68	0.774
75	1.00
100	2.17
150	8.56
200	26.45
212	33.99

Net positive suction head

- So we will now introduce a very important pump term called Net Positive Suction Head (NPSH) for which things like atmospheric pressure and vapor pressure play an important role.
- NPSH is the water pressure in psi at the eye of the impeller.
- Another way of putting it, it's the USEFUL pressure at the eye of the impeller
- This is a requirement place on a pump by the design pump manufacturer, which is called <click> Net Positive Suction Head Required, or NPSHR.
- NPSH is critical in suction lift applications.



Effects of atmosphere on NPSH

- When an NPSH calculation is needed the atmospheric pressure is usually the most abundant energy source. Calculating NPSH involves 4 major components:
- Atmospheric Pressure which is always positive, the static head above the pump inlet which would be positive or suction lift which would be negative, head loss which will be negative and lastly vapor pressure which would be negative.
- So when calculating NPSHA it ultimately comes down to basic addition and subtraction.

Atmospheric Pressure

+/- Positive Suction Head or Suction Lift

- Head loss

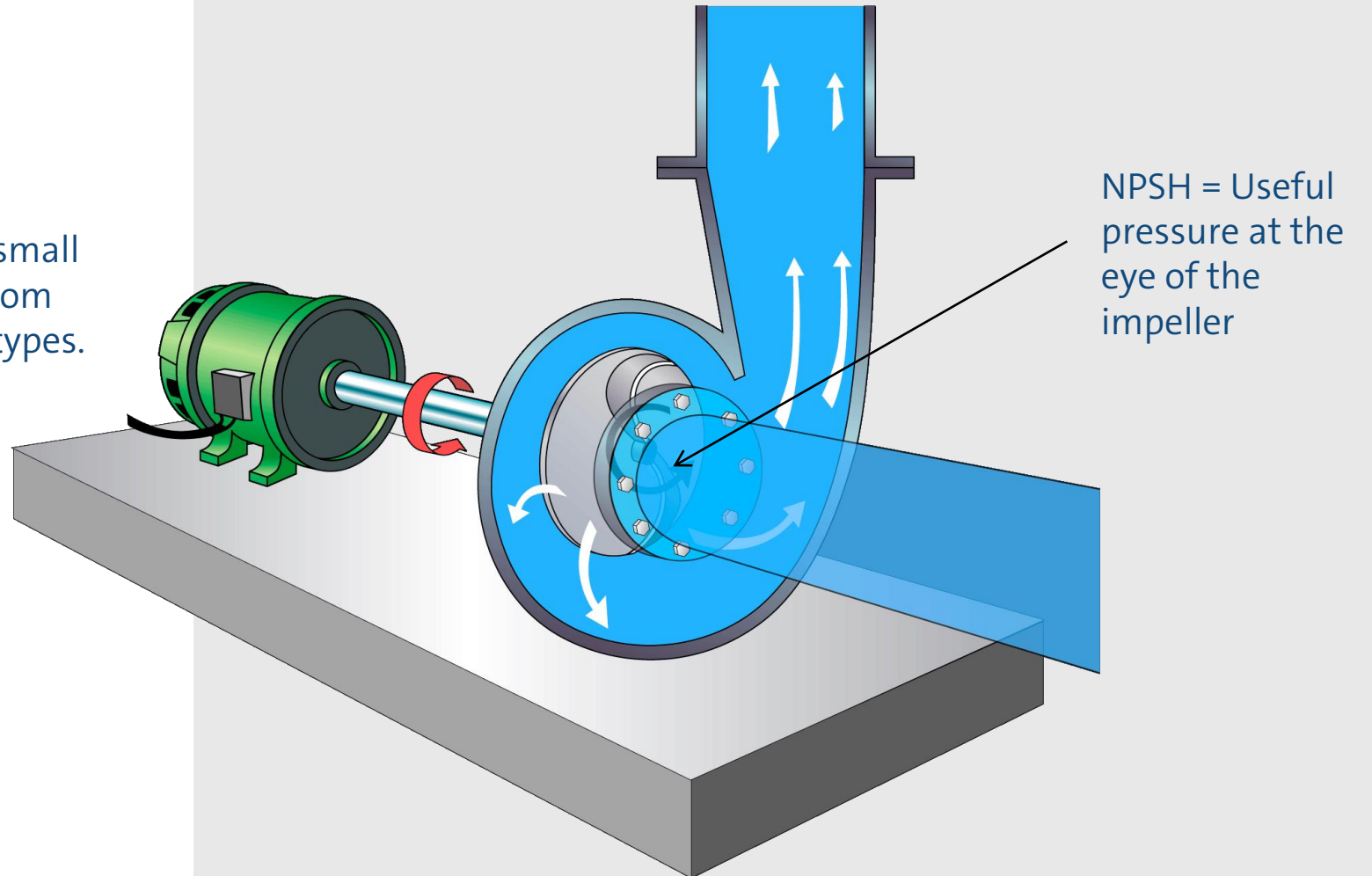
- Vapor Pressure

= Available Net Positive Suction Head
(ANPSH or NPSHA)



Net positive suction head

- Although velocity head is usually a very small number, it does need to be subtracted from the calculated NPSHA for certain pump types.

