CLEANENERGYRESULTS

# Pump Systems Optimization & Assessments
# For Municipal Drinking Water and Wastewater Facilities

**November 4, 2015**
MA Division of Fisheries & Wildlife Field Headquarters

Nancy L. Seidman, MassDEP, Assistant Commissioner

MassDEP
40th Anniversary
40 Years Cleaner
40 Years Greener
Celebrating Four Decades
of Environmental Progress

An Innovative Clean Energy Partnership:
The Massachusetts Department of Environmental Protection
The Massachusetts Department of Energy Resources
The Massachusetts Clean Energy Center

DOER
Massachusetts Department of Energy Resources

MASSACHUSETTS
CLEAN ENERGY
CENTER
JOIN THE INNOVATION REVOLUTION

# Expanding our Partnership, Getting Results

MassDEP
40th Anniversary
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of Environmental Progress

DOER
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of Energy Resources

Hydraulic
INSTITUTE
Creating Pump Standards Since 1917

nationalgrid

EVERSOURCE

In Association with:

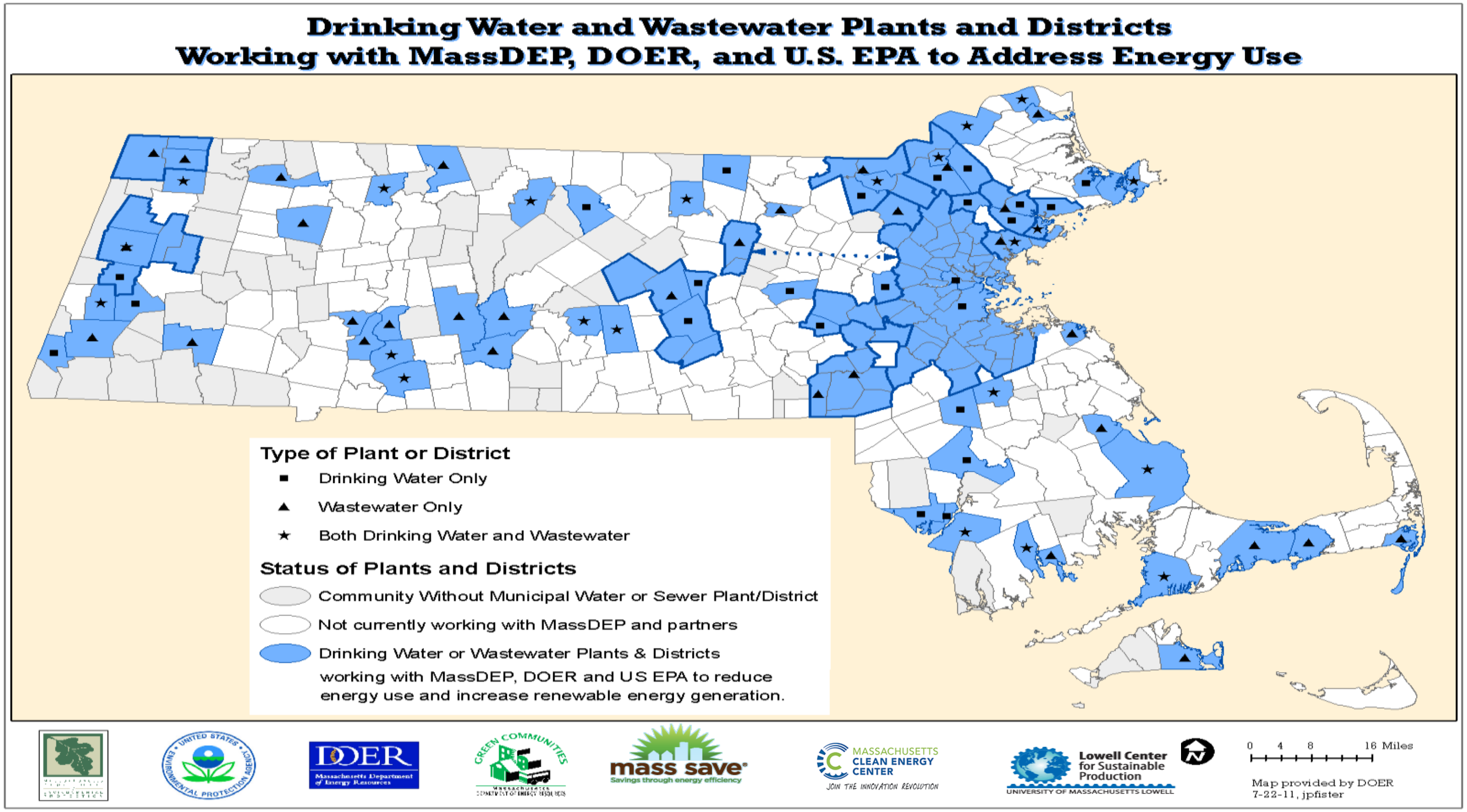
mass save
Savings through energy efficiency

mwwa

MASS
Rural Water Association

WORKING TOWARD A CLEAN ENVIRONMENT
MWPCA
FOUNDED 1965

# Energy Leader Roundtables (2010 – 2014)



Drinking Water and Wastewater Plants and Districts
Working with MassDEP, DOER, and U.S. EPA to Address Energy Use

Engaged **120 facilities statewide** (efficiency & clean energy)

Since 2010, saved communities over **$35 million** and reduced $CO_2$ emissions by **over 100,000 tons**

# Achieving Energy Savings via Pump System Optimization at Municipal Drinking Water and Wastewater Facilities

MA DOER's 2014 Mass Energy Insight (MEI) Statewide Data

| Facility Type | Electricity Usage (MWh) | Potential 10% Pumping Reduction Electricity (MWh) | Potential Annual Cost Savings ($) |
|---|---|---|---|
| Wastewater Treatment & Collection Stations | 260,674 | 5,213 | $938,427 |
| Drinking Water Treatment & Distribution Stations | 169,358 | 15,242 | $2,743,597 |
| Totals | **430,032** | **20,456** | **$3,682,025** |

↓

**- 8,500 tons / year**

MassDEP 40th Anniversary
40 Years Cleaner
40 Years Greener
Celebrating Four Decades of Environmental Progress

DOER Massachusetts Department of Energy Resources

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# Proud to be 1 of 5 Finalist in the Harvard Kennedy School's 2015 Innovations in American Government Competition

Massachusetts Clean Energy Partnership is Harvard Ash Center 2015 'Innovation in Government' Finalist

DOER
Massachusetts Department of Energy Resources

MassDEP

MASSACHUSETTS CLEAN ENERGY CENTER

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Lowell Center for Sustainable Production
UNIVERSITY OF MASSACHUSETTS LOWELL

# For More Information

Massachusetts Clean Energy Results Program Website:

http://www.mass.gov/dep/cleanenergy.htm

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# The State of Massachusetts
# Pump Systems Optimization & Assessments

## Lower Maintenance Costs, Higher Reliability, Improved Productivity, and Higher Energy Efficiency
## For
## Water & Wastewater Facilities Across the State

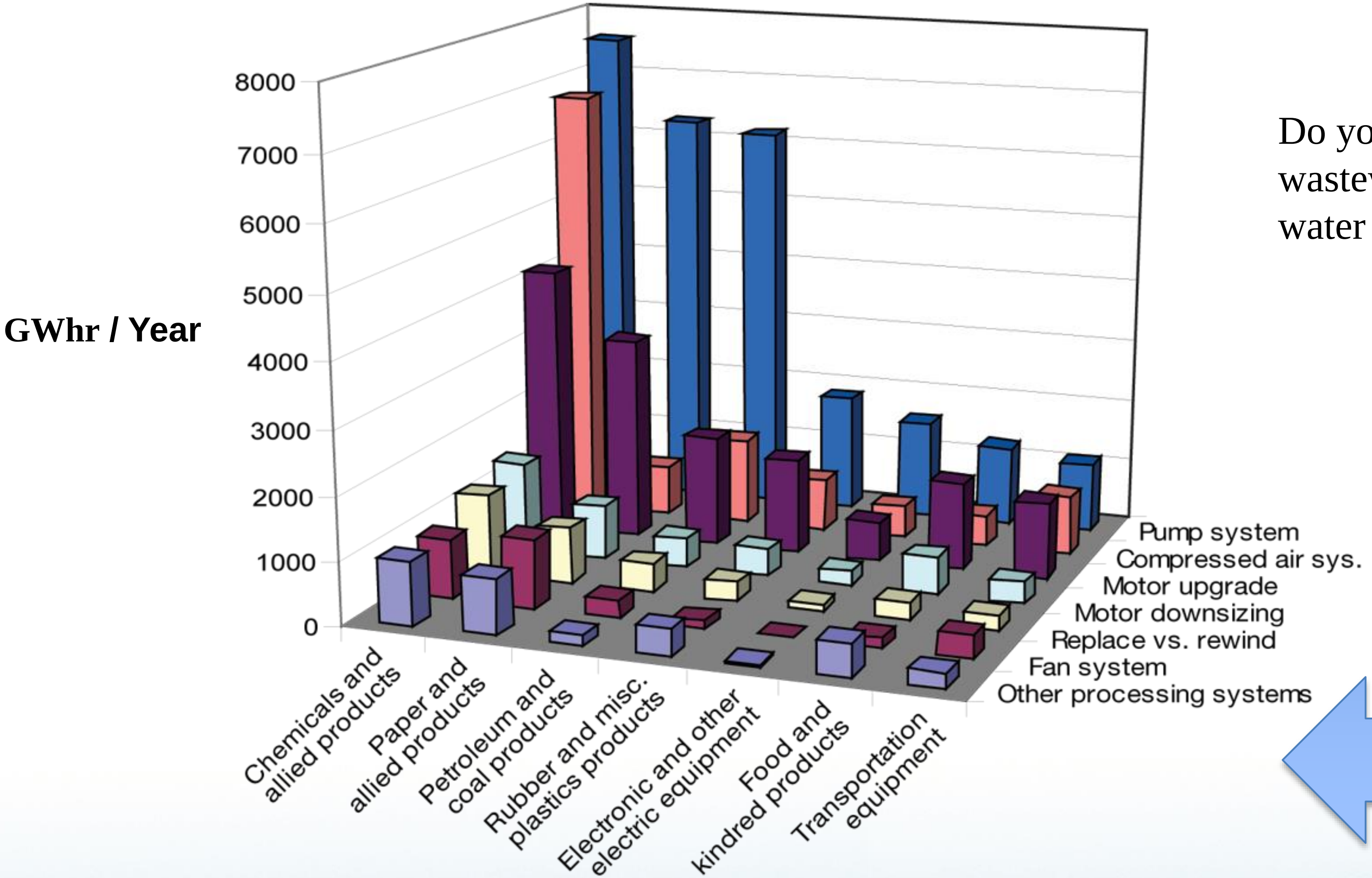
# Introduction to Today's Presentations

1. The **reasons** to optimize any pumping system
2. **Defining** the pump system optimization approach
3. **Implementing** pump system assessments

# The Reasons… Why Focus on Pumping Systems?

- Electrical motors are nearly 2/3rd of the North American Industrial Electricity usage; pumping systems accounting for 25%
- Electrical usage with motors in municipal water systems - pumping (46%) and aeration (40%)
- Pumping systems account for approximately 90% of electrical usage at water facilities and about 20-30% at wastewater plants
- Pumping systems efficiency is highly influenced by the system they are supplying
  - Improving pump efficiency will do little to reduce pump energy usage – the focus must be on the *pumping system*

