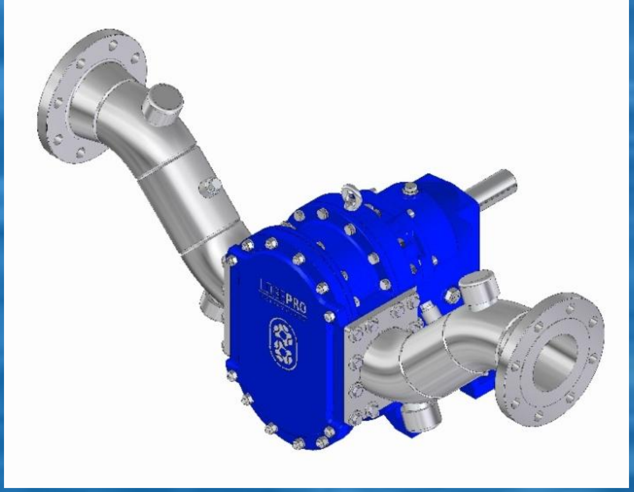




Basic Hydraulics and Pump Applications In Wastewater

9/24/2015

John Rogers

EBARA International Corporation
Rock Hill, SC

Gary Rookstool, P.E.

Winschel Environmental, LLC
Buchanan, VA

Matt Winschel, P.E.

Winschel Environmental, LLC
Glen Allen, VA

Topics for Discussion

- **Pump Types used in Wastewater**
  - **Positive Displacement**
  - **Centrifugal**
  - **Axial Flow**
- **Basic Hydraulics and Pump Sizing**

Positive Displacement Pumps

Dynamic vs. Positive Displacement

Dynamic

- Centrifugal
- Axial (Propeller)
- Turbine

Positive Displacement

- Gear *(rotary lobe falls into this category)*
- Progressive Cavity
- Piston
- Diaphragm
- Hose Pump

LOBEPRO ROTARY PUMPS

Most Positive Displacement Pumps fall into one of two categories:

- Reciprocating
- Rotary

RECIPROCATING PUMPS USE:

- Diaphragms
- Pistons
- Plungers

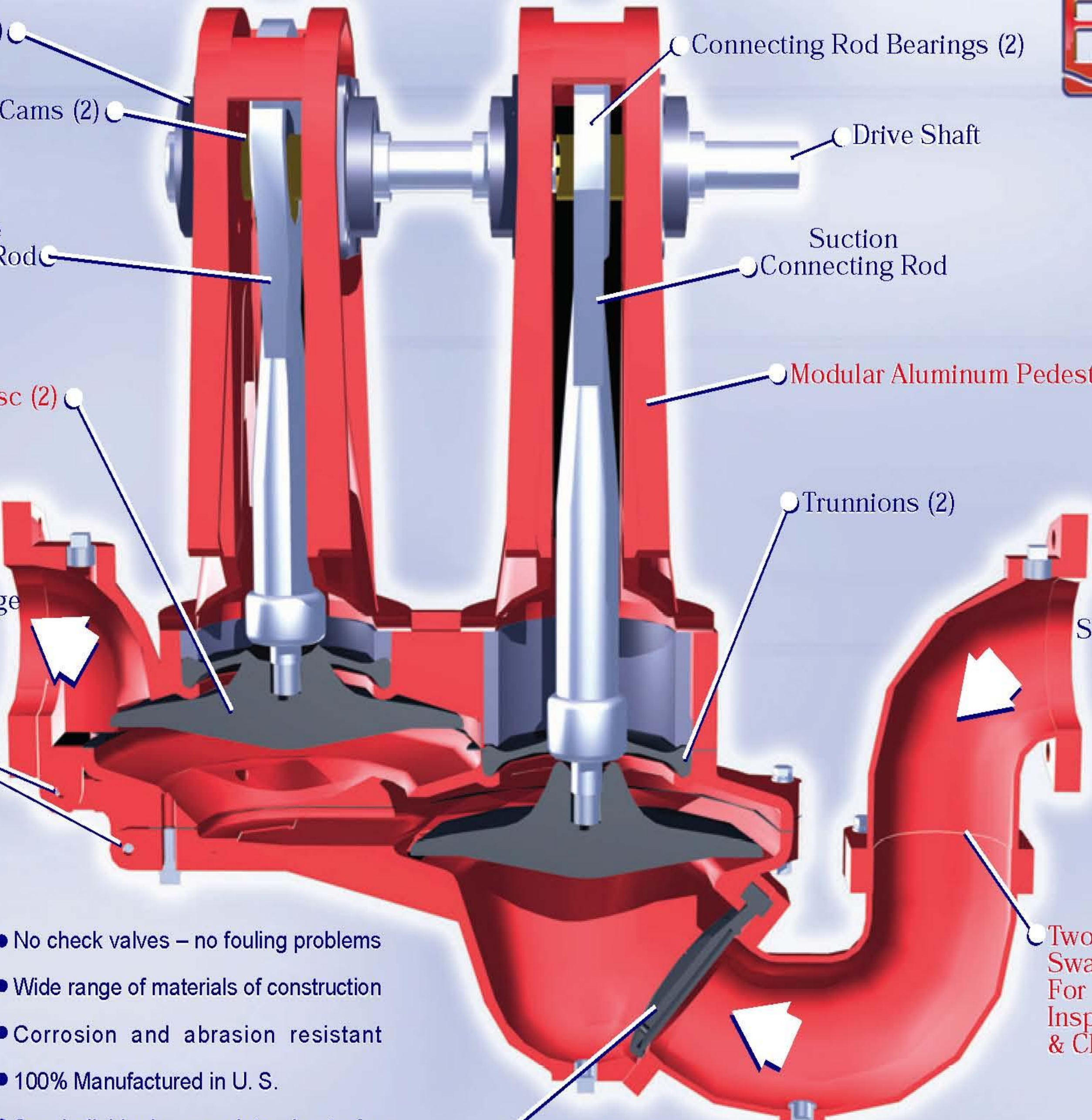
ROTARY PUMPS USE:

- Lobes
- Screws
- Peristalsis *(gets its name from the muscular action of the human digestive tract.)*

PLUNGER PUMPS

- Low pressure plunger pumps are generally found in wastewater treatment to transfer sludge (WAS, TWAS, RAS)

LOBEPRO ROTARY PUMPS



PUMP FEATURES:

- Flow Rates from 2 – 600 GPM
- Repair - In - Place Design
- Only 5 wetted parts
- Flow through construction
- Runs dry without damage
- Sealless design – no packings or mechanical seals, no seal flush water required
- No check valves – no fouling problems
- Wide range of materials of construction
- Corrosion and abrasion resistant
- 100% Manufactured in U. S.
- See individual pump data sheets for specific technical information

DIAPHRAGM PUMP

- A **diaphragm pump** is a positive displacement pump that uses a combination of the reciprocating action of a rubber, thermoplastic or teflon diaphragm and suitable non-return check valves to pump a fluid. Sometimes this type of pump is also called a **membrane pump**.

CHARACTERISTICS

These pumps can handle sludges and slurries with a good amount of grit and smaller solids content.

- Have good dry running characteristics.
- Are low-shear pumps.
- Can be used to make artificial hearts.
- Have good self priming capabilities.

CHARACTERISTICS CONT.

- Have good self priming capabilities
- Can handle highly viscous liquids
- Are available for industrial, chemical and hygienic applications
- Cause a pulsating flow that may cause water hammer (Water hammer is a pressure surge or wave caused when a fluid in motion is forced to stop or change direction suddenly)
- Usually have limited capacities

DIAPHRAGM PUMPS


Air Driven


Motor Driven


Double Diaphragm Air Driven


Engine Driven Dewatering Diaphragm Pump

DIAPHRAGM DOSING PUMPS

Solenoid

Motor Driven

Stepper Motor

Photos Courtesy

Lutz-JESCO

PERISTALTIC PUMP/HOSE PUMP

A **peristaltic pump**, or roller pump, is a type of positive displacement pump used for pumping a variety of fluids. The fluid is contained within a flexible tube fitted inside a circular pump casing (though linear peristaltic pumps have been made). A rotor with a number of "rollers", "shoes" or "wipers" attached to the external circumference compresses the flexible tube. As the rotor turns, the part of tube under compression closes (or "occludes") thus forcing the fluid to be pumped to move through the tube. Additionally, as the tube opens to its natural state after the passing of the cam ("restitution" or "resilience") fluid flow is induced to the pump.

LOBEPRO ROTARY PUMPS

PERISTALTIC (HOSE PUMP)

Photo Courtesy

FLOMOTION SYSTEMS

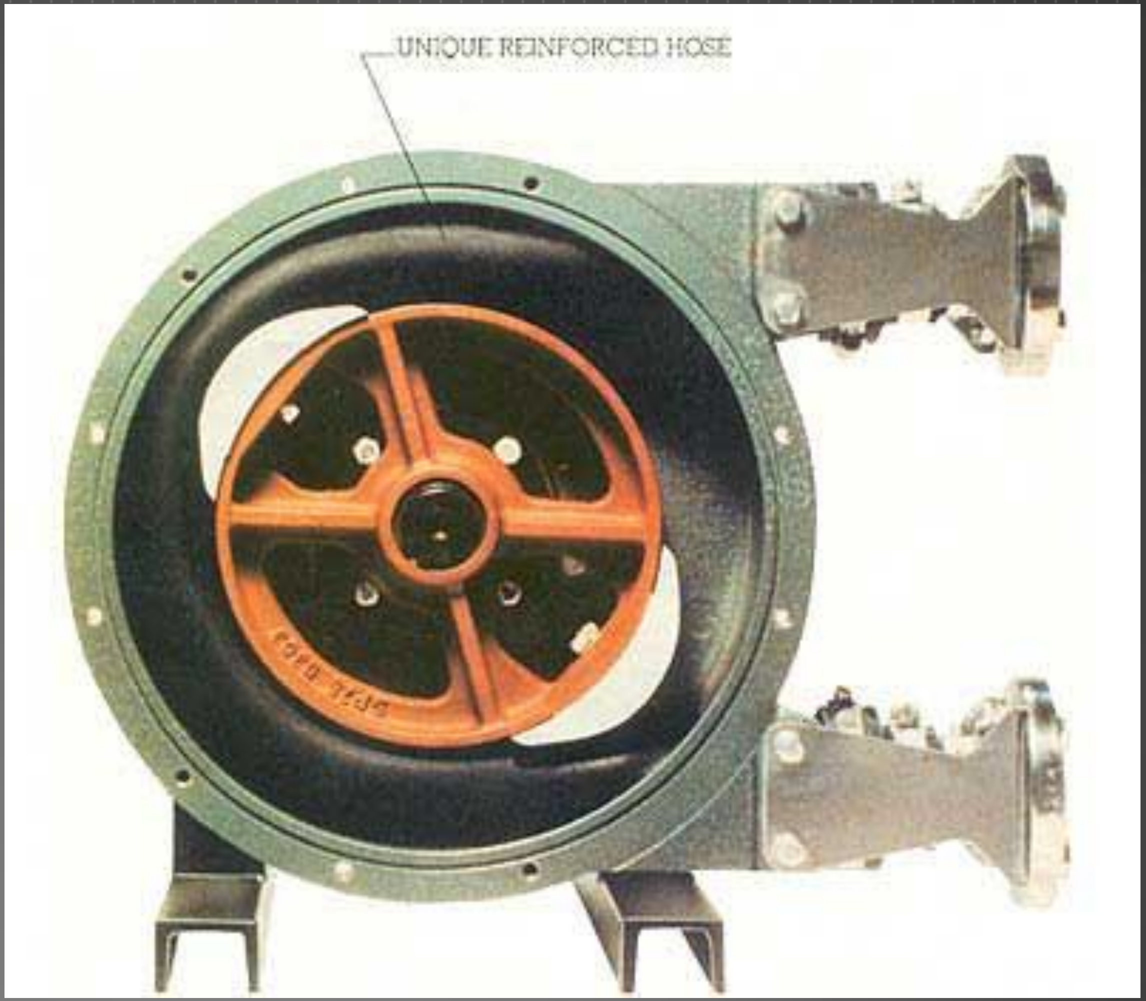
HOSE PUMPS:

Consist of a rotor which is a bar or bars that have rollers at the end.

Consist of a stator which is a U-shaped hose.

Use rollers to compress (pinch) the hose and create cavities in which the liquid is forced along the length of the hose.

Are prone to failure because of the nature of the action on the elastomeric hose.



LOBEPRO ROTARY PUMPS

PROGRESSIVE CAVITY PUMPS

PROGRESSIVE CAVITY PUMPS

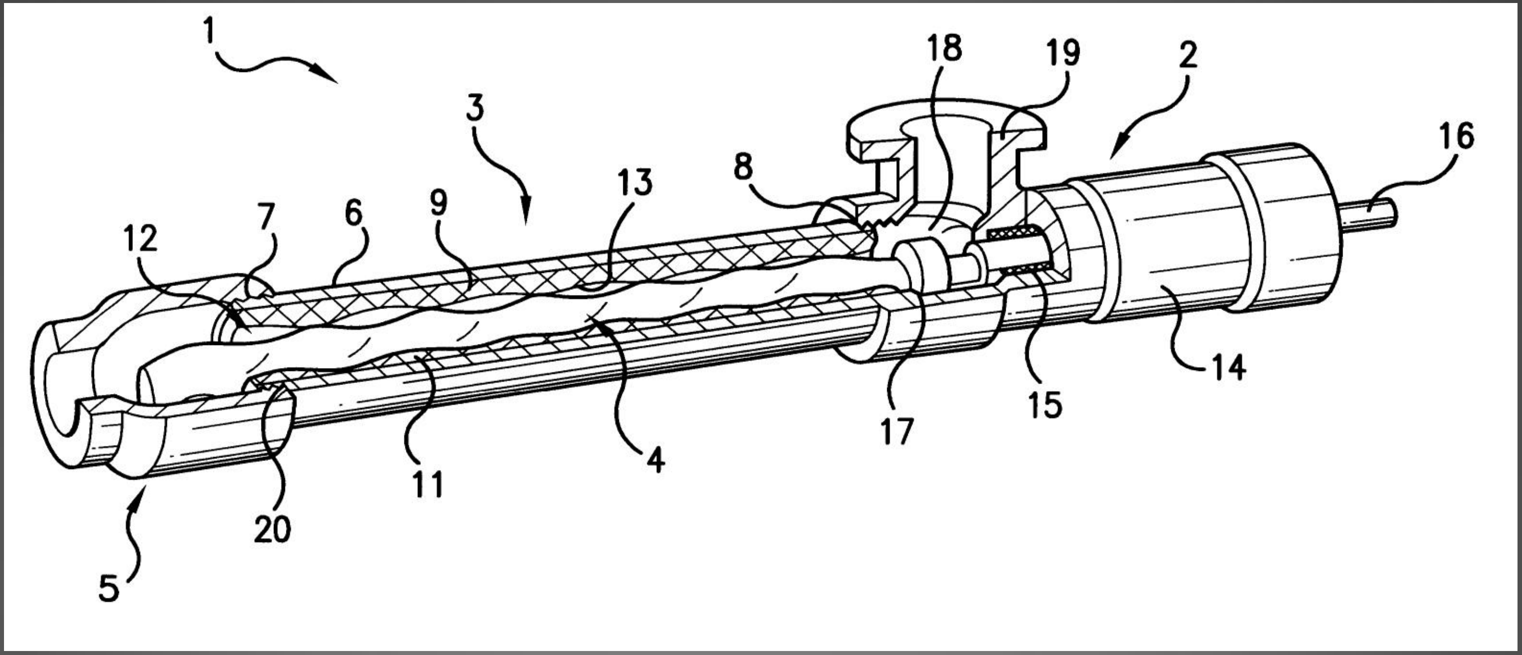
PC pumps are the closest relative to the rotary lobe pump with regard to areas of application

Liquid is carried in the pockets created by the eccentric rotating motion of the rotor inside of an elastomeric stator

Progressive Cavity pumps provide a steady, pulse less flow which is directly proportional to the speed of the pump and the degree of slip.

PC pumps are good for viscous and abrasive sludges and slurries.

PROGRESSIVE CAVITY BREAKDOWN



ROTARY LOBE PUMPS

How Lobe Pumps Work

- Lobe pumps are similar to external gear pumps in operation in that fluid flows around the interior of the casing. Unlike external gear pumps, however, the lobes do not make contact. Lobe contact is prevented by external timing gears located in the gearbox. Pump shaft support bearings are located in the gearbox, and since the bearings are out of the pumped liquid, pressure is limited by bearing location and shaft deflection.

