ENERGY EFFICIENCY ON PUMP SYSTEMS

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Pumps and Pumping System

2.1 Introduction

2.2 Type of pumps

2.3 Assessment of pumps

2.4 Energy efficiency opportunities

Introduction

- **20% of world's electrical energy demand**
- **25-50% of energy usage in some industries**
- **Used for**
  - **Domestic, commercial, industrial and agricultural services**
  - **Municipal water and wastewater services**

Objective of Pumping System

- **Transfer liquid from source to destination**
- **Circulate liquid around a system**

What Are Pumping Systems

- Main pump components
  - Pumps
  - Prime movers: electric motors, diesel engines, air system
  - Piping to carry fluid
  - Valves to control flow in system
  - Other fittings, control, instrumentation
- End-use equipment
  - Heat exchangers, tanks, hydraulic machines

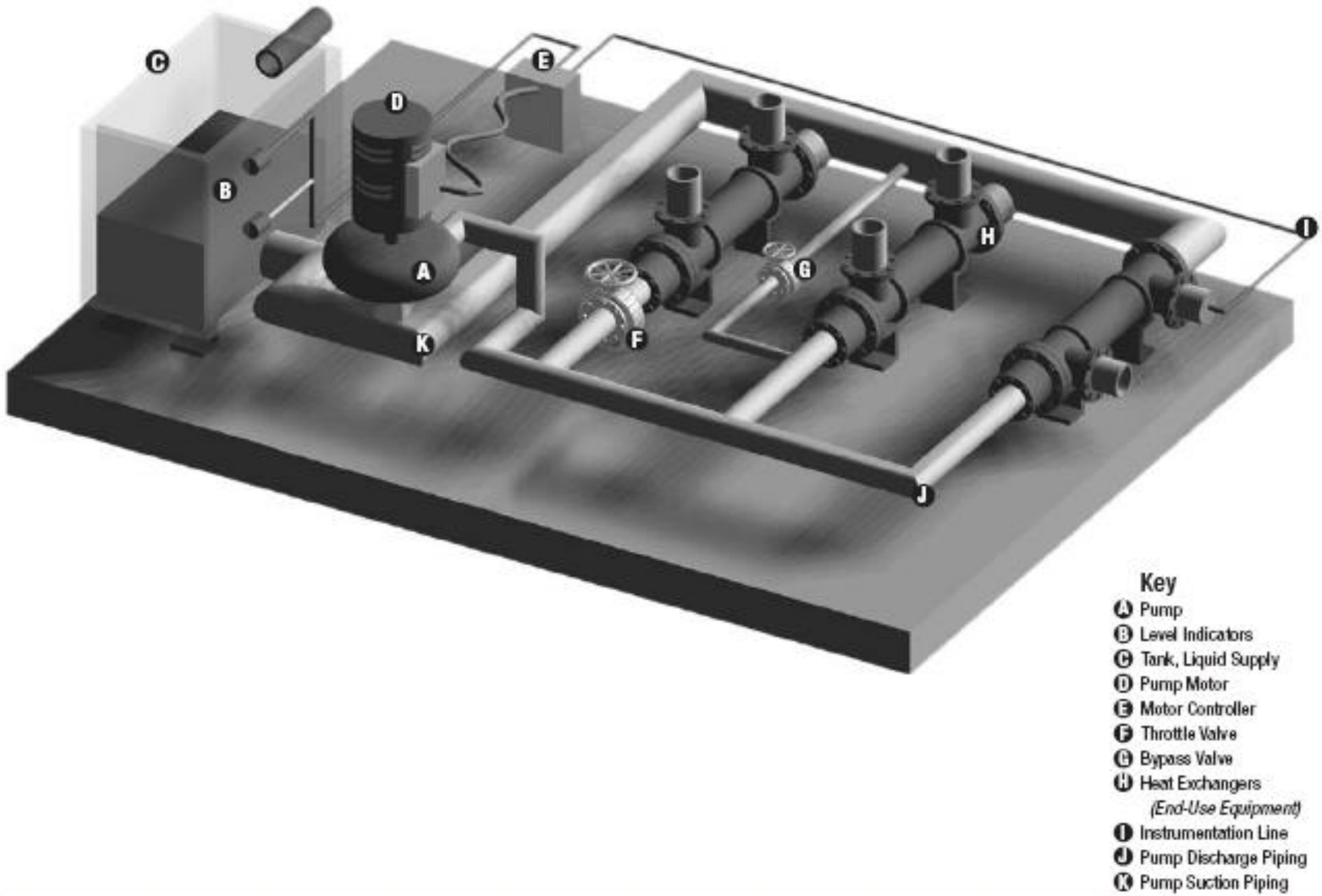
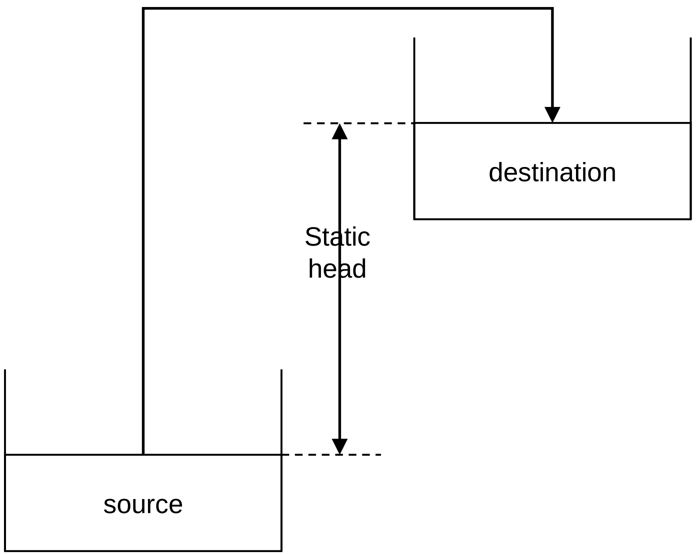
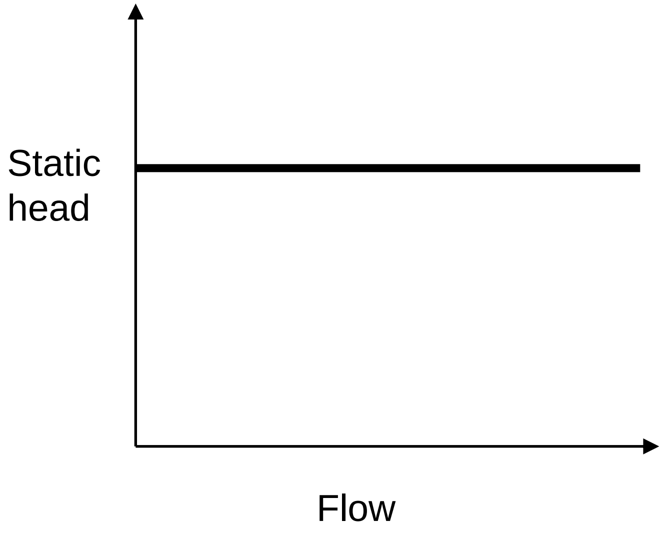


Figure 1. Typical Pumping System Components

Pumping Head

- **Head**
  - **Resistance of the system**
  - **Two types: static and friction**
- **Static head**
  - **Difference in height between source and destination**
  - **Independent of flow**





