CENTRIFUGAL PUMPS

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Session Overview

Session 1 – Centrifugal Pumps

- Introduction
- Construction
- Pump Fundamentals
- Pump and System curves
- Control
- Reliability
- Vibration Characteristics

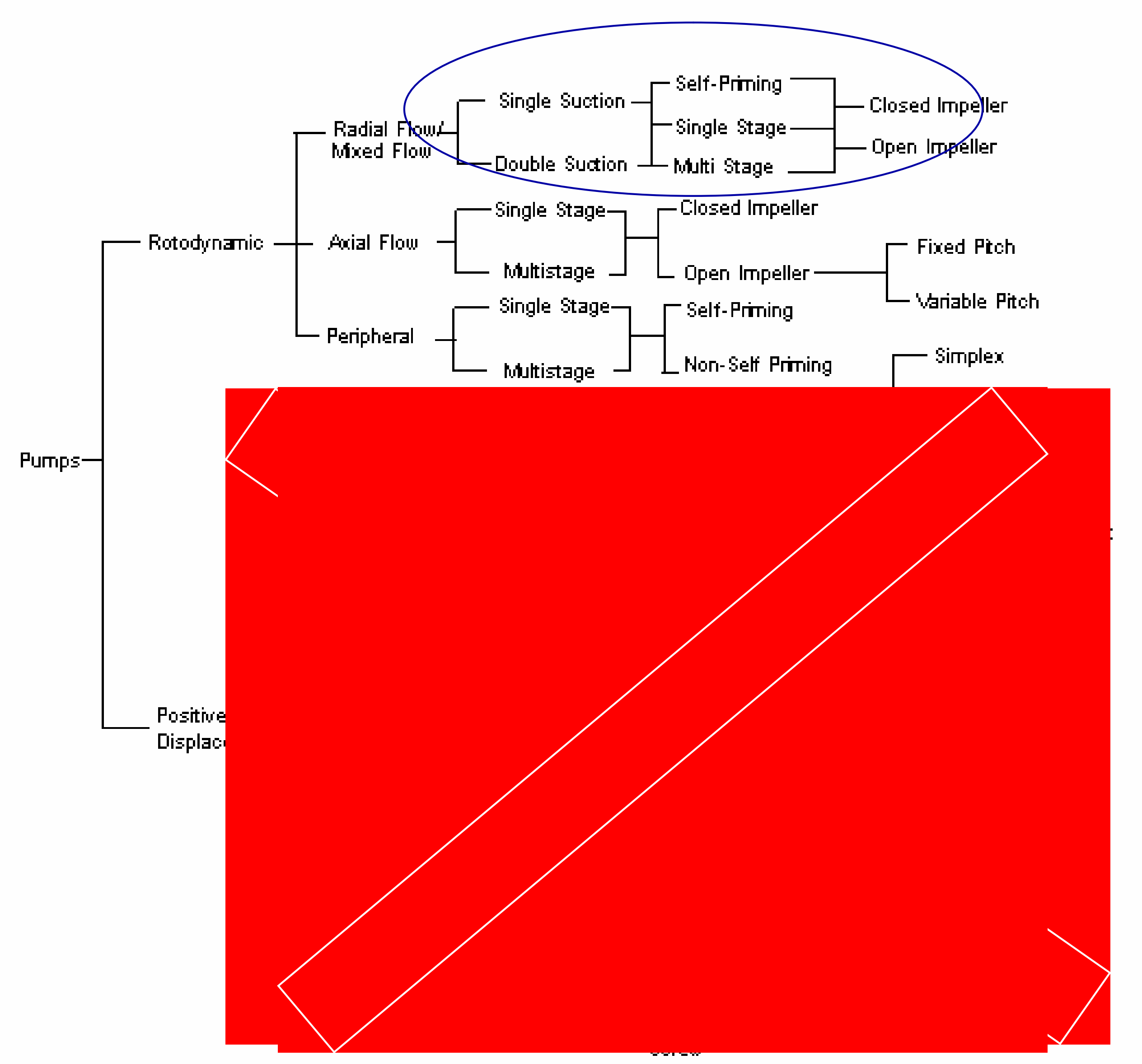
Learning Objectives

- Understand various pump constructions
- Introduce pump and system curves
- Understand relationship between flow rate and reliability
- Be able to relate typical vibration spectra to operational parameters

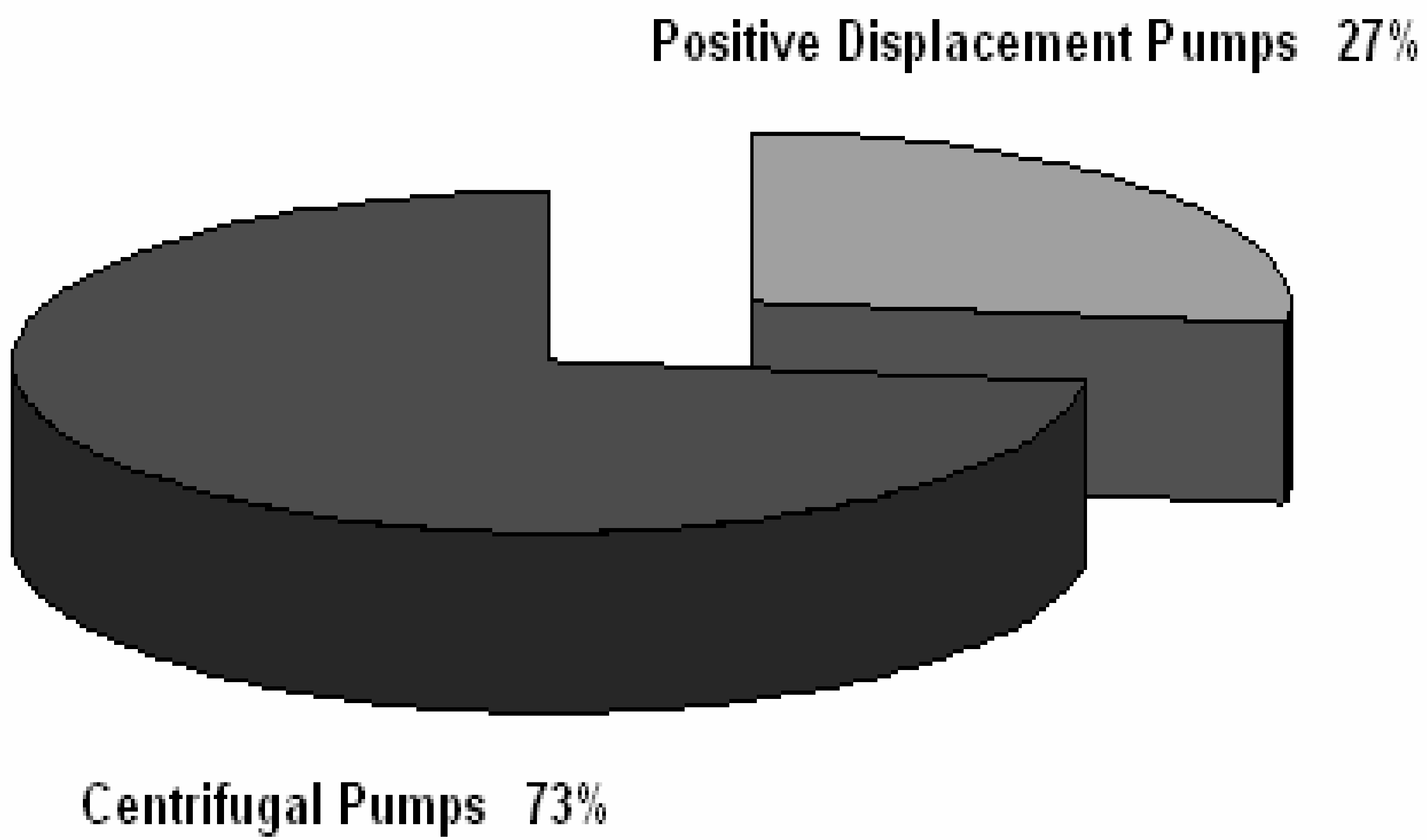
Construction

- Pumps are divided into
  - Roto-dynamic or centrifugal pumps and
  - Positive displacement pumps
- Within these main groups there are many different types of pumps

Construction



Construction

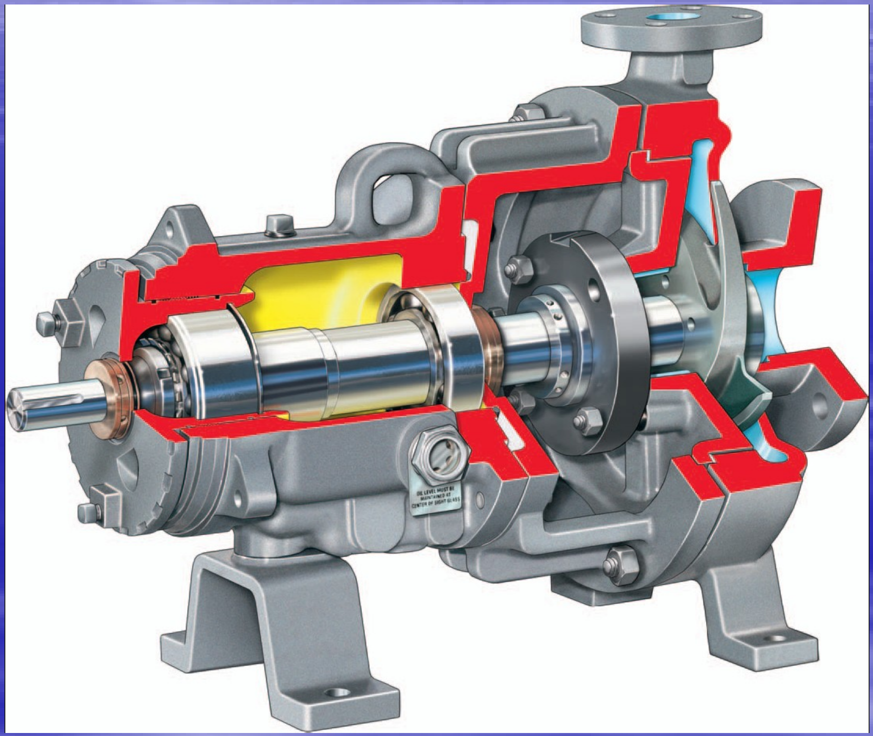


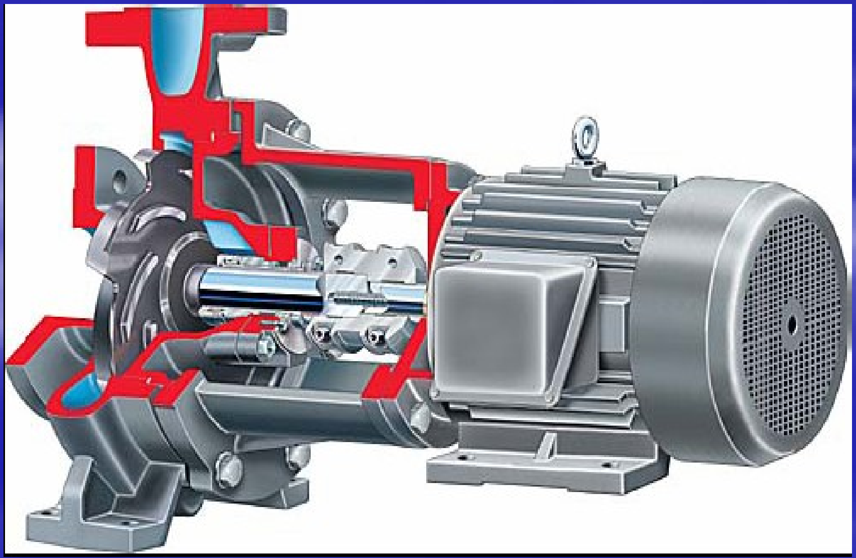
Construction

- Mechanical Construction
  - Between Bearing
    - Impeller/s supported between two sets of bearings
  - Overhung Impeller
    - Impeller overhangs a bearing support bracket