Advantages

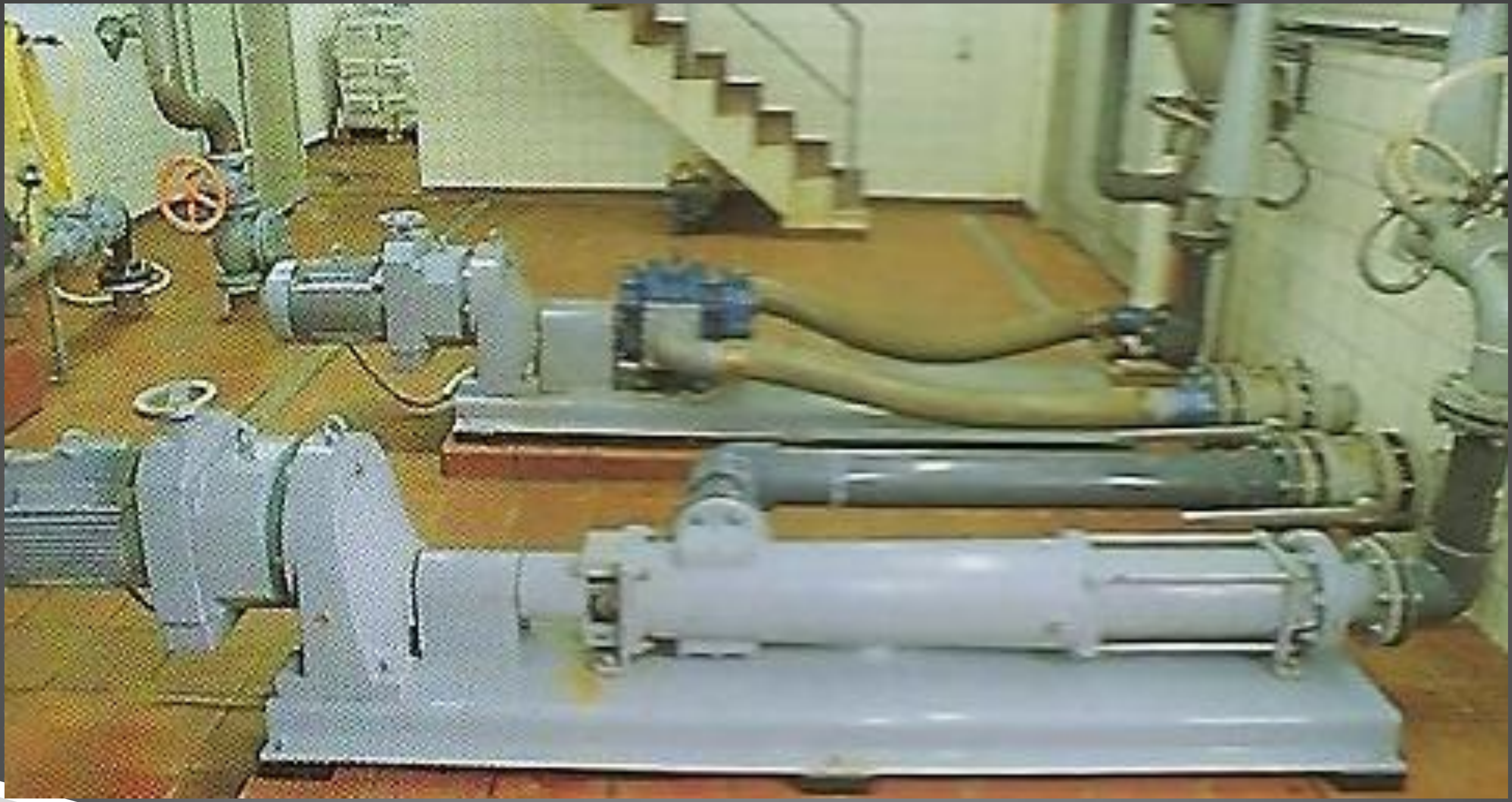
- Pass medium solids
- No metal-to-metal contact
- Superior MIP capabilities
- Long term dry run (with lubrication to seals)
- Non-pulsating discharge (Helical Lobe)

HYGIENIC ROTARY LOBE

LOBE CUTAWAY

Rotary Lobe vs Progressing Cavity Pumps

Smaller Footprint

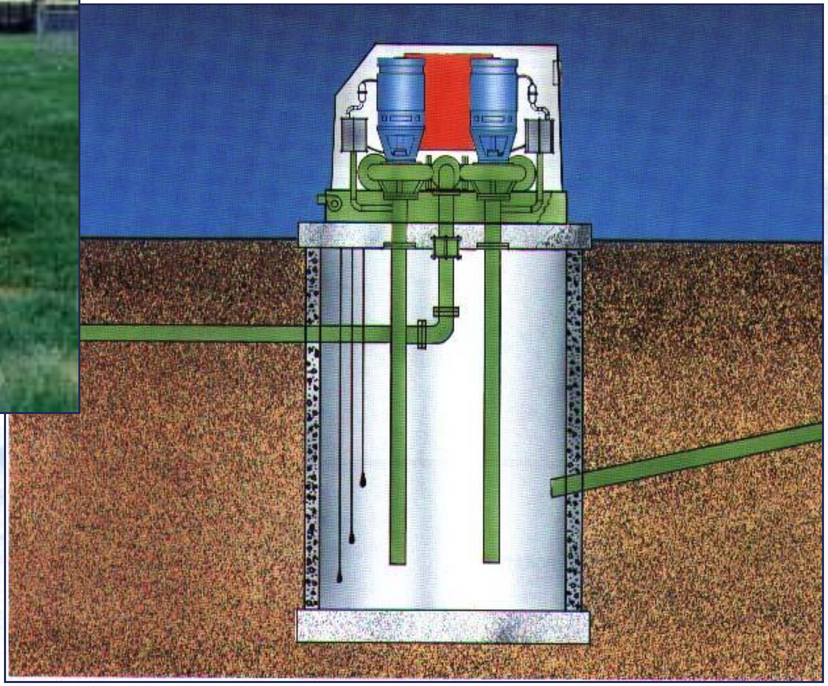


LOBEPRO ROTARY PUMPS

Centrifugal Pumps

Above Ground Pump Stations

- Vacuum Prime System

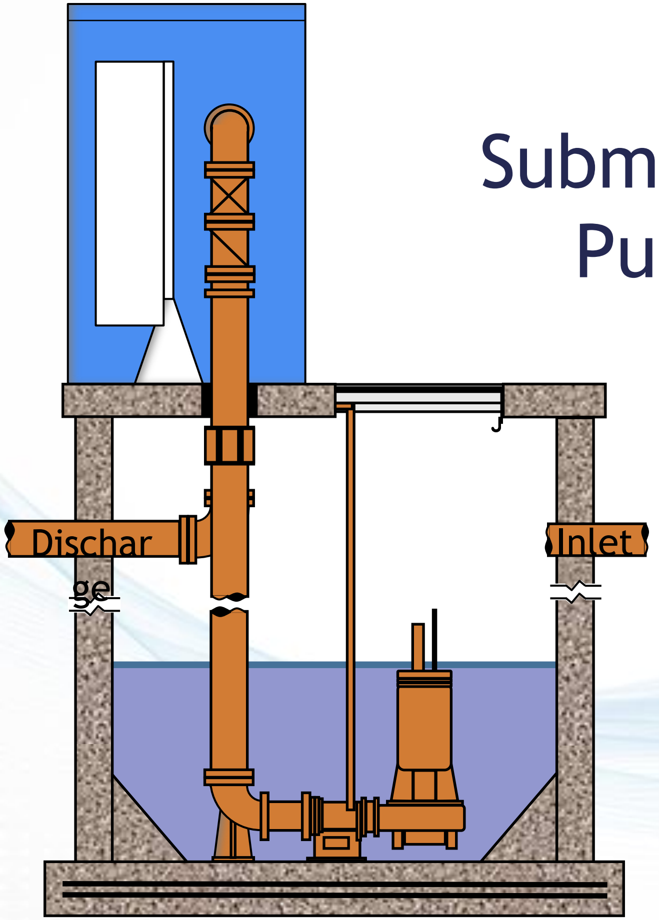


Photos Courtesy of Smith & Lovelace and Dakota Pump

Above Ground Pump Stations

Photos Courtesy of Gorman-Rupp

Above Ground Package Pump Stations

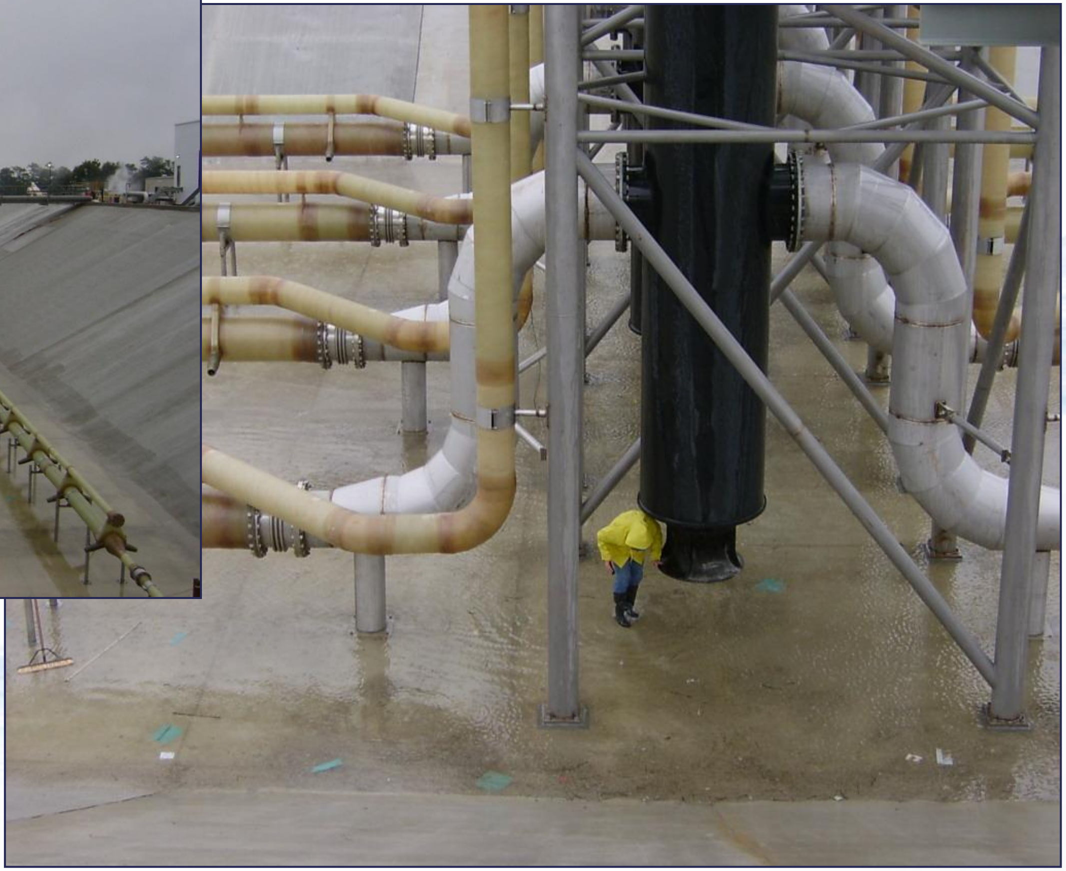


Submersible Pumps

Small Pump Stations

Submersible Pumps

Submersible Axial Flow Pumps



Photos Courtesy of

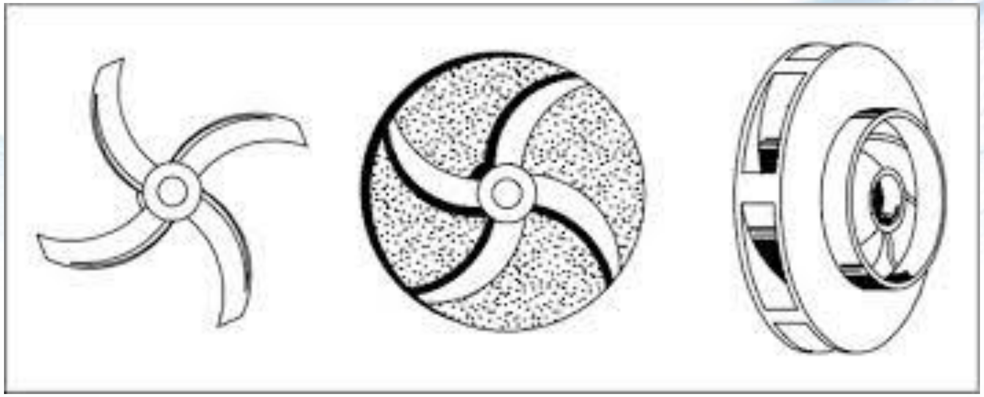
Ebara International Corp.