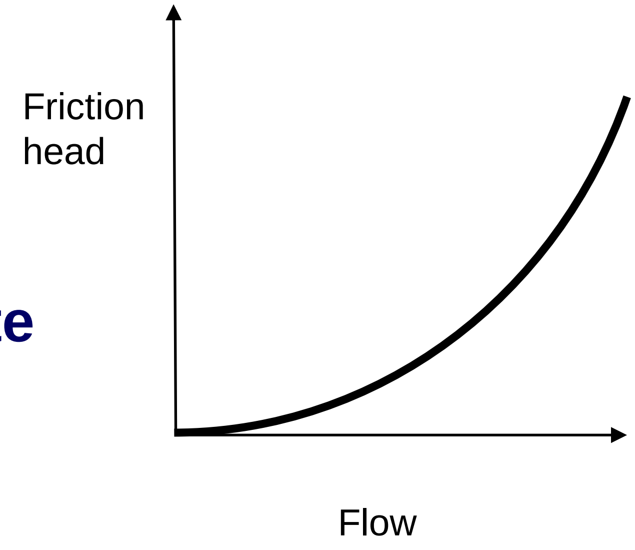
Pumping System Characteristics

- Static head consists of
  - Static suction head (hS): lifting liquid relative to pump center line
  - Static discharge head (hD) vertical distance between centerline and liquid surface in destination tank
- Static head at certain pressure

$$\text{Head (in feet)} = \frac{\text{Pressure (psi)} \times 2.31}{\text{Specific gravity}}$$

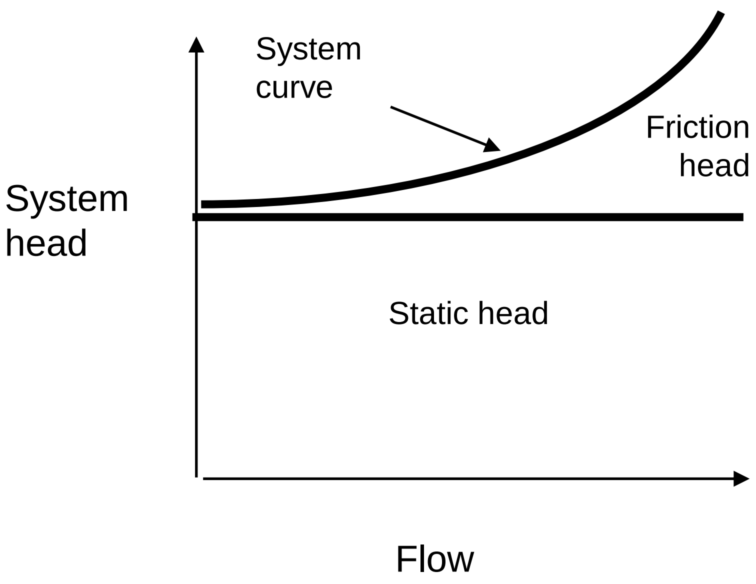
Friction Head

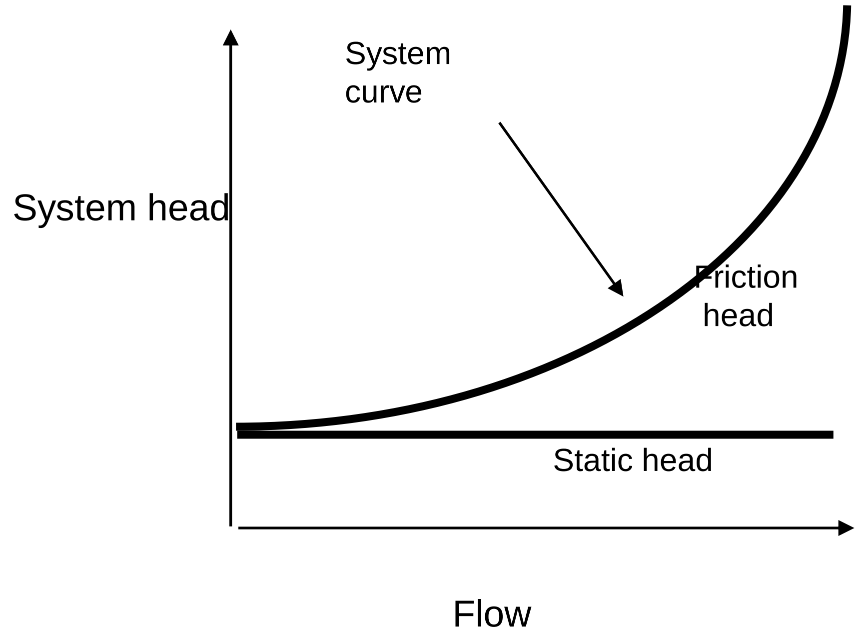
- **Resistance to flow in pipe and fittings**
- **Depends on size, pipes, pipe fittings, flow rate, nature of liquid**
- **Proportional to square of flow rate**
- **Closed loop system only has friction head (no static head)**



In most cases:

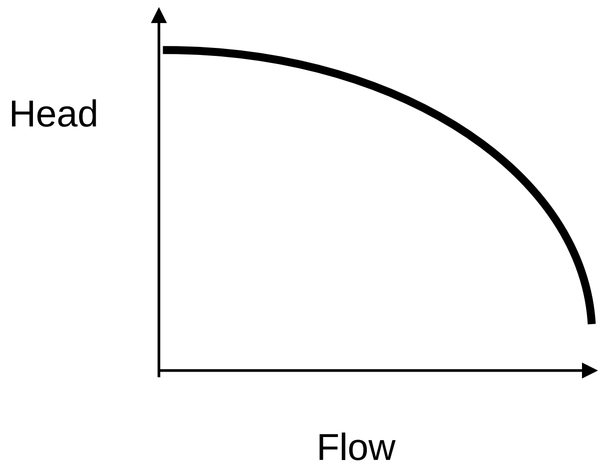
Total head = Static head + friction head





Pump Performance Curve

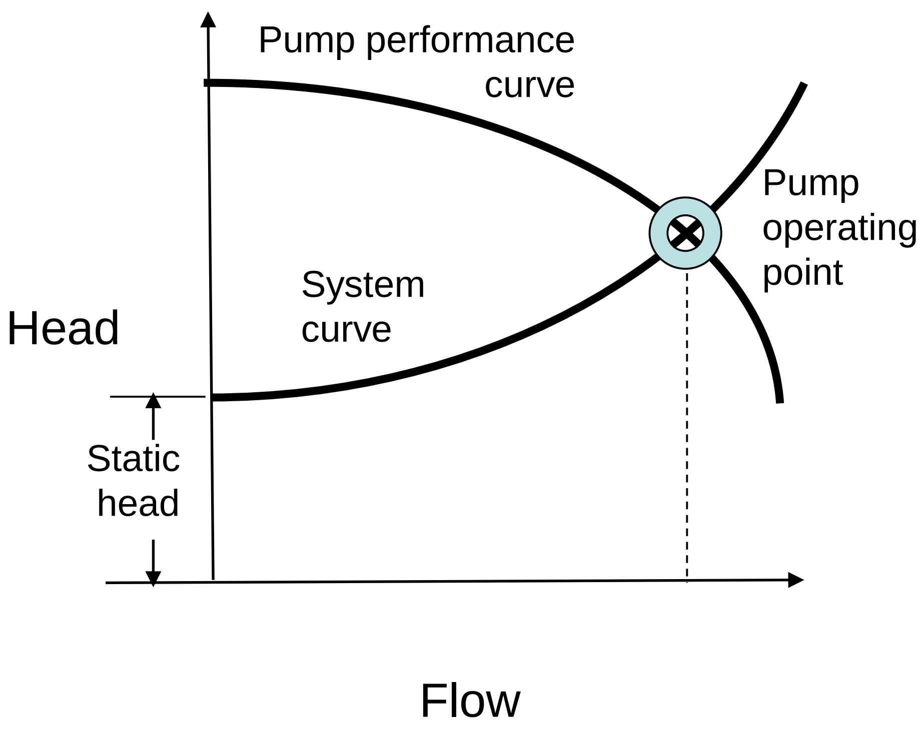
- **Relationship between head and flow**
  - **Flow increase**
  - **System resistance increases**
  - **Head increases**
  - **Flow decreases to zero**
- **Zero flow rate: risk of pump burnout**