# Looking at Benefits of Assessment Electrical Energy Savings Potential



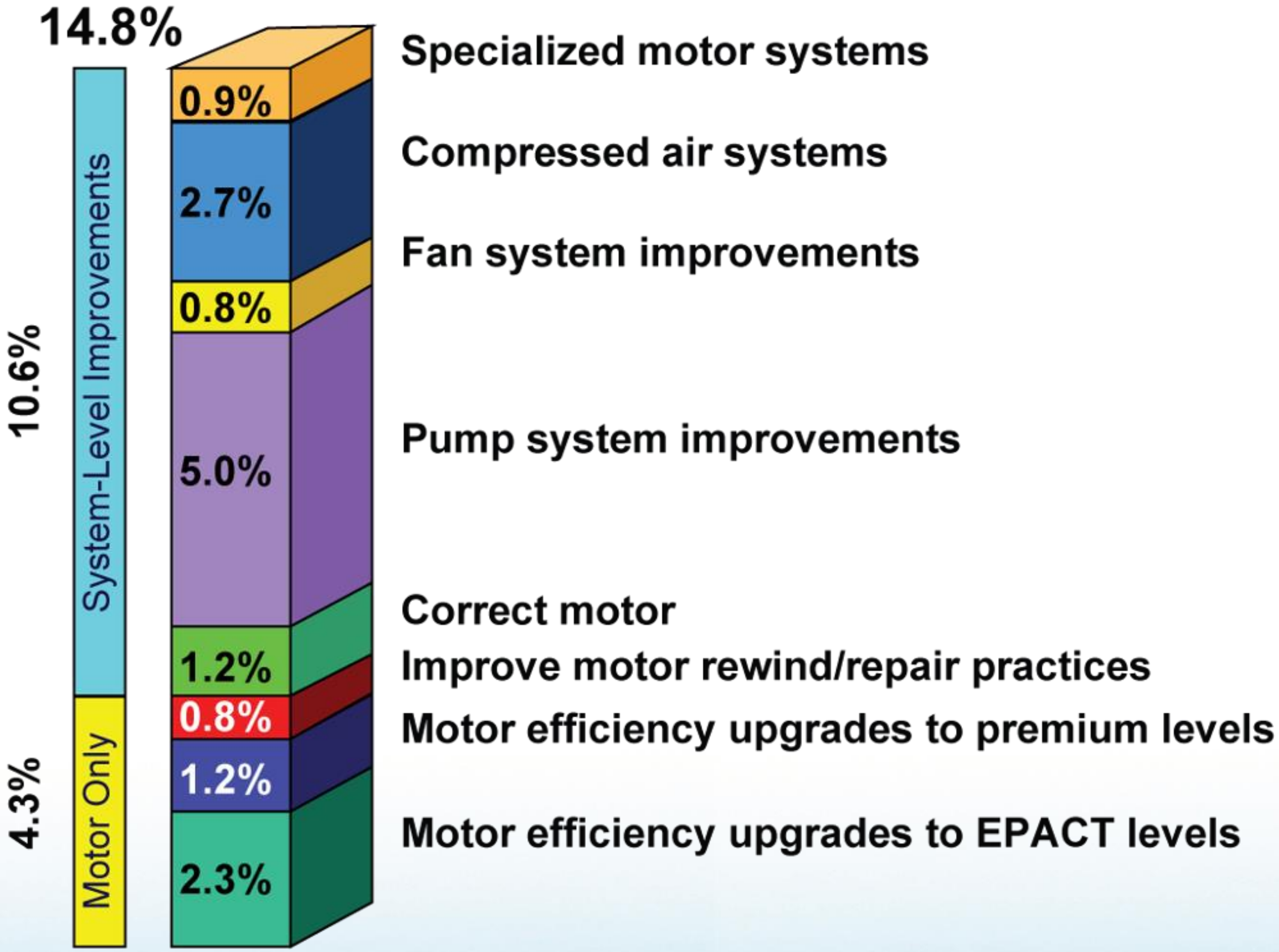
Do you see wastewater/drinking water on this bar chart?

**Pumps Systems are Energy Intensive**

Source: U.S. Industrial Motor Systems, Market Opportunities Assessment,
U.S. Department of Energy

# More Potential Energy Savings
# Motor Systems Savings Opportunity

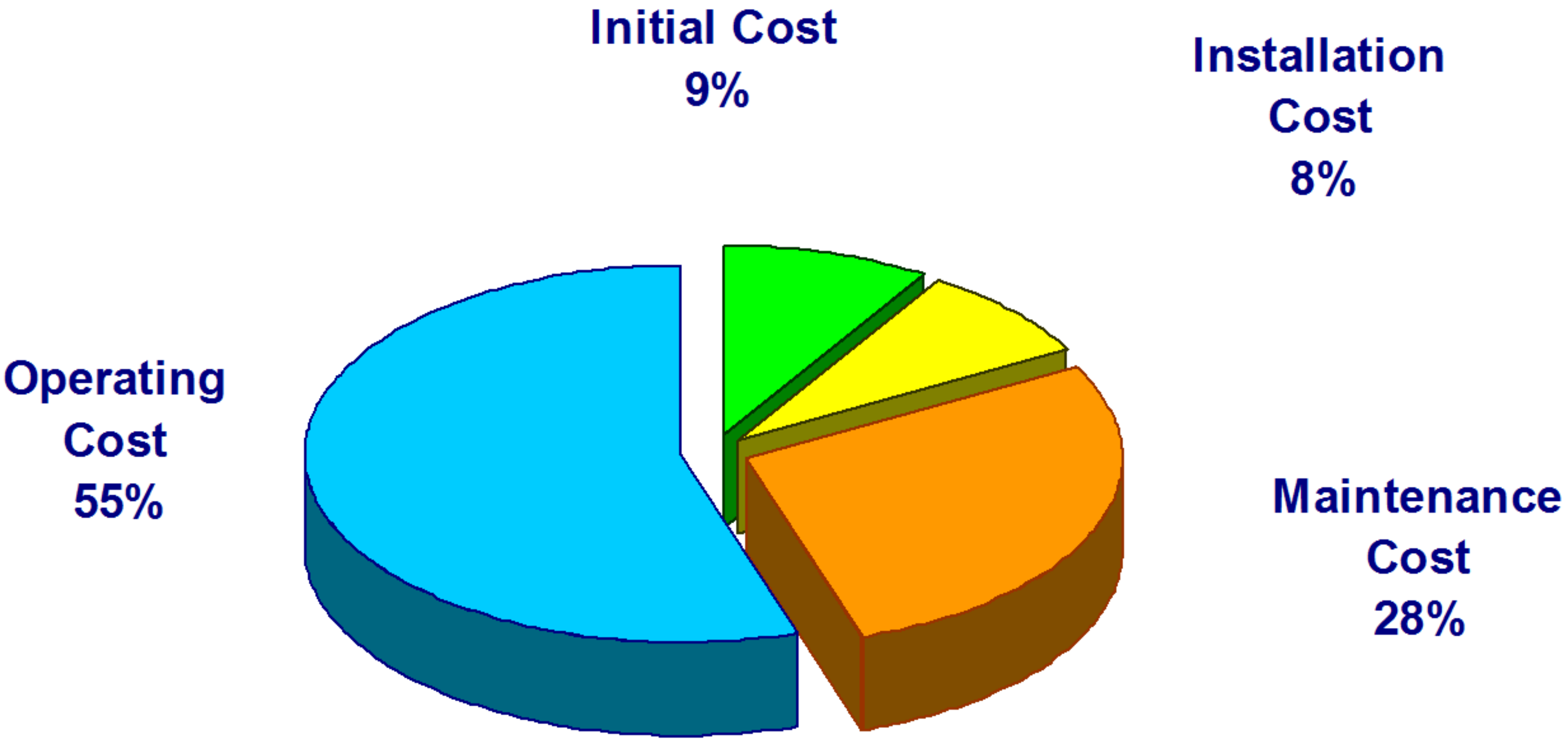
**(as a % of total motor system energy use by the manufacturing sector)**



Source: DOE – Office of Industrial Technologies
Industrial Motor Systems Market Opportunities Assessment

# Total Life Cycle Costs:

## Conventional 75 HP Pumping System 20 Year Useful Life



**Total 20 Year Life Cycle Cost = $757,145**

**Reference : CostWare Analysis**

# The Bottom-line Reasons to Show What Happens When Pumps are not Optimized?

“Expert Systems for Diagnosis of the Condition and Performance of Centrifugal Pumps”

Evaluation of 1690 pumps at 20 process plants:

- Average pumping **efficiency is below 40%**
- Over **10% of pumps** run **below 10% efficiency**
- Major factors affecting pump efficiency:
  - Throttled valves
  - Improper pump selection
- Seal leakage causes highest downtime and cost

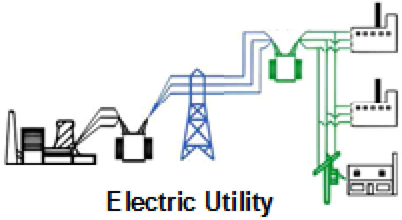
* Finnish Technical Research Center Report

# Other Benefits to Pumps System Optimization

1. Higher Reliability
2. Increase Productivity
3. Less Equipment Wear and Tear
4. Reduced Maintenance Costs
5. Reduce Production Losses
6. Increased Capacity Utilization
7. Reduce Environmental Impact

Energy cost is an important consideration, but you are also focusing on these top seven priorities which are important to your day-to-day performance….

# Defining the Pump System Optimizing Solution



Electric Utility

Transformer

Switchgear

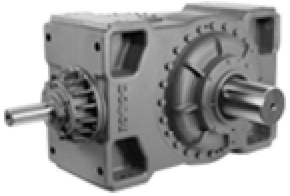
**Component Optimization** involves segregating components and analyzing in isolation.

***System Optimization*** involves looking at how the whole group functions together and how changing one can help improve the value of the entire application solution.

At each interface, there are inefficiencies. The primary objective should be to maximize the overall cost effectiveness of the entire system, or simply stated…"how much output energy is delivered per unit of input energy."