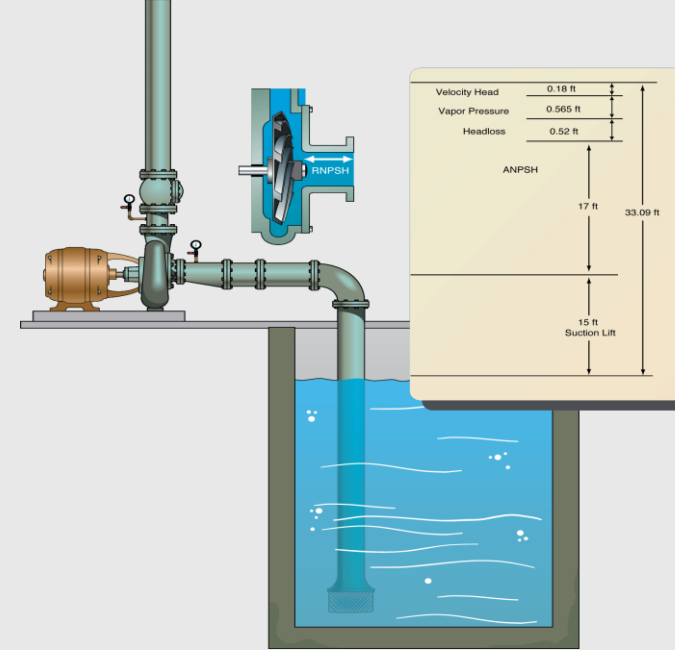


Effects of required vs available NPSH

- Here are the effects of Required vs Available NPSH
- The NPSH Required is determined by the pump manufacturer
 - This is the pressure required in order for the pump to perform in accordance with the Head-Capacity curve.
- The NPSH Available is the actual pressure at the eye of the impeller.
- For proper performance, the available NPSH must be greater than the required NPSH.

Net positive suction head calculations

- Here's an example of what's involved in calculating NPSHA.
- You start with the positive, so atmospheric pressure here is 33.09 feet.
- This is a suction lift installation so we need to subtract 15 feet.
- Then we subtract the head loss and the vapor pressure
- And we end up with a Net Position Suction Head Available of 17 feet.



Atmospheric Pressure:	33.09
Suction Lift:	- 15.00
Head loss:	- 0.52
Vapor Pressure:	- 0.57
NPSHA	17.00

NPSH considerations

- Not meeting the required NPSH is the largest single cause of cavitation
- Caution must be taken when looking at Suction Head conditions
- When the pump is exposed to high flow high flow this can be critical
- Remember that the Available Net Positive Suction Head (ANPSH) is equal to the feet of water above the eye of the impeller plus the Atmospheric pressure minus the vapor pressure minus the head loss in the suction piping