Performance curve for centrifugal pump

Pump Operating Point

- **Duty point: rate of flow at certain head**
- **Pump operating point: intersection of pump curve and system curve**



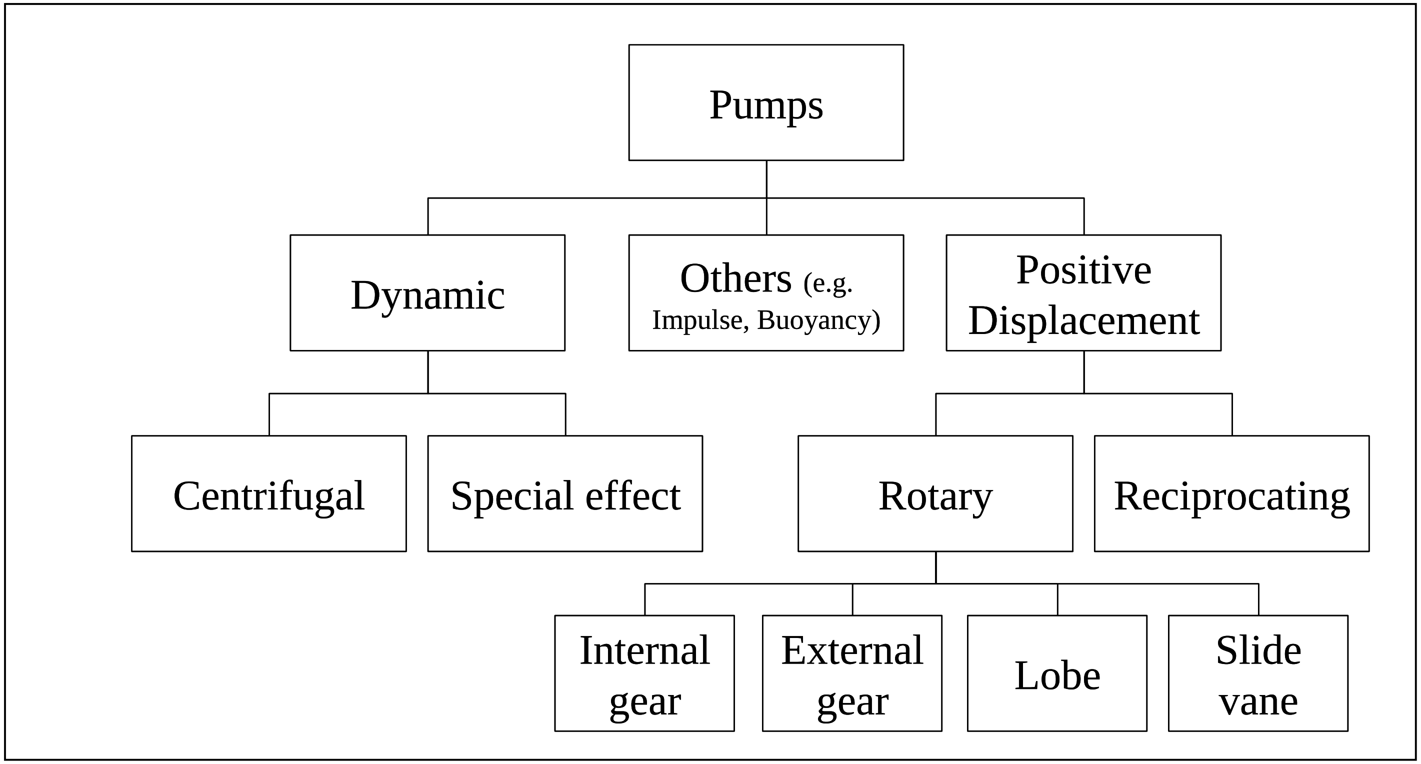
Pump Suction Performance (NPSH)

- Cavitation or vaporization: bubbles inside pump
- If vapor bubbles collapse
  - Erosion of vane surfaces
  - Increased noise and vibration
  - Choking of impeller passages
- Net Positive Suction Head
  - NPSH Available: how much pump suction exceeds liquid vapor pressure
  - NPSH Required: pump suction needed to avoid cavitation

Type of Pumps

Pump Classification

Classified by operating principle



Positive Displacement Pumps

- For each pump revolution
  - Fixed amount of liquid taken from one end
  - Positively discharged at other end
- If pipe blocked
  - Pressure rises
  - Can damage pump
- Used for pumping fluids other than water

Positive Displacement Pumps

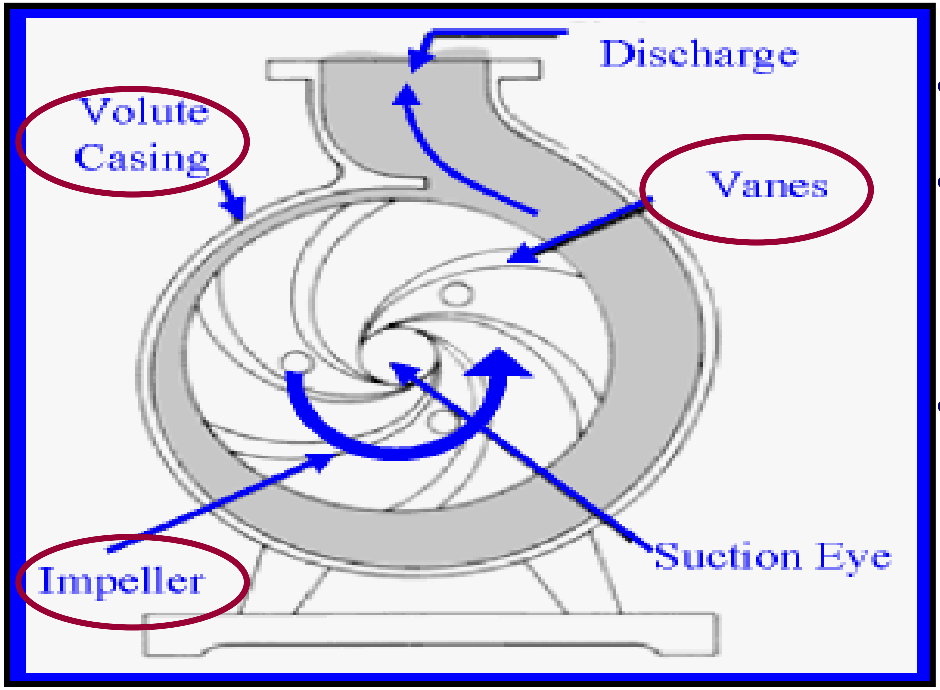
- **Reciprocating pump**
  - **Displacement by reciprocation of piston plunger**
  - **Used only for viscous fluids and oil wells**
- **Rotary pump**
  - **Displacement by rotary action of gear, cam or vanes**
  - **Several sub-types**
  - **Used for special services in industry**