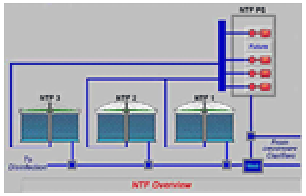
Variable Frequency Drive

Motor



Gearbox

Coupling



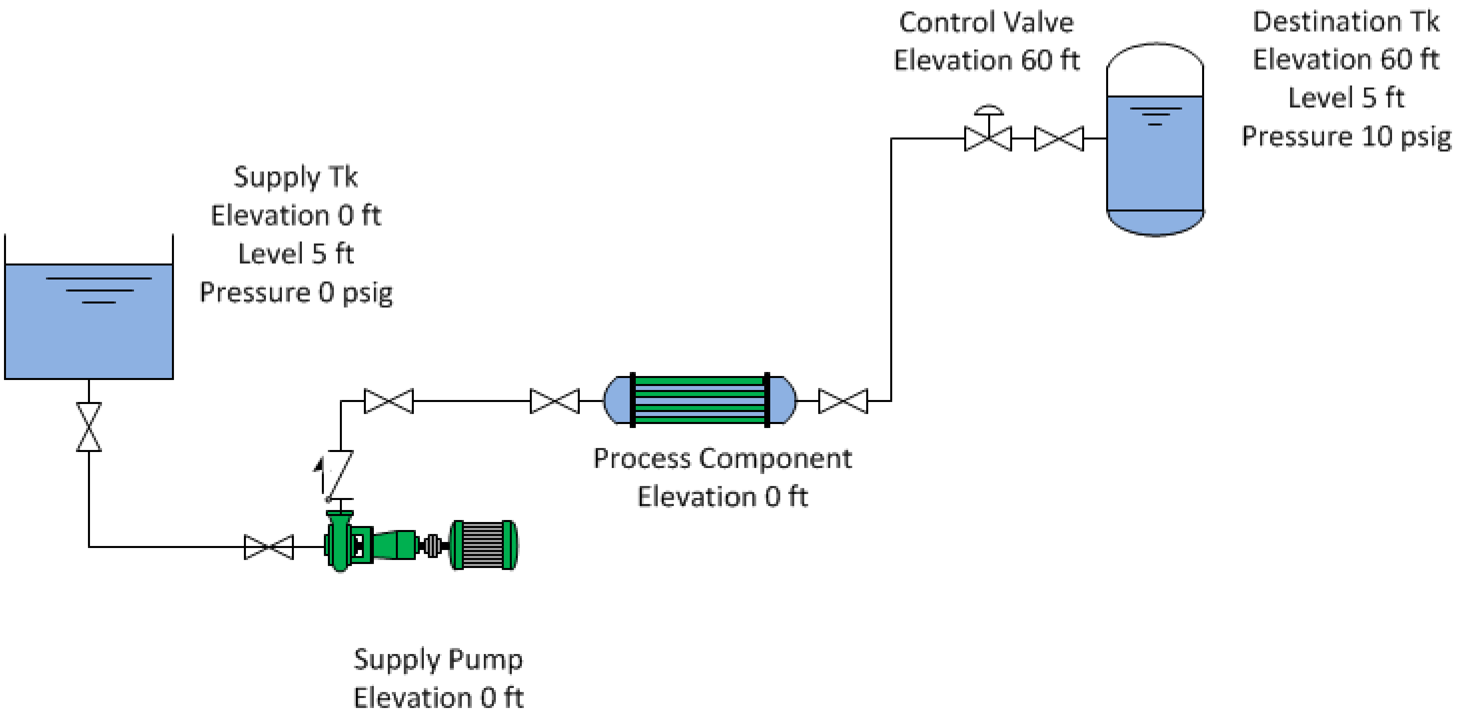
System

Energy Efficiency Improvements

# Use a Systems Approach to Manage your Pumping Systems

- Focusing on individual components overlooks potential cost-savings
- Component failures are often caused by system problems
- Use a total system approach in designing systems and evaluating repair and maintenance options
- Remember the energy bill discussion

# Defining All the Elements of a Pumping System



- Pump elements
- Process elements
- Control elements

# Implementing a Pump System Assessment

## Level I, Level II and Level III

# Key components to all three types of Pump System Assessments

| Activities | Level 1 Assessment | Level 2 Assessment | Level 3 Assessment |
|---|---|---|---|
| **Pre-screening opportunities** | Required | Required | Required |
| **Walk through** | Optional | Required | Required |
| **Identify systems with potential saving opportunities** | Required | Required | Required |
| **Evaluate systems with potential saving opportunities** | Optional | Required | Required |
| **Measurement of operating data for a typical single operating point** | Optional | Required | Non Applicable |
| **Measurement/data logging of systems with variable operating conditions** | Non Applicable | Non Applicable | Required |

# The Key Take Away Points to Defining the Pump System Assessment Approach

- System Assessments focuses on improving the reliability of the system thus reducing system costs
- Need to understand the symptoms that occur to the systems when the pump operates away from BEP
- Pumping systems change over time, therefore it pays to reassess the system
- Efficiency, reliability and energy savings go hand-in-hand

# Conclusions

- Pump Systems Optimization offers multiple benefits:
  - Higher reliability
  - Increased productivity
  - Less equipment wear and tear
  - Reduced maintenance costs
  - Reduce production losses
  - Increase capacity utilization
  - Reduce environmental impact

**And ENERGY SAVINGS**

# Introduction to William Livoti

**Certified Pump System Instructor**

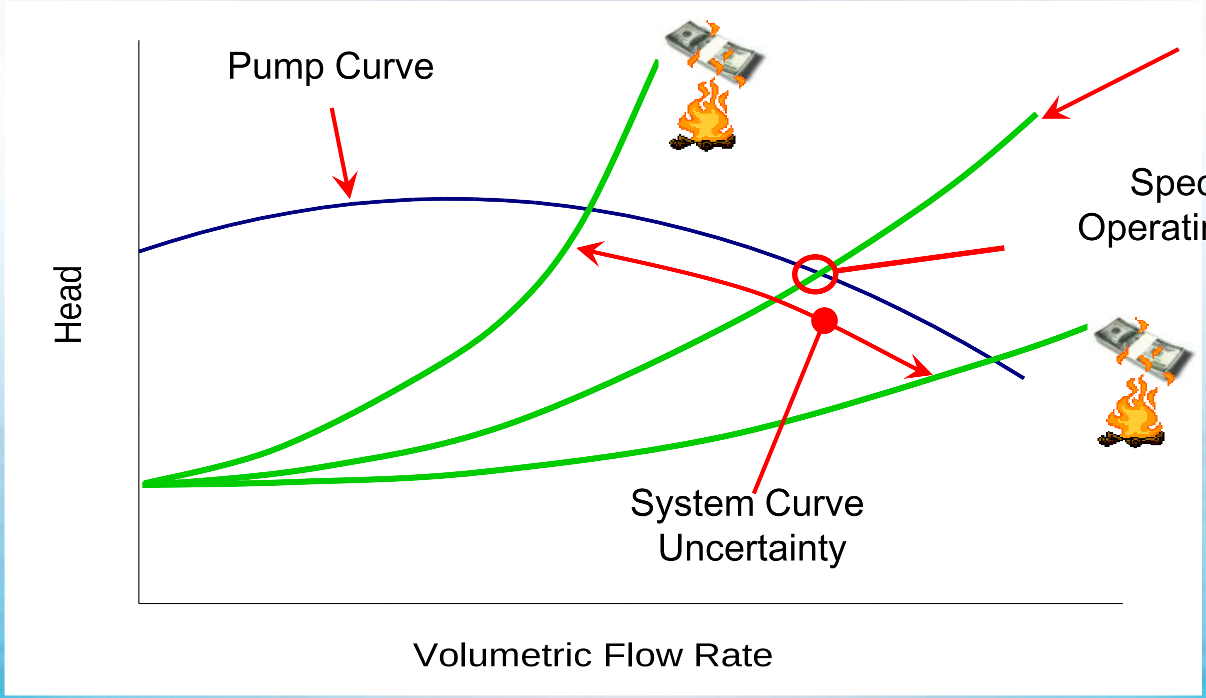
**Training Partner with the Hydraulic Institute**

**WEG Electric**

**“Pump System Management and Conducting Assessments”**

# Introduction
# To
# Pumping System Optimization:

## Energy Efficiency and Bottom-Line Savings



System Curve
(as Specified)

Pump Curve

Specified
Operating Point

System Curve
Uncertainty

# Pump vs. System Standards

## Pump Standards

Standards of design and dimensional specifications are necessary to bring unity to centrifugal pumps. Standards are provided by organizations like

**ISO** - International Standards Organizations
**HI** – Hydraulic Institute
**API** - American Petroleum Institute
**ANSI** - American National Standards Institute
**DIN** - Deutsches Institut für Normung
**NPFA** - National Fire Protection Agency
**BSi** - British Standards institute

Some commonly used centrifugal pumps standards

**ANSI/API 610-1995** - Centrifugal Pumps for General Refinery Service - Covers the minimum requirements for centrifugal pumps, including pumps running in reverse as hydraulic power recovery turbines, for use in petroleum, heavy duty chemicals, and gas industry services. The pump types covered by this standard can be broadly classified as overhung, between bearings, and vertically suspended.

**DIN EN ISO 5199** - Technical specifications for centrifugal pumps

**ASME B73.1-2001** - Specification for Horizontal End Suction Centrifugal Pumps for Chemical Process - This standard covers centrifugal pumps of horizontal, end suction single stage, centerline discharge design. This Standard includes dimensional interchangeability requirements and certain design features to facilitate installation and maintenance. It is the intent of this Standard that pumps of the same standard dimension designation from all sources of supply shall be interchangeable with respect to mounting dimensions, size and location of suction and discharge nozzles, input shafts, baseplates, and foundation bolt holes

**ASME B73.2-2003** - Specifications for Vertical In-Line Centrifugal Pumps for Chemical Process

**BS 5257:1975** - Specification for horizontal end-suction centrifugal pumps (16 bar) - Principal dimensions and nominal duty point. Dimensions for seal cavities and base plate installations.

## System Standards

- With few exceptions, there are no standards to guide system design

- Engineering contractors and owner/operators are allowed to choose (or ignore) how to calculate system hydraulics
  - Specified pump operating point not subject to standards

# Making the Business Case for Optimization

- Stock Holder Value and Profit
- Survival
- Sustainability
- Relate savings to the facility's bottom line

# Look Beyond Energy Savings

Energy cost is a top consideration, but there are also values for non-energy benefits:

- Higher Reliability
- Increase Productivity
- Less Equipment Wear and Tear
- Reduced Maintenance Cost
- Reduce Production Losses
- Increase Capacity Utilization
- Reduce Environmental Impact

**Bundled Benefits!**

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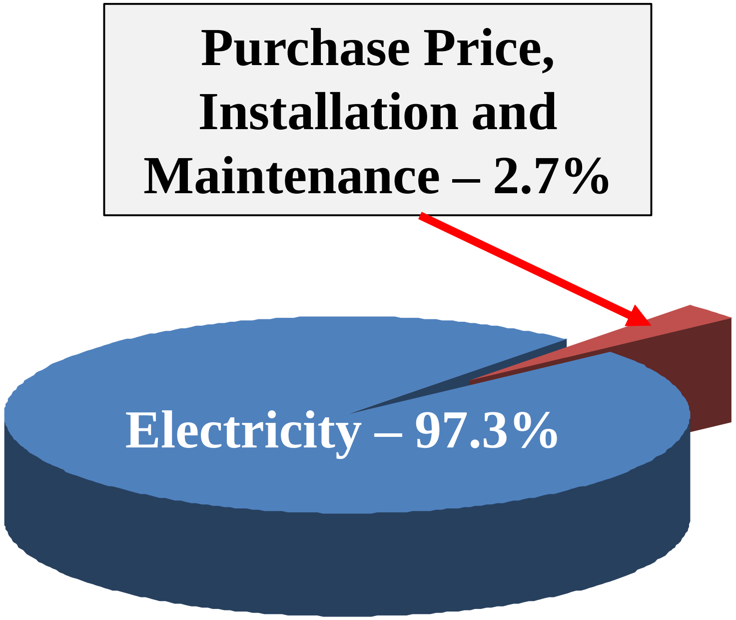
# Pump System Fundamentals
# the
# Impact on Total System Efficiency

# Motor Life Cycle Costs



- **What Does it Cost to Operate a Motor?**
- **What is the Value of One Point of Increased Efficiency?**
- **Is Choosing the More Efficient Motor the Best Solution?**

# Estimating Efficiency
# and
# Load

# Estimate Efficiency and Load

$$\text{Name Plate BHP} = \frac{1.732 \times E \times I \times EFF \times PF}{746}$$

**Where**

E = Volts
EFF = Efficiency (decimal)
BHP = Horsepower (name plate efficiency and power factor
I = Amperage
PF = Power Factor (decimal)