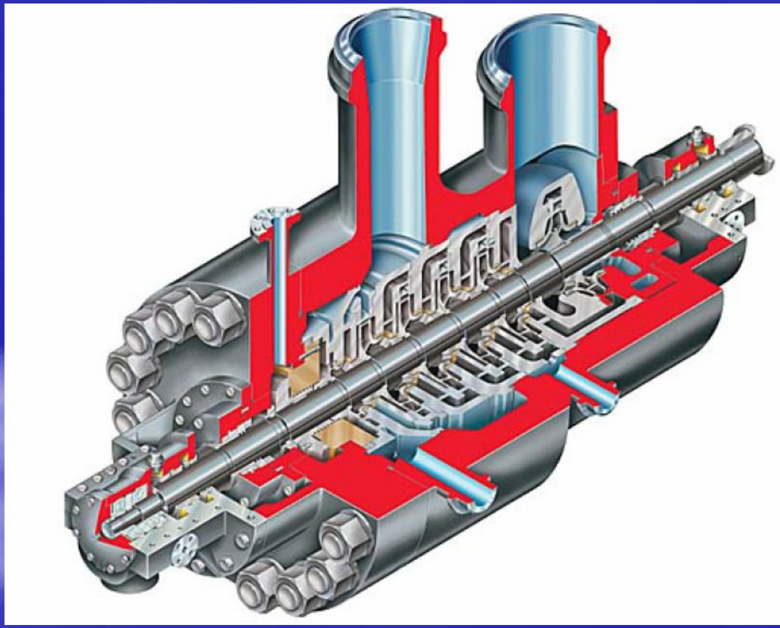
Construction

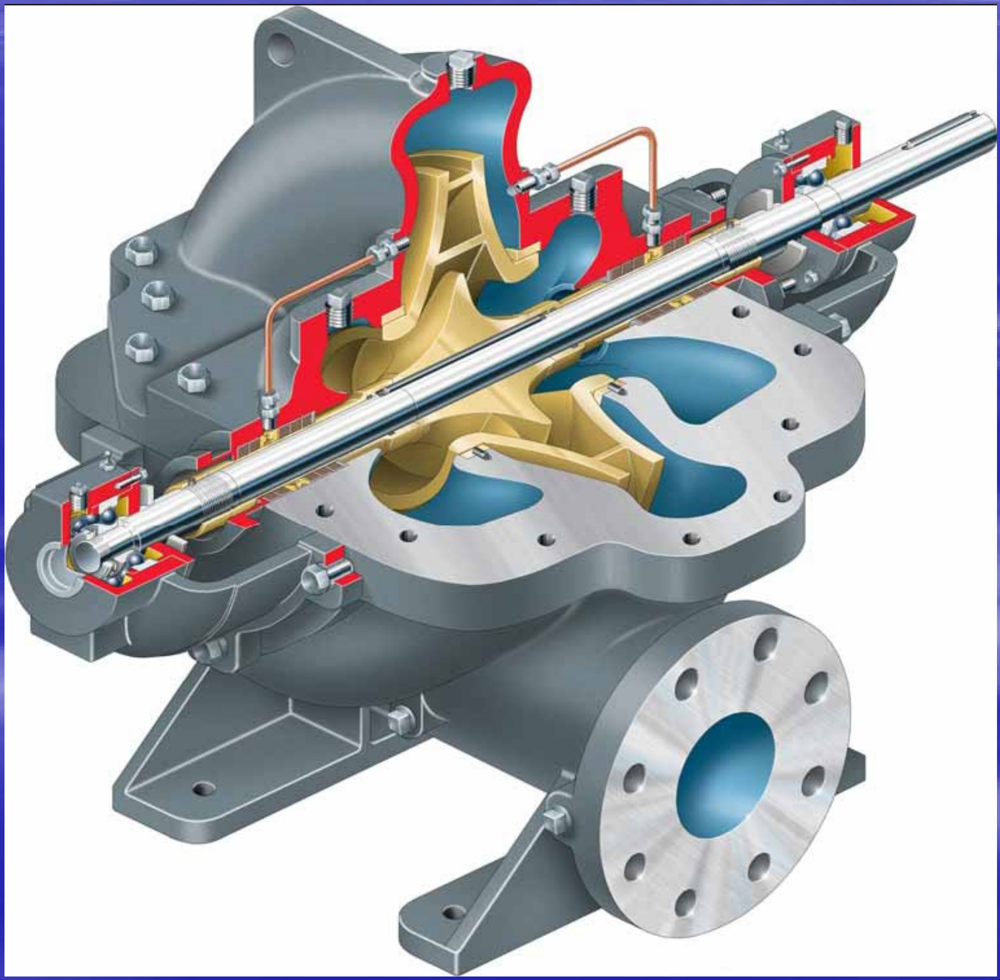
Overhung
Impeller



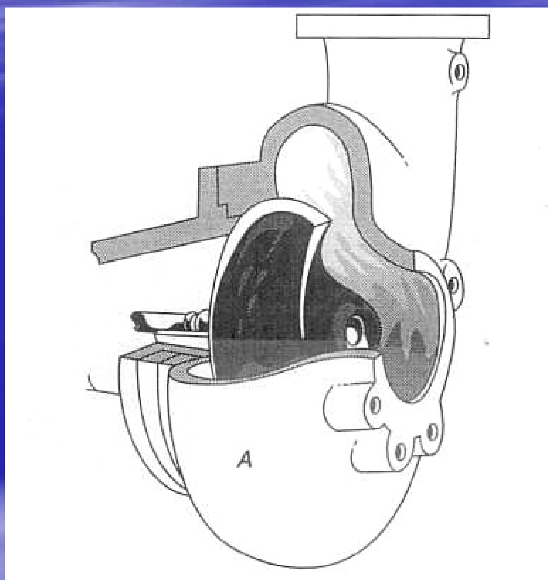


Between Bearing



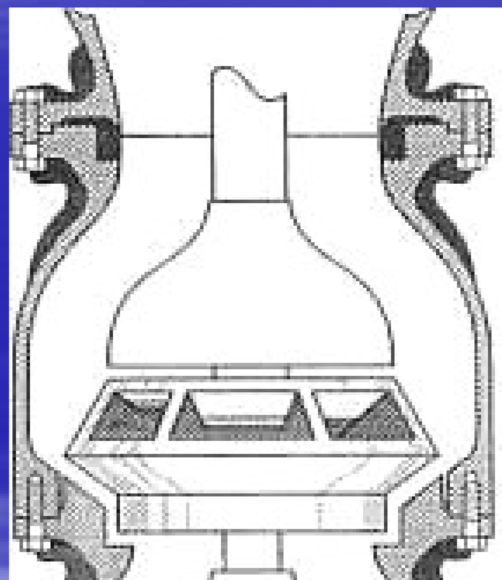


Hydraulic Types – Specific Speed

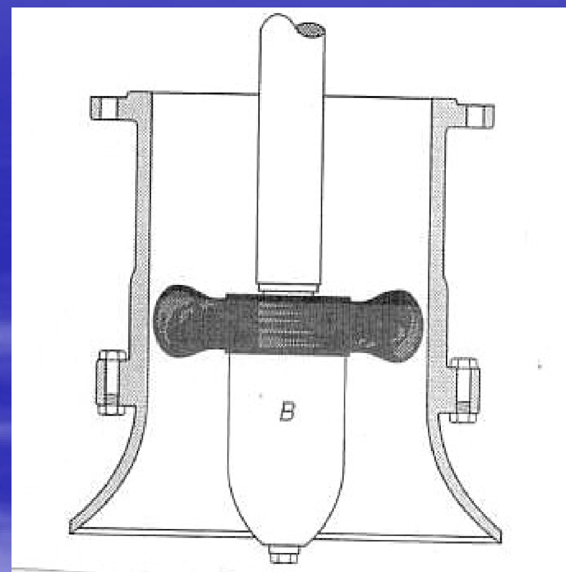


Radial Flow Pump

High head low flow



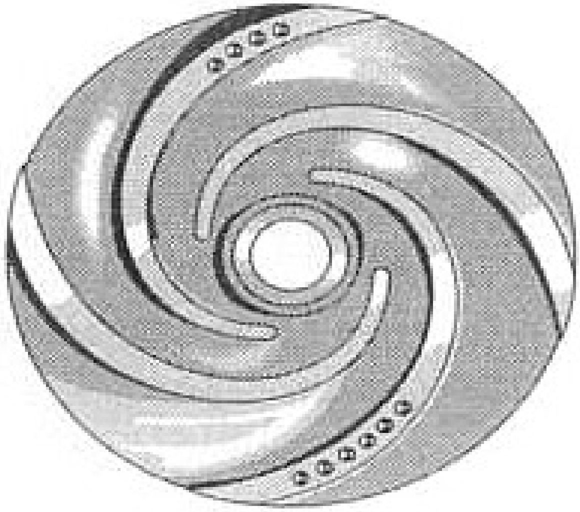
Mixed Flow Pump



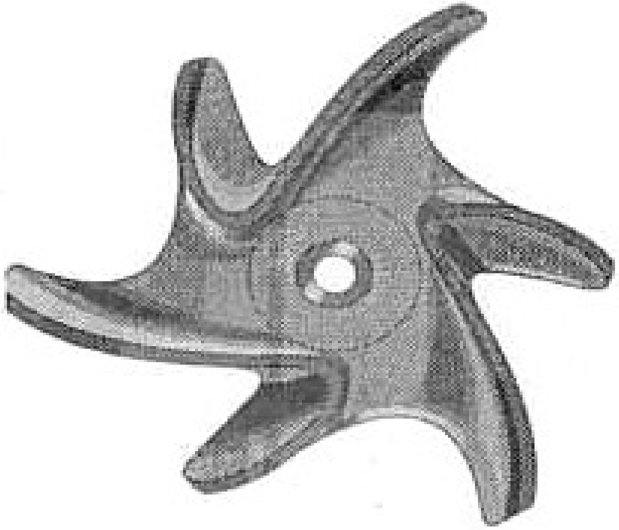
Axial Flow Pump

Low head, high flow

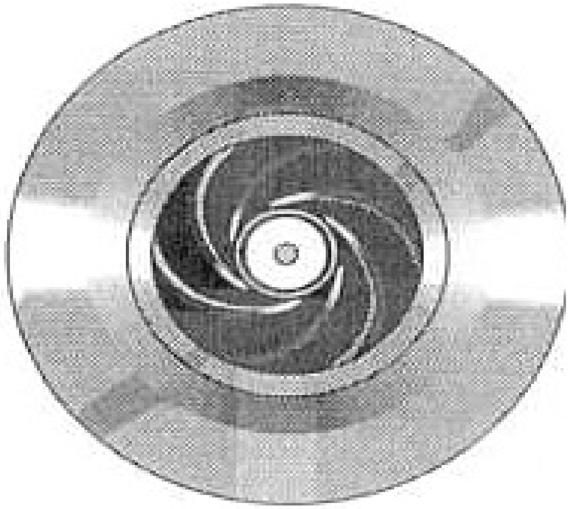
Impeller Types



Semi Open Impeller



Fully Open Impeller



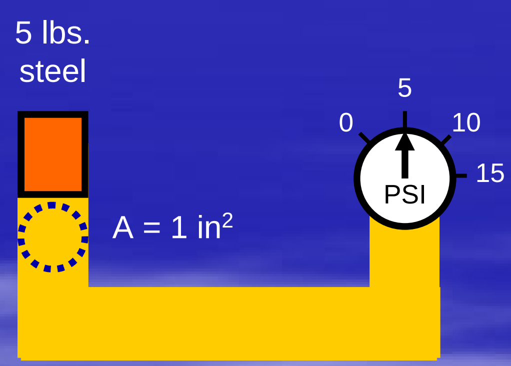
Closed Impeller

- **Pump Fundamentals**
  - Pressure
  - Head
  - Kinetic Energy
  - Potential Energy

Pump Fundamentals

- A pump adds energy (pressure) to a fluid
- Pumps can deliver: high pressure / low flow or high flow / low pressure (and everything in between)
- Reliability and energy use are highly dependent on operating point

Pressure = Force per unit area

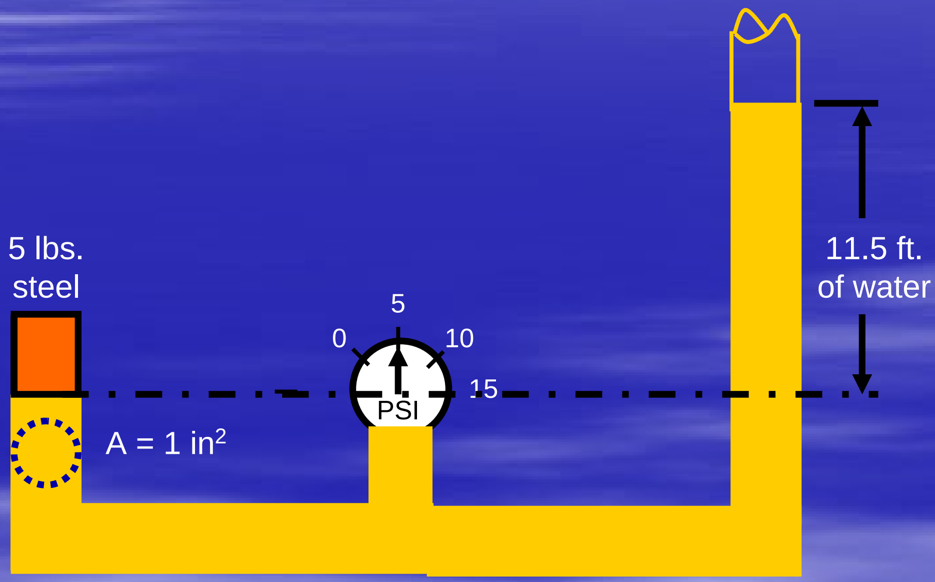


Gage Pressure (psig) – Pressure above surrounding atmospheric pressure.

Atmospheric pressure at sea level is 14.7 psig

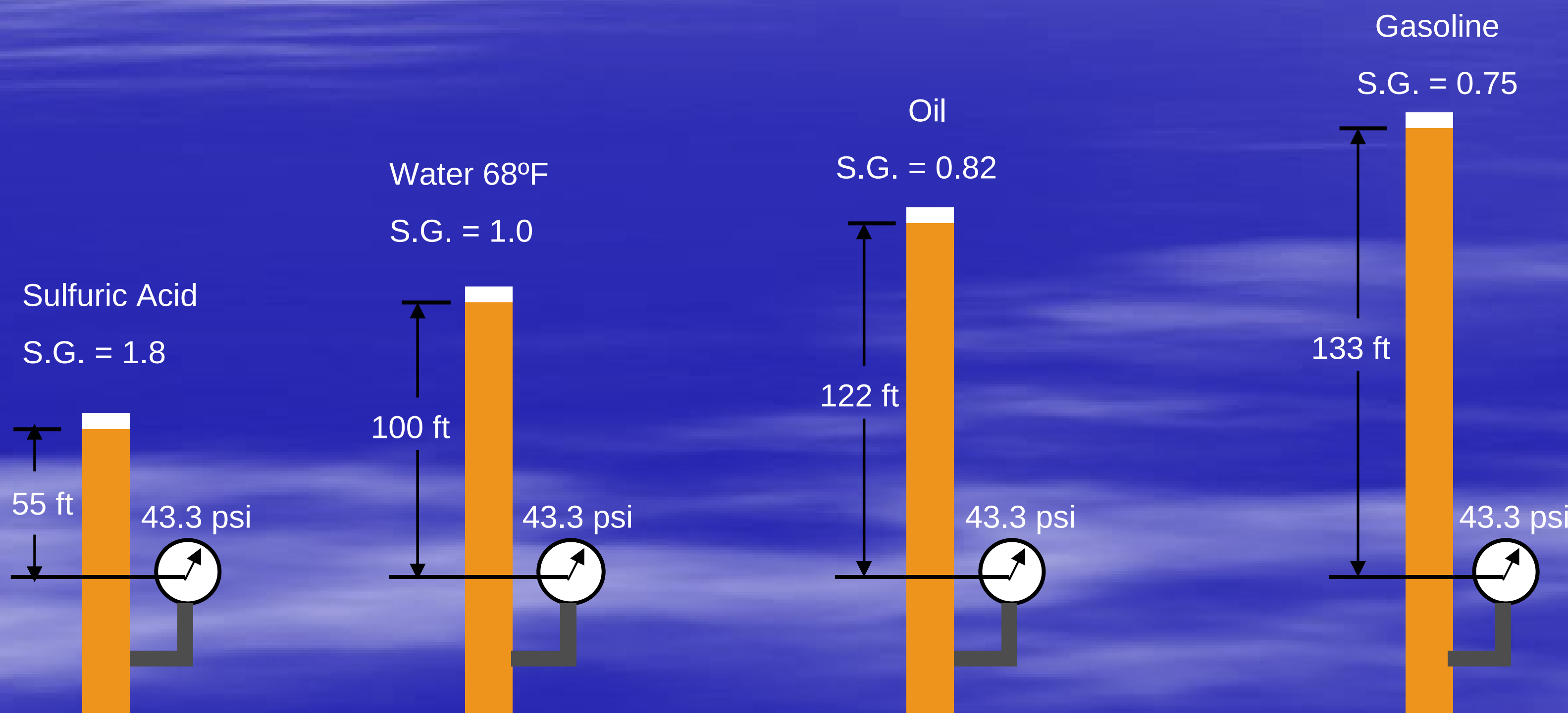
Absolute Pressure (psia) – Pressure above an absolute vacuum.

Head vs. Pressure



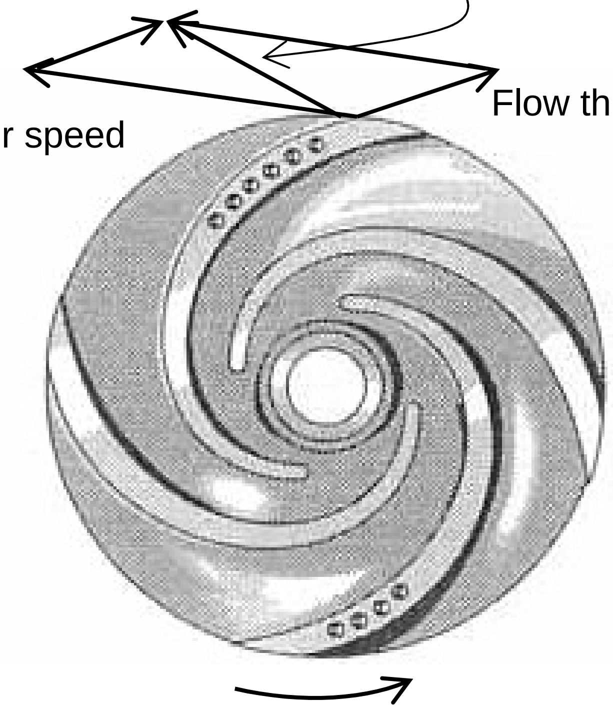
Head (ft) = 2.31 x psi / Specific Gravity

Effect of Specific Gravity on Head

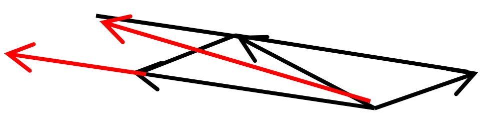


Head (ft) = 2.31 x psi / Specific Gravity

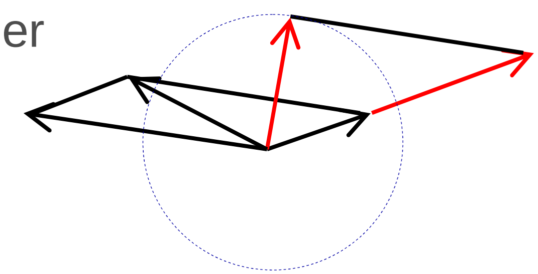
- Centrifugal pumps add energy by increasing the kinetic energy of the fluid – $V^2/2g$



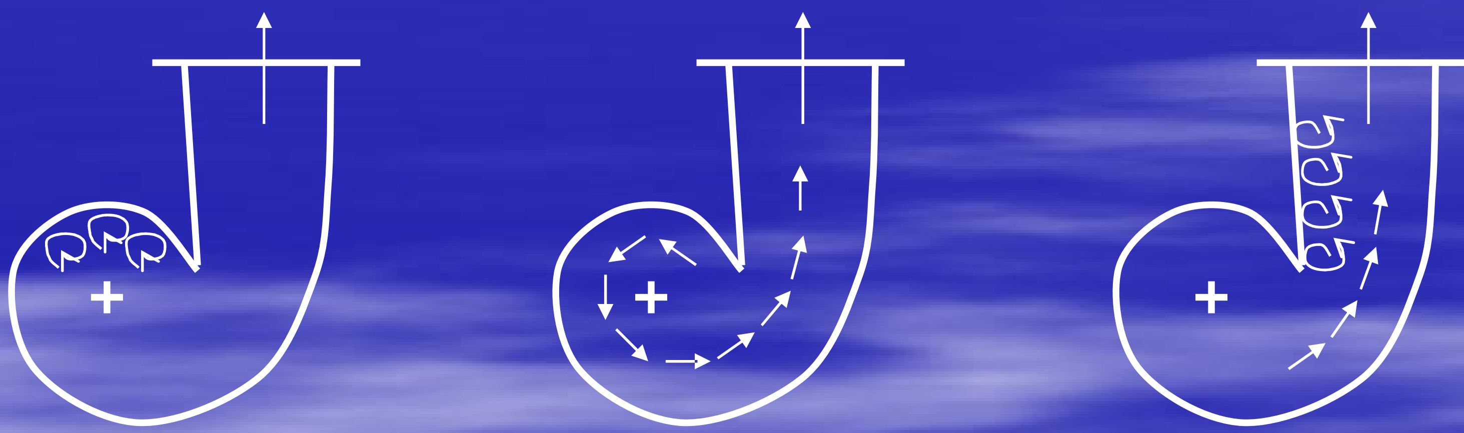
- Higher impeller tip speeds <u>increase</u> kinetic energy
  - Impeller diameter
  - Impeller speed