Dynamic Pumps

- **Mode of operation**
  - **Rotating impeller converts kinetic energy into pressure or velocity to pump the fluid**
- **Two types**
  - **Centrifugal pumps: pumping water in industry – 75% of pumps installed**
  - **Special effect pumps: specialized conditions**

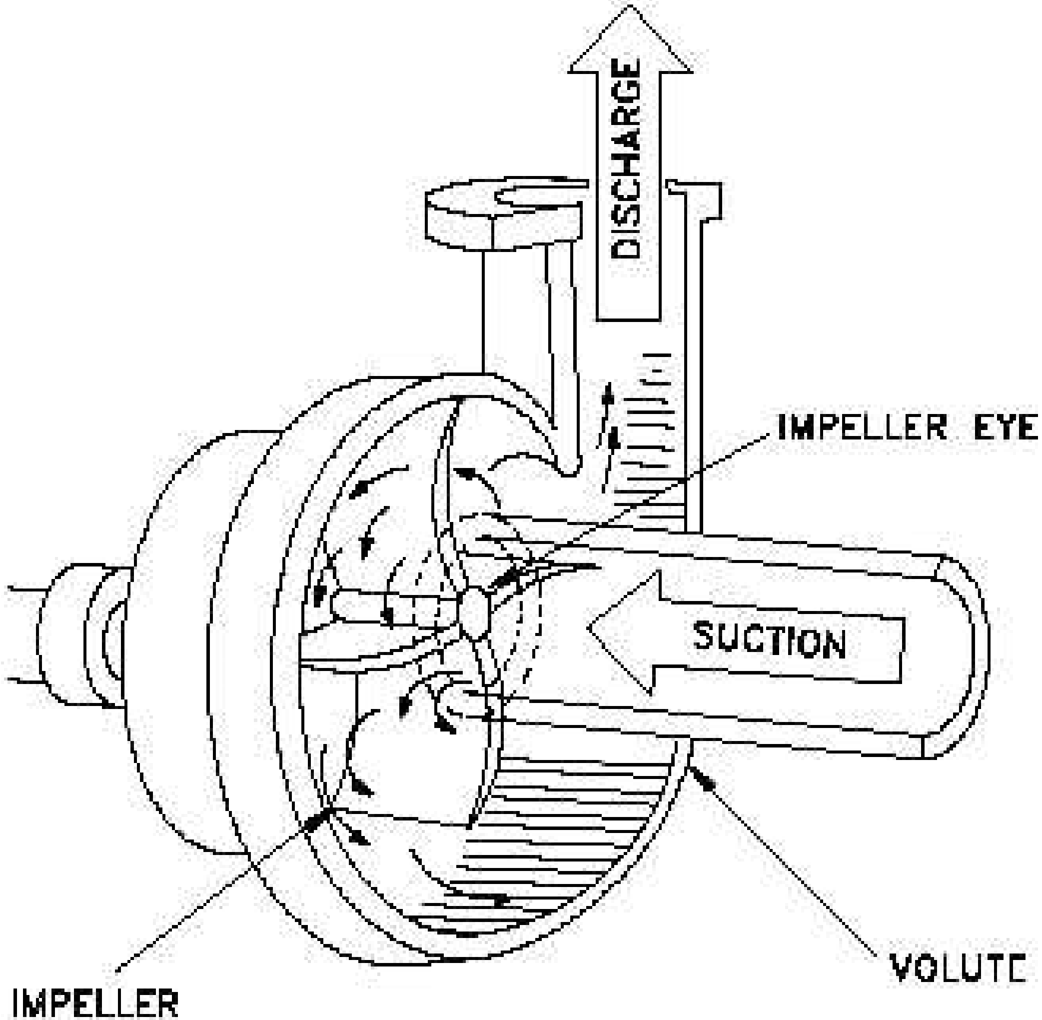
Centrifugal Pumps

How do they work?



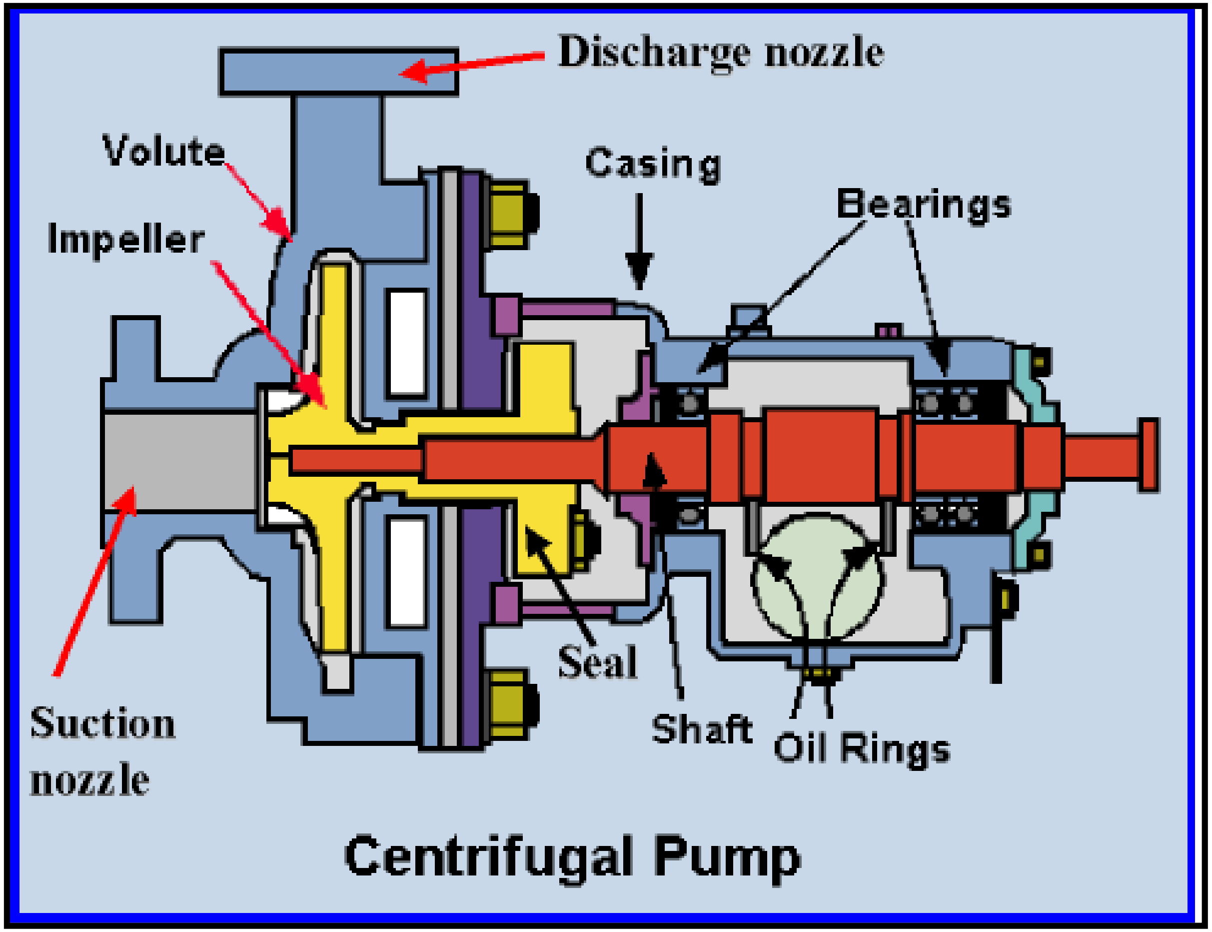
- Liquid forced into impeller
- Vanes pass kinetic energy to liquid: liquid rotates and leaves impeller
- Volute casing converts kinetic energy into pressure energy