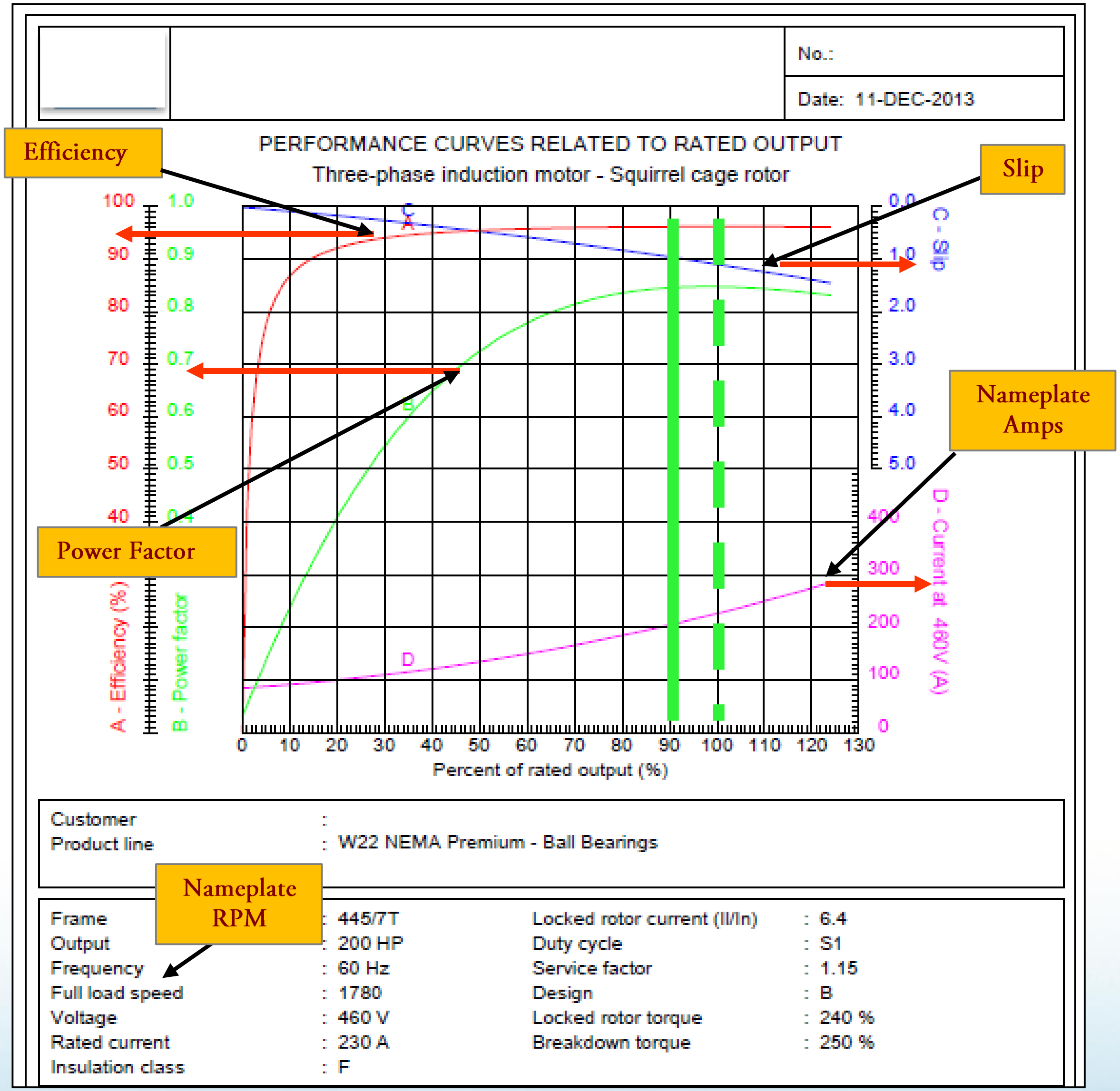
## Calculating Motor Load

- First use power, amperage, or slip measurements to identify the load imposed on the operating motor.
- Second, obtain a motor part-load efficiency value consistent with the approximated load either from the manufacturer.
- Or, if direct-read power measurements are available, derive a revised load estimate using both the power measurement at the motor terminals and the part-load efficiency as shown below.

$$\text{Actual BHP} = \frac{1.732 \times E \times I \times EFF \times PF}{746}$$

**Where**

E = Volts
EFF = Efficiency (decimal) from performance curve
BHP = Horsepower (efficiency and power factor from performance curve)
I = Amperage
PF = Power Factor (decimal)



No.:
Date: 11-DEC-2013

PERFORMANCE CURVES RELATED TO RATED OUTPUT
Three-phase induction motor - Squirrel cage rotor

Customer :
Product line : W22 NEMA Premium - Ball Bearings

| | | | |
|---|---|---|---|
| Frame | : 445/7T | Locked rotor current (Il/In) | : 6.4 |
| Output | : 200 HP | Duty cycle | : S1 |
| Frequency | : 60 Hz | Service factor | : 1.15 |
| Full load speed | : 1780 | Design | : B |
| Voltage | : 460 V | Locked rotor torque | : 240 % |
| Rated current | : 230 A | Breakdown torque | : 250 % |
| Insulation class | : F | | |

# Computing Energy Costs for Pumping Systems

## Annual Electricity Cost (measurement formula)

$$\frac{\text{(measured amps)} \times \text{(measured voltage)} \times (1.732) \times \text{pf} \times \text{hours} \times \text{rate}}{1{,}000}$$

**Where:**

**measured amps** = average of three phases
**measured voltage** = line to line voltage
**PF** = power factor $$$$
**Hours** = annual hours of operation
**Electric Rate** = electricity cost in $/kWh

**Get power factor (PF) from motor manufacturer performance data sheet**

**Note - 1.732 (the square root of 3), is a constant necessary with 3 phase**
**1000 = Watts to kW**

# Computing Energy Costs for Pumping Systems

## *Exercise 1*

### Annual Electricity Cost (measurement formula)

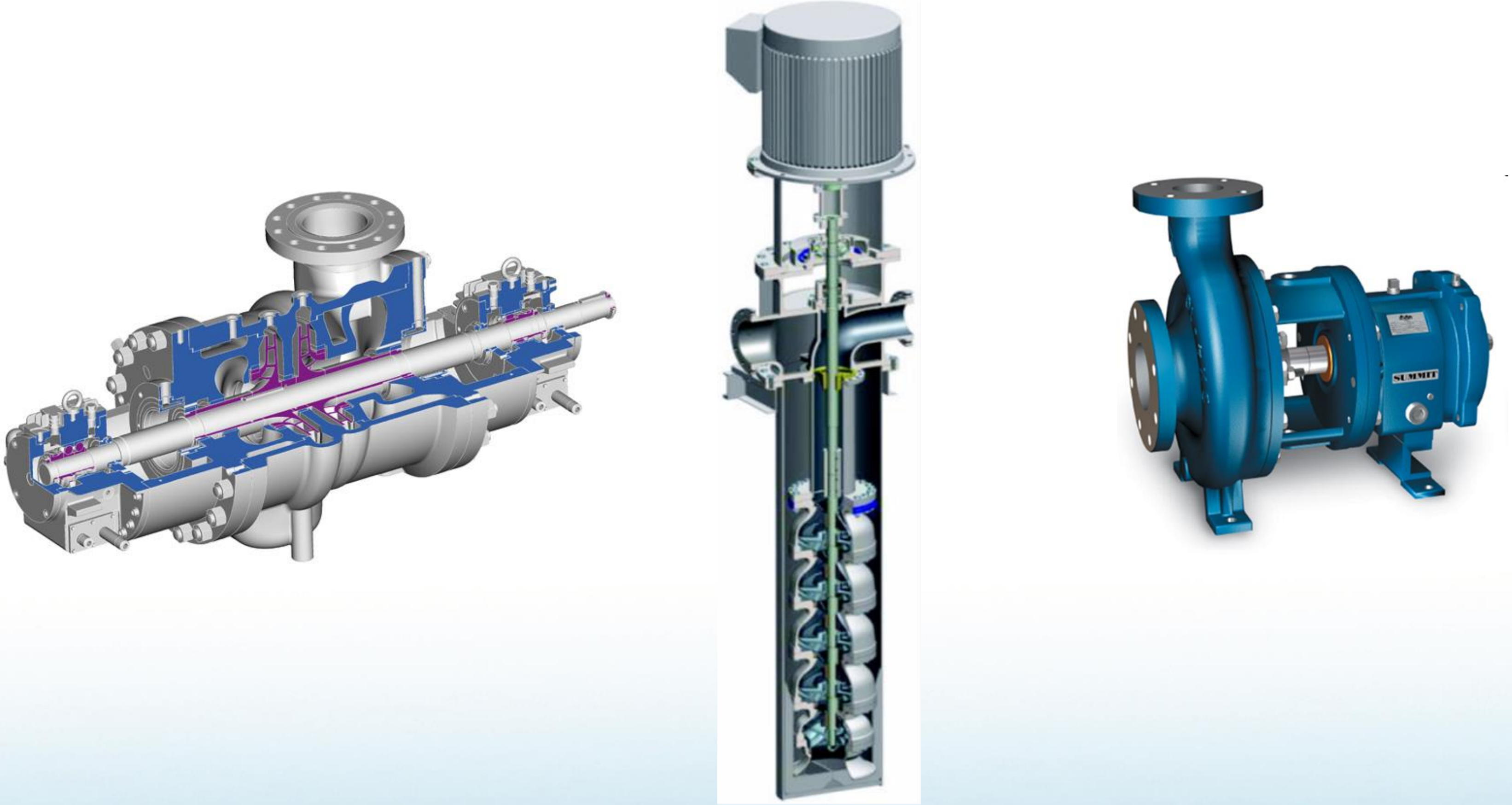
$$\frac{(\text{measured amps}) \times (\text{measured voltage}) \times (1.732) \times \text{pf} \times \text{hours} \times \text{rate}}{1{,}000}$$

**Example:**

$$\frac{(340) \times (460) \times (1.732) \times (0.85) \times 4{,}160 \times \$0.07}{1{,}000}$$