Impeller Types

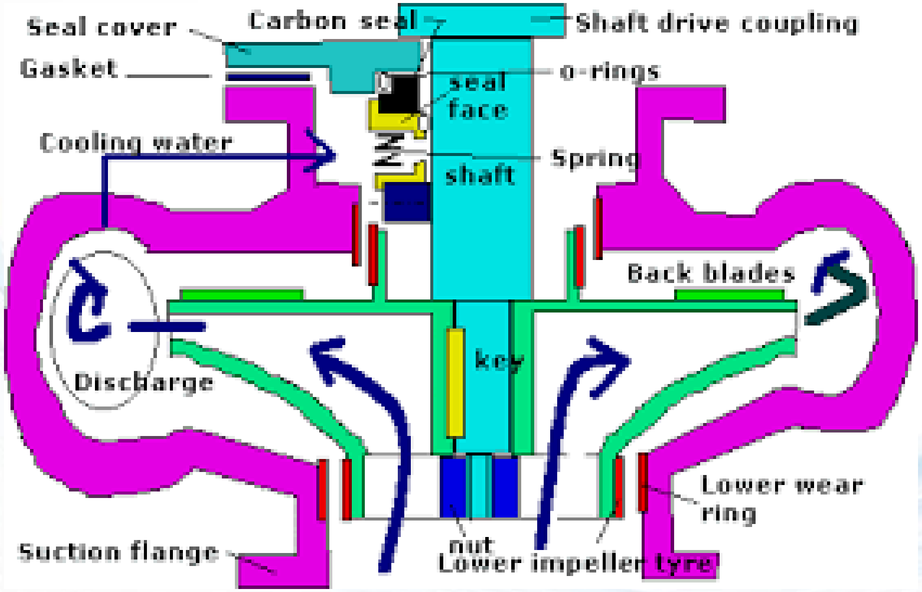
ENCLOSED

SEMI OPEN

VORTEX



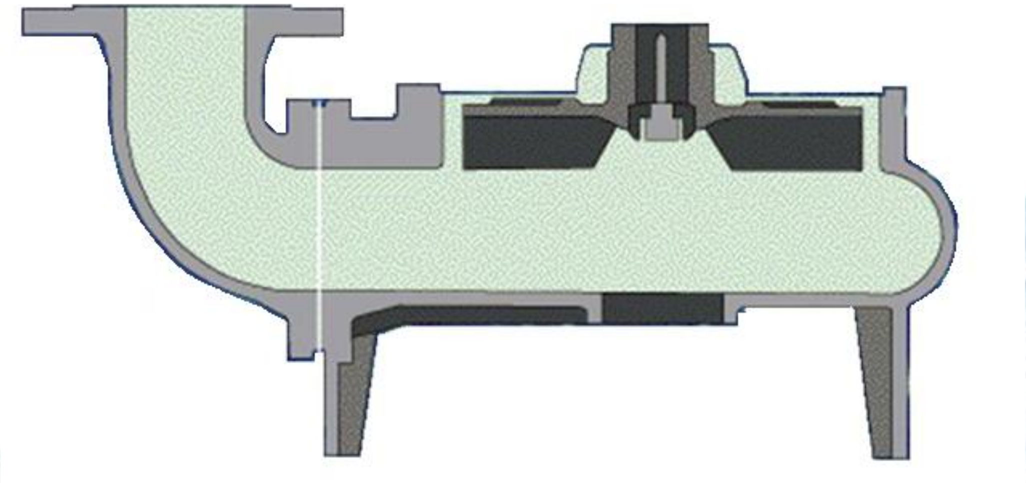
Close Clearance Prevents Recirculation



ENCLOSED
Replaceable Wear Ring Clearance

SEMI-OPEN
Adjustable/replaceable Cover Plate

Vortex (Recessed Impeller) Pumps



EBARA

Submersible Pump Installations

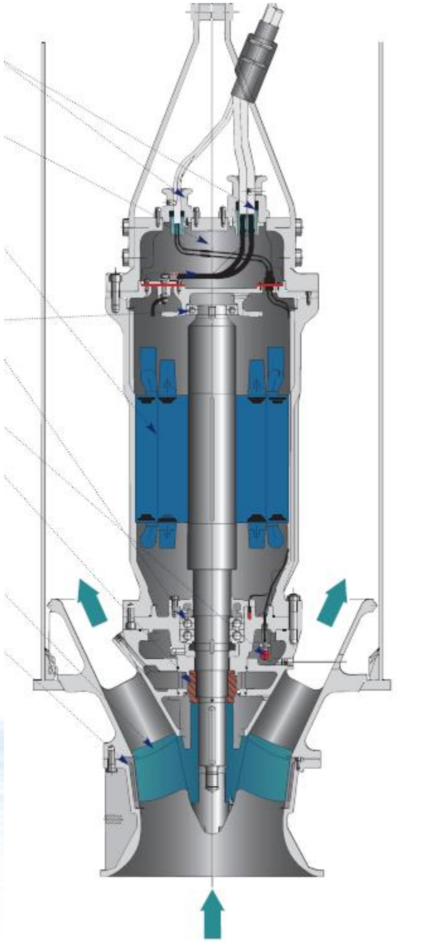
Large Pump Stations

Trench Type Wet Well Design

Oxic Recycle Pumps Charlotte, NC

Dry Pit Submersible Pumps

Axial Flow Pumps



Basic Hydraulics
&
Pump Sizing

Ebara Fluid Handling

Ebara International Corporation

1651 Cedar Line Drive

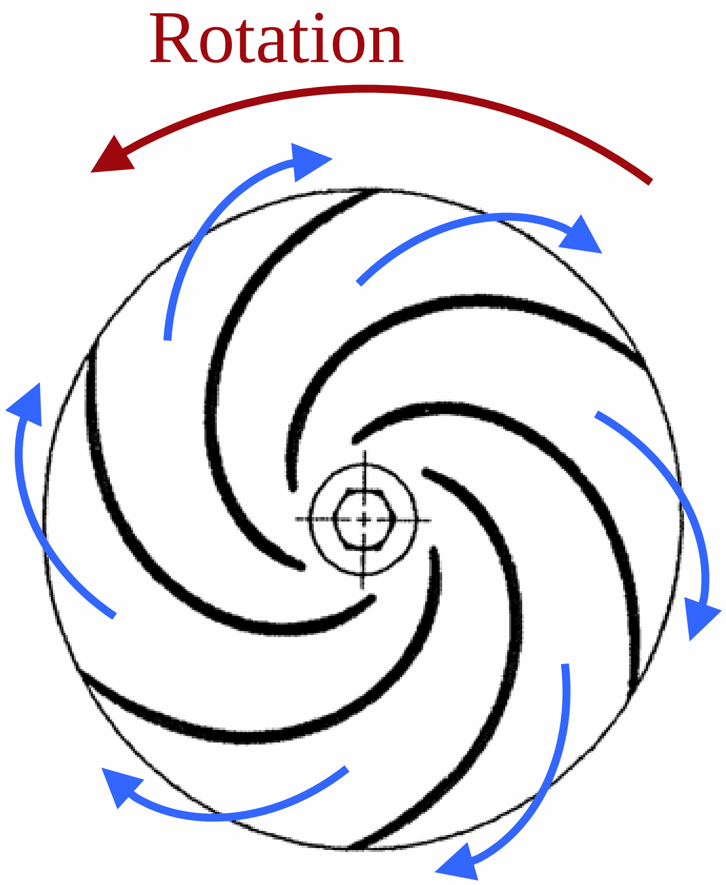
Rock Hill, SC 29730

(t) 803-327-5005 (f) 803-327-5097
www.pumpsebara.com

EBARA

The Pump Impeller

Function: To impart velocity energy to the liquid through centrifugal force



Specific Speed – Impeller Profiles

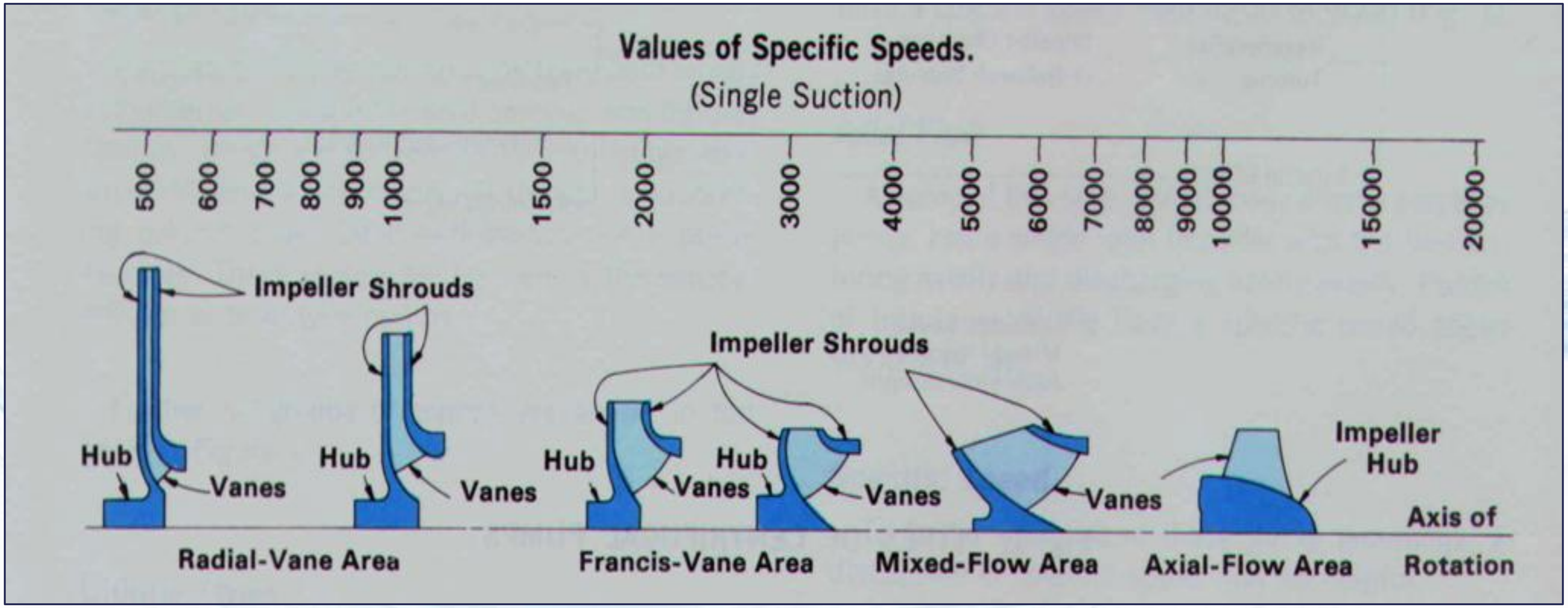


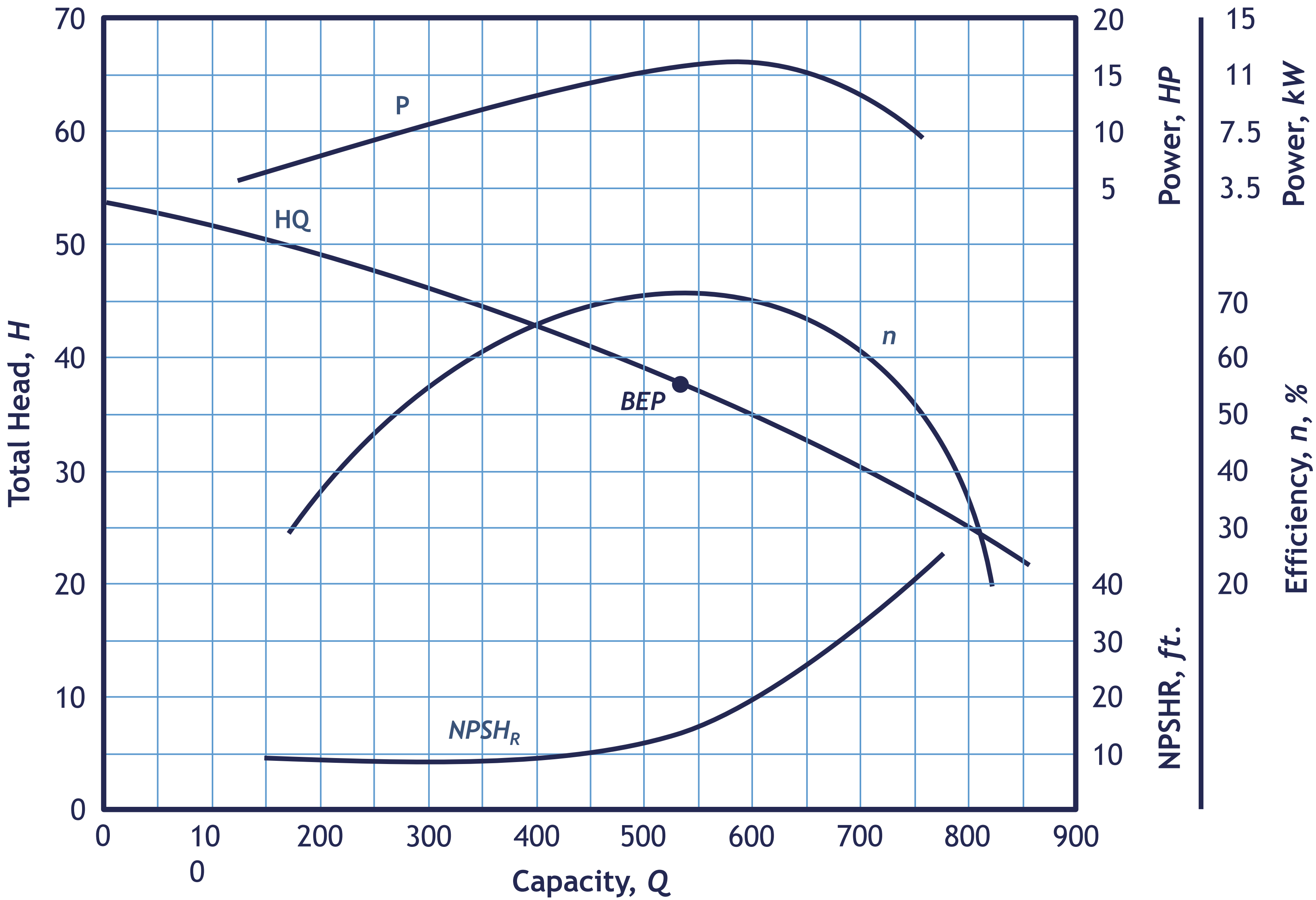
Fig. 5 Comparison of Pump Profiles

Source: Hydraulic Institute

Pump Performance Parameters

- Q = The capacity (expressed in units of volume per unit of time such as gpm)
- H = The total head (expressed in feet of liquid pumped)
- N = The speed at which the pump runs (expressed in rpm)
- η = Pump Efficiency (%)
- BHP = Brake Horsepower
- $NPSH_R$ = Net Positive Suction Head Required

Pump Curves



70
60
50
40
30
20
10
0
Total Head, H
0
10
0
200
300
400
500
600
700
800
900
Capacity, Q
P
HQ
n
BEP
NPSHR
20
15
10
5
Power, HP
15
11
7.5
3.5
Power, kW
70
60
50
40
30
20
Efficiency, n, %
40
30
20
10
NPSHR, ft.

Centrifugal Pump Performance

The useful work done by a pump is referred to as Water Horsepower (WHP) or Hydraulic Horsepower

$$WHP = \frac{QH(sp.\ gr.)}{3960}$$

The power required to drive the pump is referred to as Brake Horsepower (BHP)

$$BHP = \frac{WHP}{n_p} \quad \text{or} \quad BHP = \frac{QH(sp.\ gr.)}{3960 \times n_p}$$

Centrifugal Pump Performance

The power delivered to the motor is referred to as Motor Horsepower (MHP)

$$MHP = \frac{BHP}{h_m} \quad \text{or} \quad MHP = \frac{WHP}{h_p h_m}$$

The Overall (wire to water) Efficiency of the pump installation is the product of the pump and motor efficiencies:

$$h_o = h_p \times h_m$$

Centrifugal Pump Performance

The power delivered to the motor is referred to as Motor Horsepower (MHP)

$$MHP = \frac{BHP}{n_m} \quad \text{or} \quad MHP = \frac{WHP}{n_p\, n_m}$$

The Overall (wire-to-water) Efficiency of the pump installation is the product of the pump, motor, and drive efficiencies

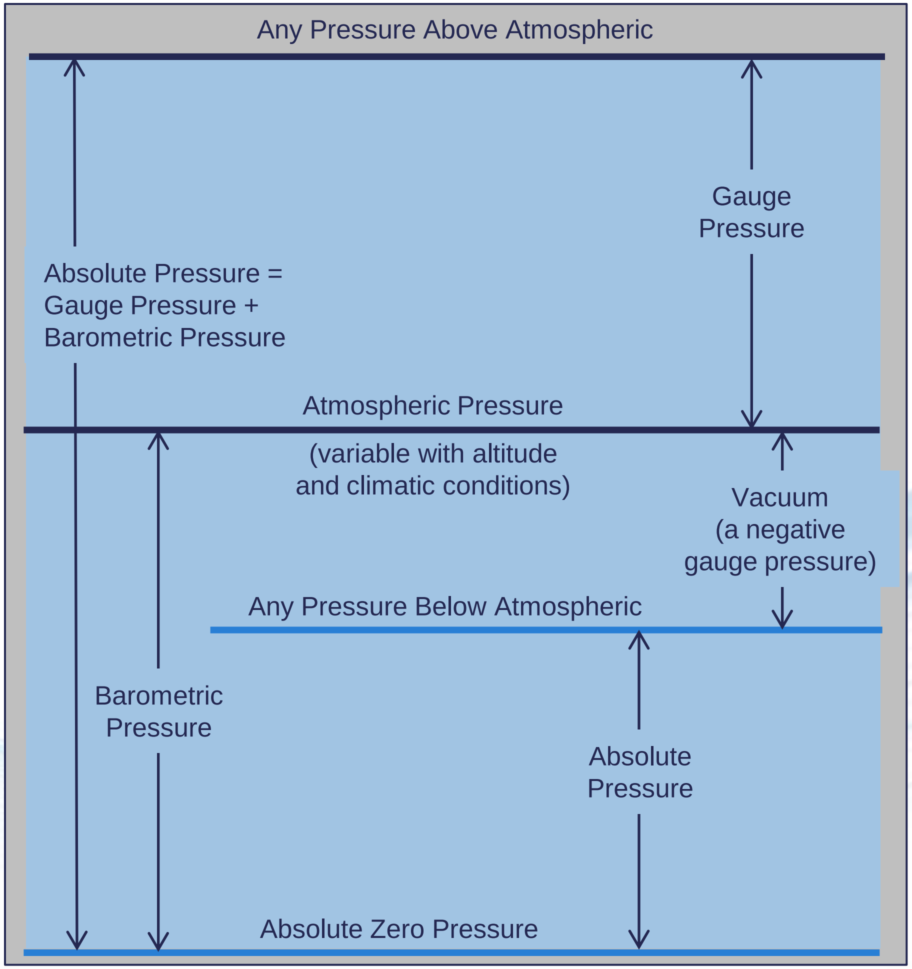
$$n_o = n_p \times n_m \times n_d$$

Overall Efficiency

$$n_o = n_p \times n_m$$

Wire to water Efficiency

Pressure



Any Pressure Above Atmospheric
Gauge Pressure
Absolute Pressure = Gauge Pressure + Barometric Pressure
Atmospheric Pressure
(variable with altitude and climatic conditions)
Vacuum (a negative gauge pressure)
Any Pressure Below Atmospheric
Barometric Pressure
Absolute Pressure
Absolute Zero Pressure

Pressure

1 Atmosphere = 14.7 psi (At Sea Level)

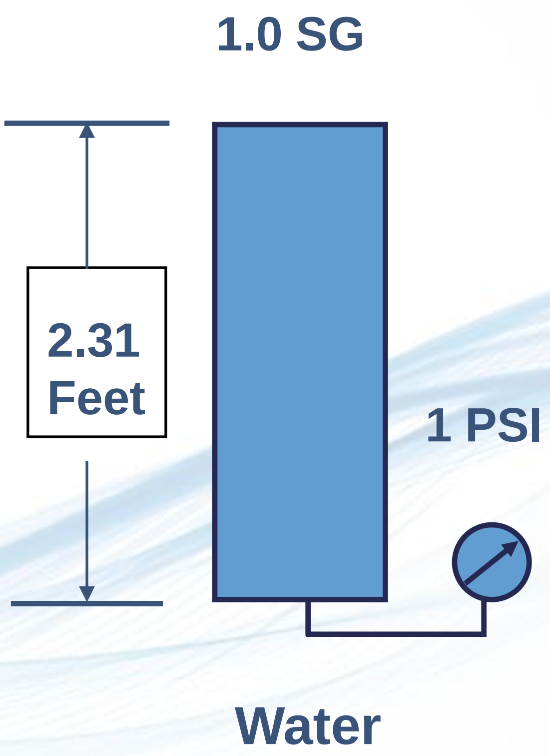
1 Atmosphere = 34 ft. Column of Cold Water

$$\frac{\textbf{34 ft.}}{\textbf{14.7 psi}} = \textbf{2.31 feet}$$

Gauge Pressure + Atmospheric Pressure = Absolute Pressure

Pressure

A column of cold water 2.31 feet high will produce a pressure of 1 psi at its base.