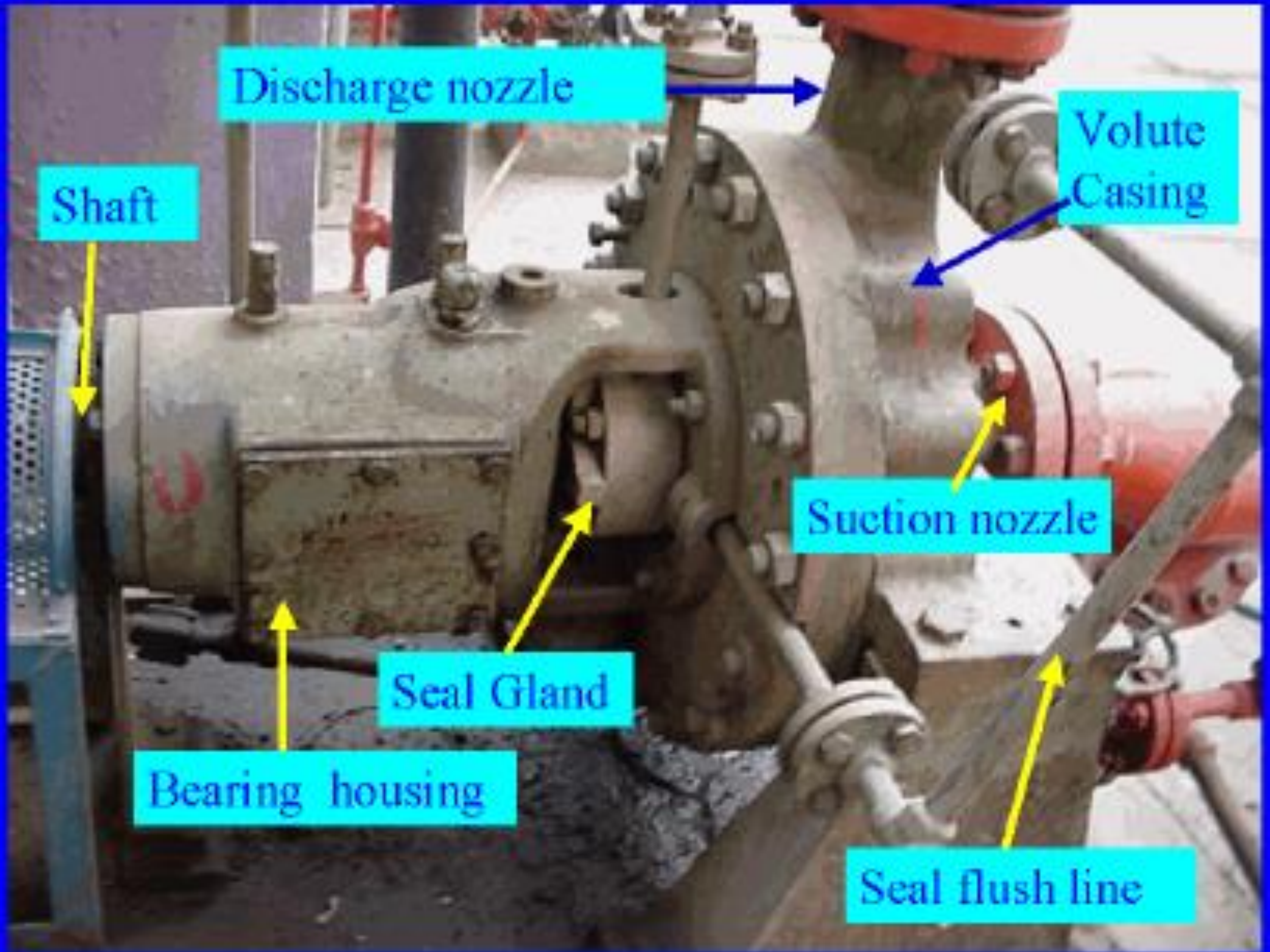
CENTRIFUGAL PUMP



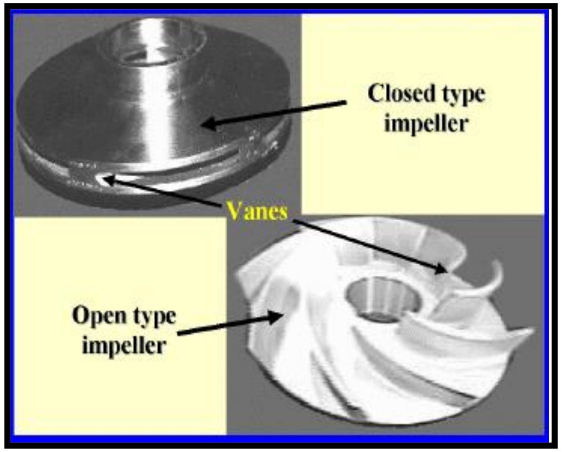
Centrifugal Pumps

Rotating and stationary components




Discharge nozzle
Volute
Casing
Shaft
Suction nozzle
Seal Gland
Bearing housing
Seal flush line

Centrifugal Pumps



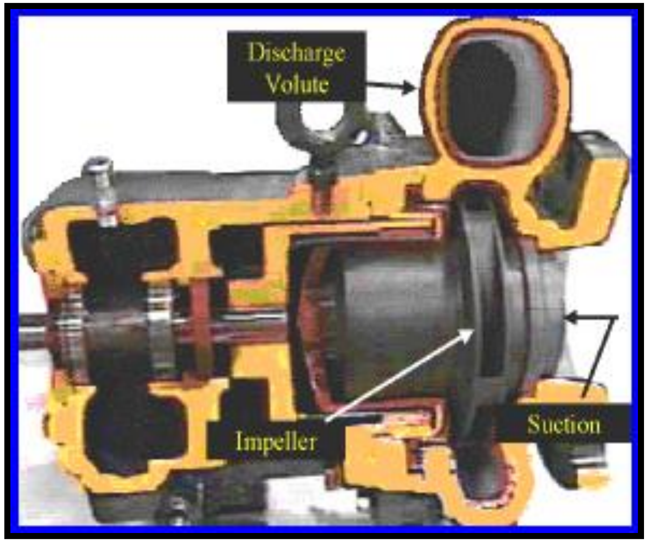
Impeller

- **Main rotating part that provides centrifugal acceleration to the fluid**
- **Number of impellers = number of pump stages**
- **Impeller classification: direction of flow, suction type and shape/mechanical construction**

Shaft

- **Transfers torque from motor to impeller during pump start up and operation**

Centrifugal Pumps



Casings

- **Functions**
  - **Enclose impeller as “pressure vessel”**
  - **Support and bearing for shaft and impeller**
- **Volute case**
  - **Impellers inside casings**
  - **Balances hydraulic pressure on pump shaft**
- **Circular casing**
  - **Vanes surrounds impeller**
  - **Used for multi-stage pumps**

PUMP CALCULATIONS

$$\text{Pump Efficiency} = \frac{\text{Hydrolic power, } P_h \times 100}{\text{Power input to the pump shaft}}$$

Where,

Hydraulic power P_h(kW) = Q(m^3/s) x Total head,(h_d-h_s)(m) x p(kg/m^3)xg(m/s^2)/1000

Q=Volume flow rate, p=density of the fluid, g=acceleration due to gravity

h_d = Delivery head, h_s = Suctionhead

POWER CALCULATIONS

Assume that we need to pump 68 m3/hr to a 47 meter head with a pump that is 60% efficient at that point, motor efficiency 90%.