= **$67,049 per year**

# How a Roto-Dynamic (Centrifugal, Mixed Flow, and Axial Flow) Pump Works



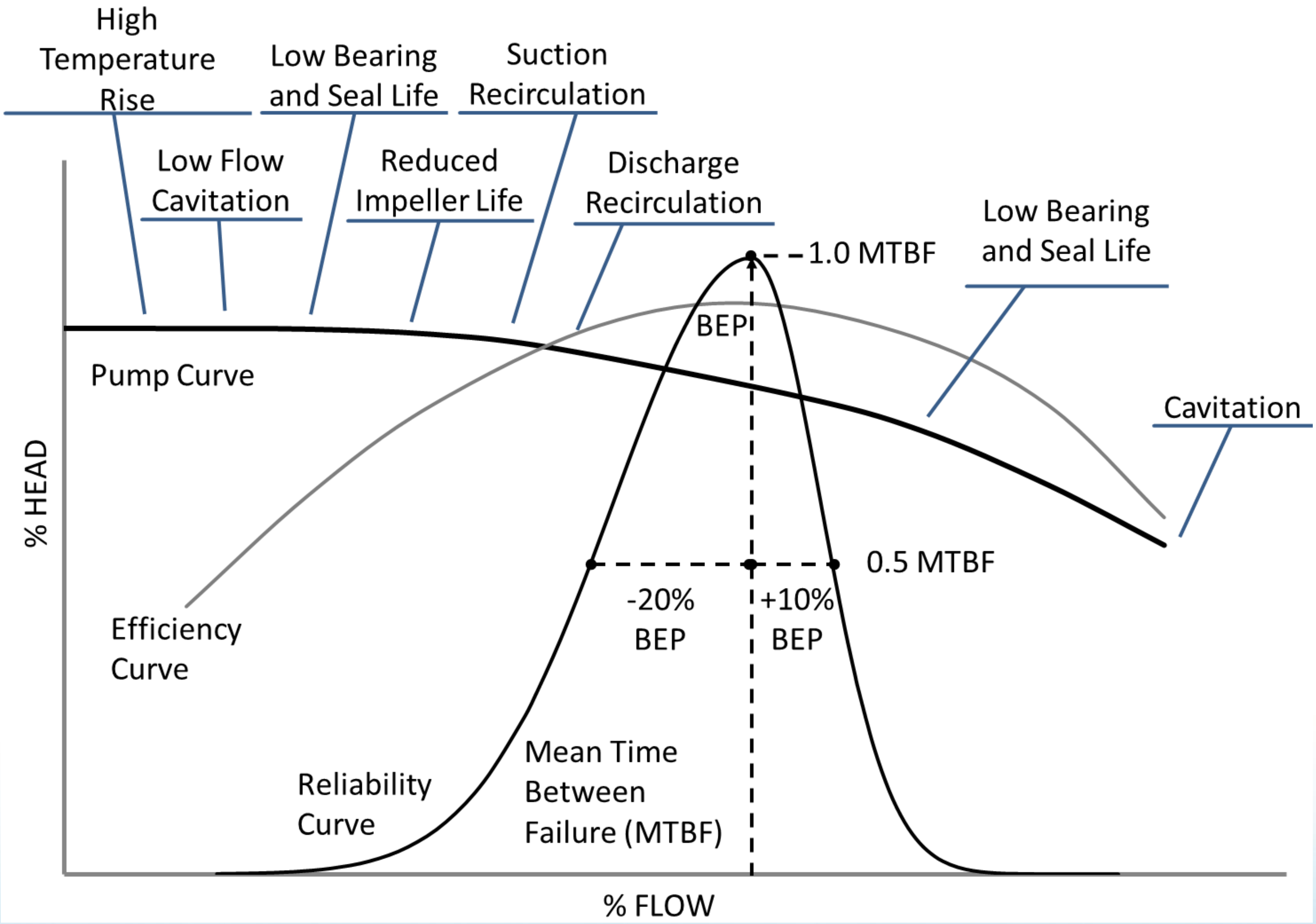
# Centrifugal Pump Facts

- Centrifugal pumps should be selected and normally operated at or near the manufacturer's design rated conditions of head and flow.

- Any pump operated at **excess capacity**, i.e. **at a flow significantly greater than BEP and at a lower head**, will surge and vibrate, creating potential bearing and shaft seal problems as well as requiring excessive power.

- When operation is at **reduced capacity**, i.e. at **a flow significantly less than BEP and at a higher head**, the fixed vane angles will now cause eddy flows within the impeller, casing, and between the wear rings.  The radial thrust on the rotor will increase, causing higher shaft stresses, increased shaft deflection, and potential bearing and mechanical seal problems while radial vibration and shaft axial movement will also increase.

# Efficiency Means Reliability



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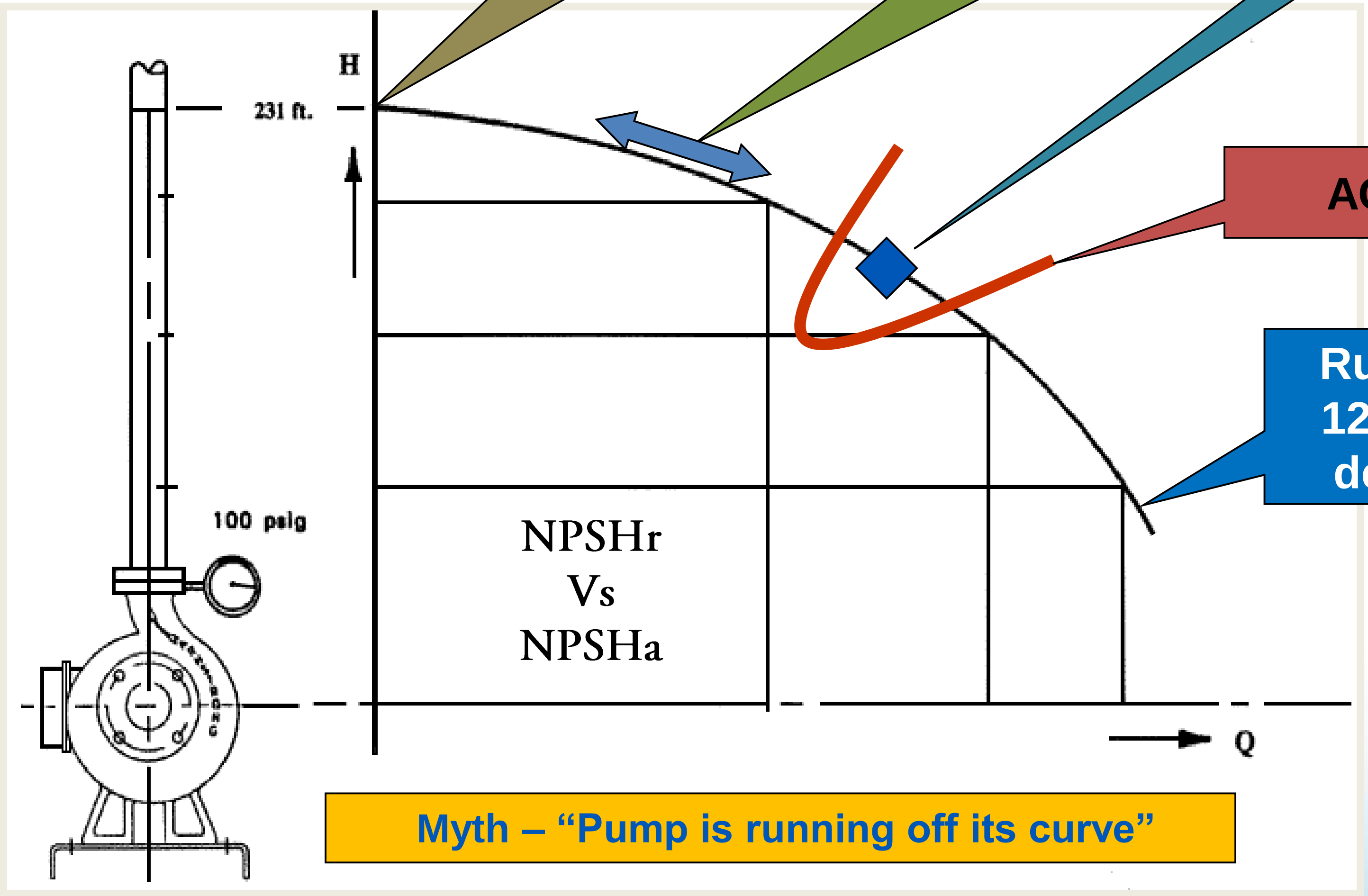
# The Pump Curve

# Reading a Pump Curve

**Five Important points you need to know**



Myth – "Pump is running off its curve"

# Specific Speed

# What is Specific Speed and Why is it important?

Specific speed is a term used to describe the geometry (shape) of a pump impeller. People responsible for the selection of the proper pump can use this Specific Speed information to:

- Select the shape of the pump curve.
- Determine the efficiency of the pump.
- Anticipate motor overloading problems.
- Predict N.P.S.H. requirements.
- Select the lowest cost pump for their application.

Specific speed is defined as "the speed of an ideal pump geometrically similar to the actual pump, which when running at this speed will raise a unit of volume, in a unit of time through a unit of head.

# Specific Speed

The performance of a centrifugal pump is expressed in terms of pump speed, total head, and required flow.

$$\text{Specific Speed (Ns)} = \frac{N\sqrt{Q}}{H^{.75}}$$

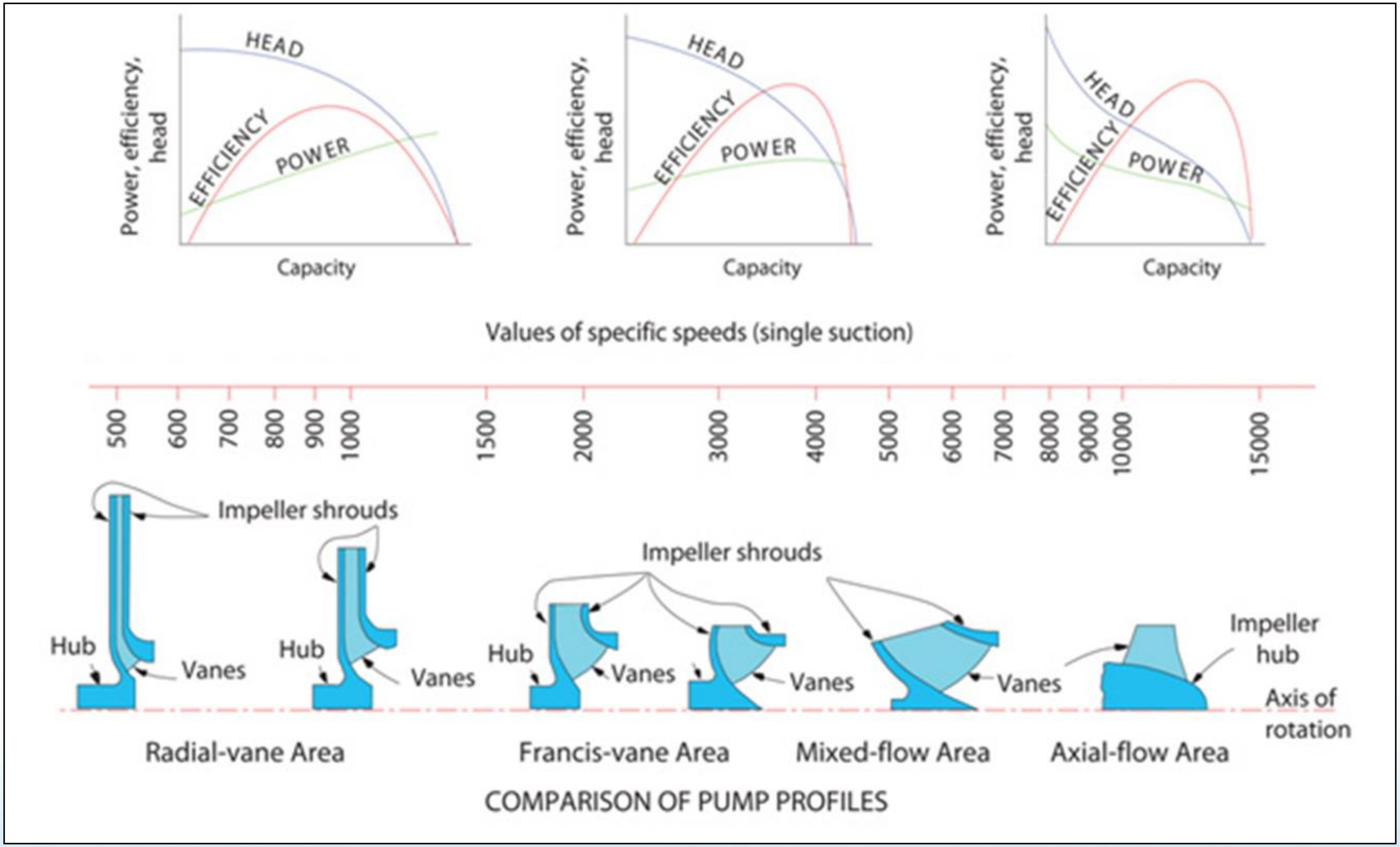
N = Revolutions per minute of pump
Q = Flow Gallon per minute
H = Total Dynamic Head in feet