- Higher flows through impeller <u>decrease</u> kinetic energy



Volutes “catch” and convert liquid kinetic energy to pressure energy

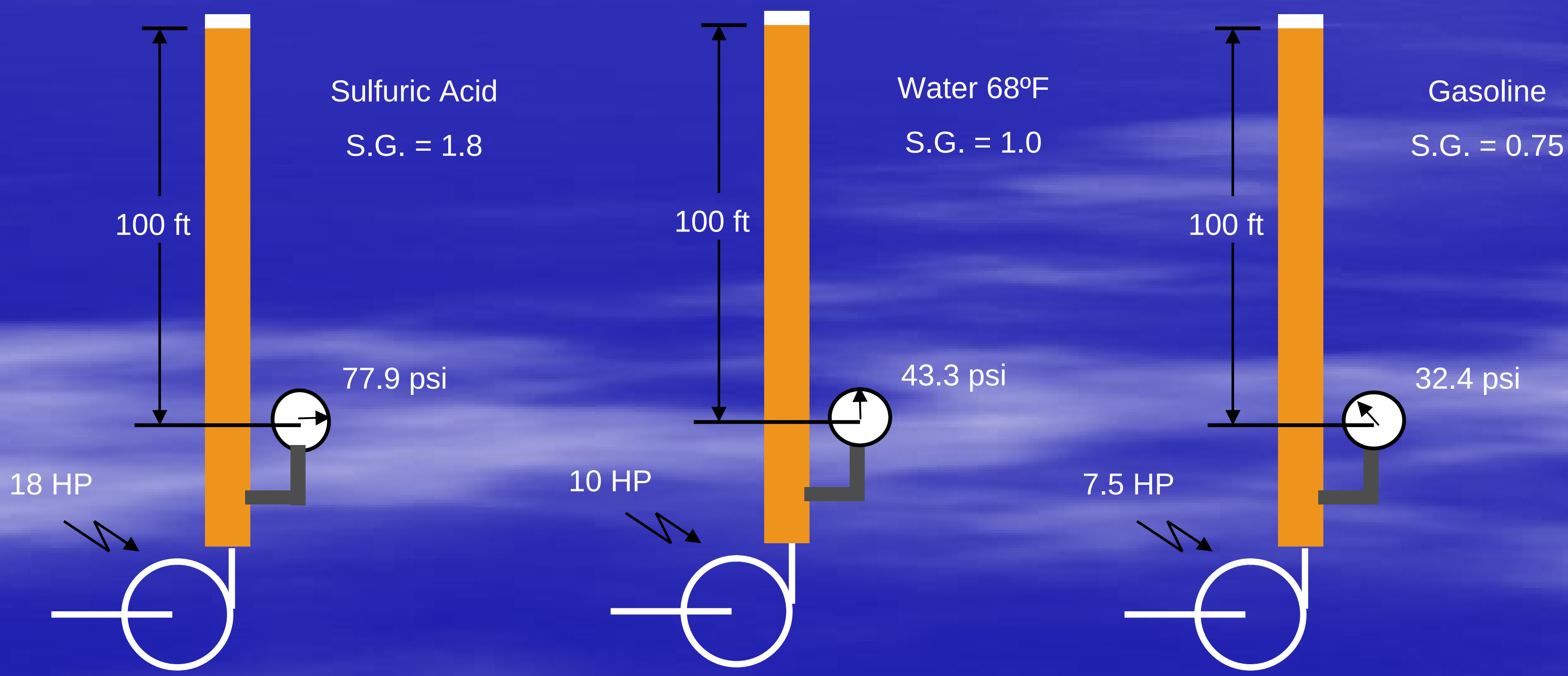


Flow Pattern at less than BEP

Flow Pattern at BEP

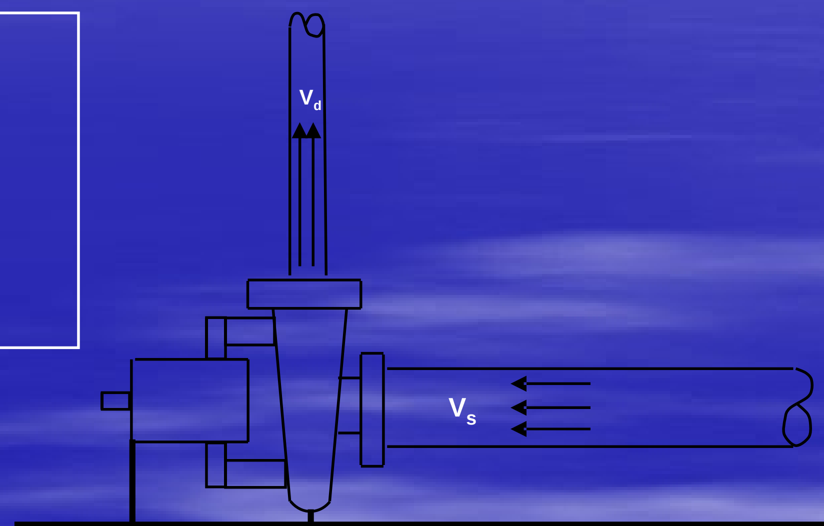
Flow Pattern at greater than BEP

Effect of Specific Gravity on Pump Performance



Effect of Fluid Velocity

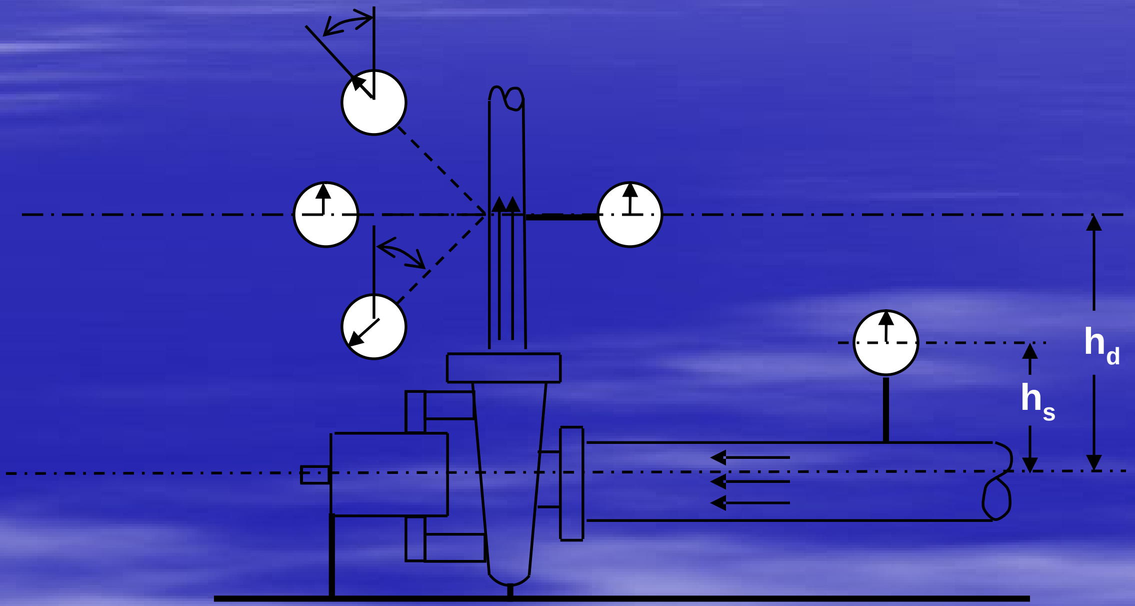
- Velocity head is the kinetic energy of the fluid
- Often suction and discharge velocity is different
- The pump delivers energy to effect the velocity change



Velocity head

$$h_v = \frac{V^2}{2g} = \frac{0.00259\ GPM^2}{D^4}$$

Gage Height Correction



- Pressure readings must be corrected to a common datum
- Normal datum is the center of the suction

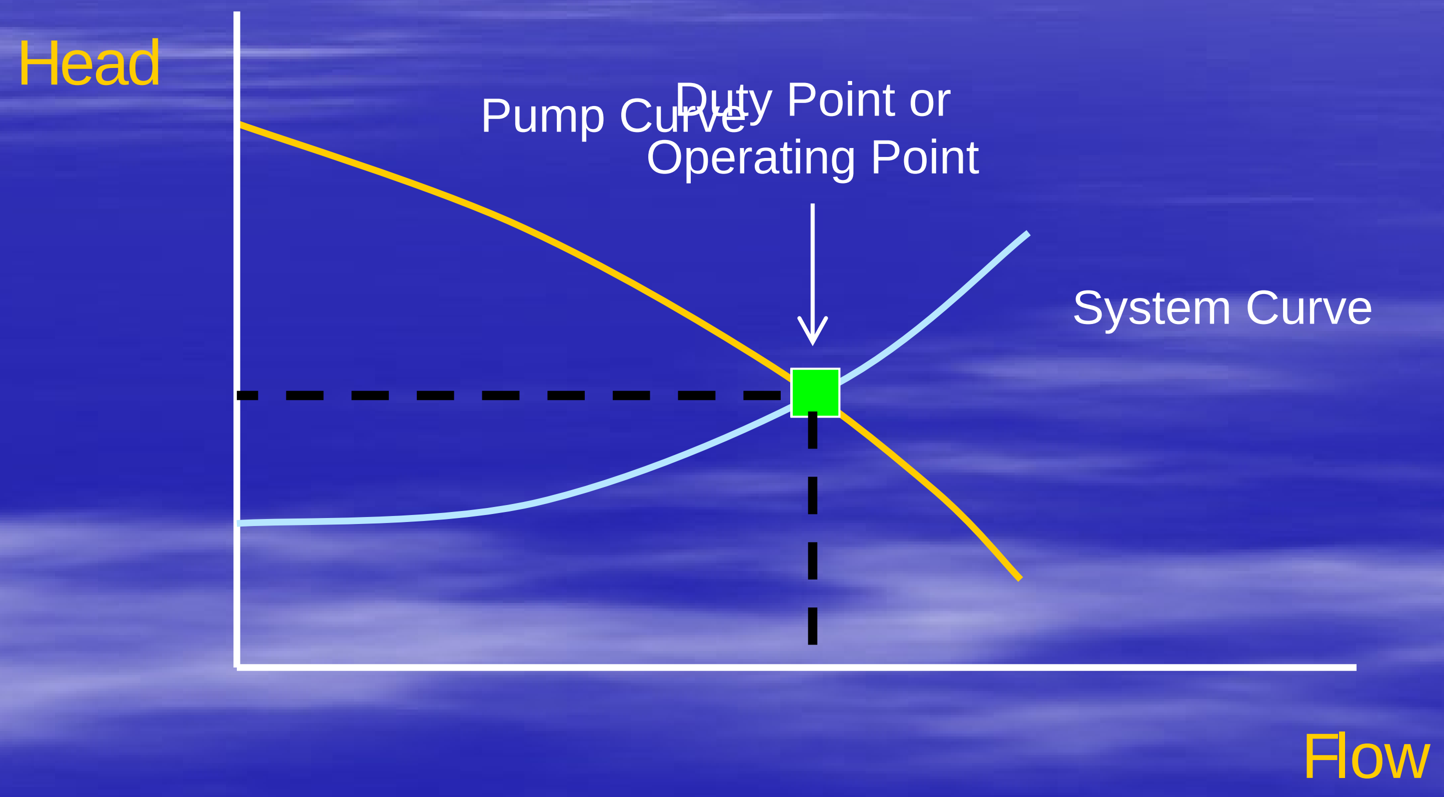
Total Differential Head – TDH

TDH = Total Discharge Head – Total Suction Head

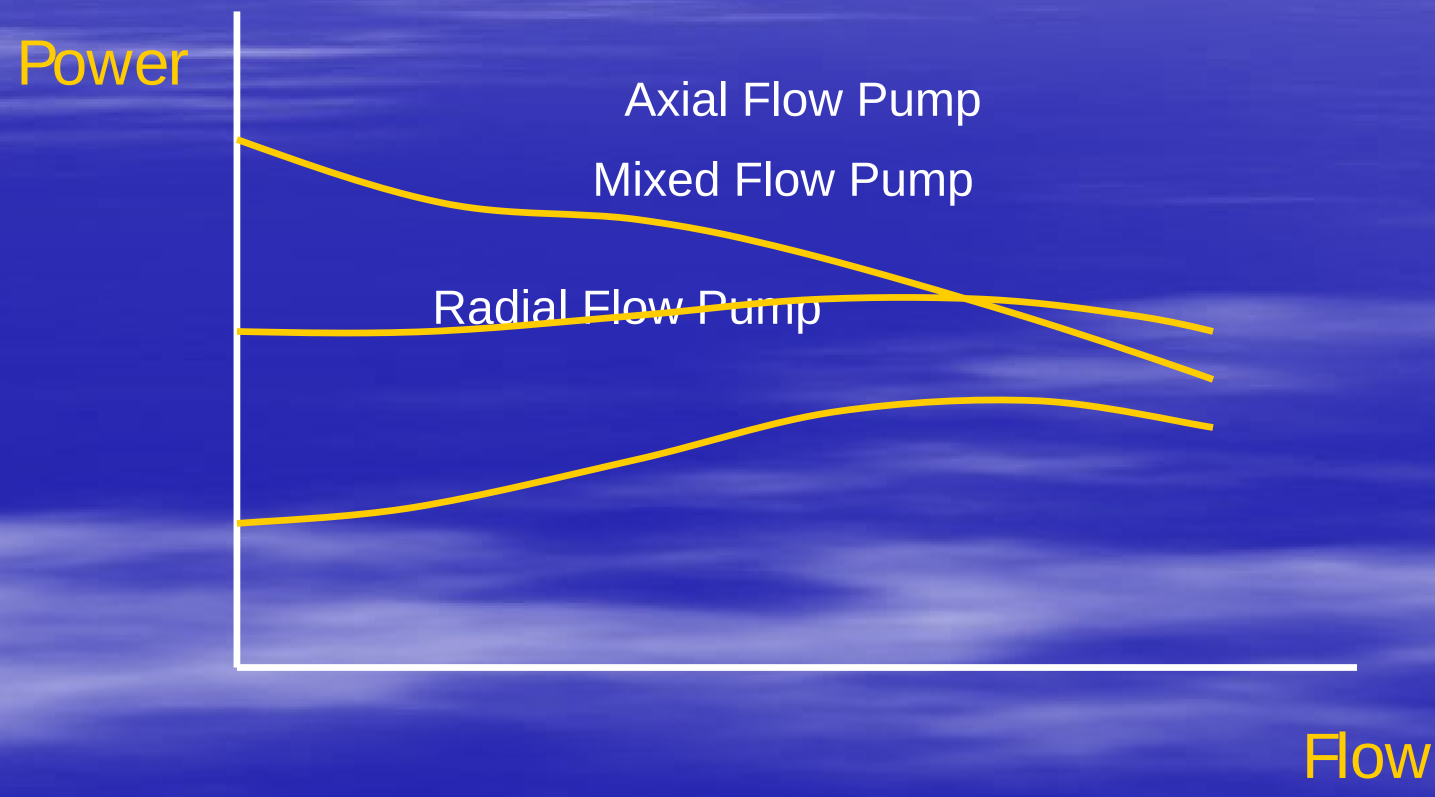
Total Head = Discharge Pressure + Velocity Head + Static head

- Pump Performance Parameters
  - Head
  - Flow Rate
  - Power
  - Efficiency
  - Net Positive Suction Head (NPSH)
  - Characteristic Curves

Pump Characteristics



Pump Characteristics



Pump Characteristics

- Every pump exhibits internal losses
  - The size of the losses depend on where the pump is operated on its curve
- The losses can be minimal or substantial
  - The pump is designed for a specific flow and pressure at a specific RPM
  - When the flow deviates from the design flow, the liquid does not hit the vanes at the correct angle and extra turbulence and losses occur.
- Losses lowest / efficiency highest, at the **B**est **E**fficiency **P**oint (BEP)
- The ratio between output power and input power is the efficiency of the pump
- Losses can be measured by comparing delivered hydraulic power to input power