Calculate motor power.

Liquid Power = 68 * 47 *1000*9.81/ 3600*1000

= 8.7 kW

Shaft Power = 8.7 / 0.60 = 14.5 kW

Motor Power = 14.5 / 0.9 = 16.1 kW

Pump Efficiency Example

Illustration of calculation method outlined

A chemical plant operates a cooling water pump for process cooling and refrigeration applications. During the performance testing the following operating parameters were measured;

Measured Data

Pump flow, Q	0.40 m^3/ s
Power absorbed, P	325 kW
Suction head (Tower basin level), h_1	+1 M
Delivery head, h_2	55 M
Height of cooling tower	5 M
Motor efficiency	88 %
Type of drive	Direct coupled
Density of water	996 kg/ m^3

Pump Efficiency Example

Flow delivered by the pump : 0.40 m^3/s
Total head, h2 -(+h1) : 54 M
Hydraulic power : 0.40 x 54 x 996 x 9.81/1000 = 211 kW
Actual power consumption : 325 kW
Overall system efficiency : (211 x 100) / 325 = 65 %
Pump efficiency : 65/0.88 = 74 %

Assessment of Pumps

How to Calculate Pump Performance

- **Pump shaft power (Ps) is actual horsepower delivered to the pump shaft**

Pump shaft power (Ps):
Ps = Hydraulic power Hp / pump efficiency ηPump

Pump Efficiency (ηPump):
ηPump = Hydraulic Power / Pump Shaft Power

- **Pump output/Hydraulic/Water horsepower (Hp) is the liquid horsepower delivered by the pump**

Hydraulic power (Hp):
Hp = Q (m3/s) x Total head, hd - hs (m) x ρ (kg/m3) x g (m/s2) / 1000

hd - discharge head
hs – suction head,
ρ - density of the fluid
g – acceleration due to gravity

Difficulties in Pump Assessment

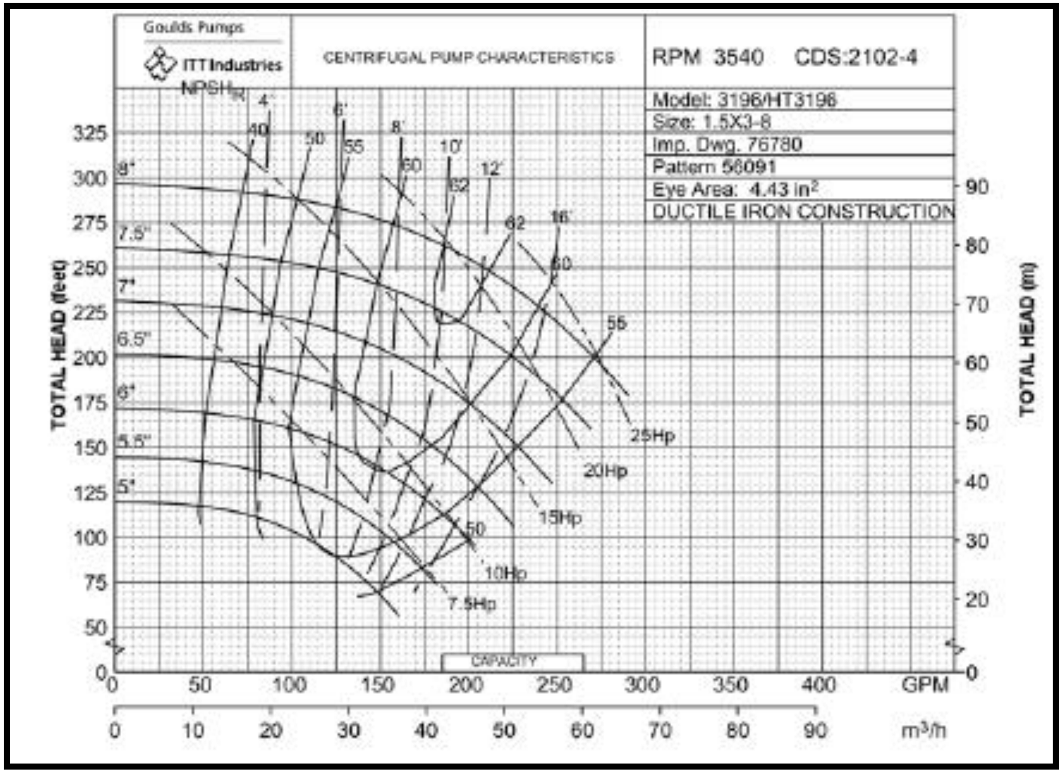
- **Absence of pump specification data to assess pump performance**
- **Difficulties in flow measurement and flows are often estimated**
- **Improper calibration of pressure gauges & measuring instruments**
  - **Calibration not always carried out**
  - **Correction factors used**

Energy Efficiency Opportunities

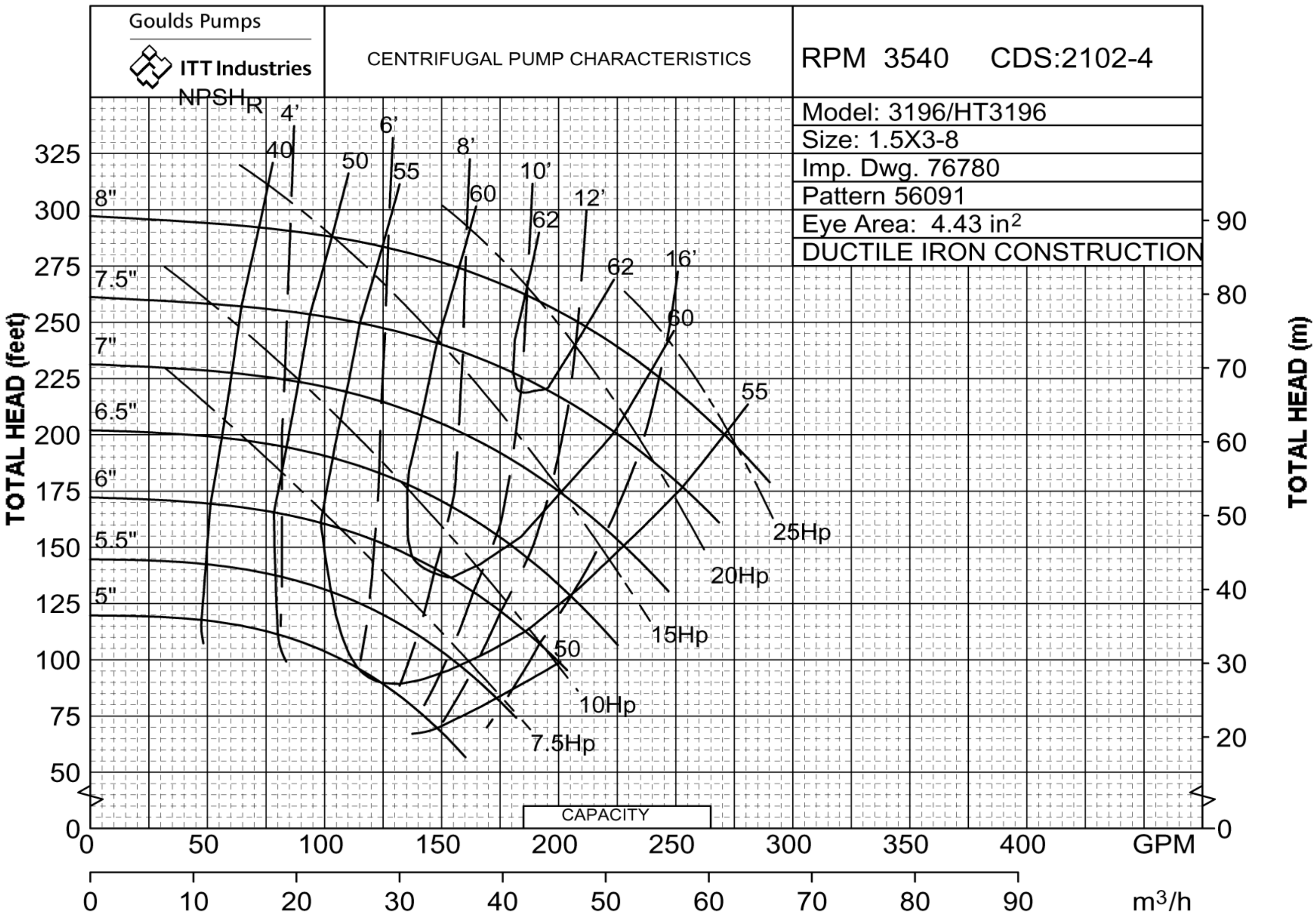
1. Selecting the right pump
2. Controlling the flow rate by speed variation
3. Pumps in parallel to meet varying demand
4. Eliminating flow control valve
5. Eliminating by-pass control
6. Start/stop control of pump
7. Impeller trimming