**OR**

Specific Speed = RPM x GPM ^.5 / Head ^.75

RPM = Revolutions per minute
GPM = Gallon per minute
HEAD = Feet

# Specific speed values for the different pump designs



**N**et

**P**ositive

**S**uction

**H**ead

# Net Positive Suction Head (NPSH)

NPSH (Net Positive Suction Head) is the total suction head in feet of the liquid being pumped (at the centerline of the impeller eye) less the absolute vapor pressure of the liquid being pumped.

$$\mathrm{NPSHa} = h_a - h_{vpa} \pm h_{st} - h_{fs}$$

**Where:**

$\mathbf{h_a}$ = absolute pressure (in feet of liquid being pumped) on the surface of the liquid supply level (if open tank, barometric pressure); or the absolute pressure existing in a closed tank

$\mathbf{h_{vpa}}$ = the head in feet corresponding to the **vapor pressure of the liquid at the temperature being pumped**

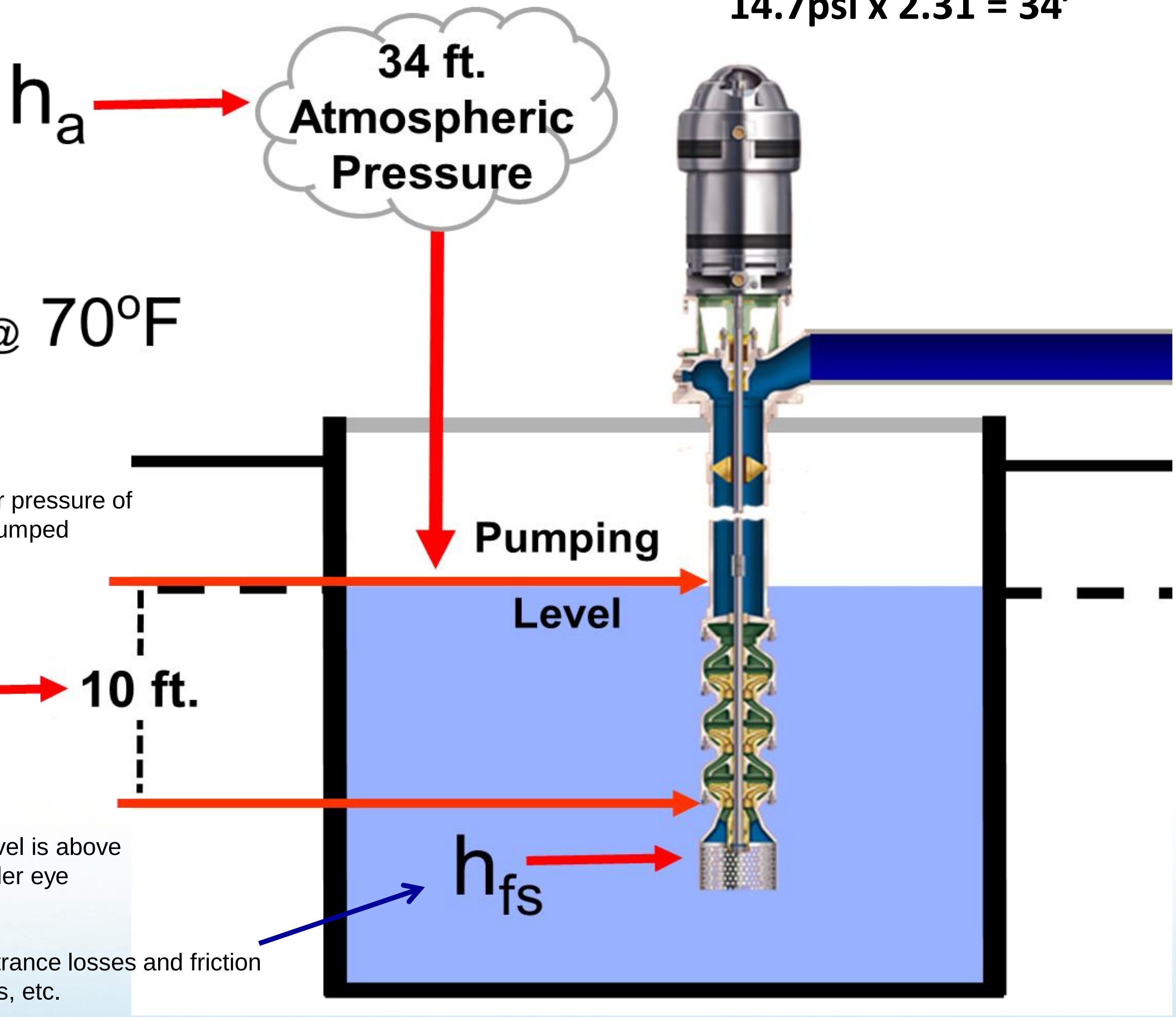
$\mathbf{h_{st}}$ = static height in feet that the liquid supply level is above or below the pump centerline or impeller eye

$\mathbf{h_{fs}}$ = all suction losses (in feet) including entrance losses and friction losses through pipe, valves, and fittings, etc.

# NPSH Calculation

absolute pressure (in feet of liquid being pumped) on the surface of the liquid supply level (if open tank, barometric pressure); or the absolute pressure existing in a closed tank → $h_a$

**14.7psi x 2.31 = 34’**



$h_{vpa}$ =.839’ @ 70°F

the head in feet corresponding to the vapor pressure of the liquid at the temperature being pumped

$h_{st}$ → 10 ft.

static height in feet that the liquid supply level is above or below the pump centerline or impeller eye

all suction losses (in feet) including entrance losses and friction losses through pipe, valves, and fittings, etc.

# Cavitation

If the pressure of water drops below its vapor pressure, vapor pockets will form.

When the pressure of the water is later increased above its vapor pressure, the vapor pockets will collapse. The pressure of this implosion can be 100,000 PSI!!!

The collapse of these vapor pockets is known as ***cavitation***.

# Cavitation

Cavitation means that cavities or bubbles are forming in the liquid that is being pumped. These cavities form at the low pressure or suction side of the pump, causing several things to happen all at once:

The cavities or bubbles will collapse when they pass into the higher regions of pressure, causing noise (audible cavitation), vibration, and damage to many of the components.

- Loss in capacity
- The pump can no longer build the same head (pressure)
- The pump's efficiency drops

The cavities form for five basic reasons and it's common practice to lump all of them into the general classification of cavitation.

You must understand why they occur and how to fix them. Here they are in no particular order :

- **Vaporization** (pressure too low / temperature too high)
- **Air ingestion** (Not really cavitation, but has similar symptoms)
- **Internal recirculation**
- **Flow turbulence**
- **The Vane Passing Syndrome** - OD of the impeller passes too close to the pump cutwater. The velocity of the liquid increases as it flows through this small passage, lowering the fluid pressure and causing local vaporization.

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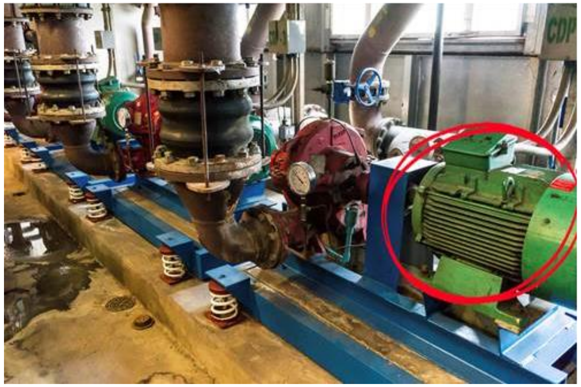
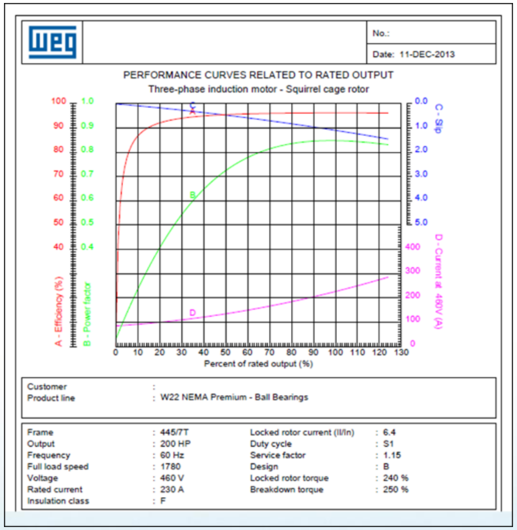
# System Optimization and Improvement Opportunities

# Motor / Pump



**Electric motors maintain high efficiency**
**Over a wide range**
**35% load to 120% load**



No.:
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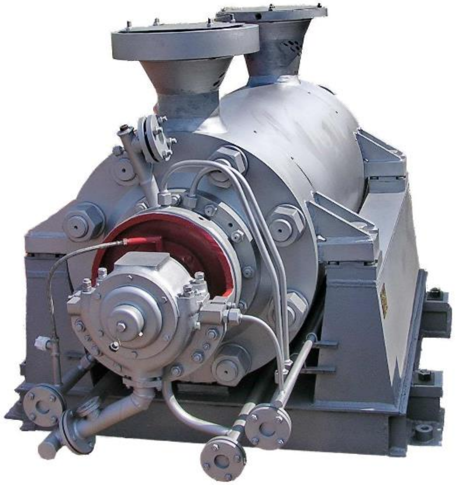
PERFORMANCE CURVES RELATED TO RATED OUTPUT
Three-phase induction motor - Squirrel cage rotor

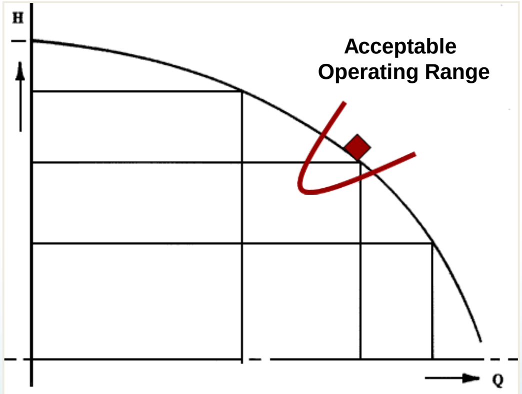
Customer :
Product line : W22 NEMA Premium - Ball Bearings

Frame : 445/7T
Output : 200 HP
Frequency : 60 Hz
Full load speed : 1780
Voltage : 460 V
Rated current : 230 A
Insulation class : F

Locked rotor current (Il/In) : 6.4
Duty cycle : S1
Service factor : 1.15
Design : B
Locked rotor torque : 240 %
Breakdown torque : 250 %



**Centrifugal pumps have a very narrow operating range**
**+20% - 10%**



**The motor and pump react to system requirements and therefore operate based on system resistance.**
**The pump reliability and performance is highly influenced by the system**