Pressure

1 Atmosphere = 14.7 psi (At Sea Level)

1 Atmosphere = 34 ft. Column of Cold Water

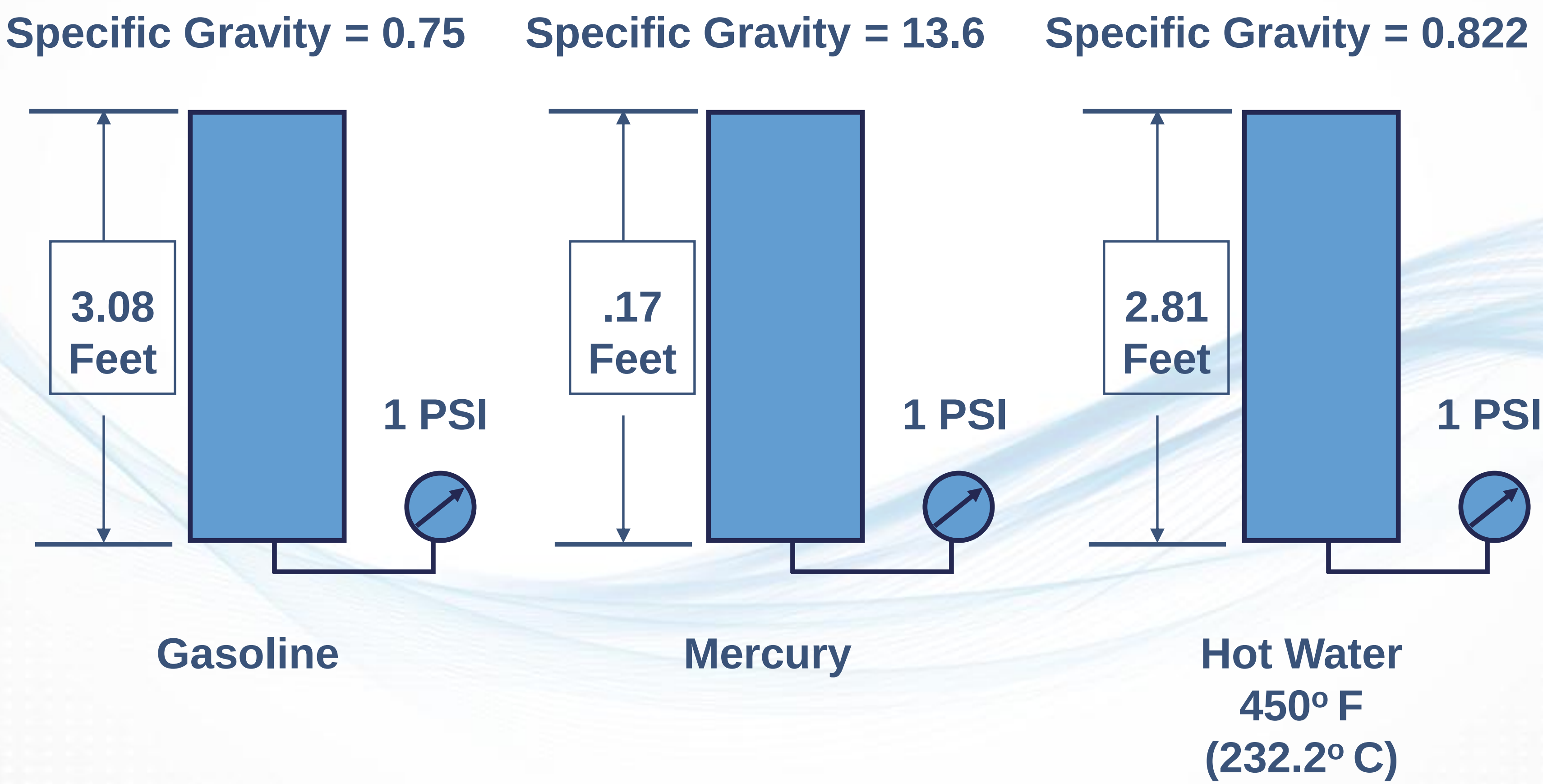
$$\frac{34\text{ ft.}}{14.7\text{ psi}} = 2.31\text{ feet}$$

$$\text{psi} = \frac{\text{Head in Feet}}{2.31\text{ psi}} \times \text{Specific Gravity}$$

$$\text{Head in Feet} = \frac{\text{psi} \times 2.31}{\text{Specific Gravity}}$$

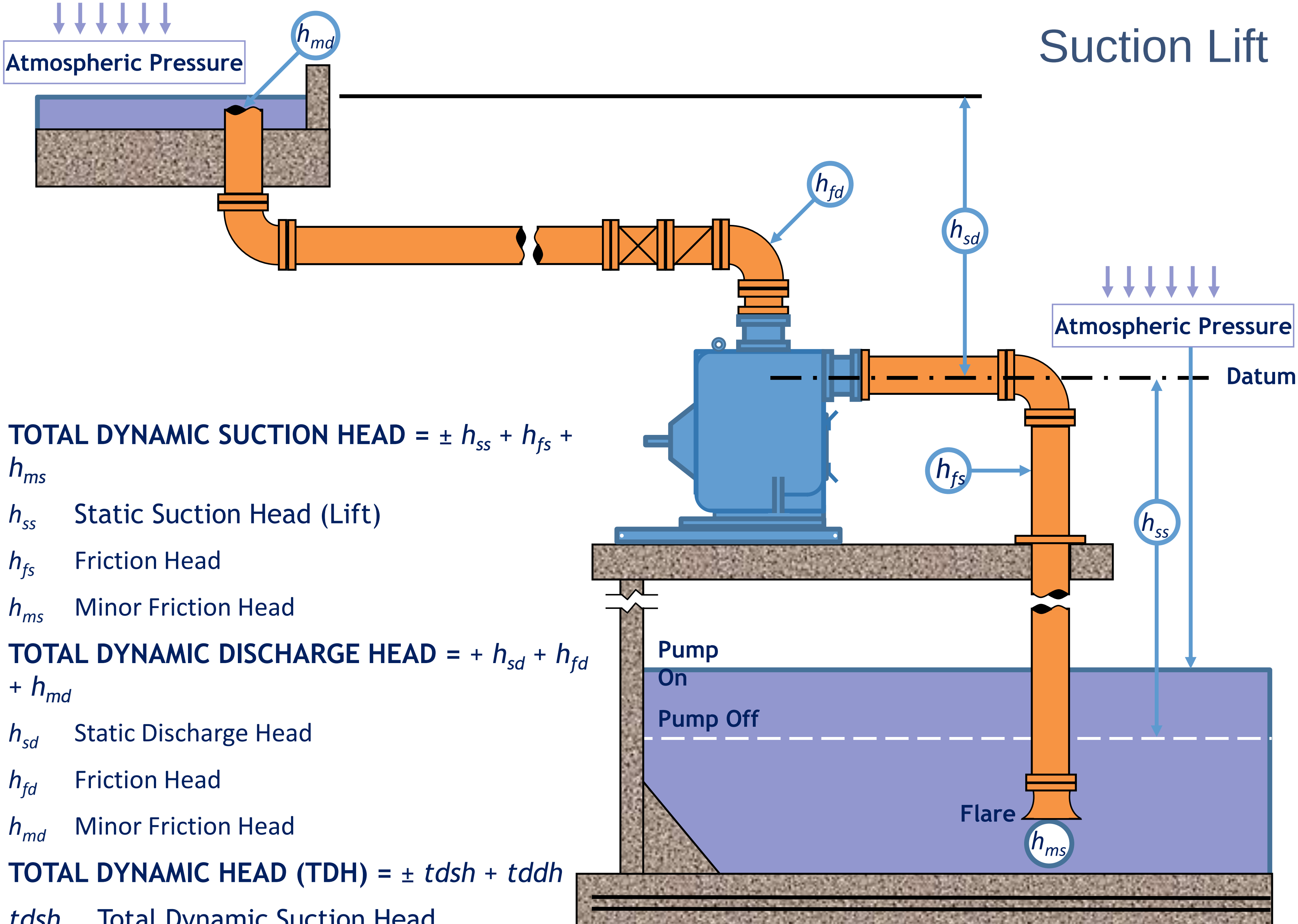
Gauge Pressure + Atmospheric Pressure = Absolute Pressure

Effects of Specific Gravity on Feet of Head



Now let's take a look at the system…

Suction Lift



TOTAL DYNAMIC SUCTION HEAD = $\pm h_{ss} + h_{fs} + h_{ms}$

h_{ss} Static Suction Head (Lift)

h_{fs} Friction Head

h_{ms} Minor Friction Head

TOTAL DYNAMIC DISCHARGE HEAD = $+ h_{sd} + h_{fd} + h_{md}$

h_{sd} Static Discharge Head

h_{fd} Friction Head

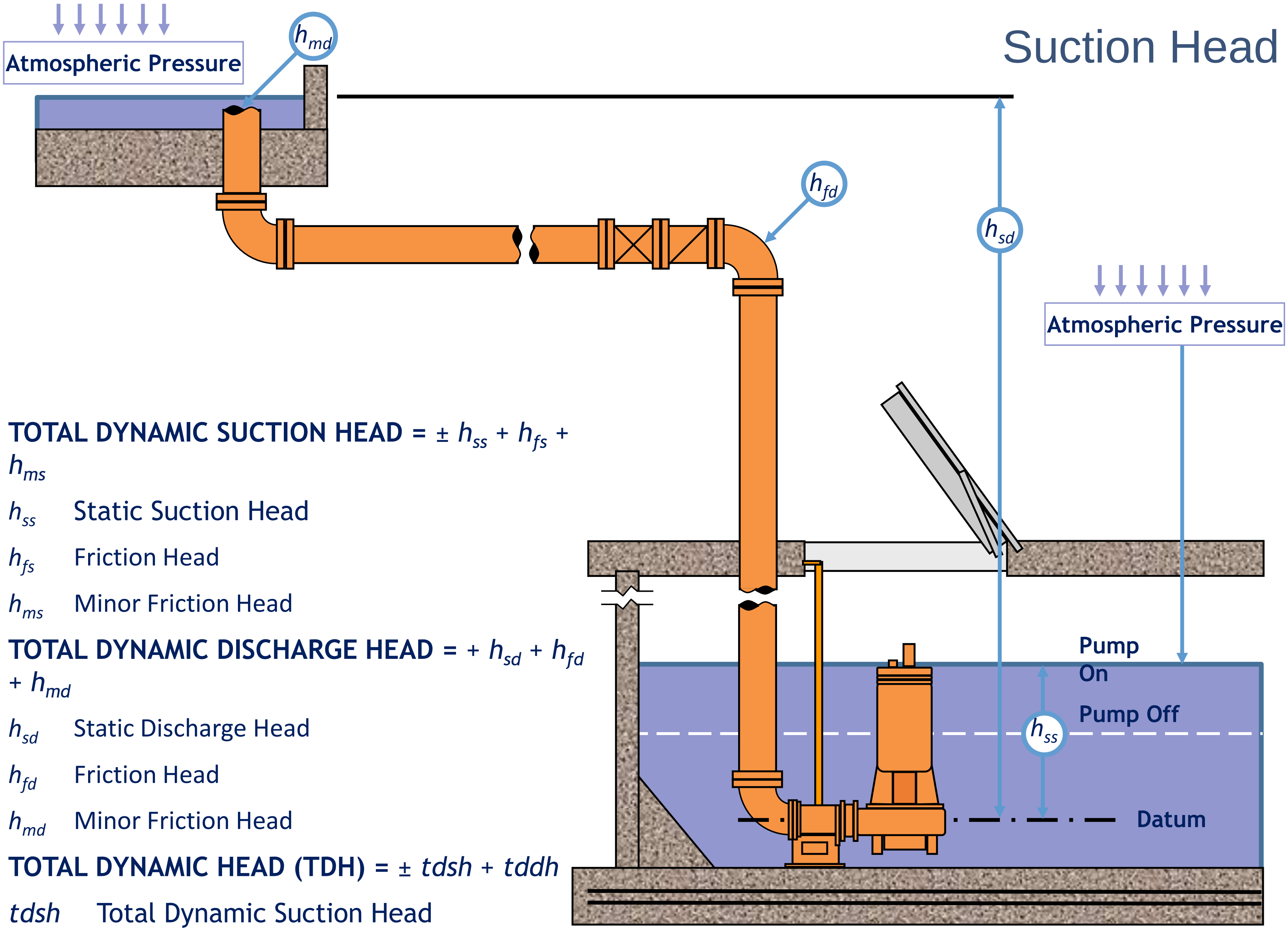
h_{md} Minor Friction Head

TOTAL DYNAMIC HEAD (TDH) = $\pm\, tdsh + tddh$

tdsh Total Dynamic Suction Head

tddh Total Dynamic Discharge Head

Suction Head



TOTAL DYNAMIC SUCTION HEAD = $\pm h_{ss} + h_{fs} + h_{ms}$

h_{ss} Static Suction Head

h_{fs} Friction Head

h_{ms} Minor Friction Head

TOTAL DYNAMIC DISCHARGE HEAD = $+ h_{sd} + h_{fd} + h_{md}$

h_{sd} Static Discharge Head

h_{fd} Friction Head

h_{md} Minor Friction Head

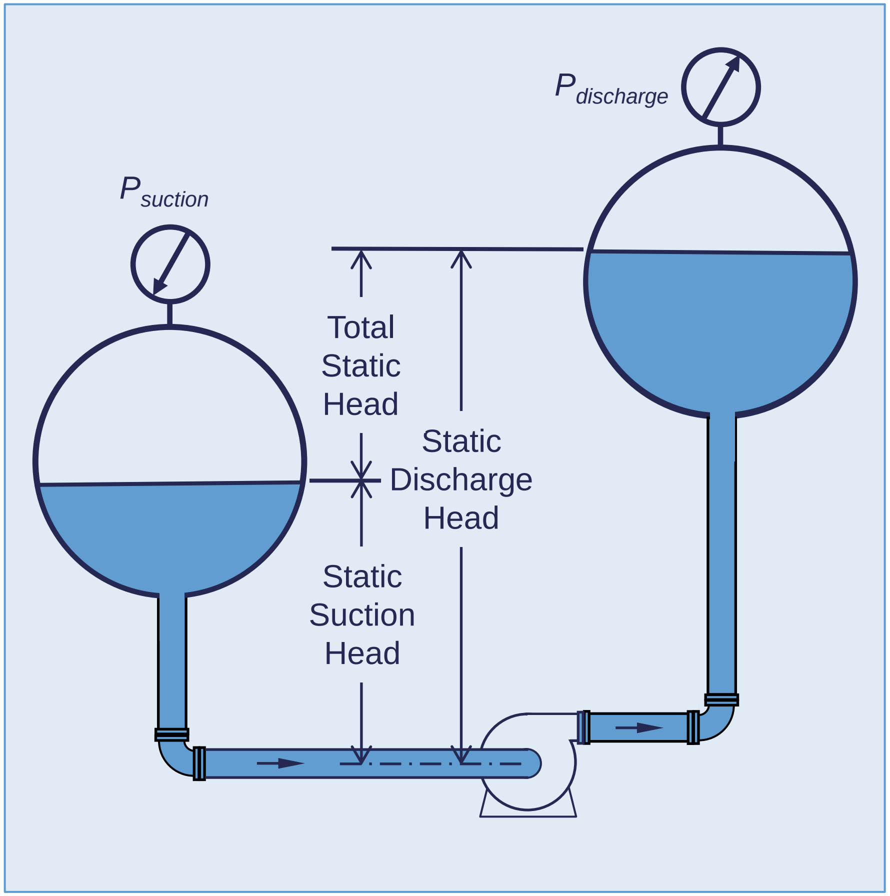
TOTAL DYNAMIC HEAD (TDH) = $\pm$ *tdsh* + *tddh*

tdsh Total Dynamic Suction Head

tddh Total Dynamic Discharge Head

Enclosed/Pressurized Systems

Suction & Discharge Under Pressure



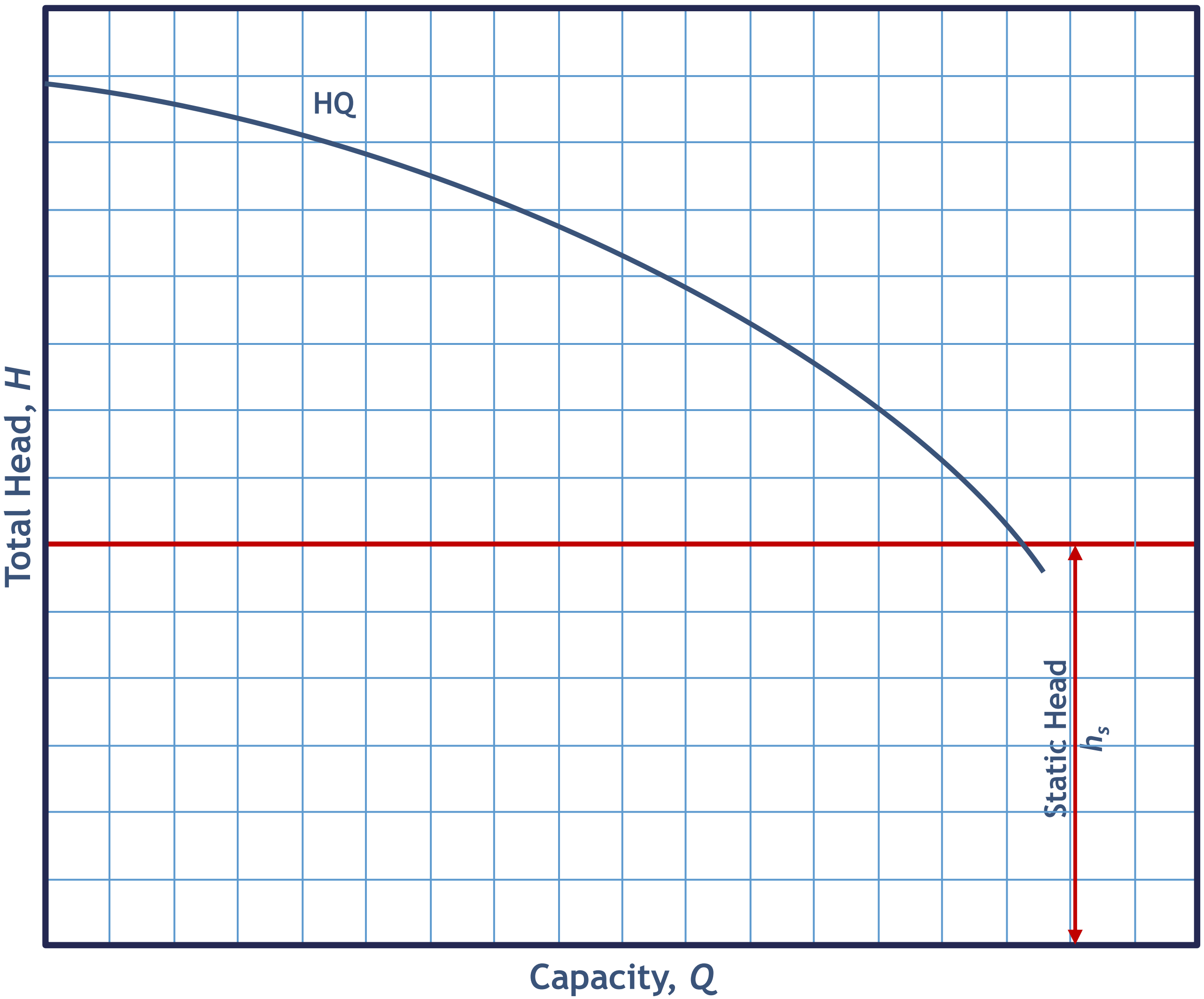
System Head

- Static head
- Difference in pressure on liquid surfaces
- Friction head
- Entrance and exit losses

Total Head (Total Dynamic Head)

	Static Discharge Head
+	Static Suction Lift or – Static Suction Head
+	Friction Head (suction & discharge)
+	Differential Pressure (discharge vs. suction)
	Total Head (Total Dynamic Head)

Total Static Head, (h_s)



Friction Head (h_f)

The amount of head loss depends on:

- The length of the pipe
- The internal diameter of the pipe
- Velocity of the fluid
- The roughness of the interior pipe surface
- The number and size of Valves, Fittings, etc.