1. Selecting the Right Pump

Pump performance curve for centrifugal pump



TYPICAL PUMP CHARACTERISTIC CURVES



- **Oversized pump**
  - **Requires flow control (throttle valve or by-pass line)**
  - **Provides additional head**
  - **System curve shifts to left**
  - **Pump efficiency is reduced**
- **Solutions if pump already purchased**
  - **VSDs or two-speed drives**
  - **Lower RPM**
  - **Smaller or trimmed impeller**

2. Controlling Flow: speed variation

Explaining the effect of speed

- **Affinity laws: relation speed N and**
  - **Flow rate Q α N**
  - **Head H α N^2**
  - **Power P α N^3**
- **Small speed reduction (e.g. ½) = large power reduction (e.g. 1/8)**

2. Controlling Flow: speed variation

Variable Speed Drives (VSD)

- **Speed adjustment over continuous range**
- **Power consumption also reduced!**
- **Two types**
  - **Mechanical: hydraulic clutches, fluid couplings, adjustable belts and pulleys**
  - **Electrical: eddy current clutches, wound-rotor motor controllers, Variable Frequency Drives (VFDs)**

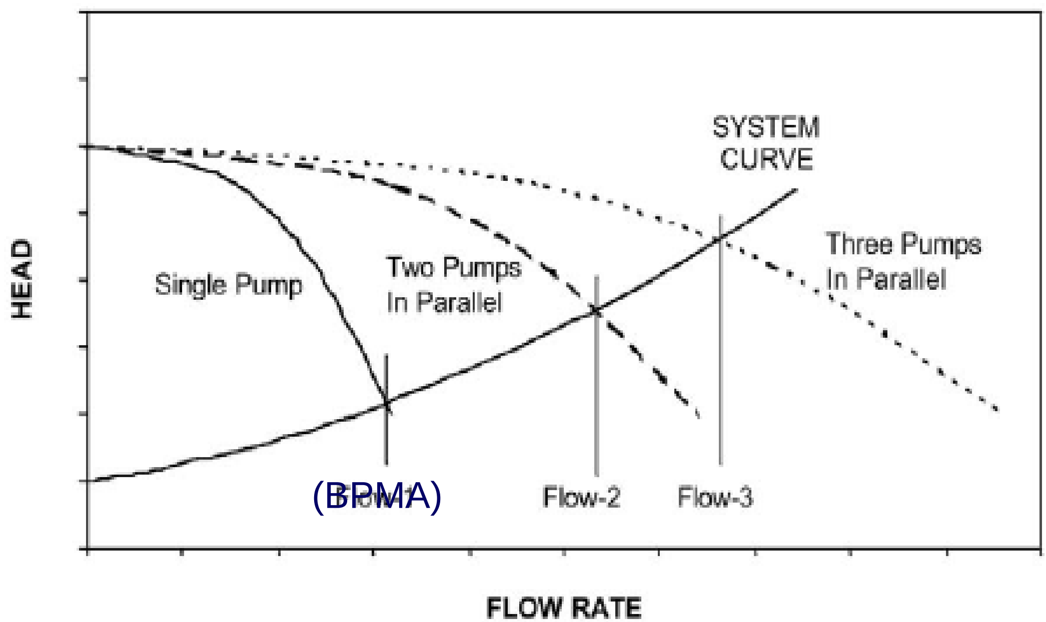
2. Controlling Flow: speed variation

Benefits of VSDs

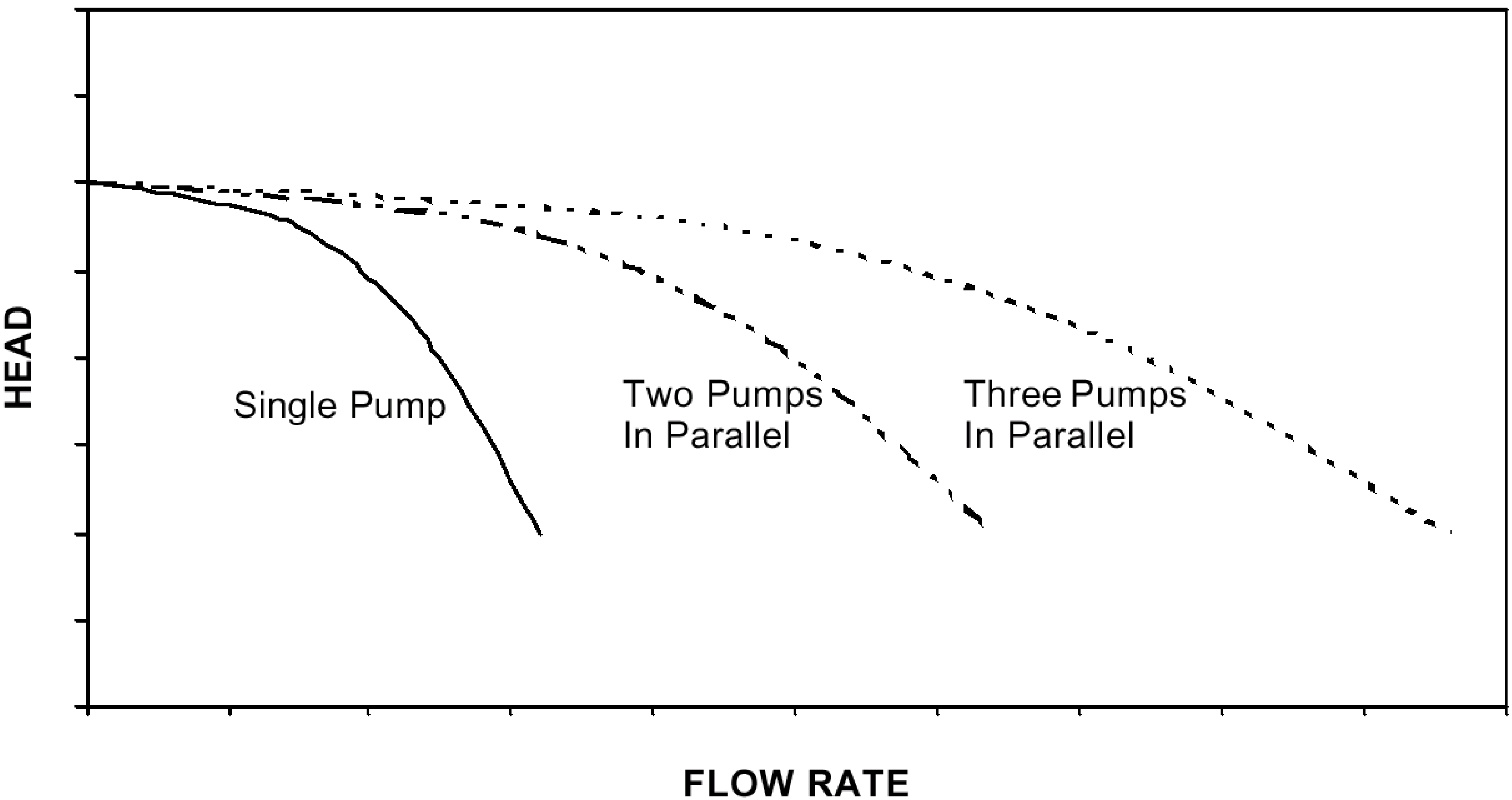
- **Energy savings** ***(not just reduced flow!)***
- **Improved process control**
- **Improved system reliability**
- **Reduced capital and maintenance costs**
- **Soft starter capability**