Pump Characteristics

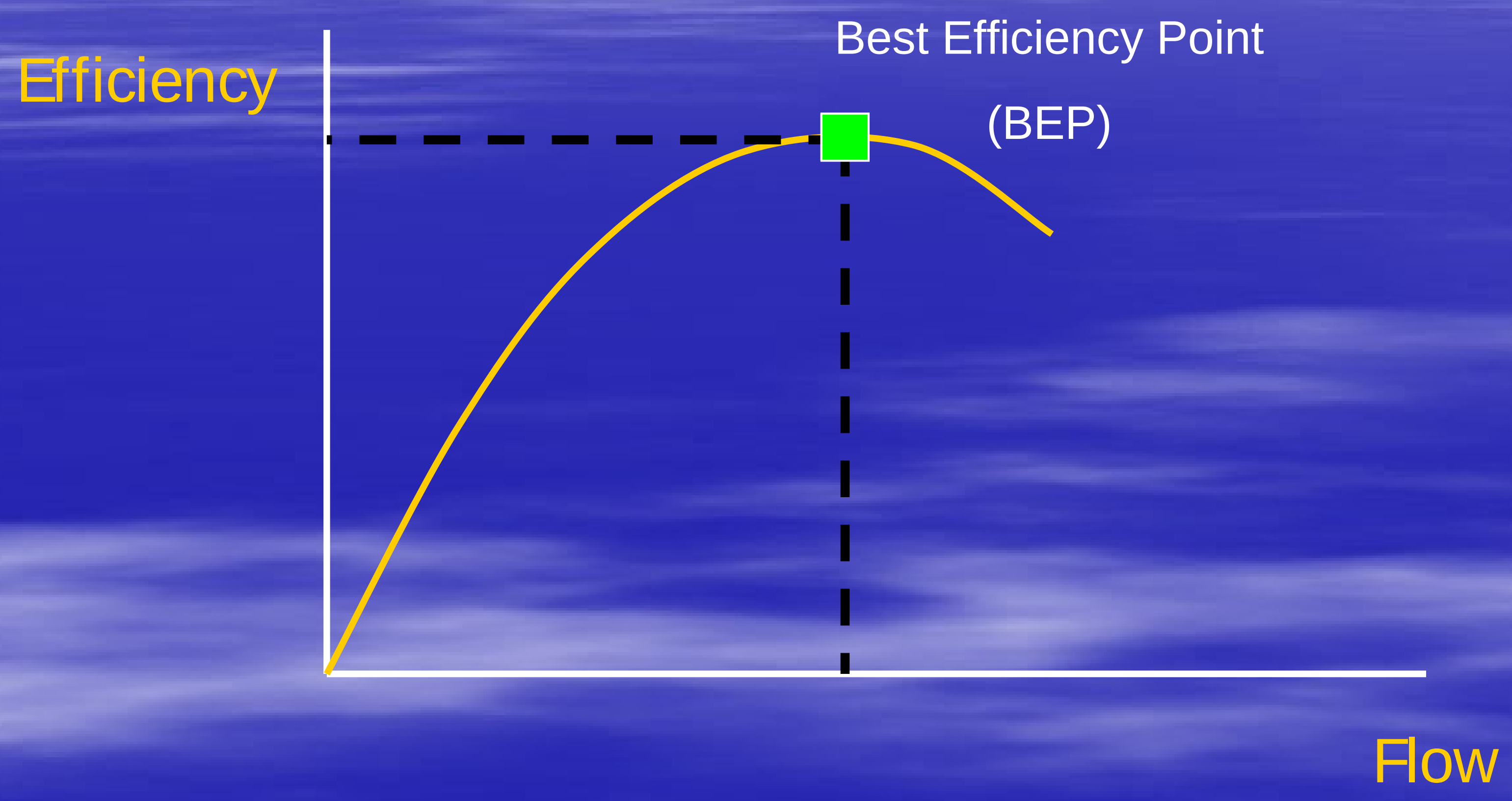
- Pump Efficiency

η = What is sought / What it costs

η_p = Water Power / Pump input power

η_p = GPM x TDH / (HP x 3960)

Pump Characteristics

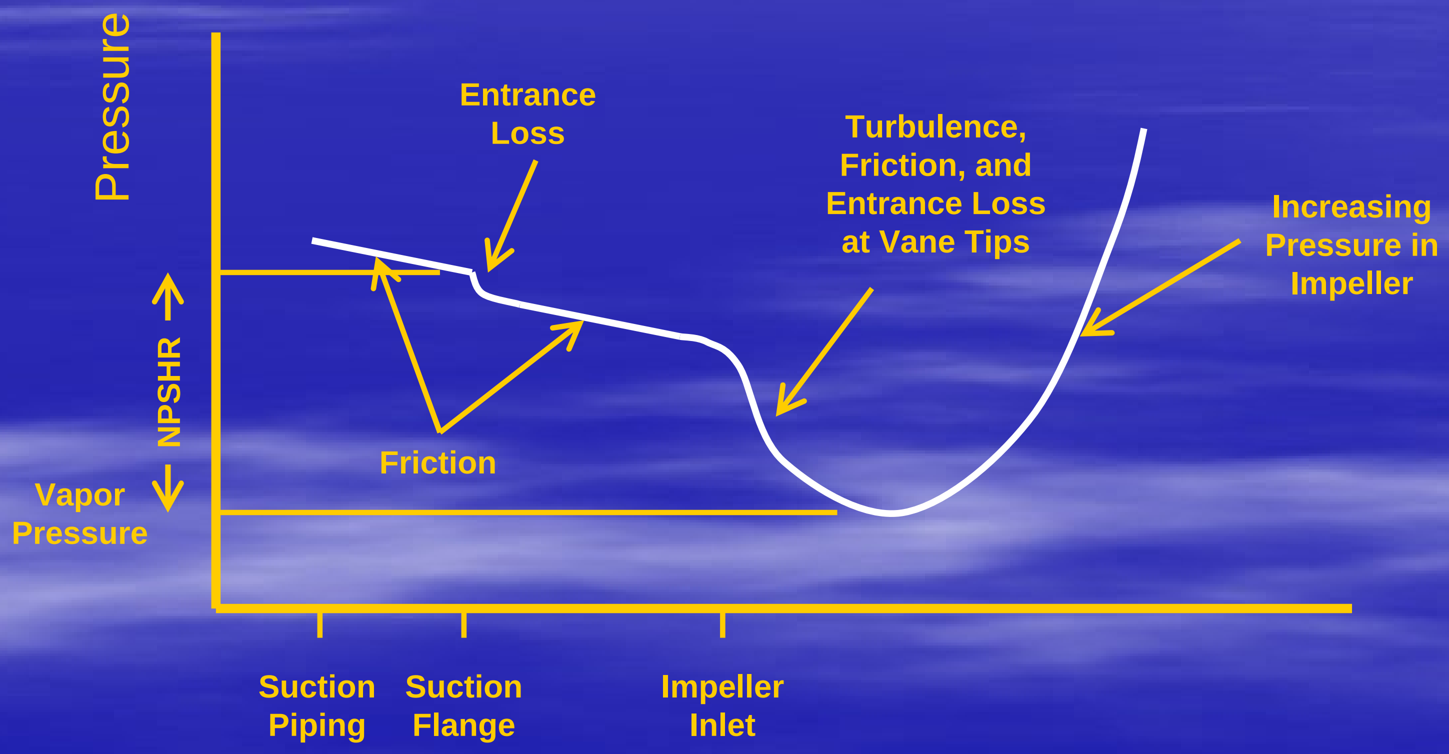


Pump Characteristics

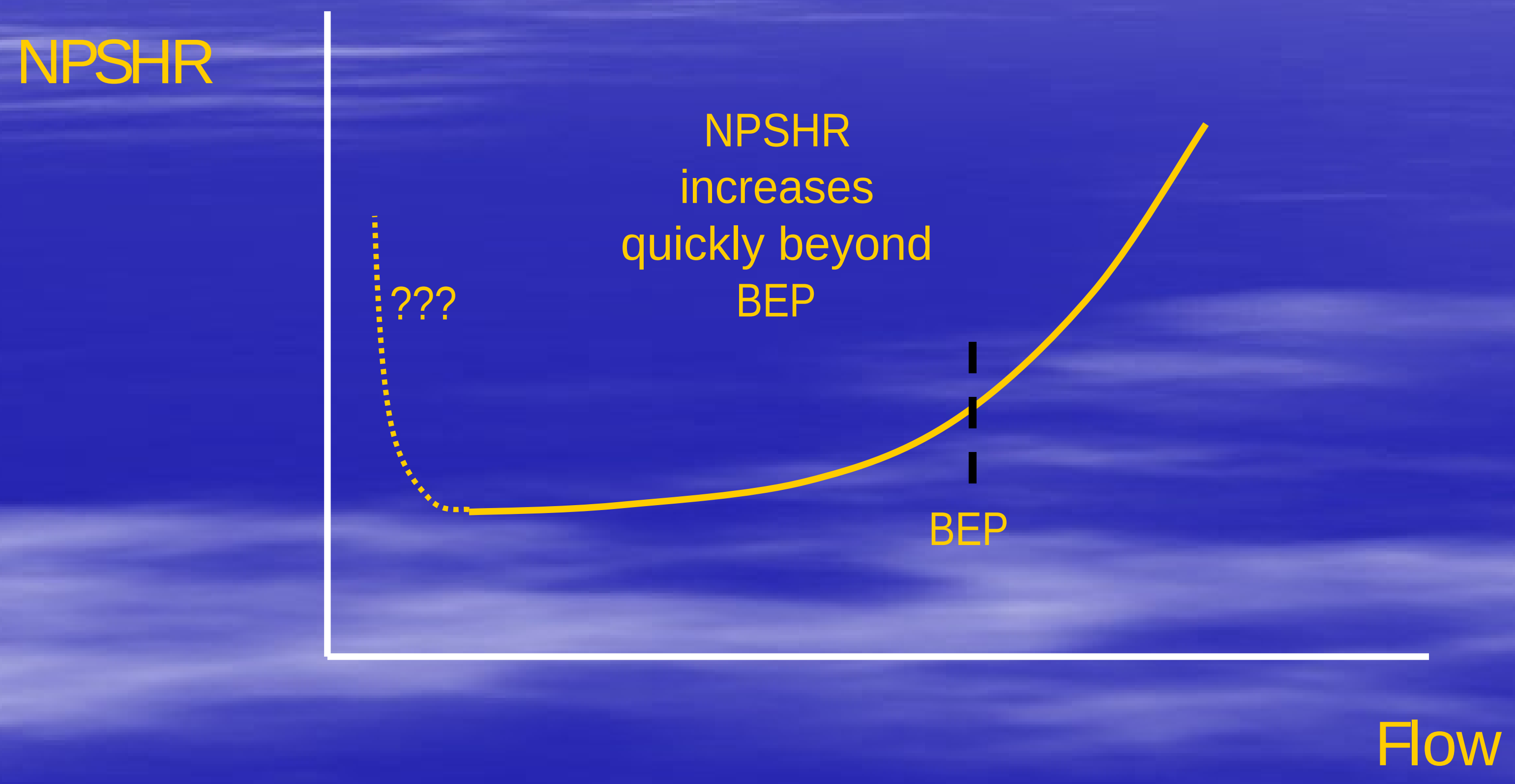
- Net Positive Suction Head (NPSH)
  - NPSH Required (NPSHR)
  - NPSH Available (NPSHA)
- NPSH is a measure of the energy (pressure) in a liquid above the vapor pressure
- If the pressure drops below the vapor pressure – the liquid boils
  - That condition is called cavitation
- All pumps require the NPSHA to be > 0
- How much, is called the NPSHR

Pump Characteristics

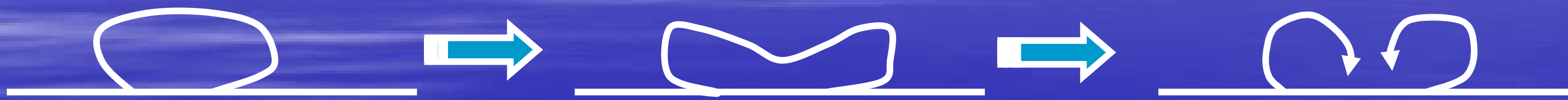
Net Positive Suction Head



Pump Characteristics



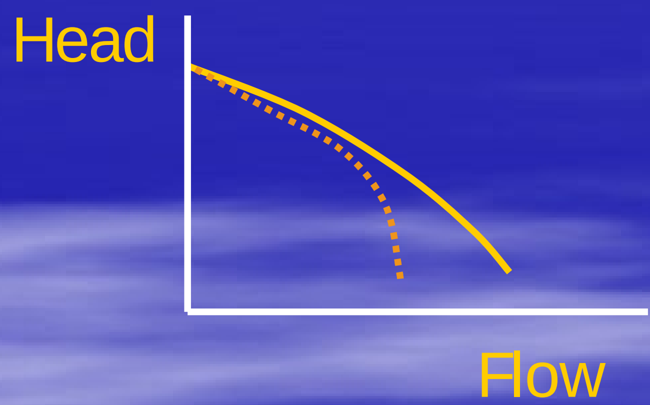
Cavitation Process



Vapor Bubble Forms

Bubble Expands into colder liquid and begins to condense

Bubble Collapses creating intense pressure (10,000 psi) and shock waves

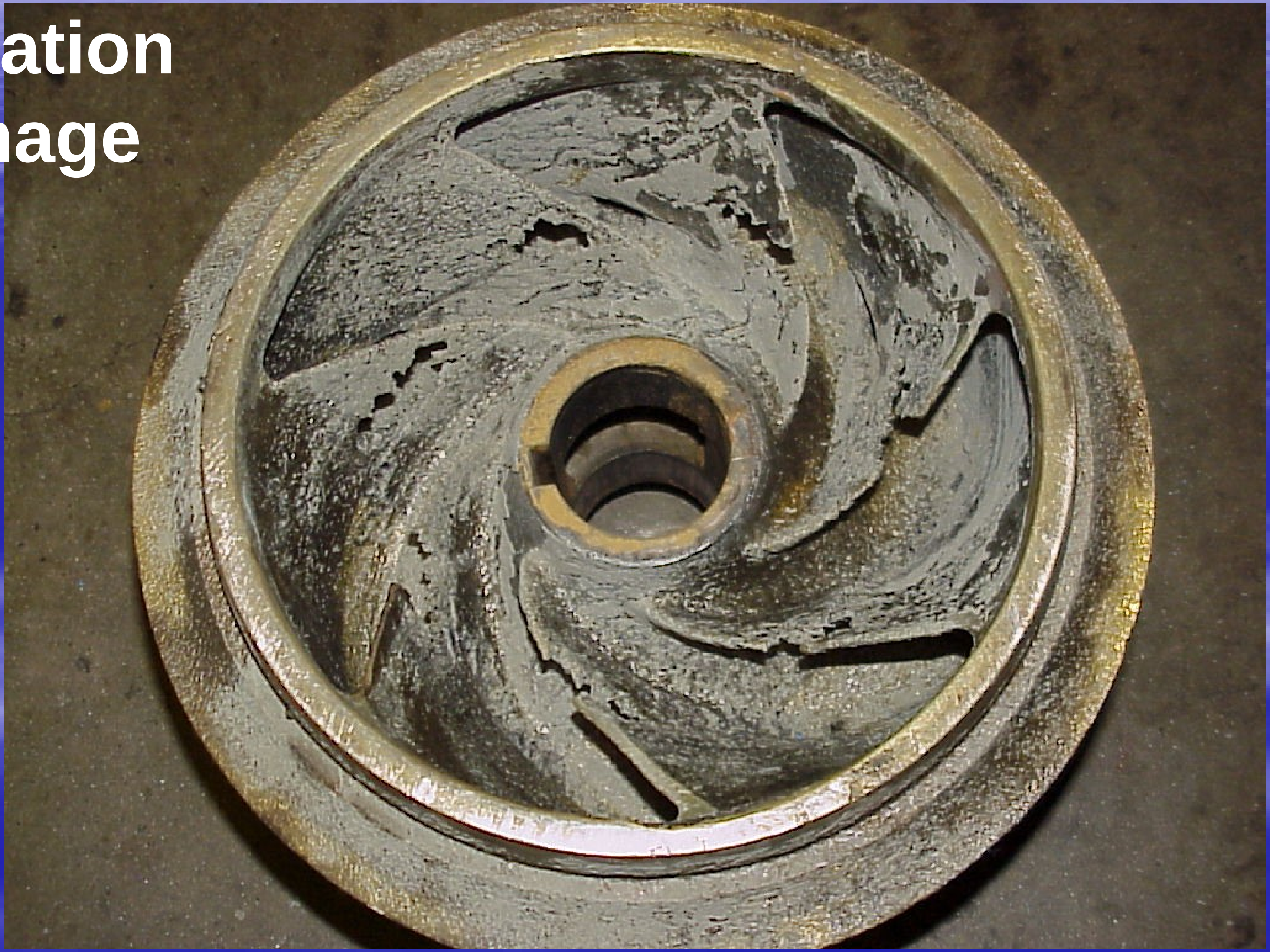


Large vapor volumes can cause reduction in head and loss of prime.