These factors are related in the formulas for computing head losses, pipe sizes, and carrying capacities in pumping systems.

Hazen-Williams

Friction Head (C Factors)

$$h_f = \frac{10.44\, L\, Q^{1.85}}{C^{1.85} D^{4.87}}$$

Pipe Type	Typical C Factors	
	Initial Service	End of Service
DIP	140	120
PVC	150	130
HDPE	150	130

Hazen-Williams

Friction Head (C Factors)

Beware…

$$h_f = \frac{10.44\,L\,Q^{1.85}}{C^{1.85}D^{4.87}}$$

Pipe Type	Typical C Factors	
	Initial Service	End of Service
DIP	120	70
PVC	140	100
HDPE	140	100

Hazen-Williams

Friction Loss Formula

$$h_f = \frac{10.44\ L\ Q^{1.85}}{C^{1.85} D^{4.87}}$$

How much headloss will be in a 16 inch DIP pipe flowing at 5,000 gpm, over a distance of 1 mile?

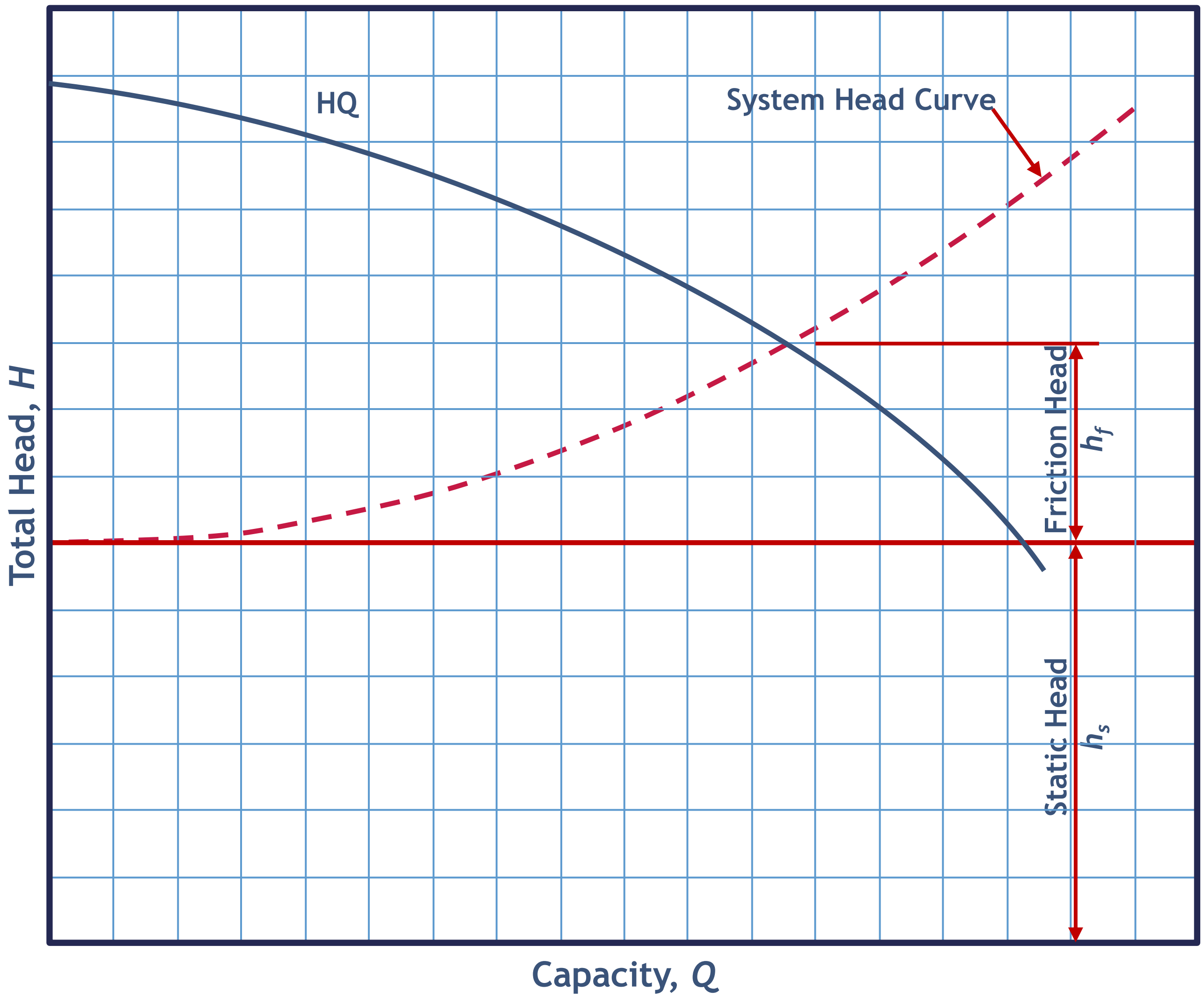
$$h_f = \frac{10.44\ (5280)\ (5000)^{1.85}}{(140)^{1.85}\ (16)^{4.87}} = 56.24\ \text{ft.}$$

$$h_f = \frac{10.44\ (5280)\ (5000)^{1.85}}{(100)^{1.85}\ (16)^{4.87}} = 104.8\ \text{ft.}$$

Additional Friction Losses

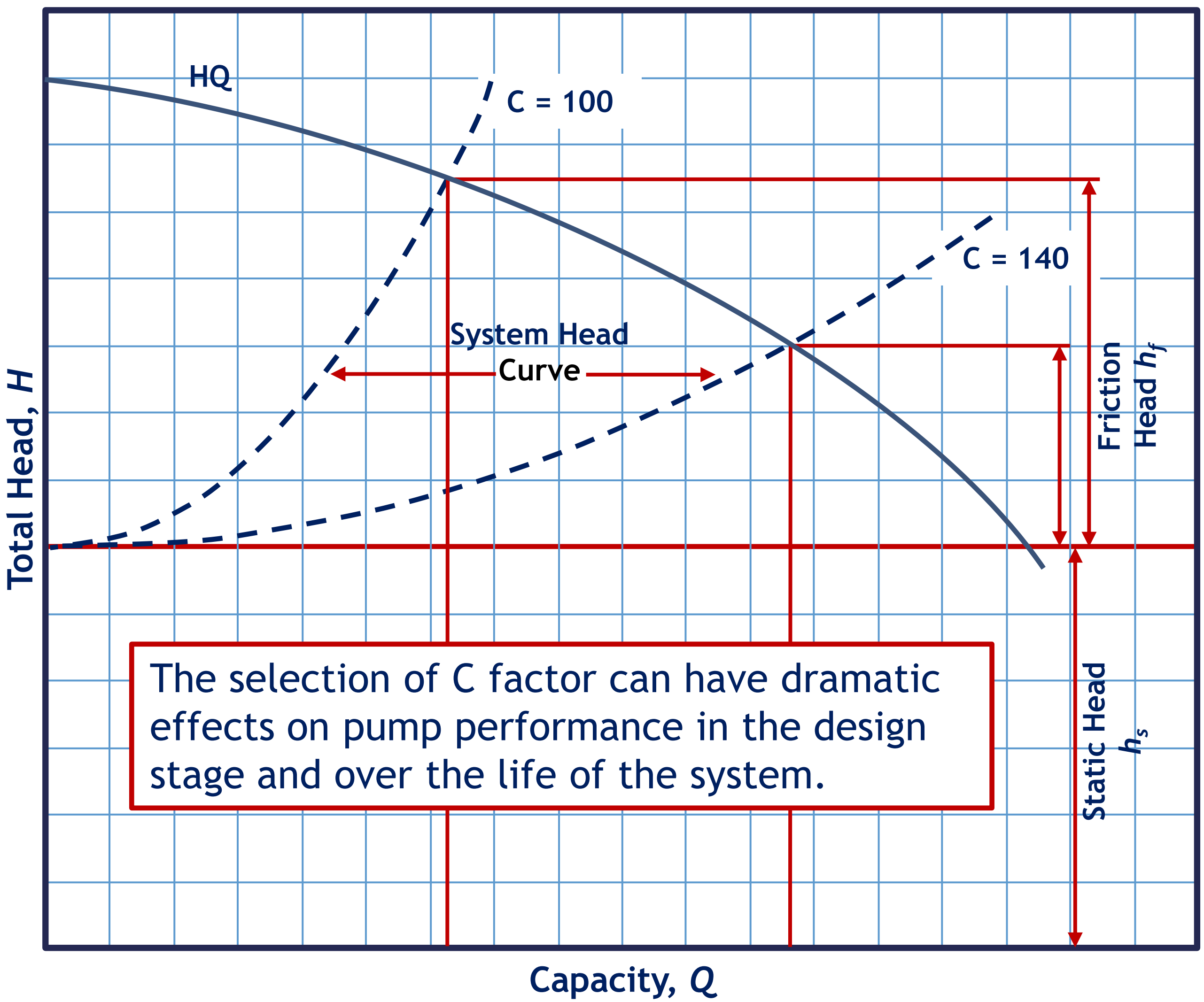
- Frictional resistance through fittings such as a elbows, valves, entrance, exit, orifices, etc. must be considered in addition to frictional losses through piping
- Most often these losses are calculated as a percentage of the velocity head.
- The formula is usually written as: $h_f = K \left(\frac{V^2}{2g}\right)$
- "K" is a coefficient and can be found in hydraulic handbooks published by pump manufacturers, valve manufacturers, etc.

Total Head (Total Dynamic Head)