# Use a Systems Approach to Manage Pumping System Operation

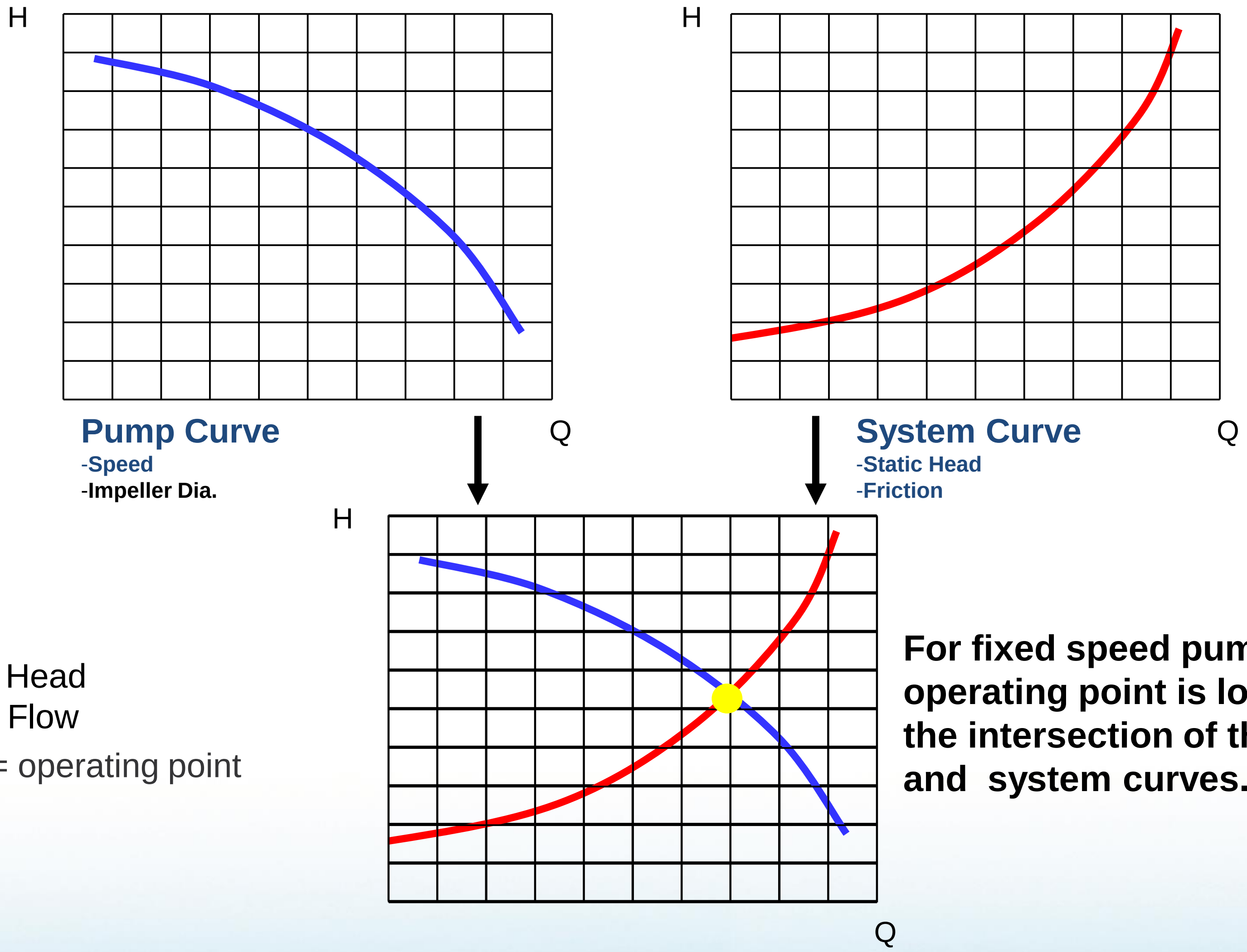
- Focusing solely on individual components overlooks potential cost-savings
- Component failures are often caused by system problems **(How do you identify these problems?)**
- Use a life cycle cost approach in designing systems and evaluating repair and maintenance options
- Remember the energy bill discussion

# System Curve

# What Is a System Curve?

- A system curve represents the sum of the static head and the friction loss due to flow of fluid through a system.
- The pumping system will operate where the pump and system curves intersect

# Basic Curves



**Pump Curve**
-Speed
-Impeller Dia.

**System Curve**
-Static Head
-Friction

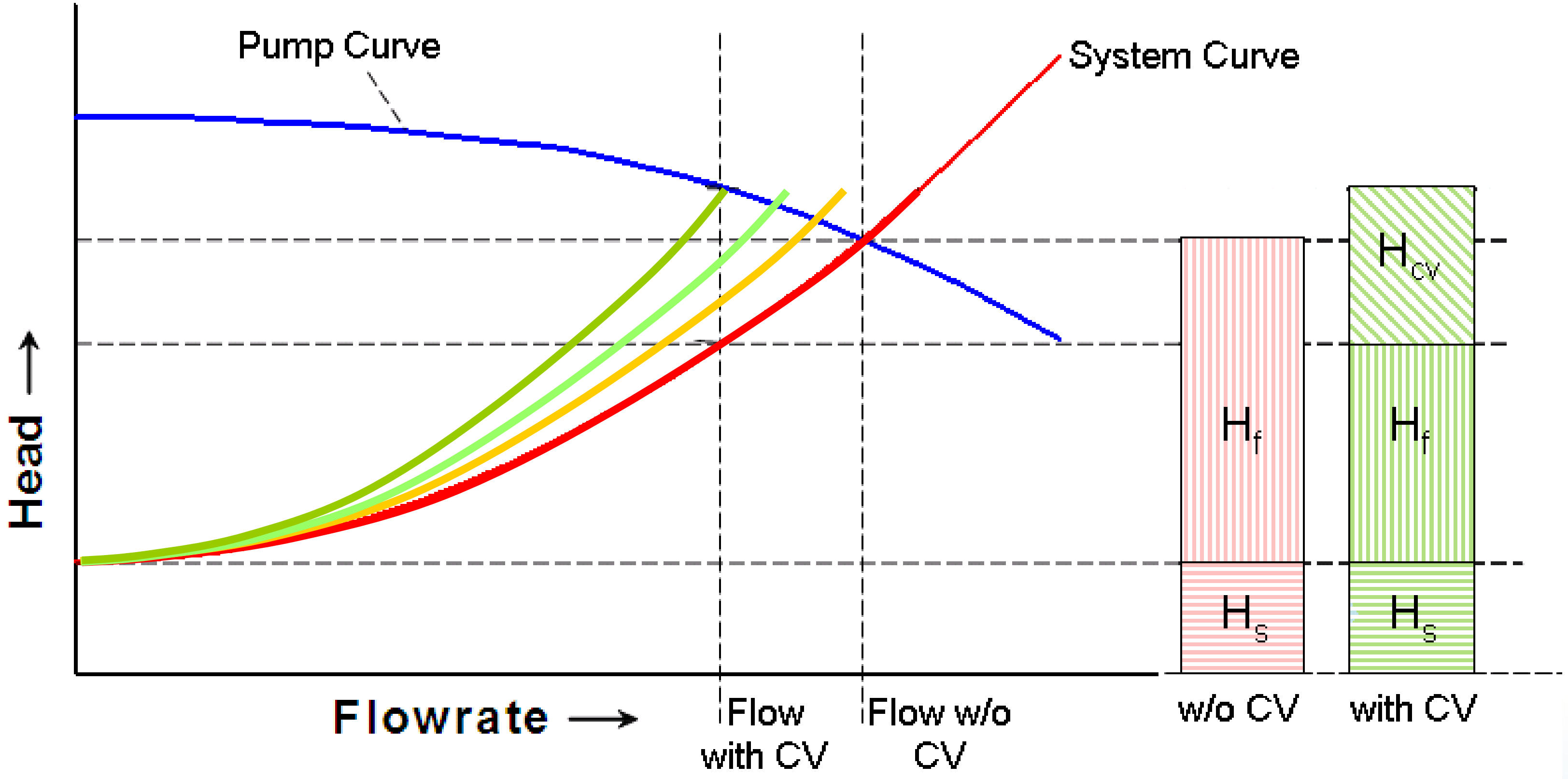
H = Head
Q = Flow
● = operating point

**For fixed speed pumps, the operating point is located at the intersection of the pump and system curves.**

# Friction in Pump Systems

- Friction occurs in pump systems due to **irrecoverable** hydraulic losses in:
  - Piping
  - Valving
  - Fittings (e.g., elbows, tees)
  - Equipment (e.g., heat exchangers)
- Friction is also used to control flow or pressure, **recoverable hydraulic losses**
  - Automated flow and pressure control valves
  - Orifices
  - Manual throttling valves

# Effect of Control Valves



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# Pump Affinity Laws

# The Affinity Laws

The Affinity Laws are mathematical expressions that define changes in pump capacity, head, and BHP when a change is made to pump speed, impeller diameter, or both. According to *Affinity Laws*:

- Capacity, Q changes in direct proportion to impeller diameter D ratio, or to speed N ratio:

$$Q_2 = Q_1 \times [D_2/D_1]$$
$$Q_2 = Q_1 \times [N_2/N_1]$$

- Head, H changes in direct proportion to the square of impeller diameter D ratio, or the square of speed N ratio:

$$H_2 = H_1 \times [D_2/D_1]^2$$
$$H_2 = H_1 \times [N_2/N_1]^2$$

- BHP changes in direct proportion to the cube of impeller diameter ratio, or the cube of speed ratio:

$$BHP_2 = BHP_1 \times [D_2/D_1]^3$$
$$BHP_2 = BHP_1 \times [N_2/N_1]^3$$

Where the subscript: 1 refers to initial condition, 2 refer to new condition
If changes are made to both impeller diameter and pump speed the equations can be combined to:

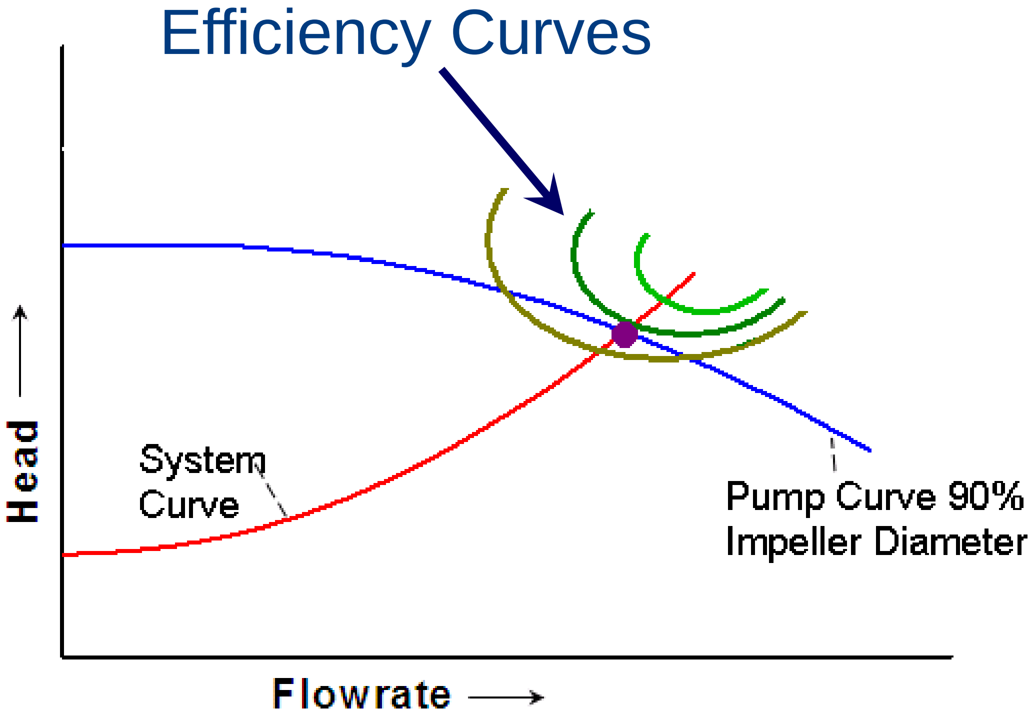
$$Q_2 = Q_1 \times [(D_2 x N_2)/(D_1 x N_1)]$$
$$H_2 = H_1 \times [(D_2 x N_2)/(D_1 x N_1)]^2$$
$$BHP_2 = BHP_1 \times [(D_2 x N_2)/(D_1 x N_1)]^3$$

This equation is used to hand-calculate the impeller trim diameter from a given pump performance curve at a bigger diameter.