Surging and unstable flow often results

- Intense pressures on metal surfaces exceed material strength resulting in surface fatigue failure
- Creates a pitted surface similar to coral or course sandpaper

Cavitation Damage



Cavitation Damage

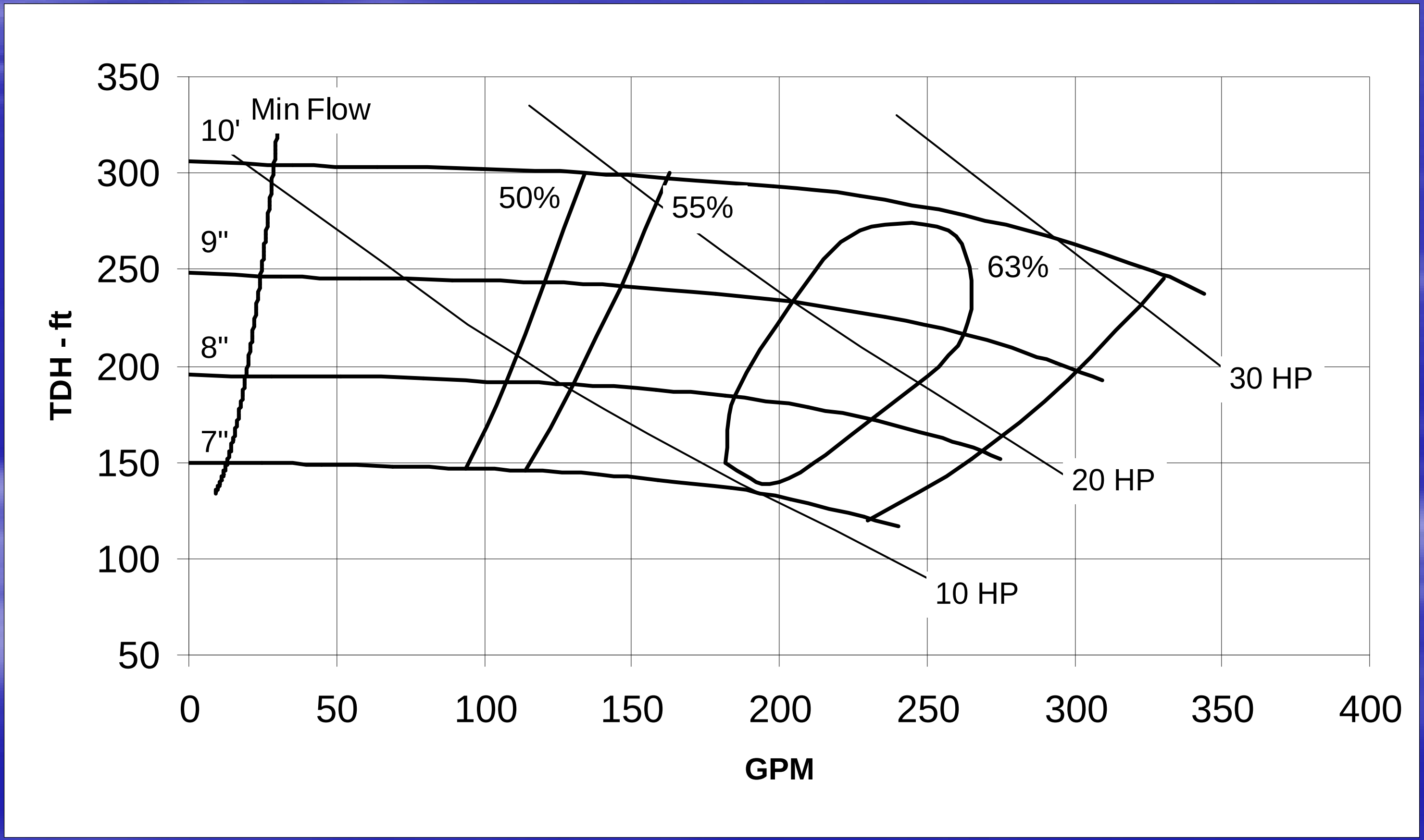
Pump Characteristics

- Preferred Operating Range (POR)
  - – That range of operation where normal life can be expected
  - – Typically 40% - 110% of BEP
  - – Often not shown on pump curves
  - – Primarily used in the petroleum and refining industries

Pump Characteristics

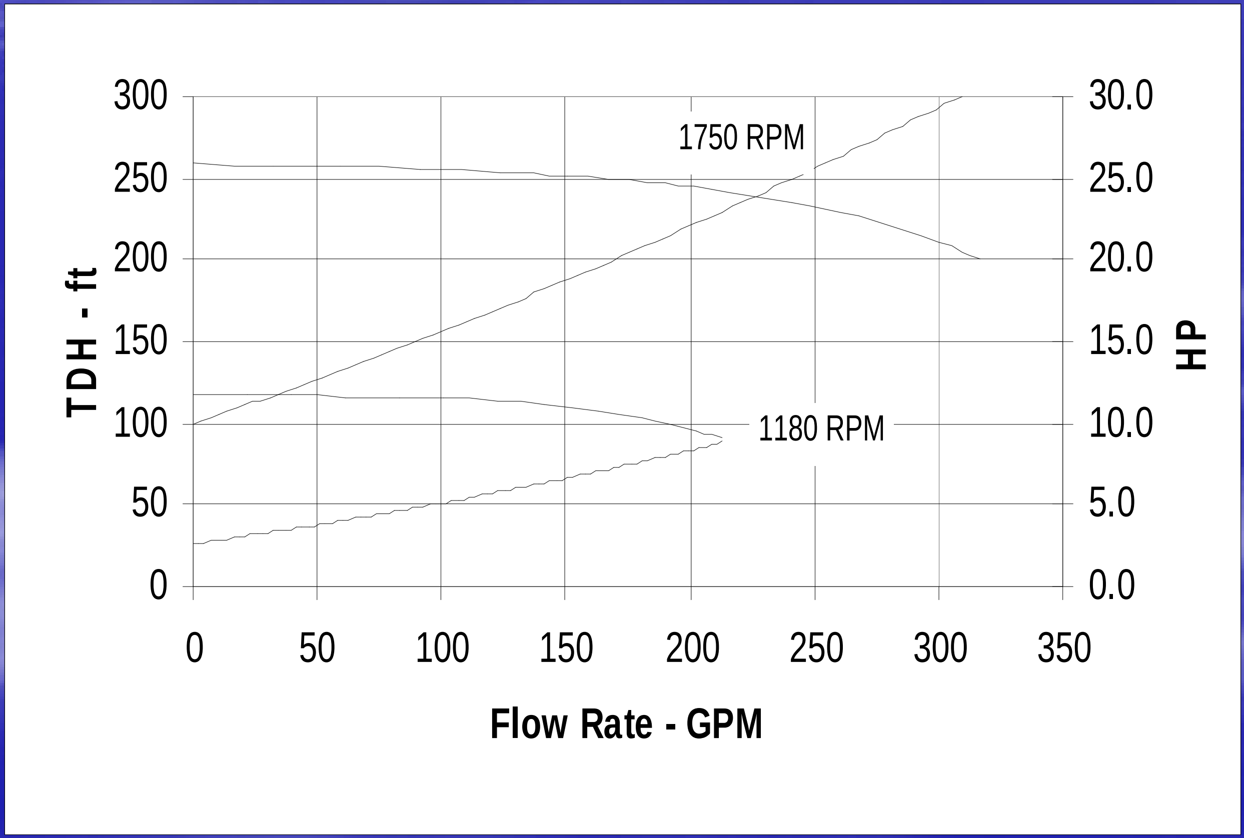
- Allowable Operating Range (AOR)
  - That range of flow rates over which the pump will operate with some reduction in reliability and increase in noise and vibration
  - Typically 10% - 120% BEP
  - Often labeled on characteristic curves as “Minimum Flow”
  - Maximum flow often limited by NPSH margin

Pump Characteristic Curve



Pump Characteristics

Effect of RPM



$GPM_2 = GPM_1 \times (RPM_2/RPM_1)$

$TDH_2 = TDH_1 \times (RPM_2/RPM_1)^2$

$HP_2 = HP_1 \times (RPM_2/RPM_1)^3$

- System Curves

  – Static Head
  – Dynamic Head
  – Pipe Friction
  – Fitting Losses

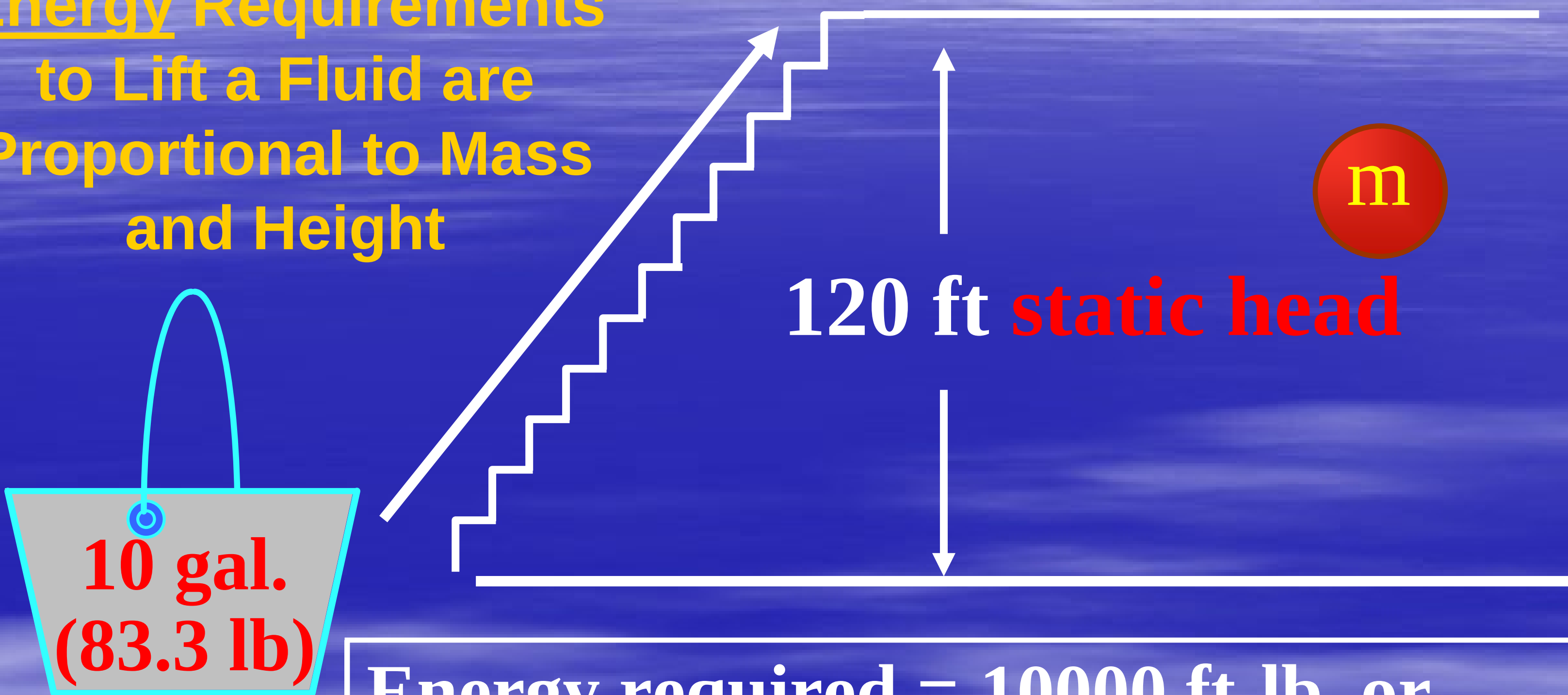
System Curves

- It takes Energy to move fluid though a system of pipes and other equipment.
  - The pressure (head) used to overcome friction is called the *dynamic head*.
  - The head required is *proportional to the square of the fluid velocity*
- It takes Energy to lift fluid from one level to another
  - The pressure used to lift fluid is called *static head* ,
  - The head required to lift a certain volume of fluid is *independent of velocity*

System Head = Static Head + Dynamic Head

System Curves

<u>Energy</u> Requirements to Lift a Fluid are Proportional to Mass and Height

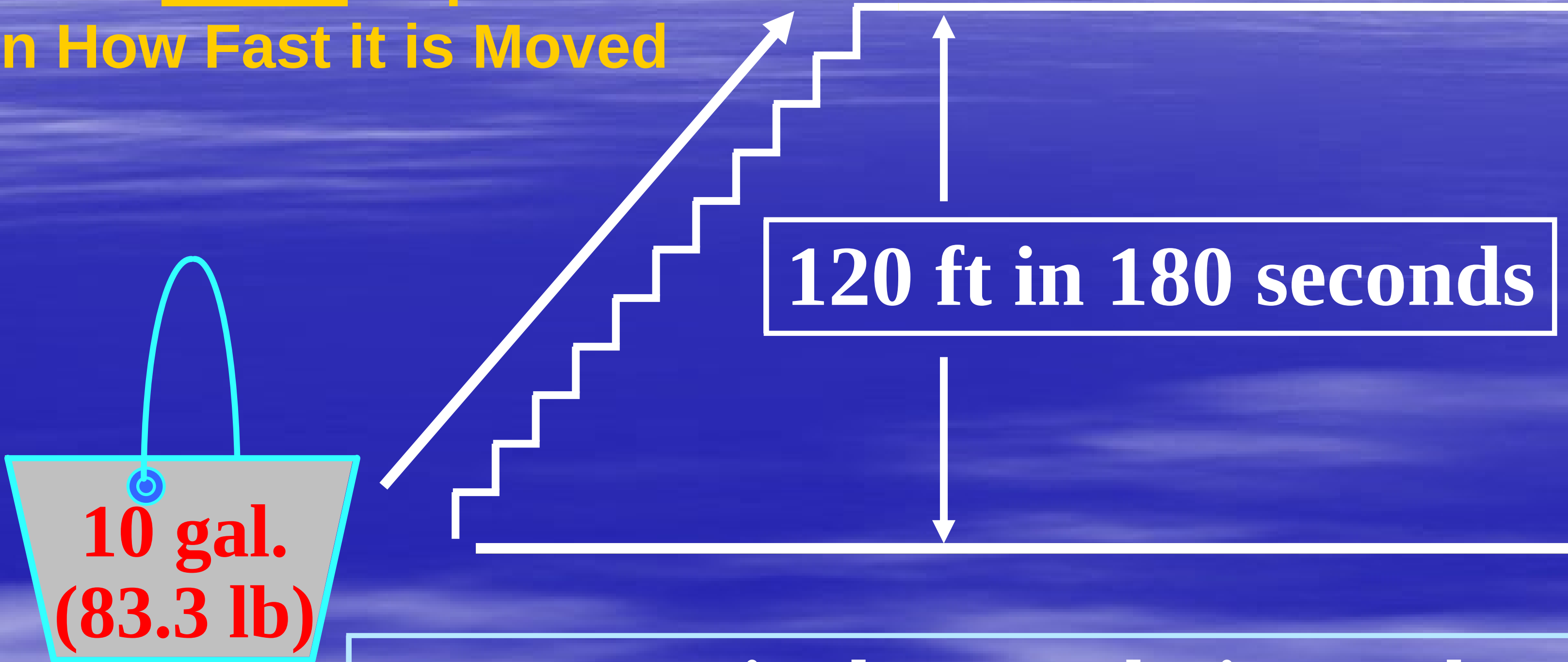


Energy required = 10000 ft-lb, or 3.24 calories (less than one M&M)

THIS IS INDEPENDENT OF SPEED

System Curves

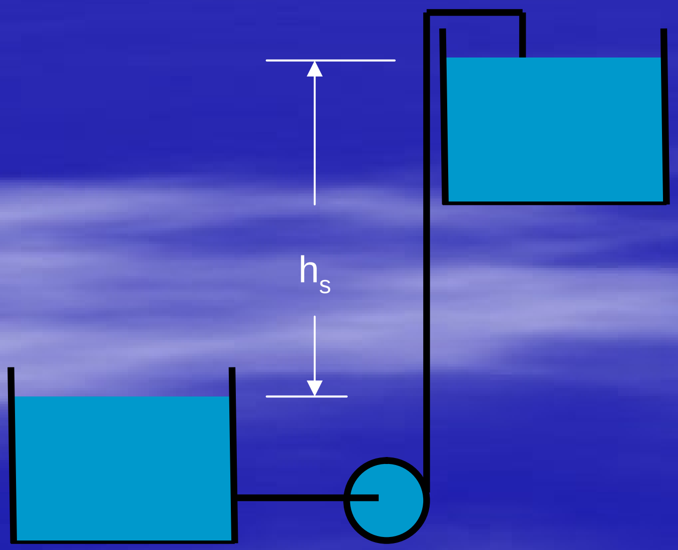
Ideal Power Depends on How Fast it is Moved



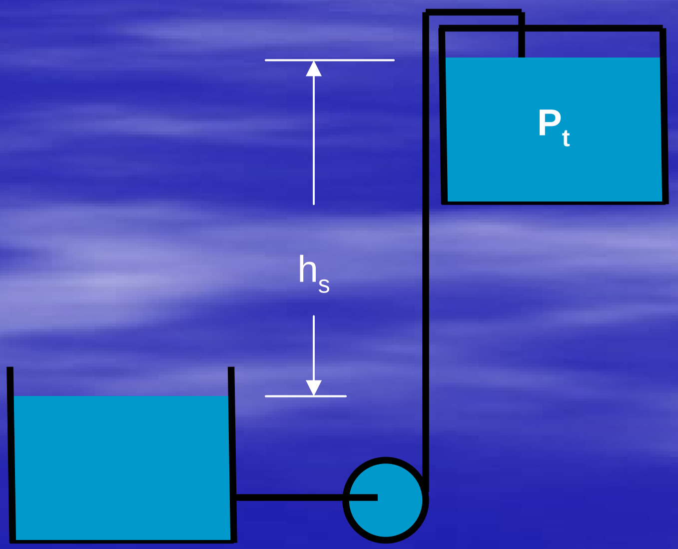
Power required = 65 calories per hour or 0.1 horsepower

Static Head

Static Head = h_s



Static Head = $h_s + 2.31 \times P_t / SG$



Dynamic Head

The friction head loss:

- Function of water velocity
- Lower flow gives lower head loss
- Proportional to the square of velocity
- Reduced to 25% when velocity is cut in half !
- Increased by a factor of 4 when the velocity is doubled !