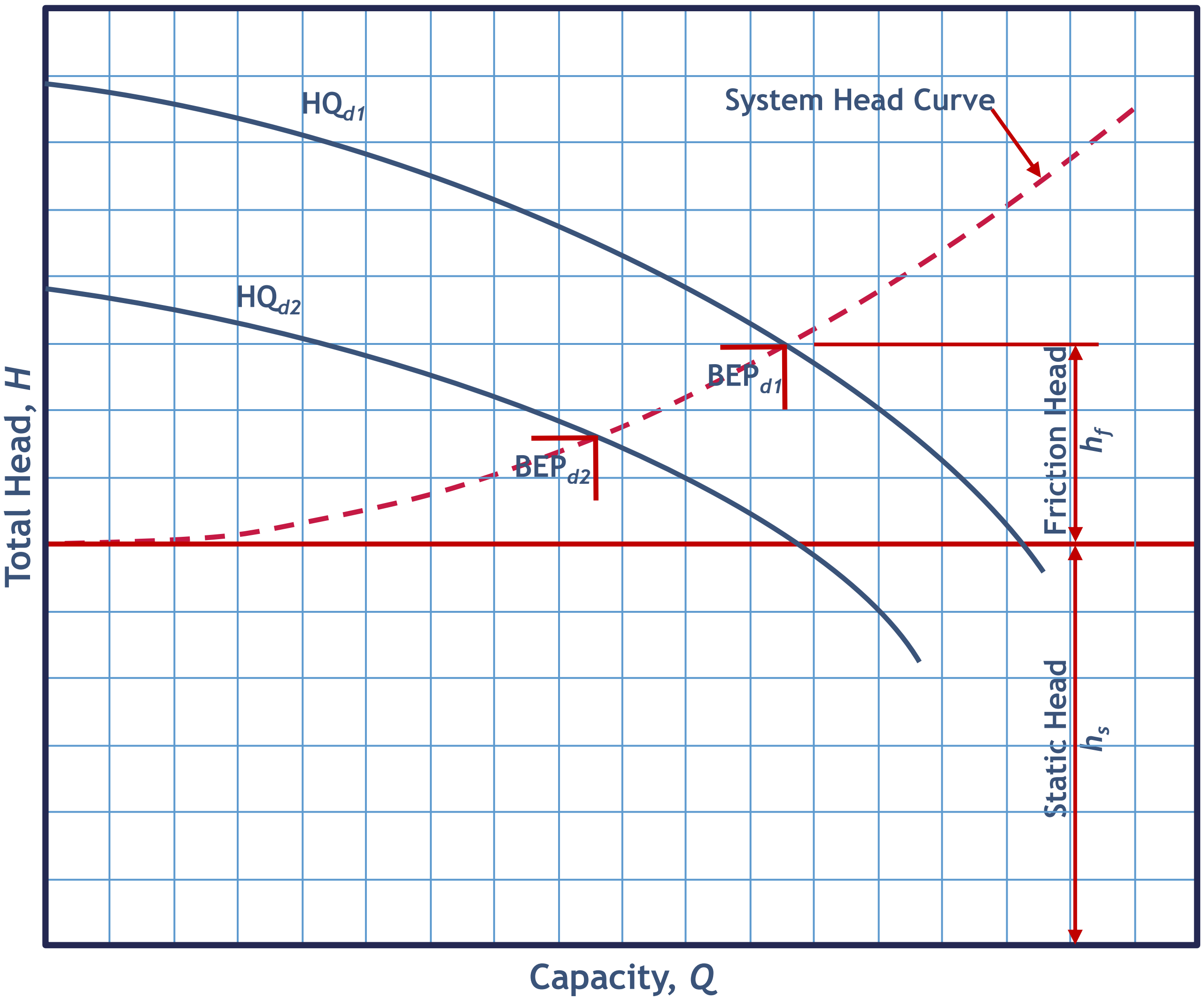


Friction Head

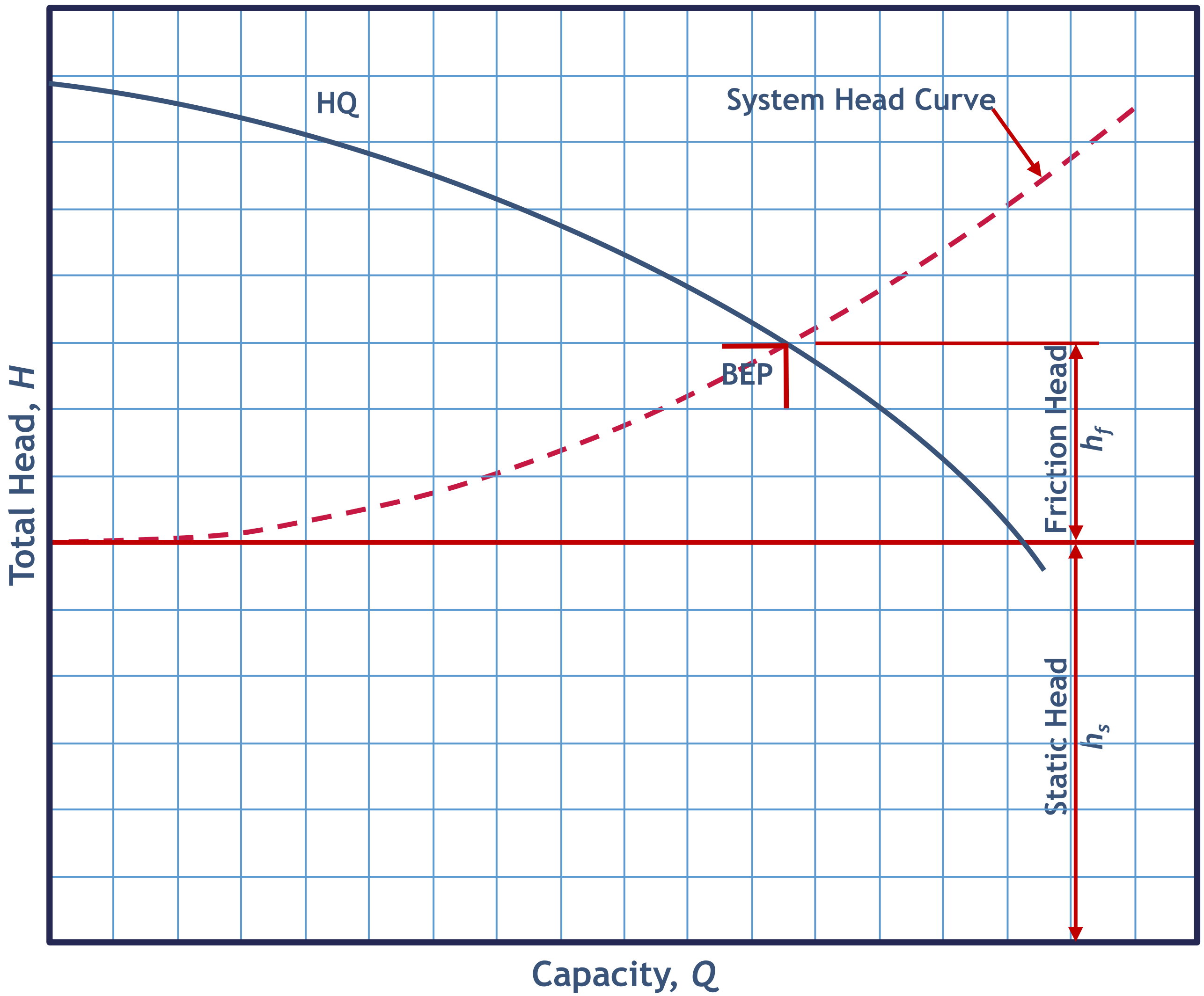
Effects of C Factor



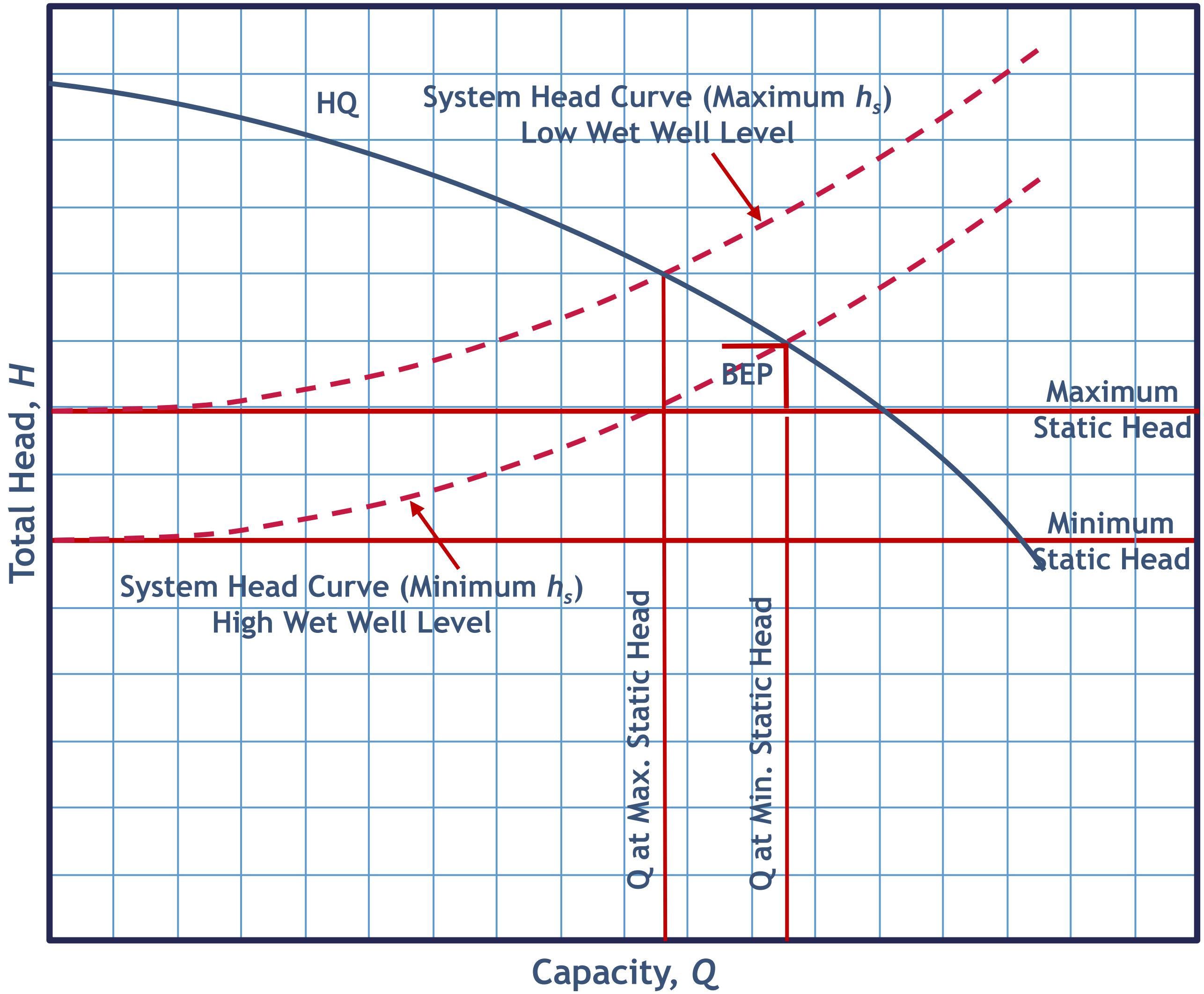
System Head Curve



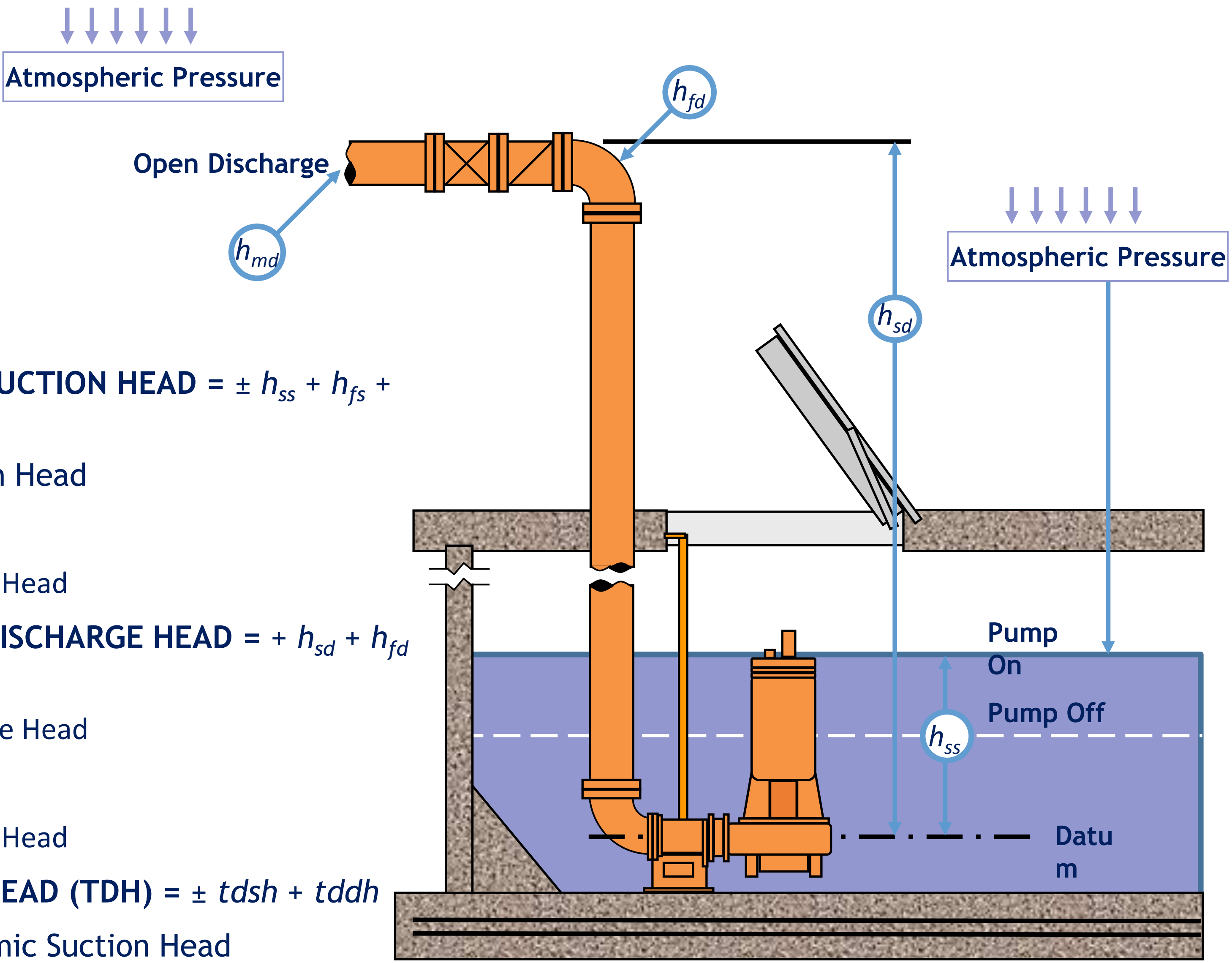
System Head Curve



System with Varying Static Head



Suction Head



TOTAL DYNAMIC SUCTION HEAD = $\pm h_{ss} + h_{fs} + h_{ms}$

h_{ss} Static Suction Head

h_{fs} Friction Head

h_{ms} Minor Friction Head

TOTAL DYNAMIC DISCHARGE HEAD = $+ h_{sd} + h_{fd} + h_{md}$

h_{sd} Static Discharge Head

h_{fd} Friction Head

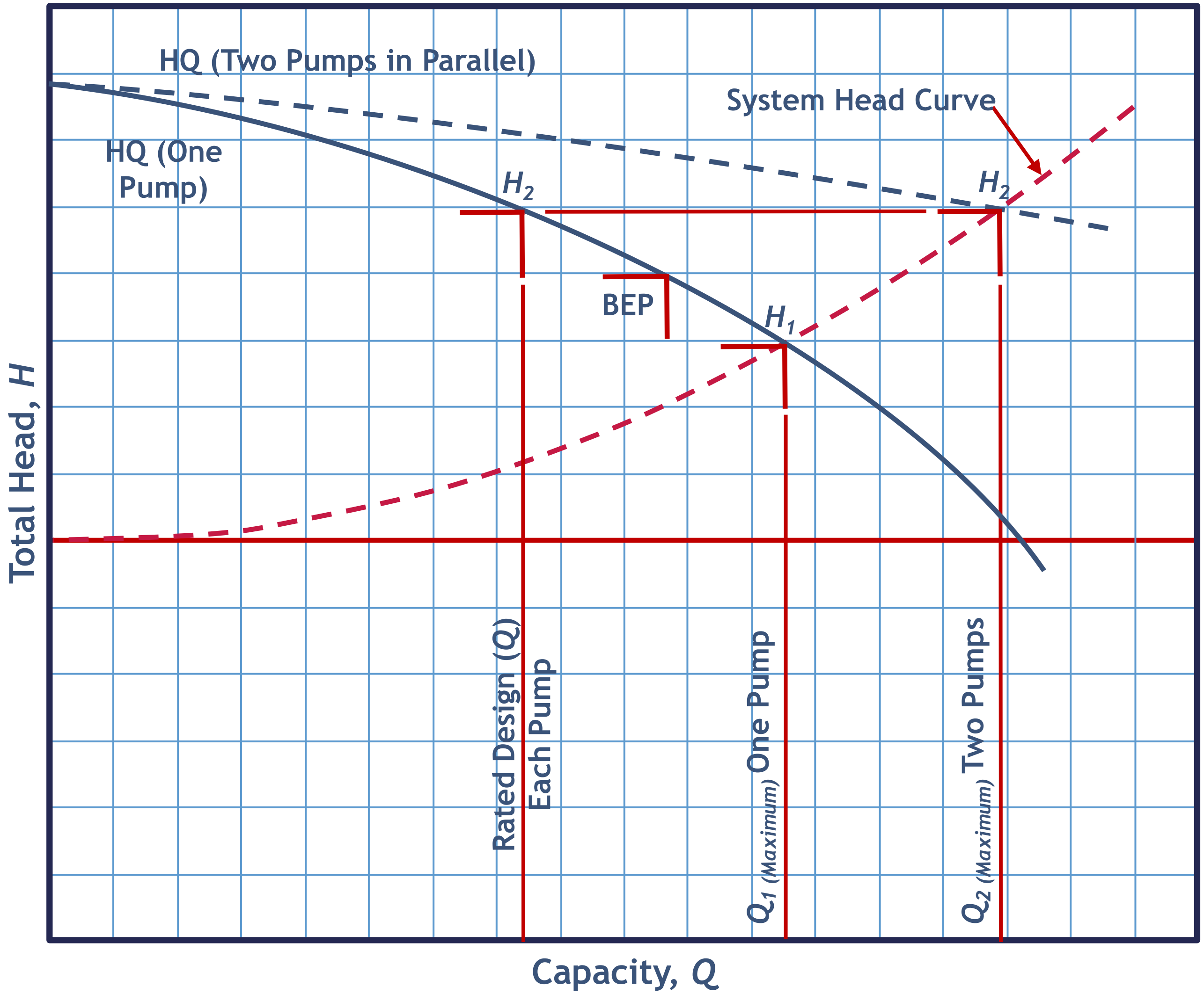
h_{md} Minor Friction Head

TOTAL DYNAMIC HEAD (TDH) = $\pm tdsh + tddh$

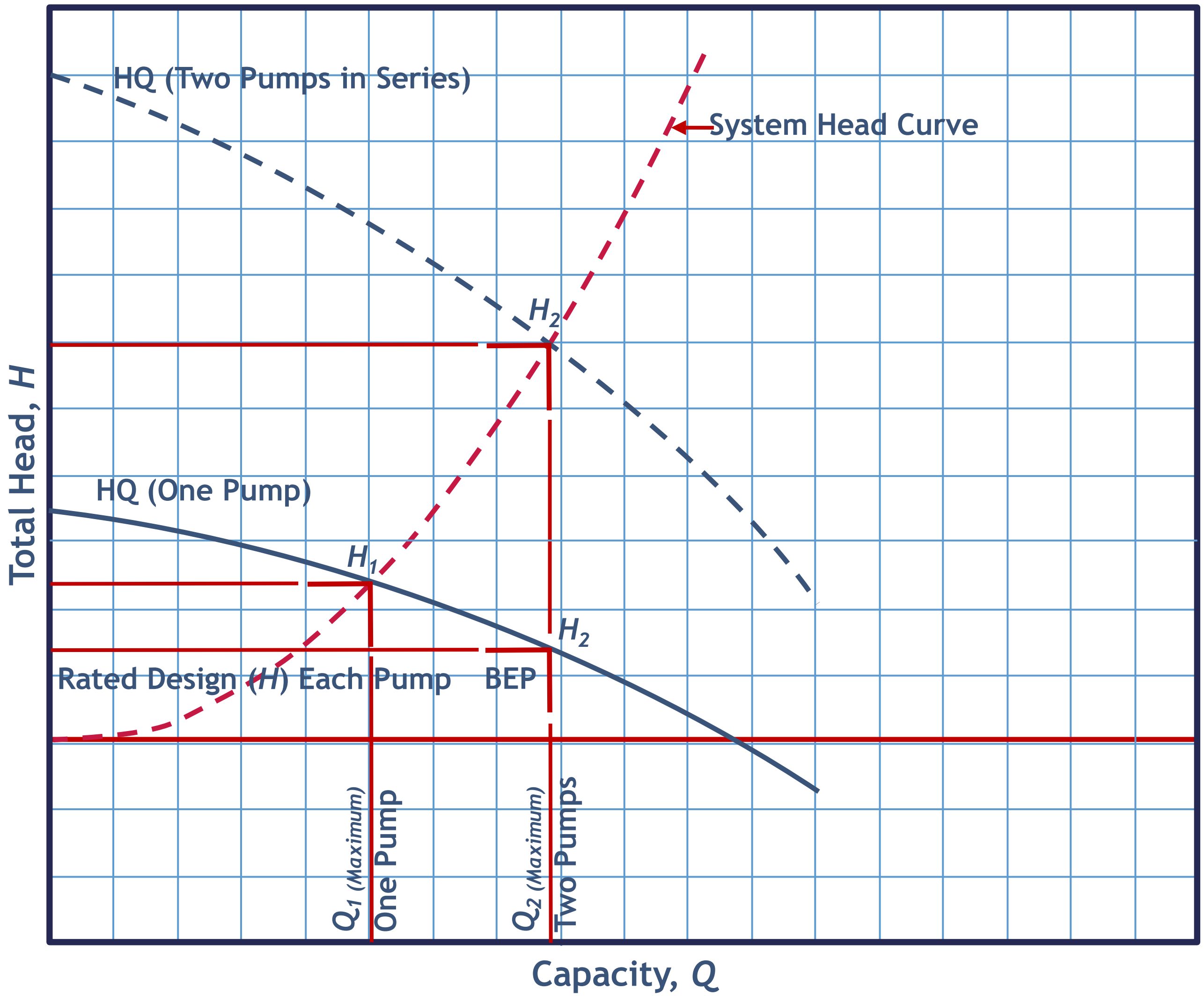
tdsh Total Dynamic Suction Head

tddh Total Dynamic Discharge Head

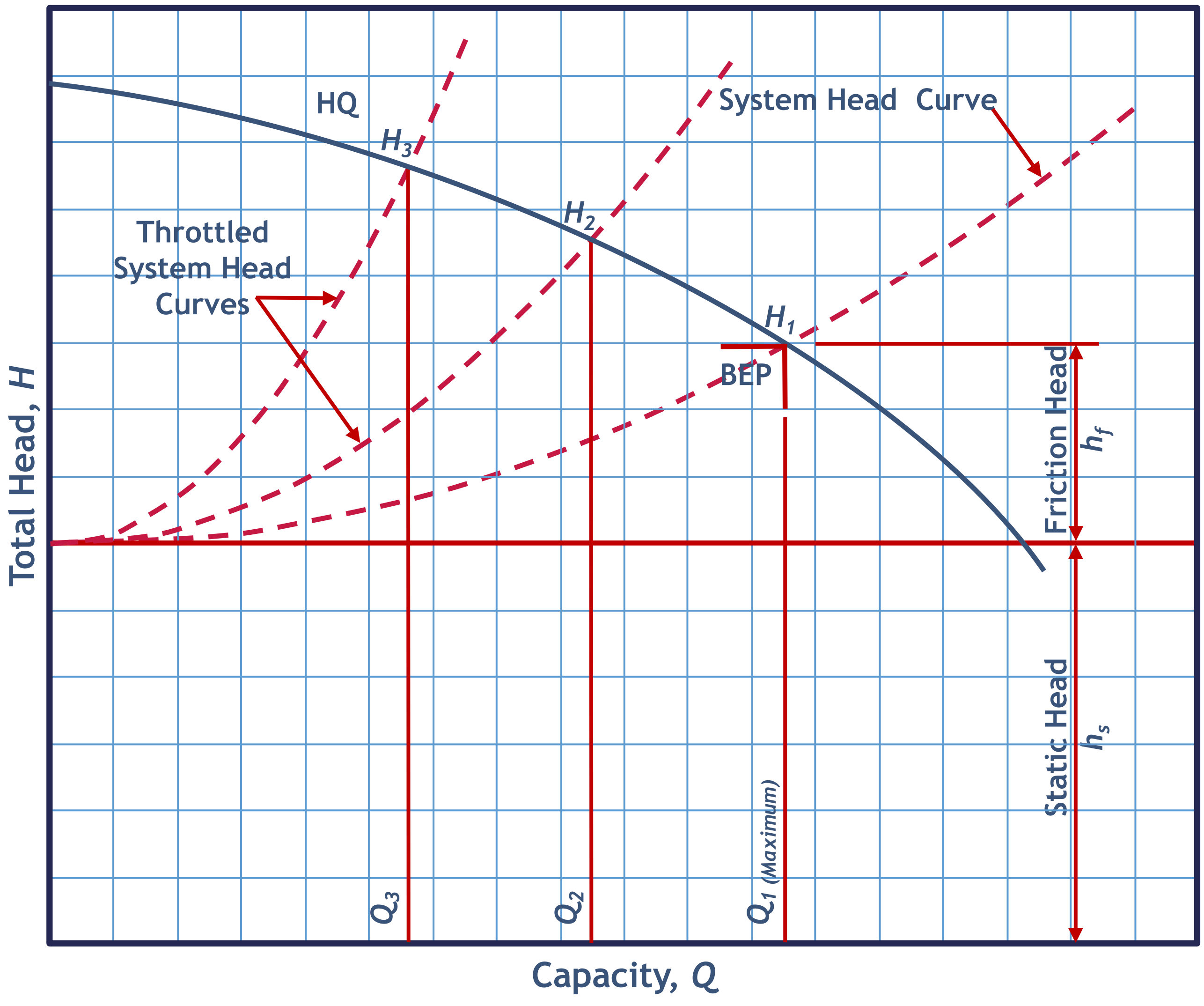
Parallel Operation



Series Operation



Throttled System Head



The Affinity Laws

$$\frac{Q_1}{Q_2} = \frac{N_1}{N_2} = \frac{D_1}{D_2}$$

$$\frac{H_1}{H_2} = \left(\frac{N_1}{N_2}\right)^2$$

$$\frac{P_1}{P_2} = \left(\frac{N_1}{N_2}\right)^3$$

Where:

Q = Capacity (GPM)

D = Impeller Diameter

H = TDH (Feet)

P = HP

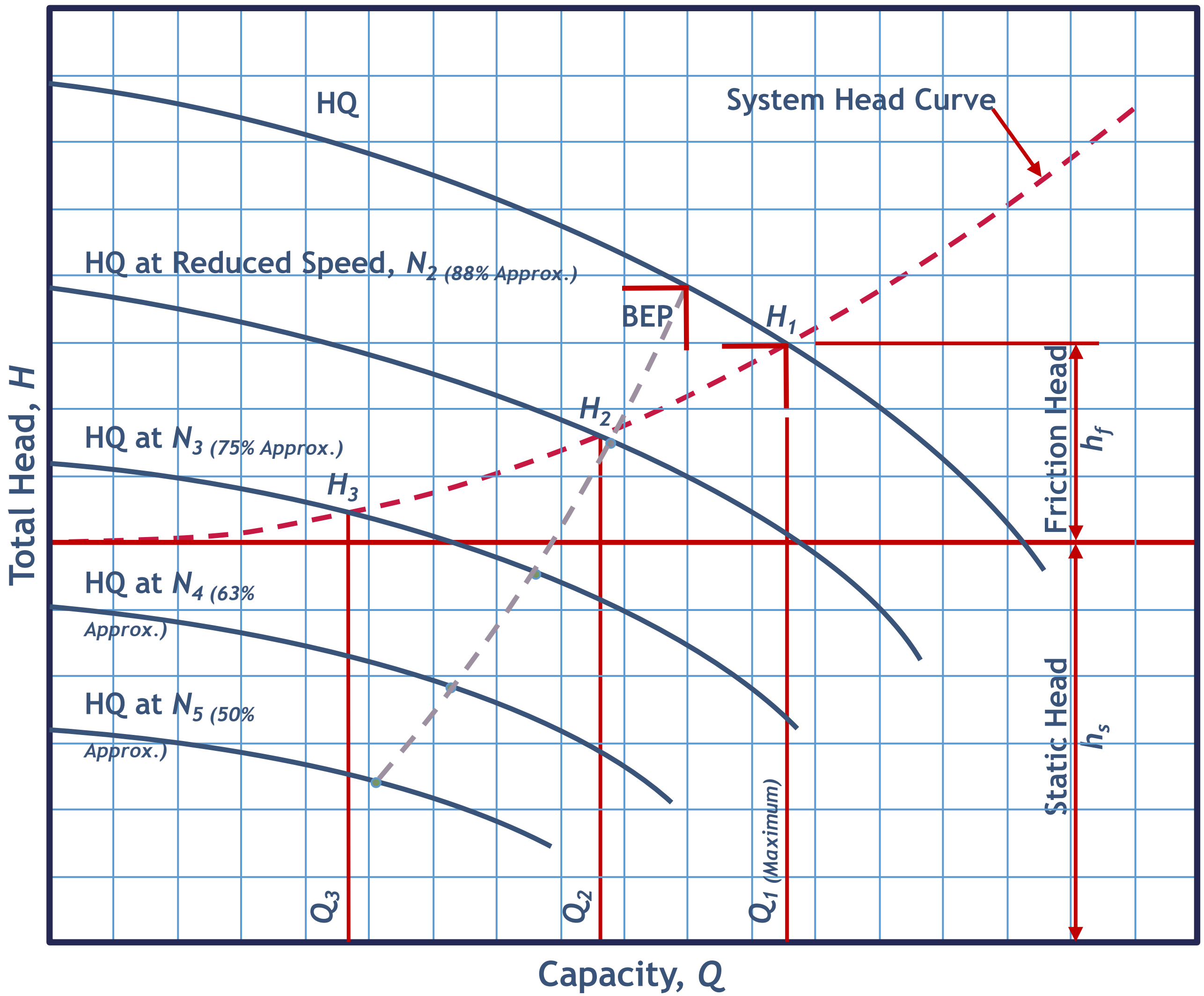
N = RPM

The Affinity Laws… Simply Stated

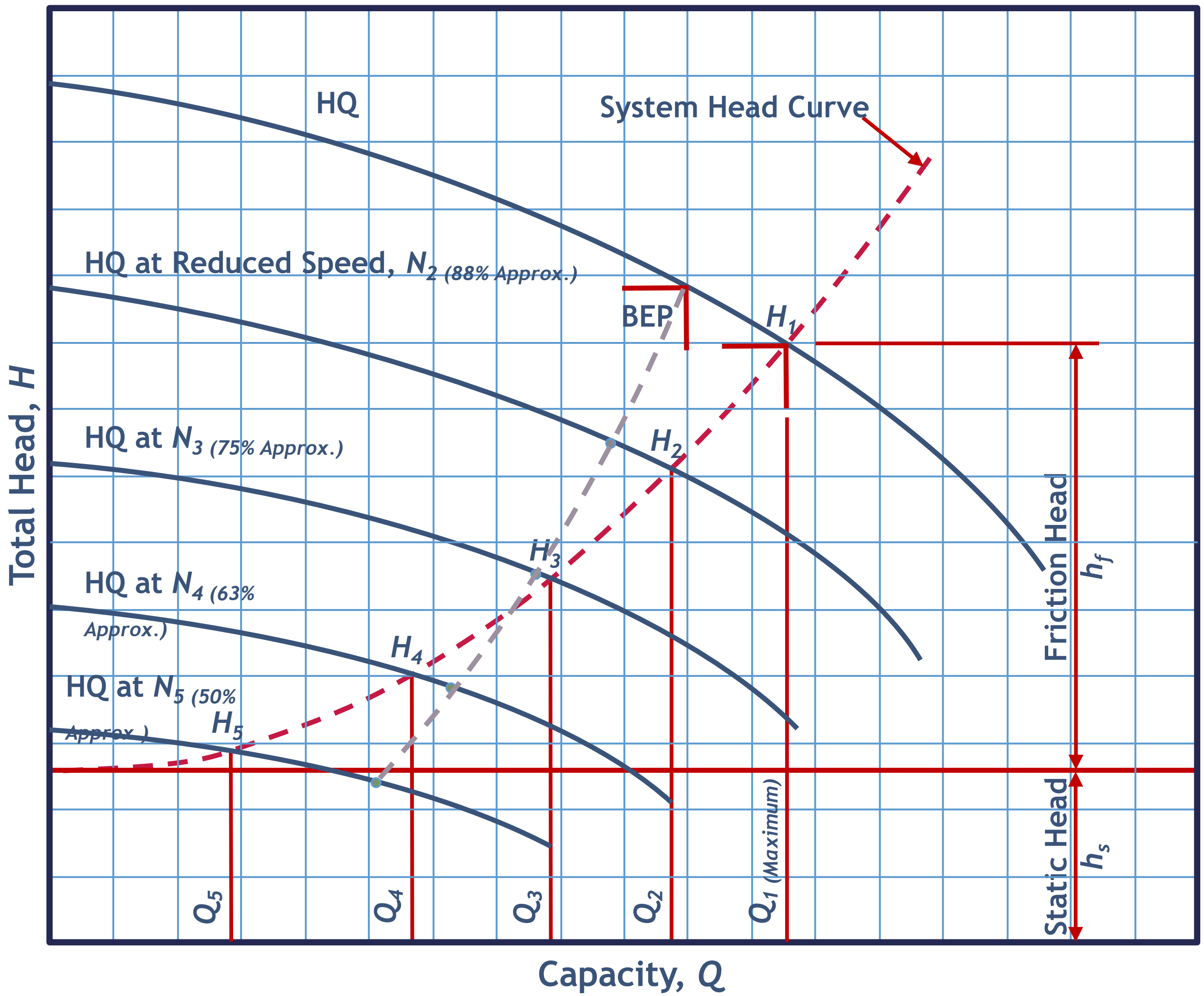
- Double (2^1) the Speed (N)
- Double (2^1) the Flow (Q)
- Four Times (2^2) the Head (H)
- Eight Times (2^3) the Horsepower (P)

- Operation Above Rated Speed Could Exceed Pressure Limitations of the Pump
- Turndown is Often Limited by the Characteristics of the System Head Curve

Variable Speed Operation



Variable Speed Operation

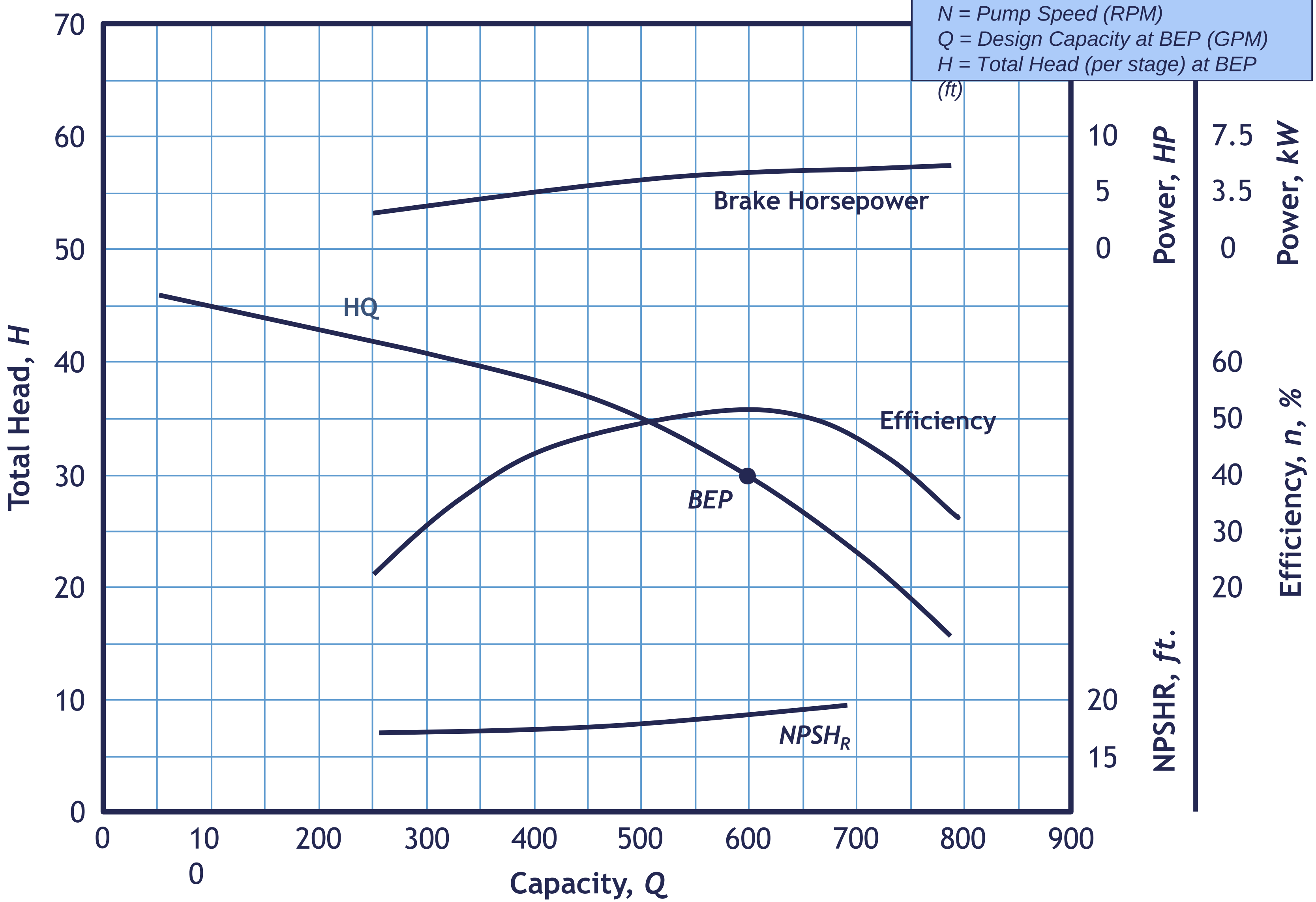


Pump Curves

Specific Speed

$$N_S = \frac{N(Q)^{1/2}}{H^{3/4}}$$

N = Pump Speed (RPM)
Q = Design Capacity at BEP (GPM)
H = Total Head (per stage) at BEP (ft)



Pump Operation & BEP

Best Efficiency Point

- Right of BEP (Cavitation)
- Left of BEP (Internal Recirculation)
- Shaft Deflection
- Thrust Loads
  - Radial
  - Axial (Pump-out Vanes)

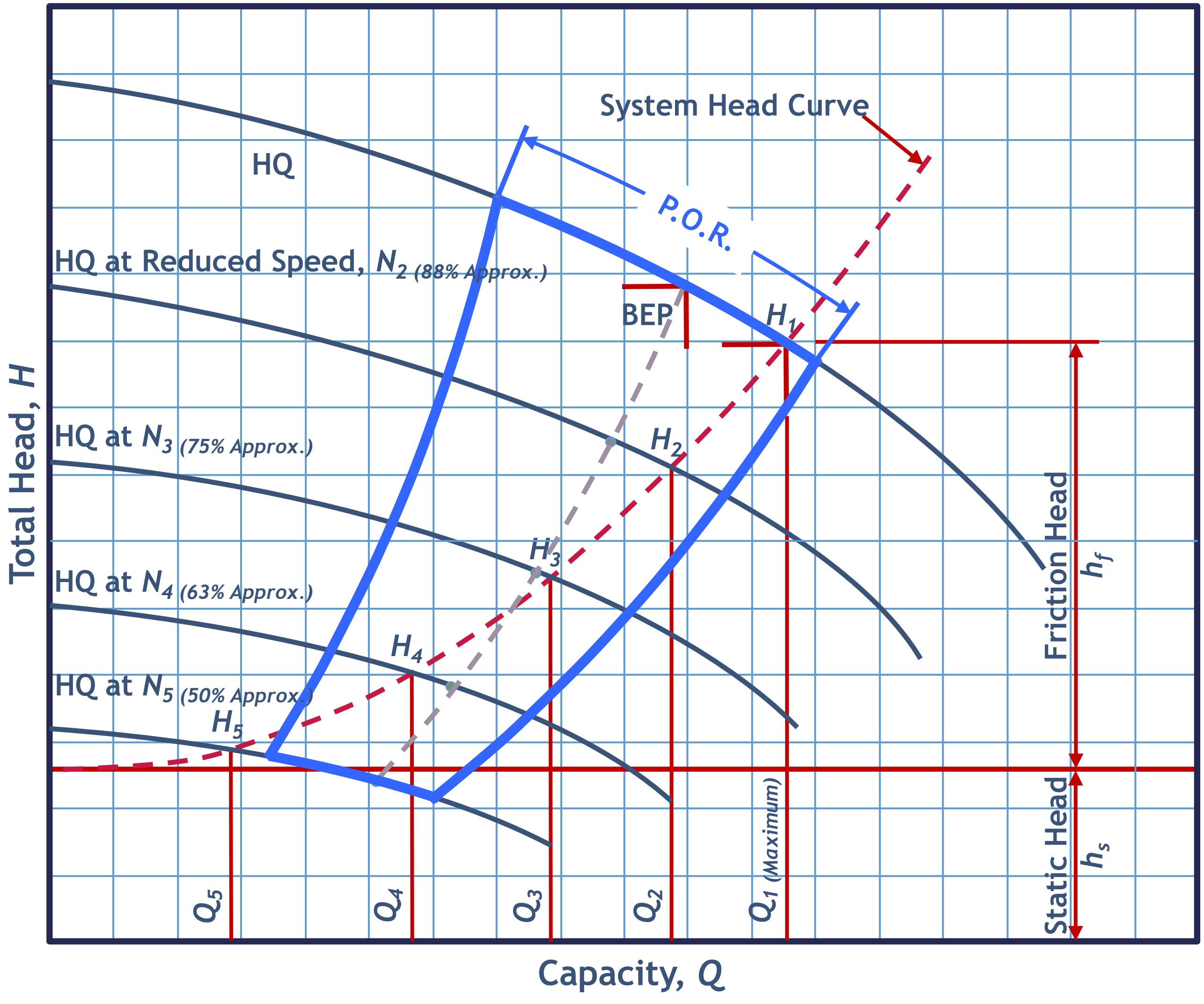
Preferred Operating Range

(Ref: Hydraulic Institute 9.6.3-1997)