**The Affinity Laws are valid only under conditions of constant Load.**

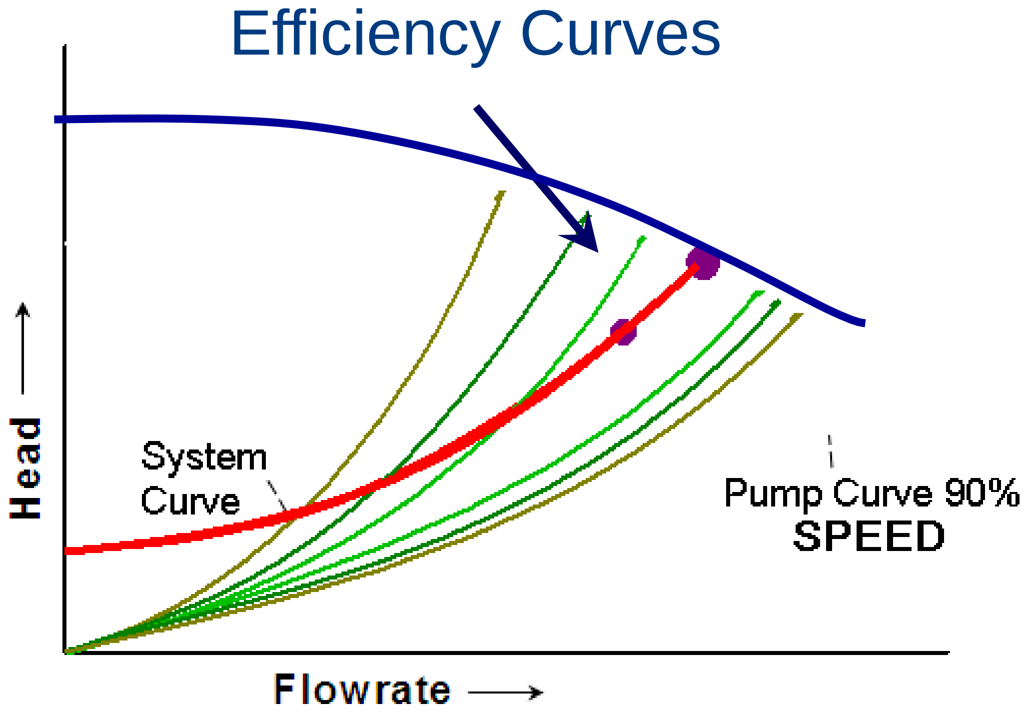
# Impeller Size Changes

- Using the affinity rules the pump head curve can be adjusted for a different diameter impeller



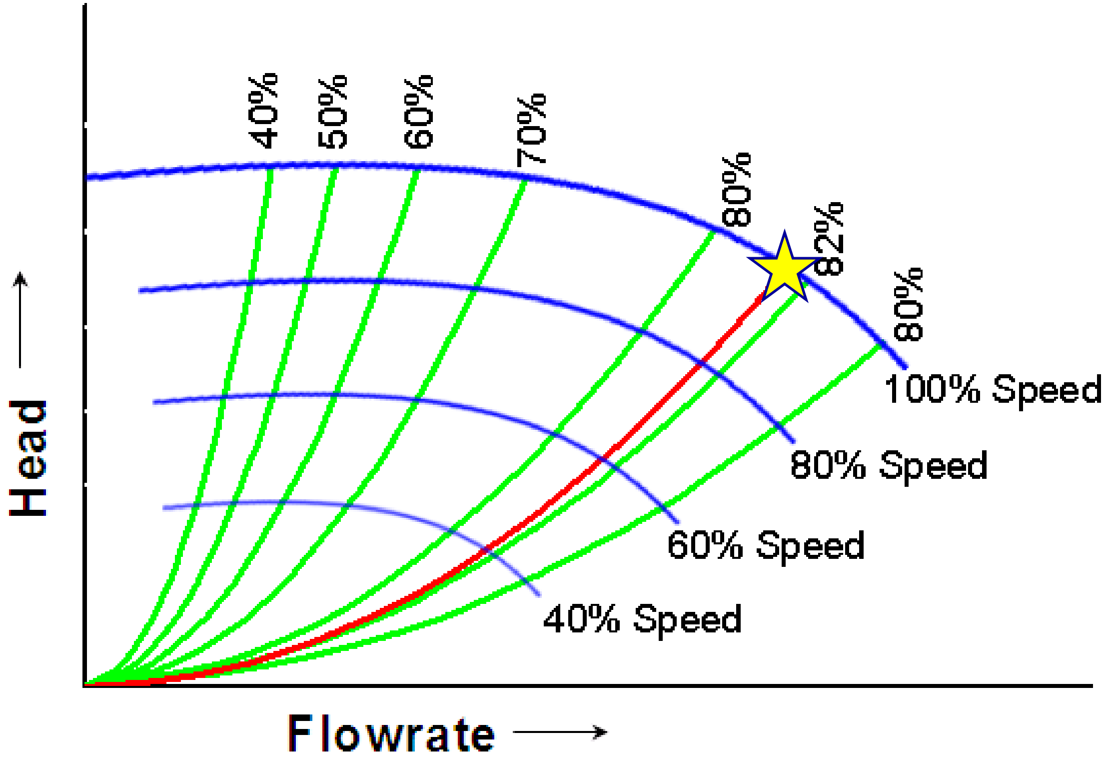
# Pump Speed Changes

- Using the affinity rules the pump head curve can be adjusted for a different SPEEDS.



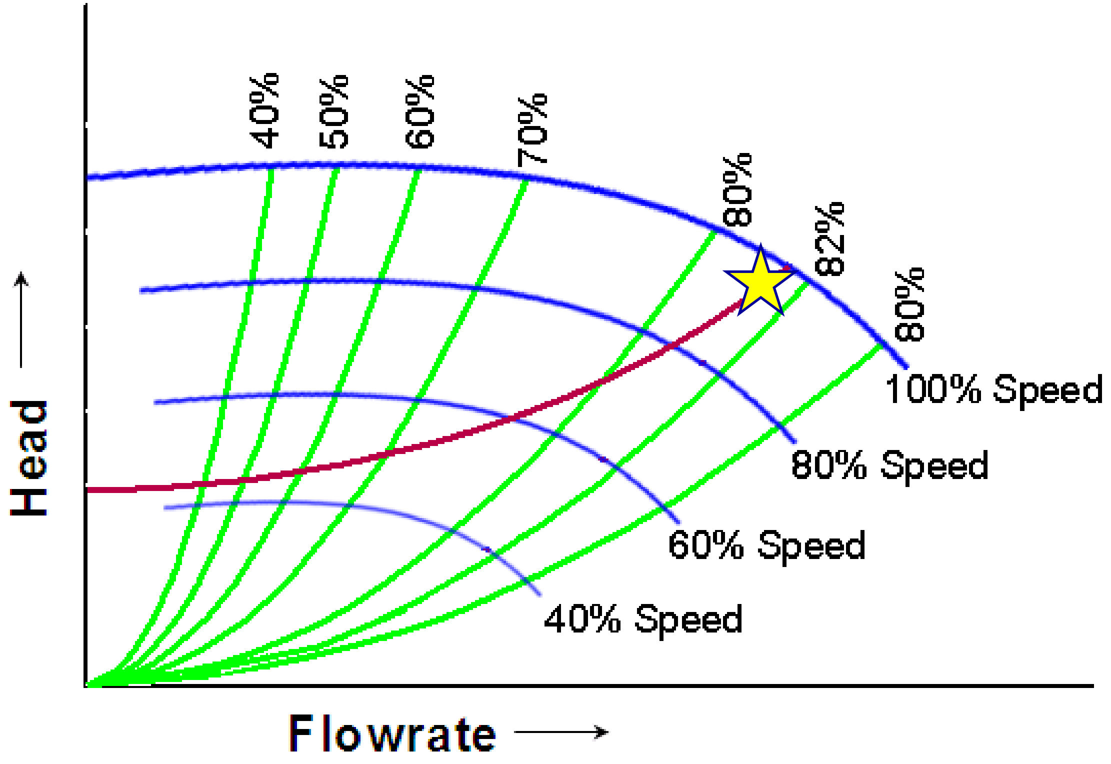
# Pump Speed Changes

## Friction-Dominated Systems



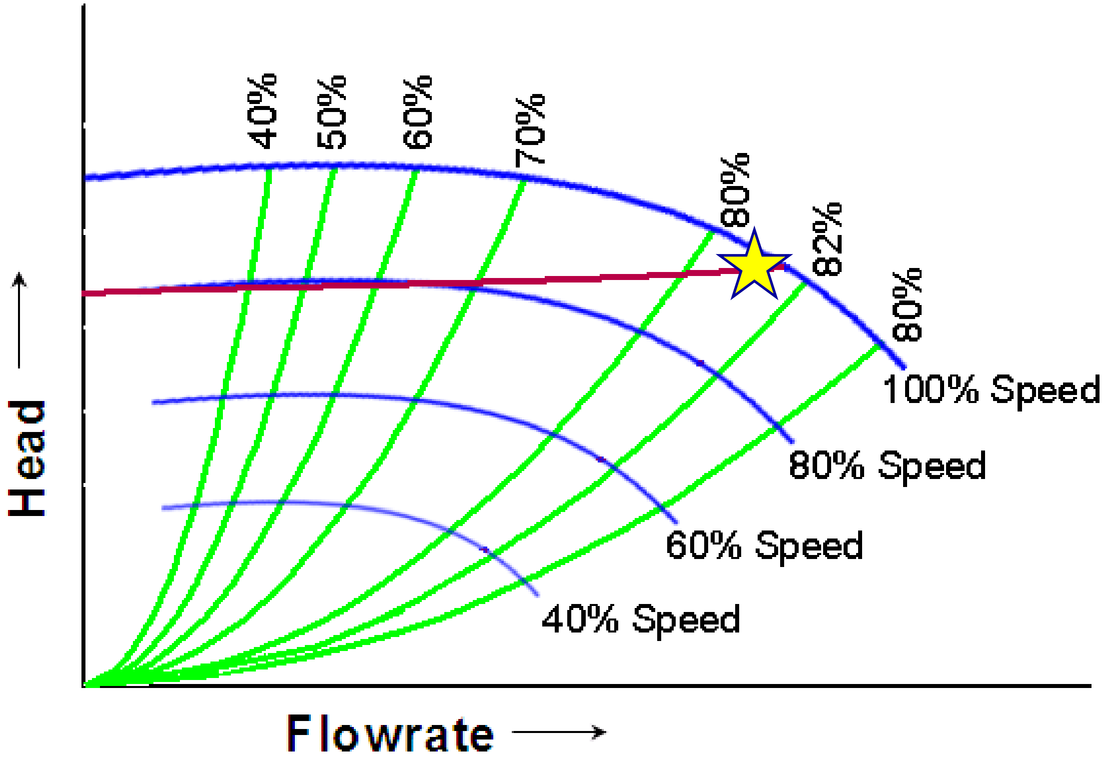
# Pump Speed Changes

## Mixed Friction-Static Systems



# Pump Speed Changes

## Static-Dominated Systems



# Key Points

- Getting the pump performance curve from the manufacturer is important
- You need to understand system curves and pump curves to know how a pumping system is operating
- Pump/system curves help demonstrate pumping system behavior in a graphical manner
- Pump/system curves help identify the impacts of pump and/or system modifications

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# Screening Pumping Systems