Sources of Friction

- Pipe walls
- Valves
- Elbows
- Tees
- Reducers/expanders
- Expansion joints
- Tank inlets/outlets

(In other words, almost everything the pumped fluid passes through, as well as the fluid itself)

System Curves

What parameters influence *frictional* losses in piping?

$$H_f = f \cdot \frac{L}{d} \cdot \frac{V^2}{2g}$$

H_f = pressure drop due to friction (ft)
f = Darcy friction factor
L = pipe length (ft)
V = velocity(ft/sec),
g = gravitational acceleration(ft/sec^2)
d = pipe diameter (ft)
$\frac{V^2}{2g}$ = velocity head (ft)

System Curves

- Standard Pipe Head Loss Tables
  - Tabulated values for head loss per 100 ft of pipe
  - Available for most common pipe

8" New Steel Pipe						
	Sch 40			Sch 80		
Flow Rate gpm	Velocity fps	Vel Head	Head Loss per 100 ft	Velocity fps	Vel Head	Head Loss per 100 ft
500	3.21	0.16	0.42	3.51	0.19	0.52
1000	6.41	0.64	1.55	7.03	0.77	1.95
2000	12.8	2.56	5.91	14.1	3.1	7.46

Cameron Hydraulic Data
Flowserve Corp

System Curves

For pipe components, frictional losses have generally been estimated based on the velocity head.

$$H_f = K \cdot \frac{V^2}{2g}$$

K = Loss coefficient

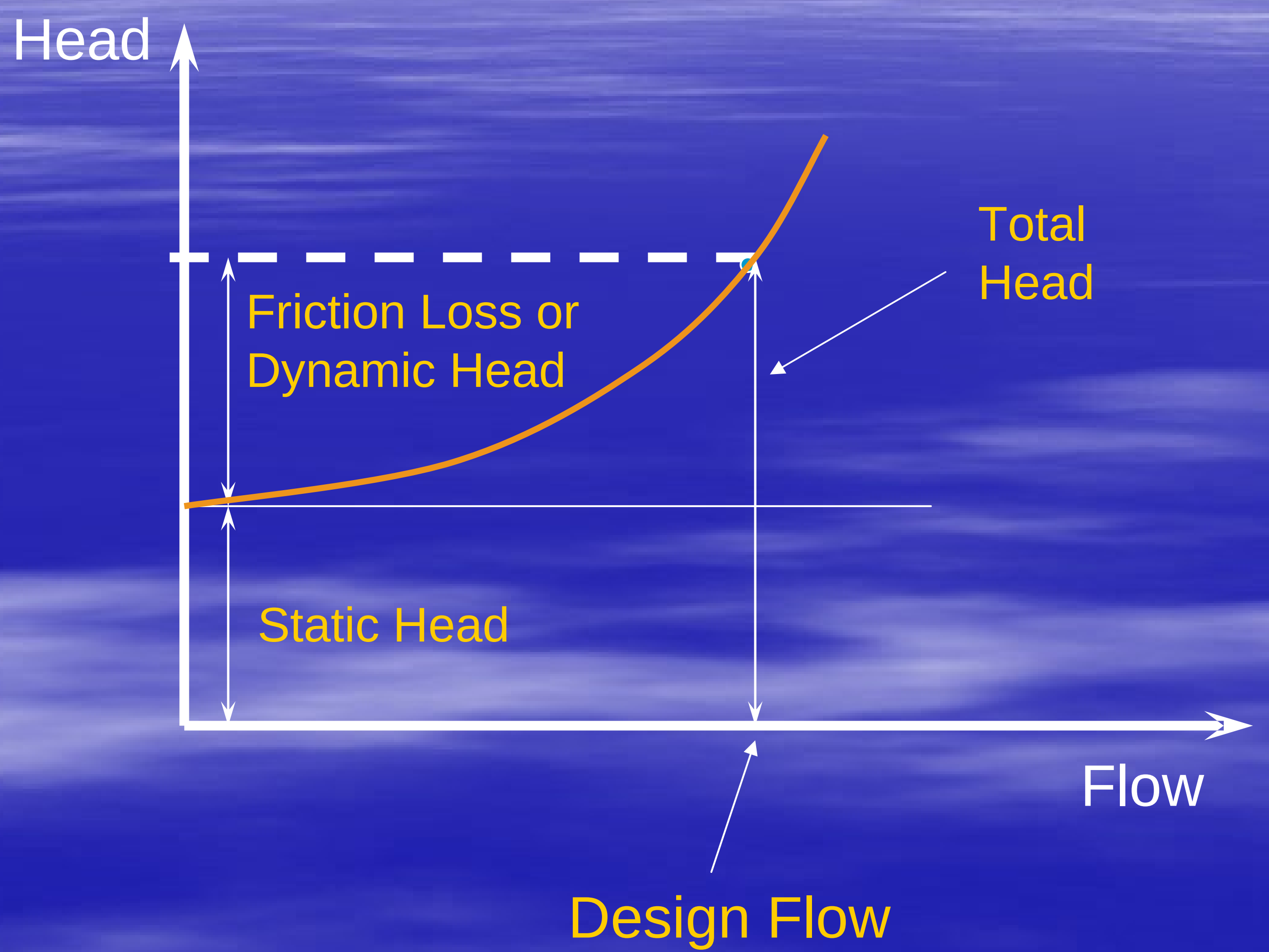
$\frac{V^2}{2g}$ = velocity head

K is determined by pipe size, valve type, % valve open, type of component and other physical factors.

System Curves

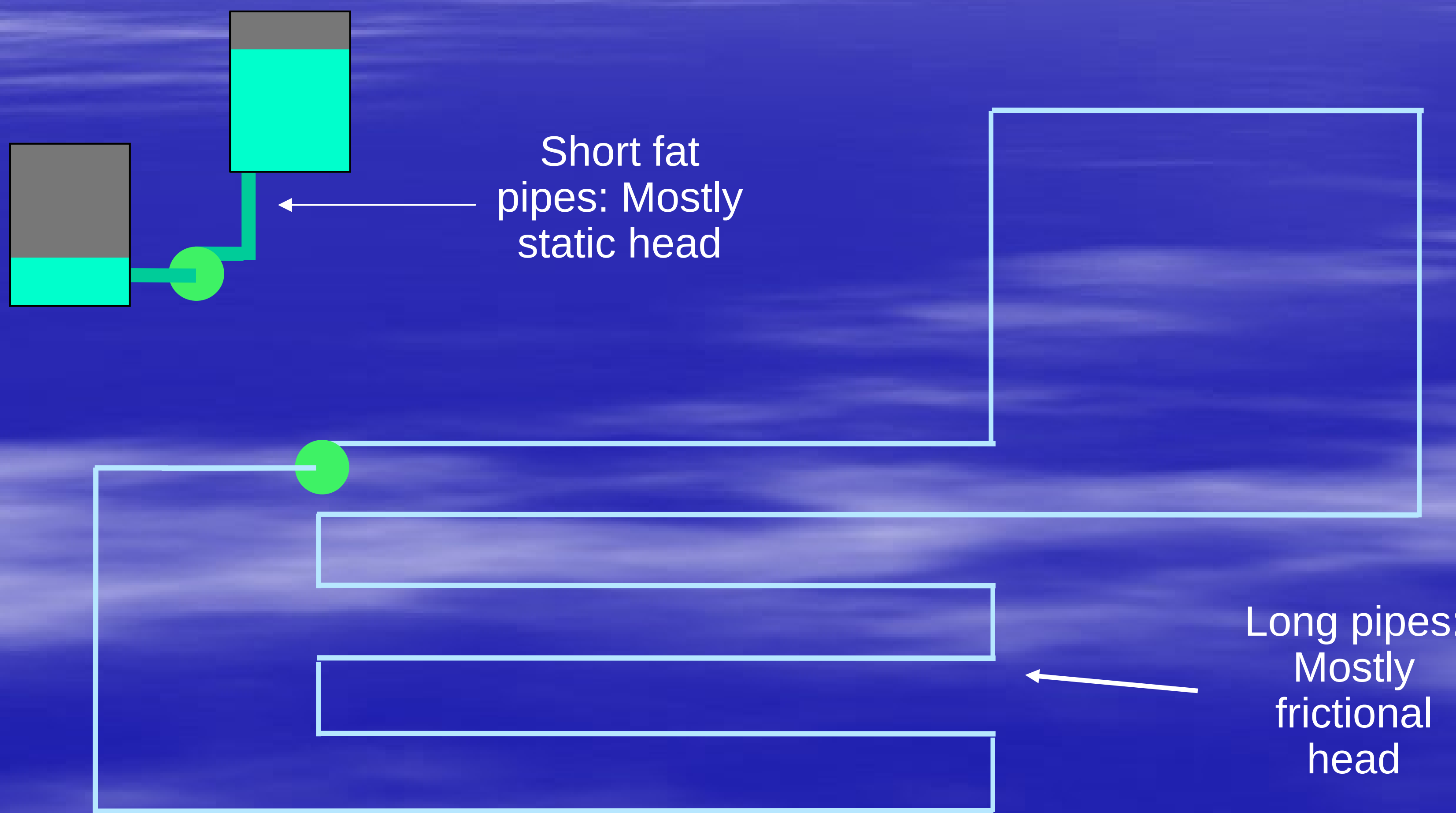
Component	Loss Coefficient(K)
90° elbow, standard	0.2 - 0.3
90° elbow, long radius	< 0.1 - 0.3
Square-edged inlet (from tank)	0.5
Discharge into tank	1
Check valve	2
Gate valve (full open)	0.03 - 0.2
Globe valve (full open)	3 - 8
Butterfly valve (full open)	0.5 - 2
Ball valve (full open)	0.04 - 0.1