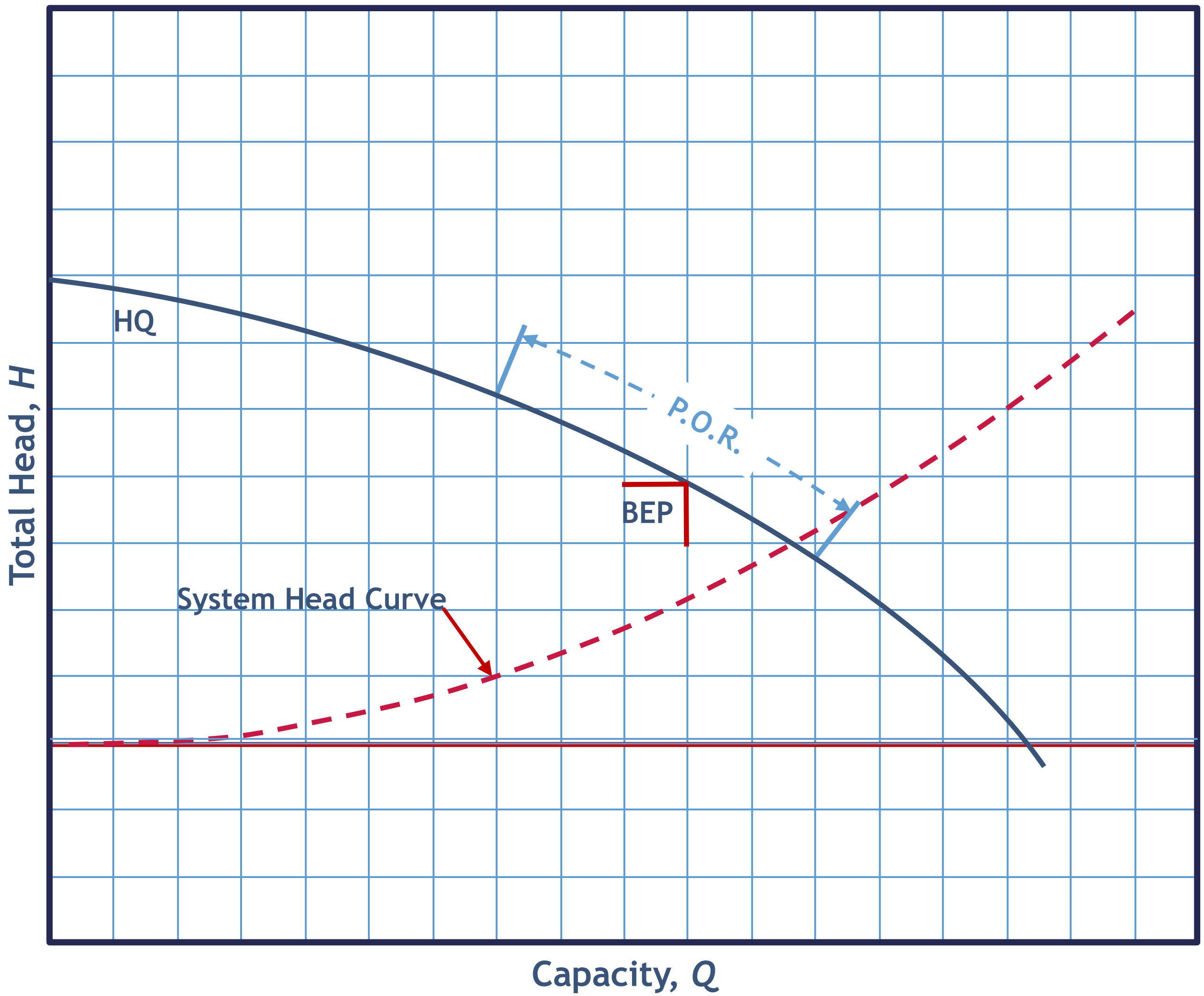
- At Best Efficiency Point (BEP) the hydraulic efficiency is maximum.
- Flow through the impeller is uniform, free of separation, and is well controlled.
- The flow remains well controlled within a range of rates of flow designated as the Preferred Operating Region (POR).
- Within this region the service life of the pump will not be significantly affected by hydraulic loads, vibration, or flow separation.
- The Preferred Operating Region (POR) for most centrifugal pumps is between 70% – 120% of BEP.

Preferred Operating Range (POR)

Variable Speed Operation

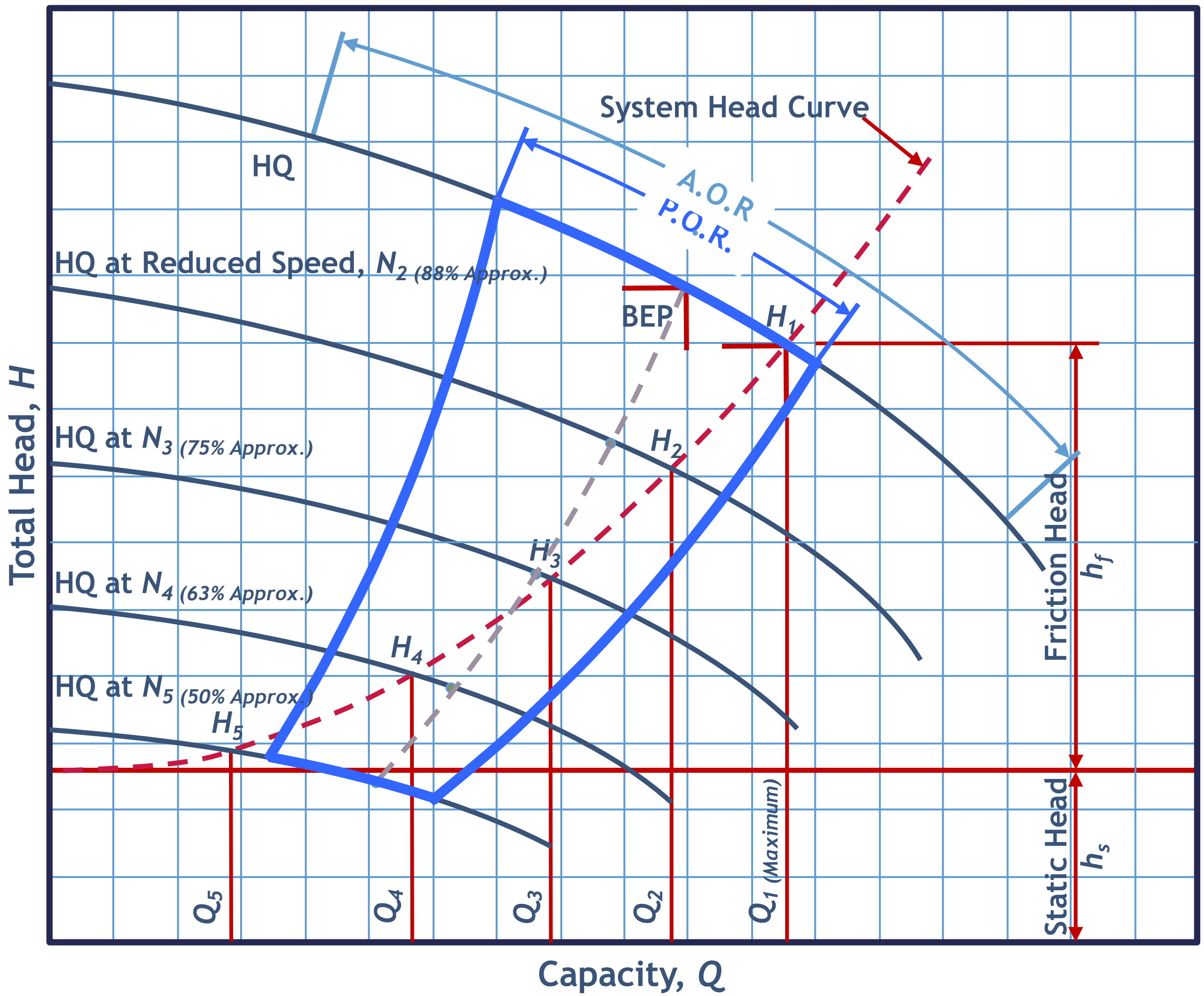


Preferred Operating Range (POR)

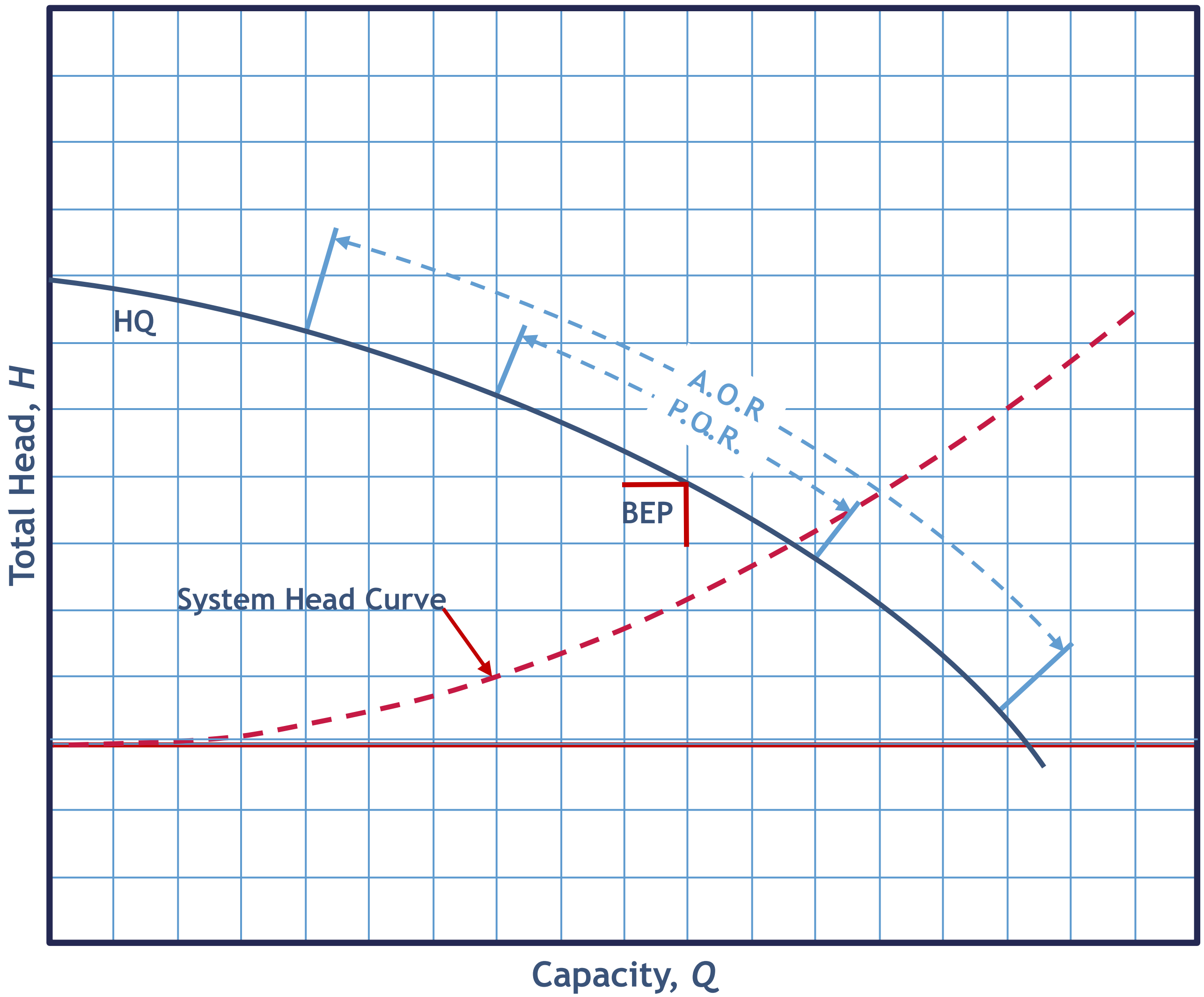


Preferred Operating Range (POR)

Variable Speed Operation



Allowable Operating Range (AOR)



Cavitation

Occurs when the absolute pressure within an impeller falls below the vapor pressure of the liquid, and bubbles of vapor are formed.

Signs include: noise, vibration, decreased performance (head-capacity), increased horsepower resulting from reduced efficiency, and - over time - damage to the impeller by pitting and erosion.

Cavitation

NPSH

Net Positive Suction Head

$NPSH_R$

The energy in feet of liquid head required at the pump suction over and above the vapor pressure of the liquid, to permit the pump to deliver a given capacity at a given speed.

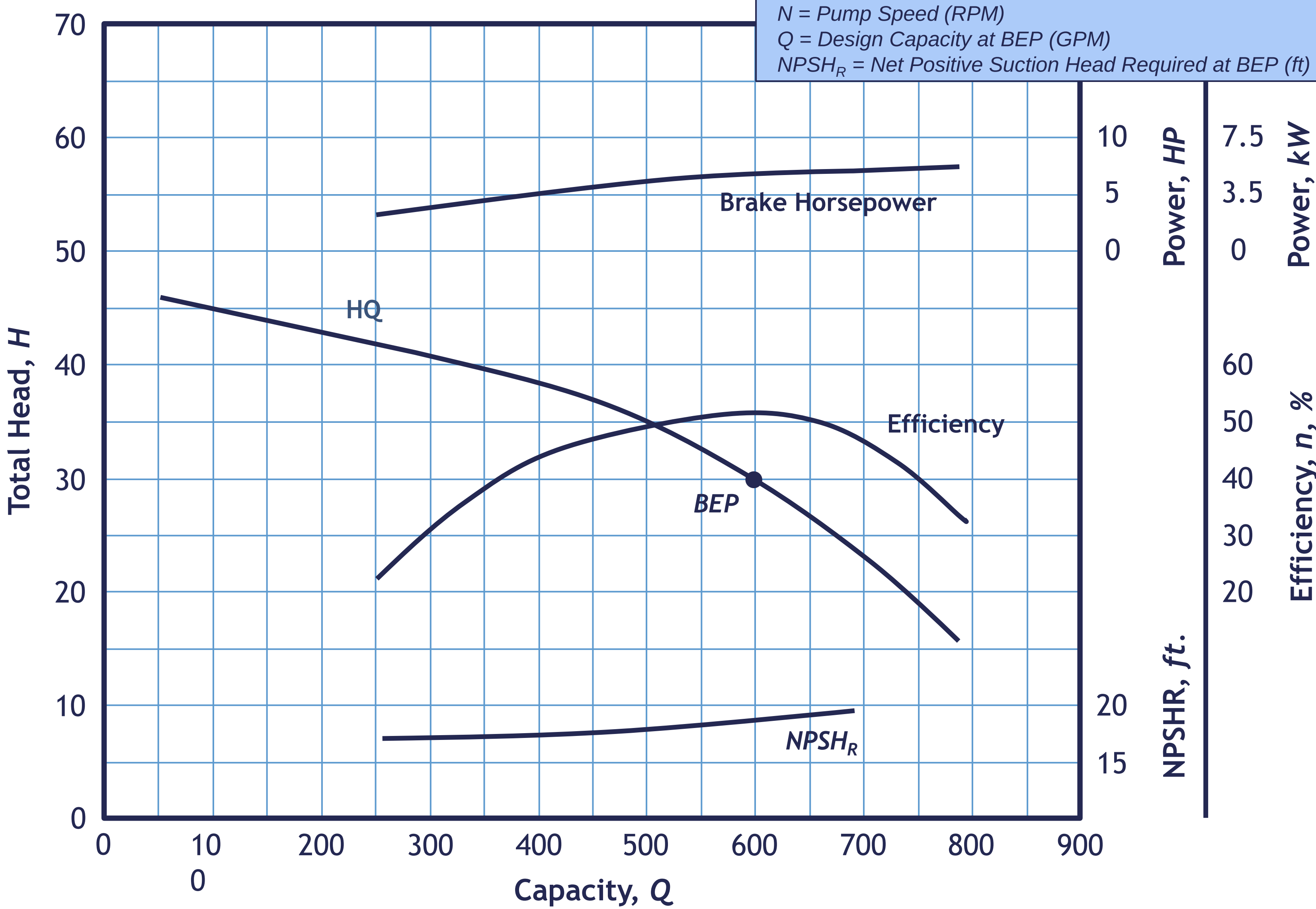
$NPSH_A$

NPSH Curves

Suction Specific Speed

$$S = \frac{N(Q)^{1/2}}{NPSH_R^{3/4}}$$

N = Pump Speed (RPM)
Q = Design Capacity at BEP (GPM)
$NPSH_R$ = Net Positive Suction Head Required at BEP (ft)



Net Positive Suction Head

$$NPSH_R < NPSH_A$$