System Curves



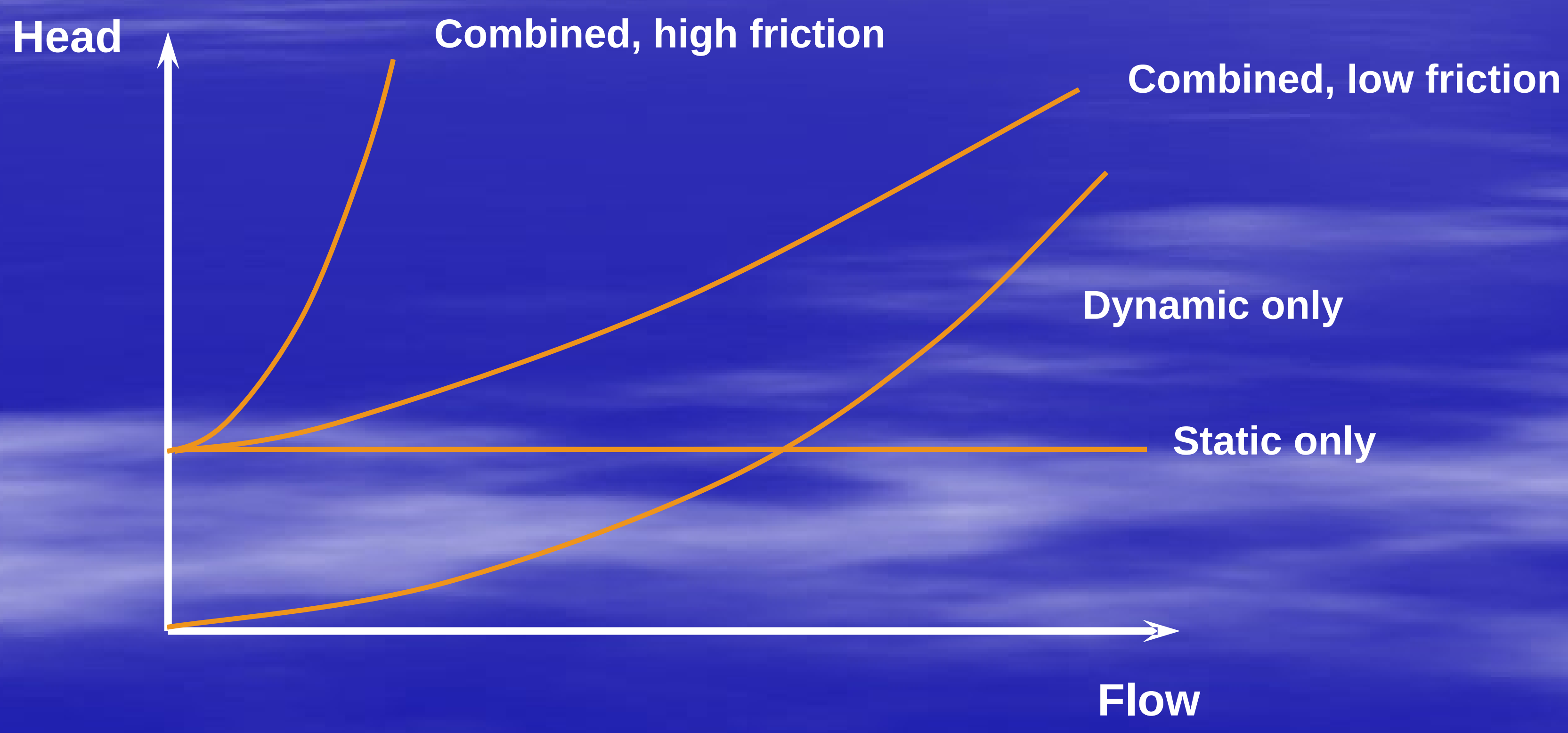
System Curves

Two System Types



System Curves

TYPES OF SYSTEM CURVES



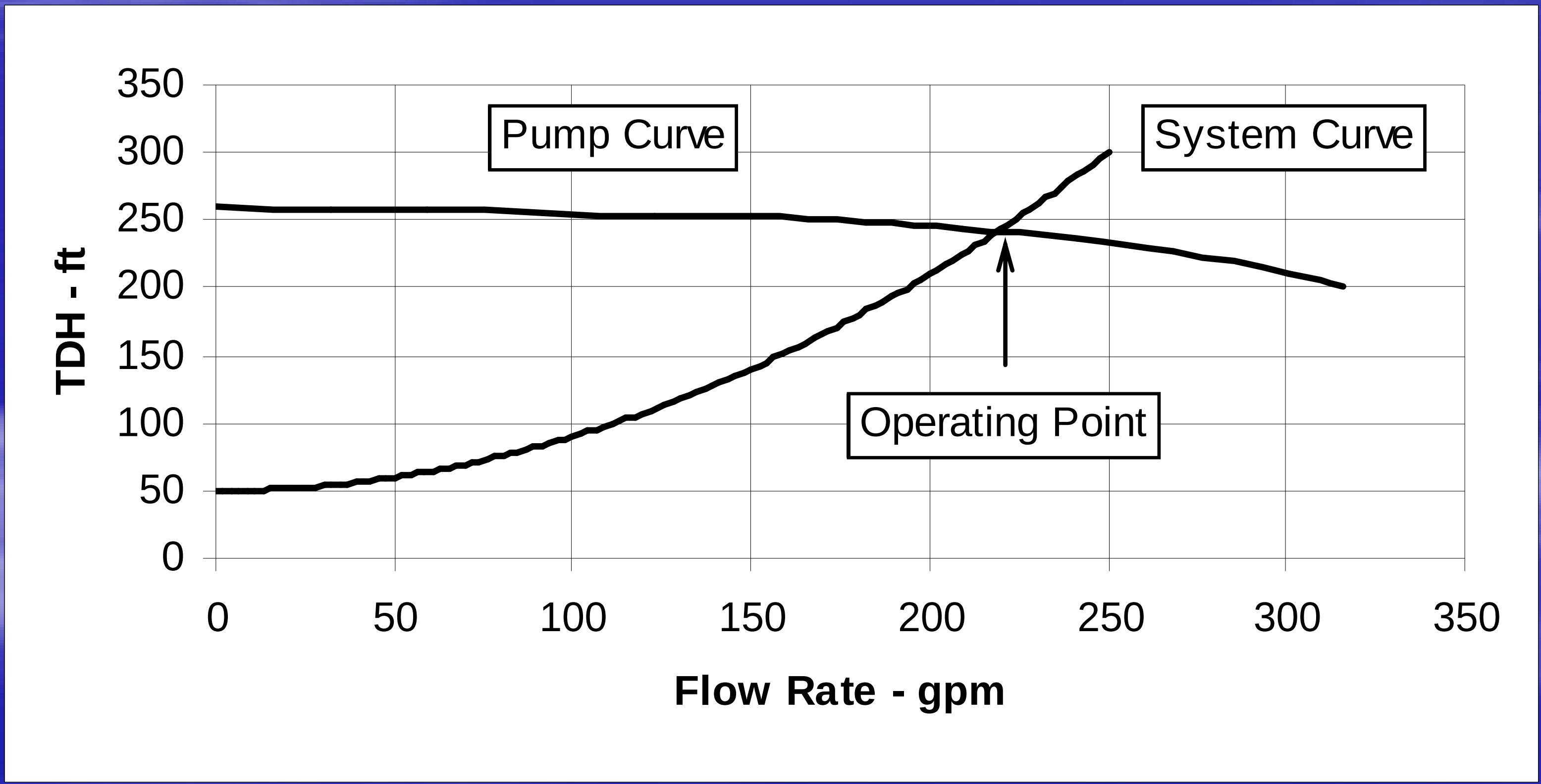
Where will the pump operate?

- The operating point will be found when the pump and system curves are drawn on the same diagram
- The operating point is <u>always</u> where these curves intersect
- The pump will operate where there is balance between the head the pump can deliver and what is demanded by the system

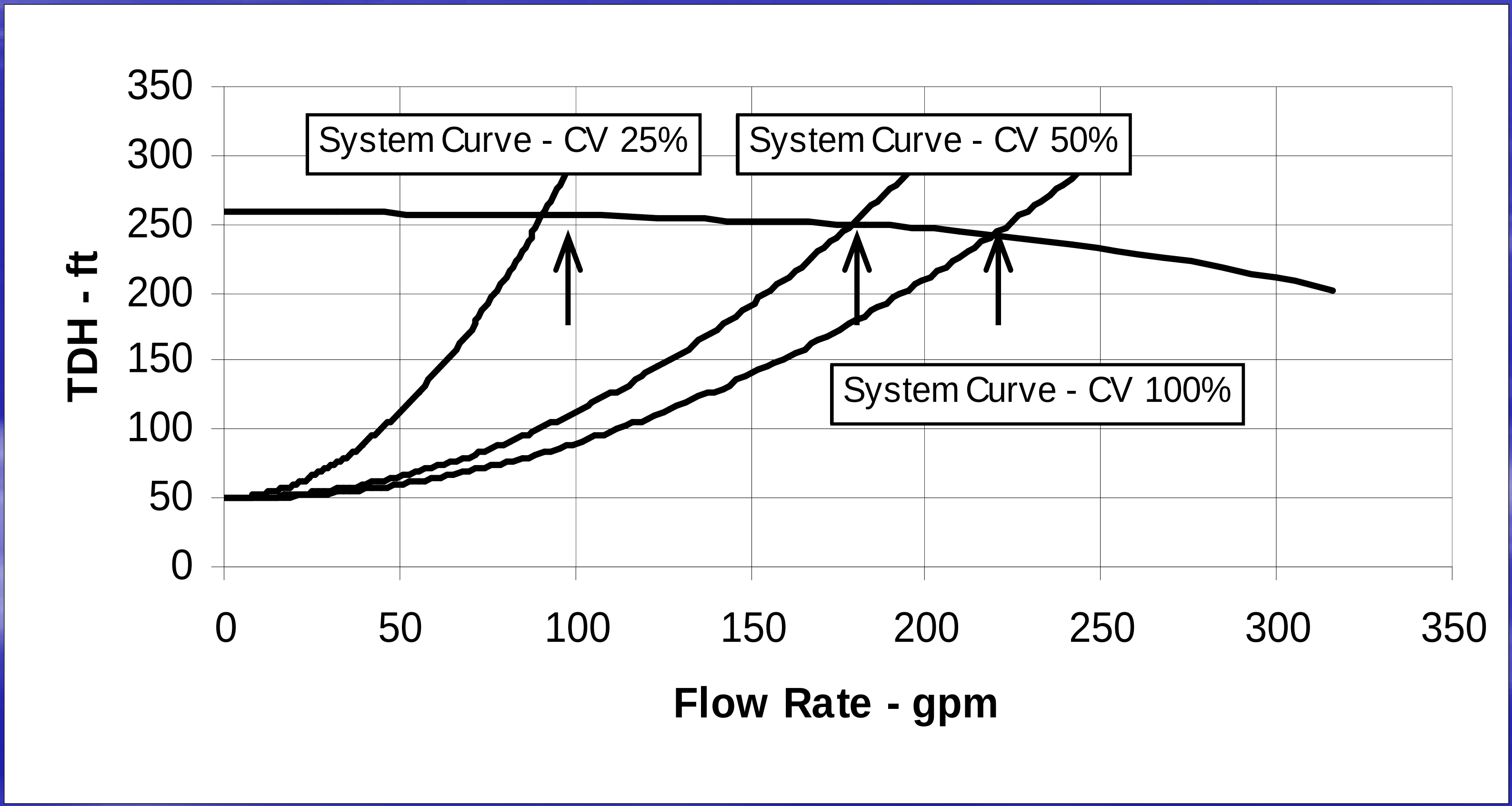
- **Pump and System Curves**
  - Control Valves
  - Pump Changes
  - Parallel Pumping
  - Series Pumping

Pump and System Curves

System Curve – No Control Valve

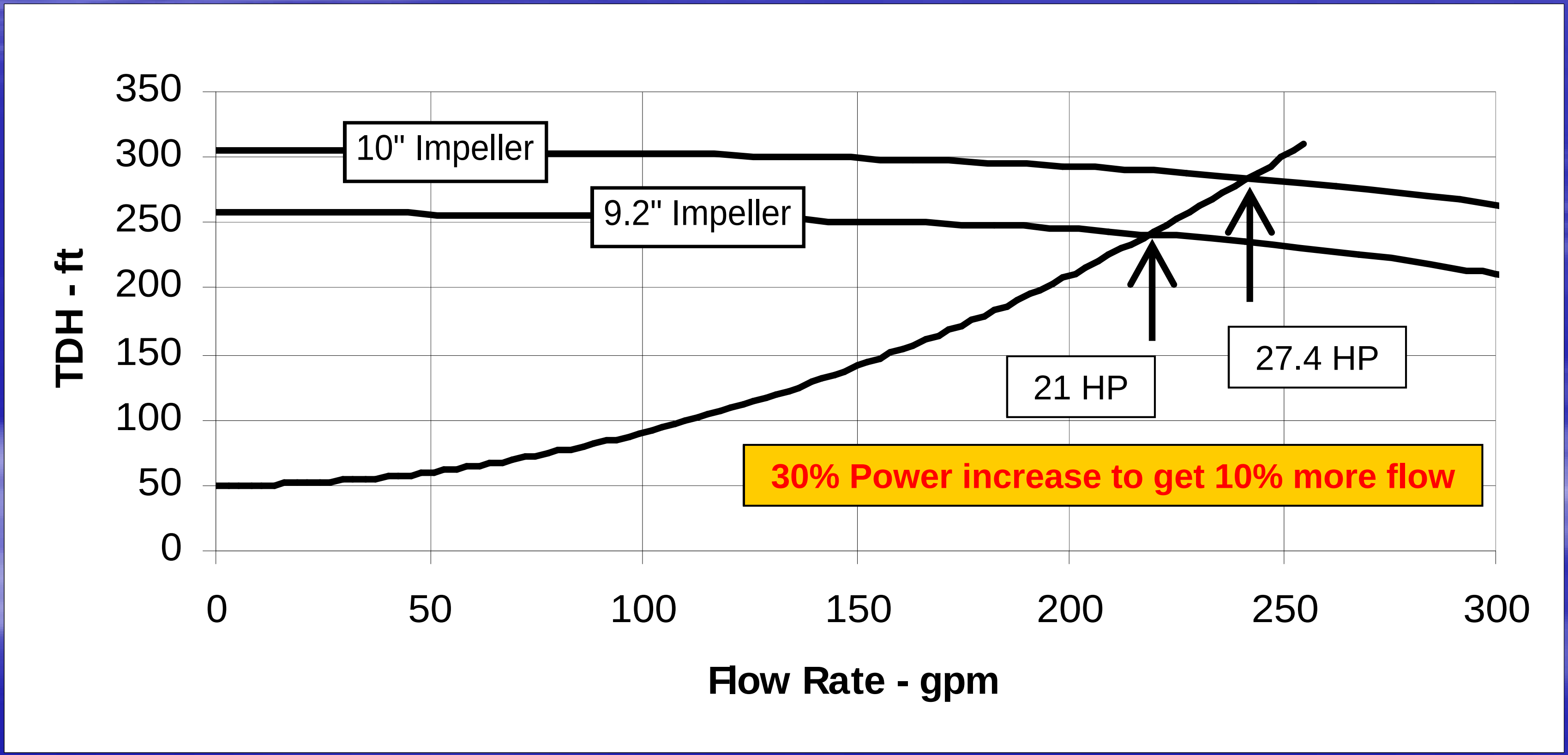


System Curve With Control Valve

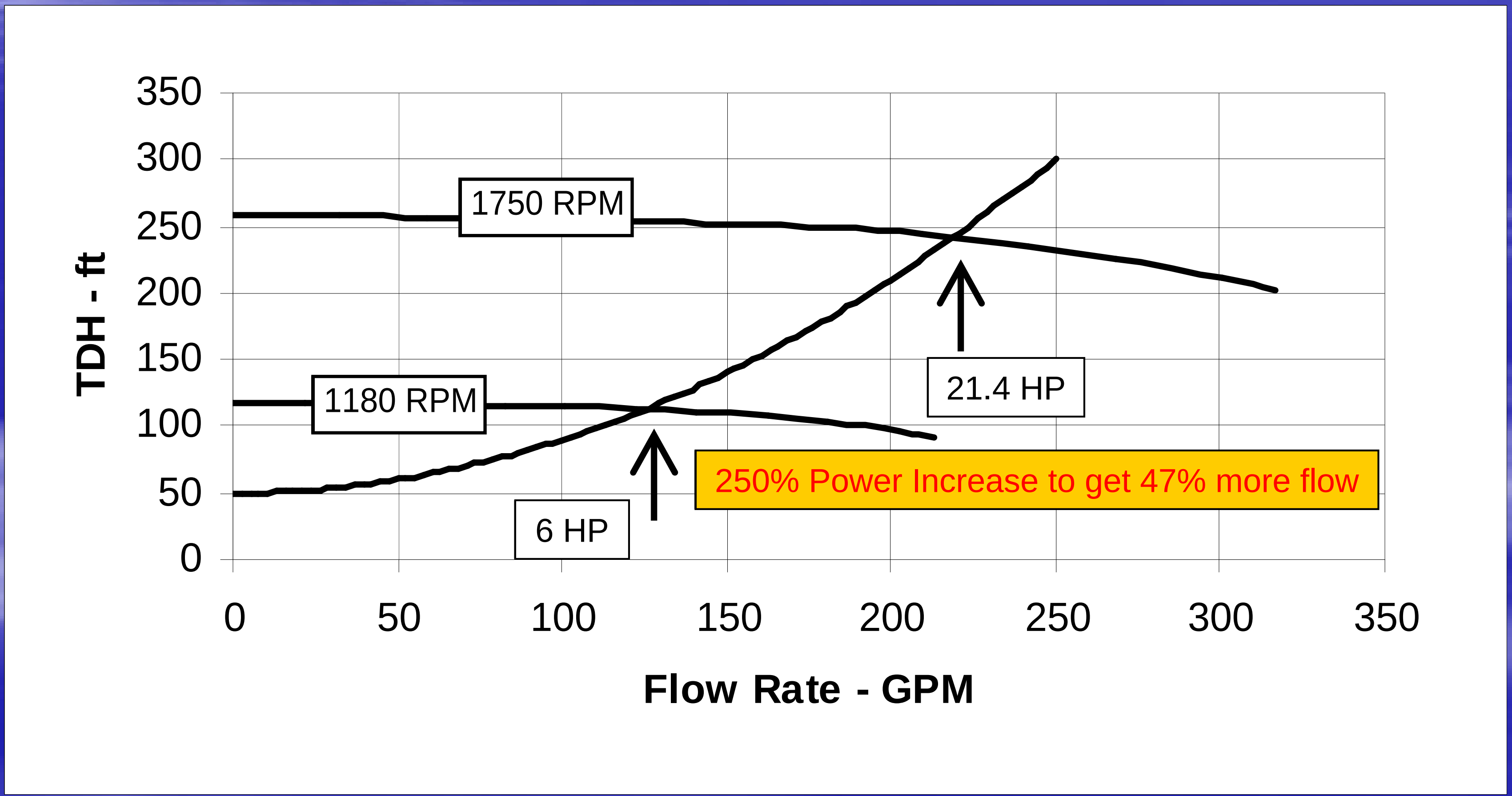


Pump and System Curves

Effect of Impeller Diameter



Effect of RPM

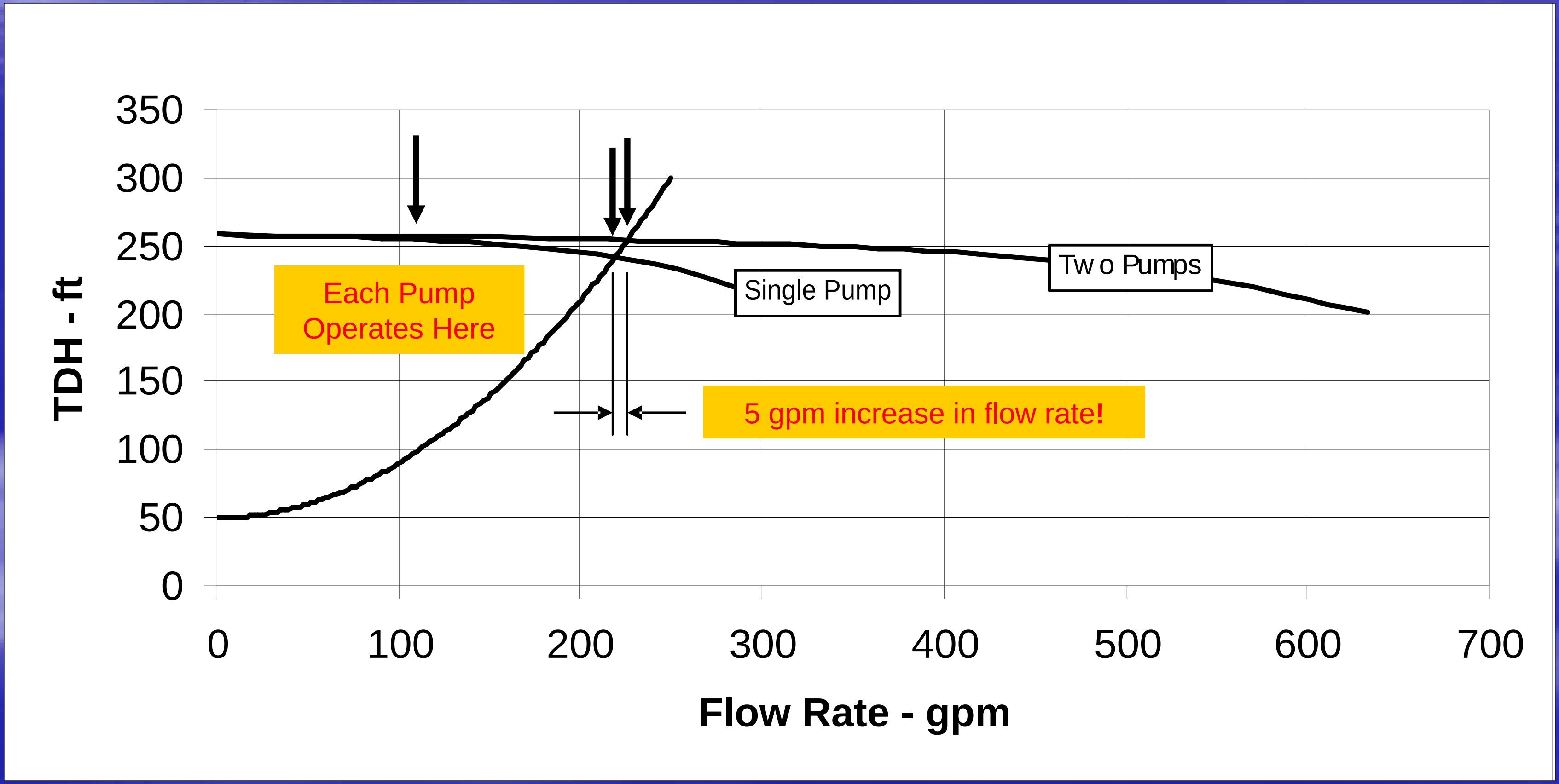


Parallel Pumps

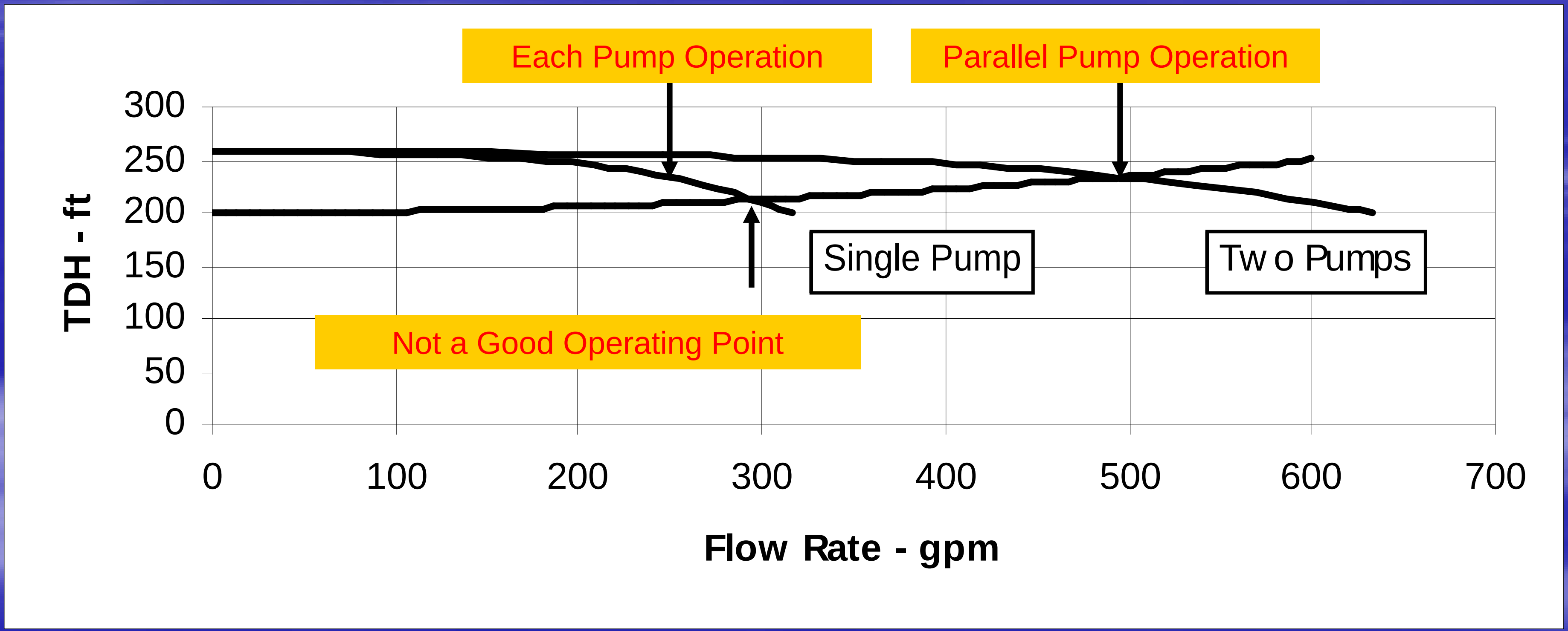
- At the same head flow rates add
- Pumps must be “matched” for effective operation
- Provision must be made to observe minimum flow criteria
- Can be a good way to handle wide flow rate variations

Pump and System Curves

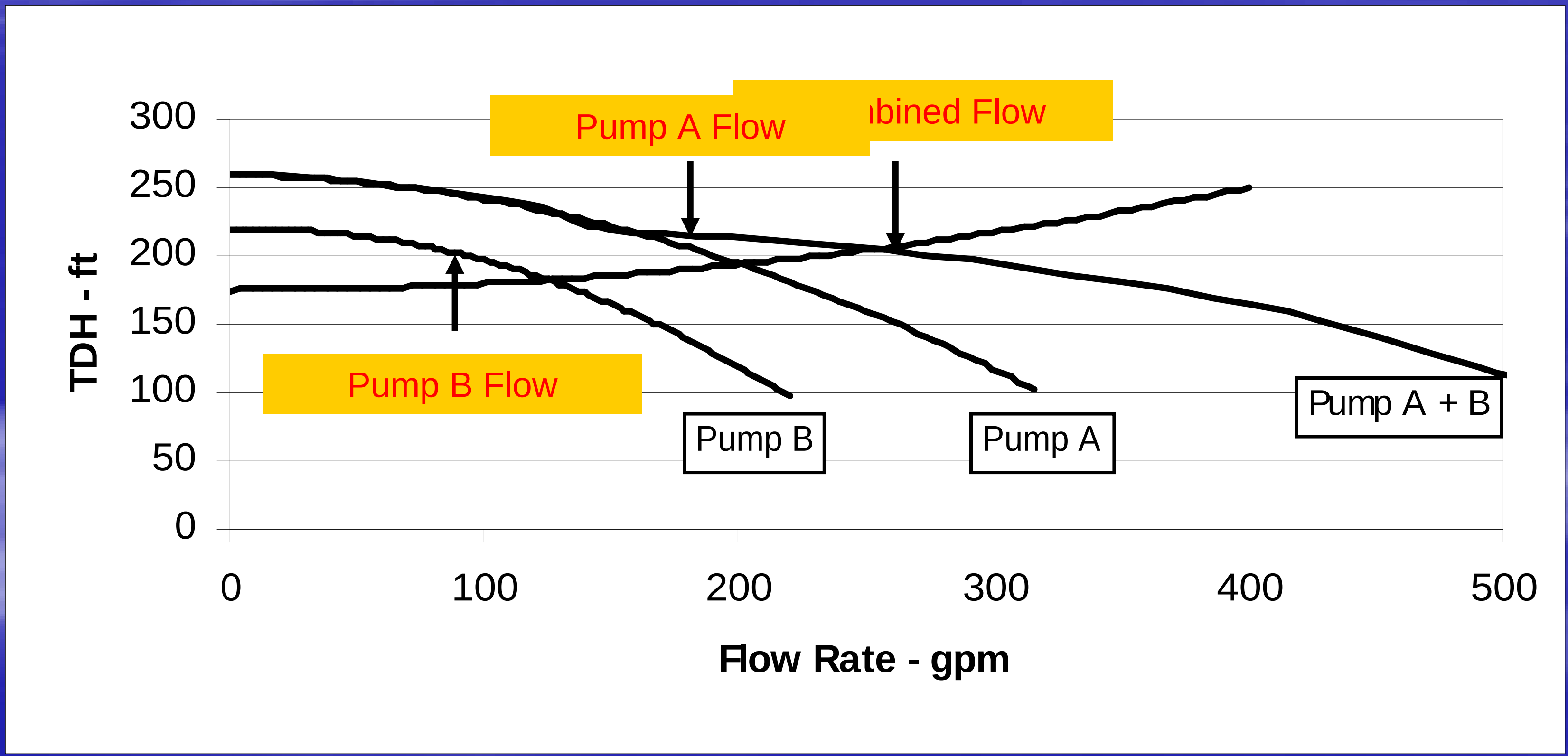
Parallel Pumping System



Parallel Pumping System – Low Friction



Parallel Pumping – Mismatched Pumps

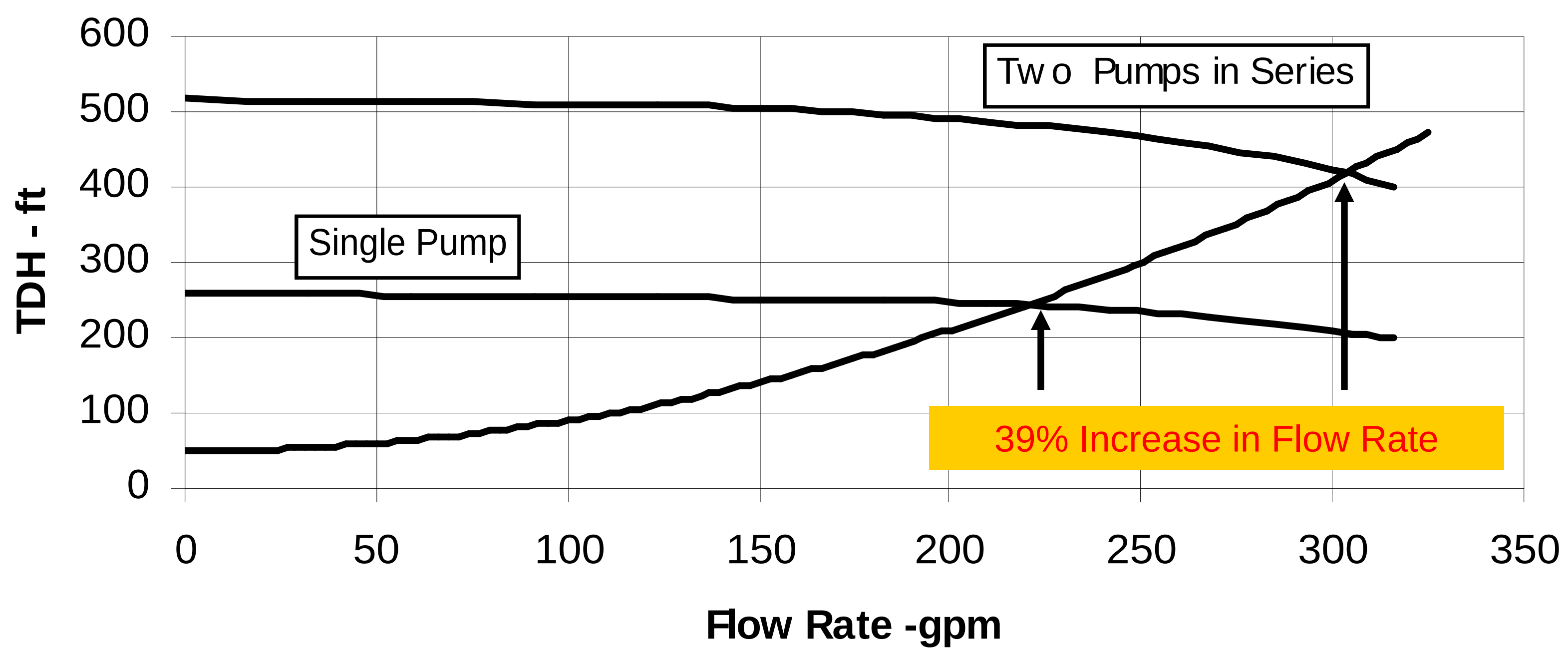


Series Pumping

- Heads add at the same flow rate
- Second stage pump must be rated for discharge pressure
- Start up and shutdown procedures are critical

Pump and System Curves

Series Pumping



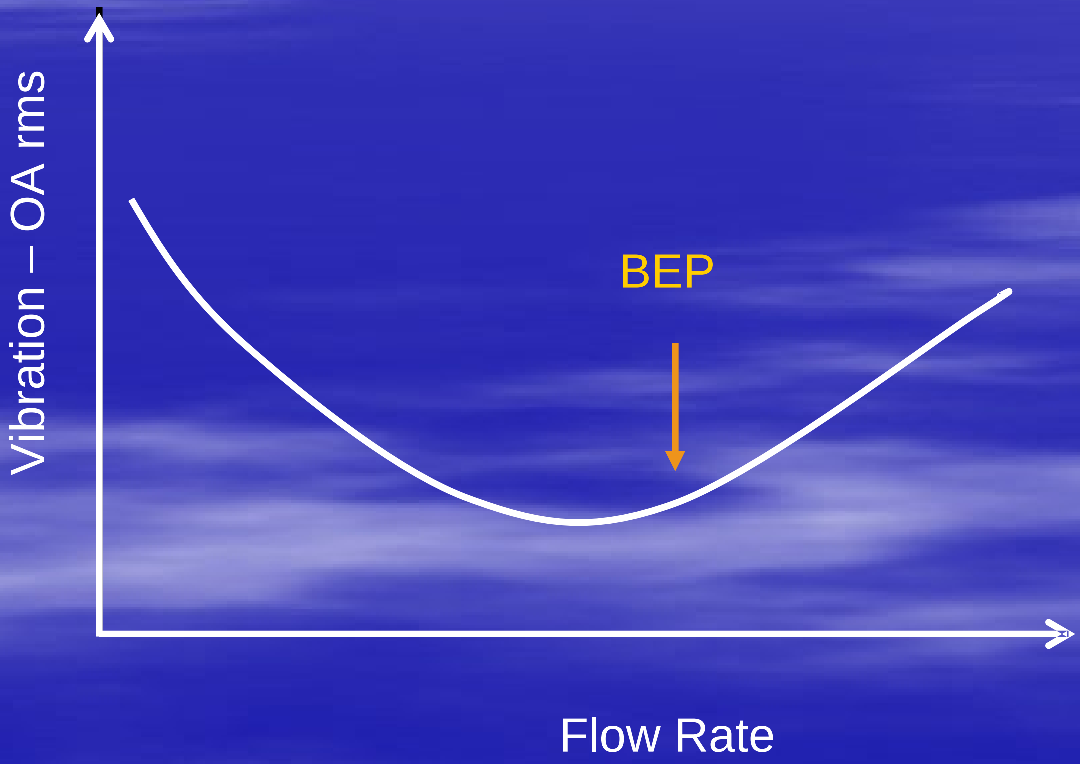
Pump Vibration

- What are Acceptable Vibration Levels
  - Hydraulic Institute Standards: www.pumps.org
    - ANSI/HI 9.6.4 Covers Horizontal and Vertical Centrifugal Pumps
    - Recommends use of RMS velocity
    - Distinguishes between types of pumps
    - Limits flow rates to the Allowable Operating Range
    - Lower limits within the Preferred Operating Range

      ~ 40% - 110% of BEP

- Pump Vibration Characteristics
  - Normal
  - Abnormal

Typical Vibration Characteristic



Pump Vibration

- Normal Characteristics
  - Within the Preferred Operating Range
    - Dominated by rotation frequency and it’s multiples
  - Outside POR , within AOR
    - Blade pass will began to dominate
      - Number of vanes x rotational frequency (single volute pumps)
      - More prominent in pumps with few impeller vanes (wastewater)
      - More prominent when impeller is near maximum diameter

- Abnormal Operation
  - Cavitation
    - Broad Spectrum – toward higher frequencies
    - Vibration levels may, or may not, be high
    - More likely to be high in higher HP pumps (> 50 HP)
    - More likely to be high in higher speed pumps (2 pole)

Pump Vibration

- Abnormal Operation
  - – Low flow (< 20% BEP)
    - Broad spectrum, toward lower frequencies
    - High vane pass frequency content (80% of total)
    - More severe in high HP pumps (> 100 HP)
    - More severe with higher speeds (2 pole)

- **Natural Frequency**
  - Shafts
    - The lateral natural frequency of most shafts is above operating speed (2 pole)
    - Shaft torsional natural frequencies can be a problem, particularly on long vertical drives

Vibration

- **Natural Frequency**
  - Pump Structure
    - Horizontal pumps rarely have natural frequencies in the operating range
    - Vertical pumps often have structural natural frequencies in the operating range
    - Particularly a problem when equipped with variable speed drives

Thank you!

Questions?