3. Parallel Pumps for Varying Demand

- Multiple pumps: some turned off during low demand
- Used when static head is > 50% of total head
- System curve does not change
- Flow rate lower than sum of individual flow rates



PUMPS IN PARALLEL OPERATION



CENTRIFUGAL PUMPS IN PARALLEL

- The total head for the **combination** is the same as the total head for each pump

$$\Delta h_T = \Delta h_1 = \Delta h_2$$

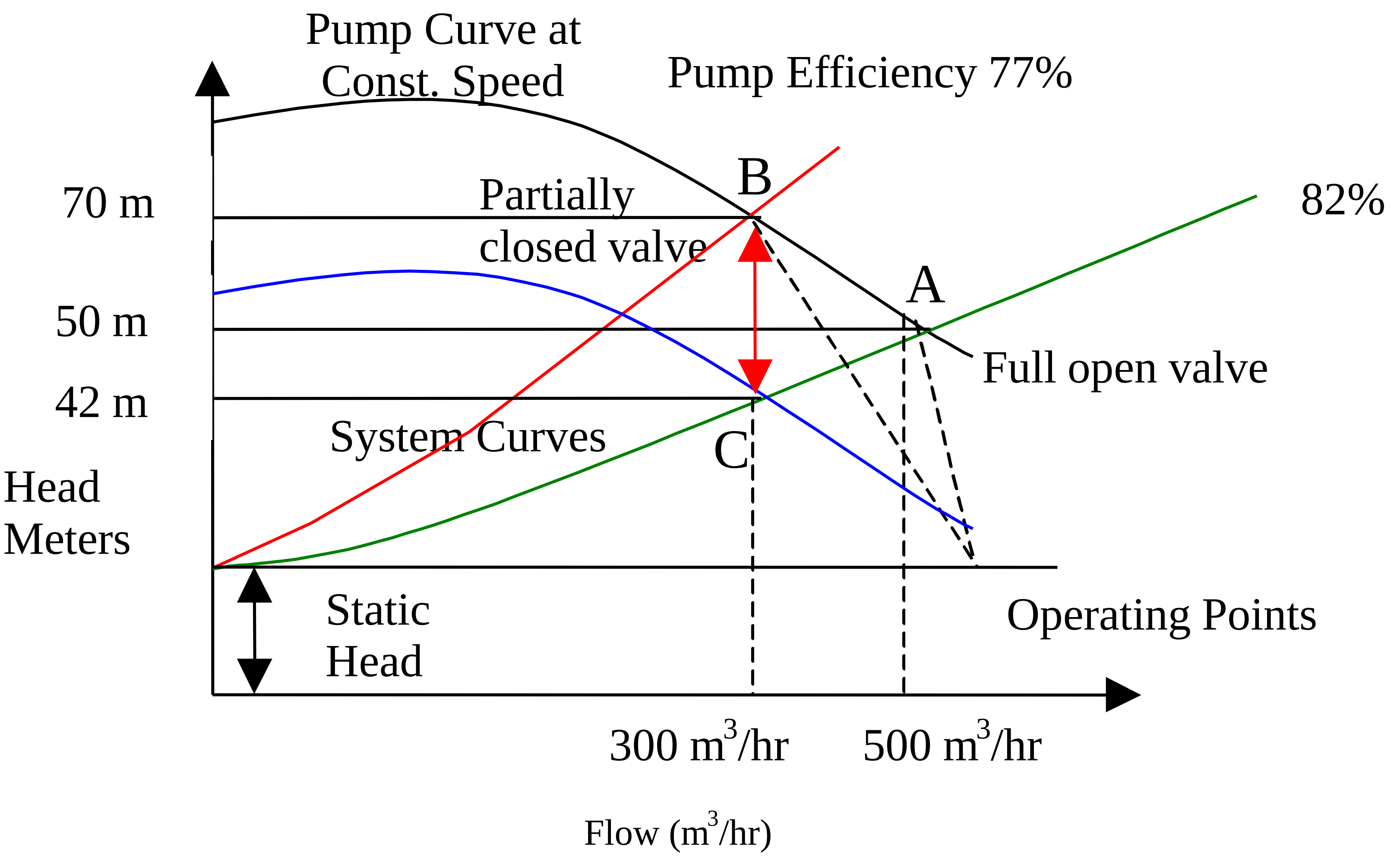
- The flowrate or capacity is the sum of the two pumps

$$Q_T = Q_1 + Q_2$$

4. Eliminating By-pass Control

- Pump discharge divided into two flows
  - One pipeline delivers fluid to destination
  - Second pipeline returns fluid to the source
- Energy wastage because part of fluid pumped around for no reason

EFFECT OF THROTTLING



5. Eliminating By-pass Control

- **Pump discharge divided into two flows**
  - **One pipeline delivers fluid to destination**
  - **Second pipeline returns fluid to the source**
- **Energy wastage because part of fluid pumped around for no reason**

6. Start/Stop Control of Pump

- Stop the pump when not needed
- Example:
  - Filling of storage tank
  - Controllers in tank to start/stop
- Suitable if not done too frequently
- Method to lower the maximum demand (pumping at non-peak hours)

7. Impeller Trimming

- **Changing diameter: change in velocity**
- **Considerations**
  - **Cannot be used with varying flows**
  - **No trimming >25% of impeller size**
  - **Impeller trimming same on all sides**
  - **Changing impeller is better option but more expensive and not always possible**

THE AFFINITY LAW FOR A CENTRIFUGAL PUMP

Flow:

$Q1 / Q2 = N1 / N2$

Example:

$100 / Q2 = 1750/3500$

$Q2 = 200\ m^3/hr$

Head:

$H1/H2 = (N1^2) / (N2^2)$

Example:

$100 / H2 = 1750^2 / 3500^2$

$H2 = 400\ m$

Power :

$P1 / P2 = (N1^3) / (N2^3)$

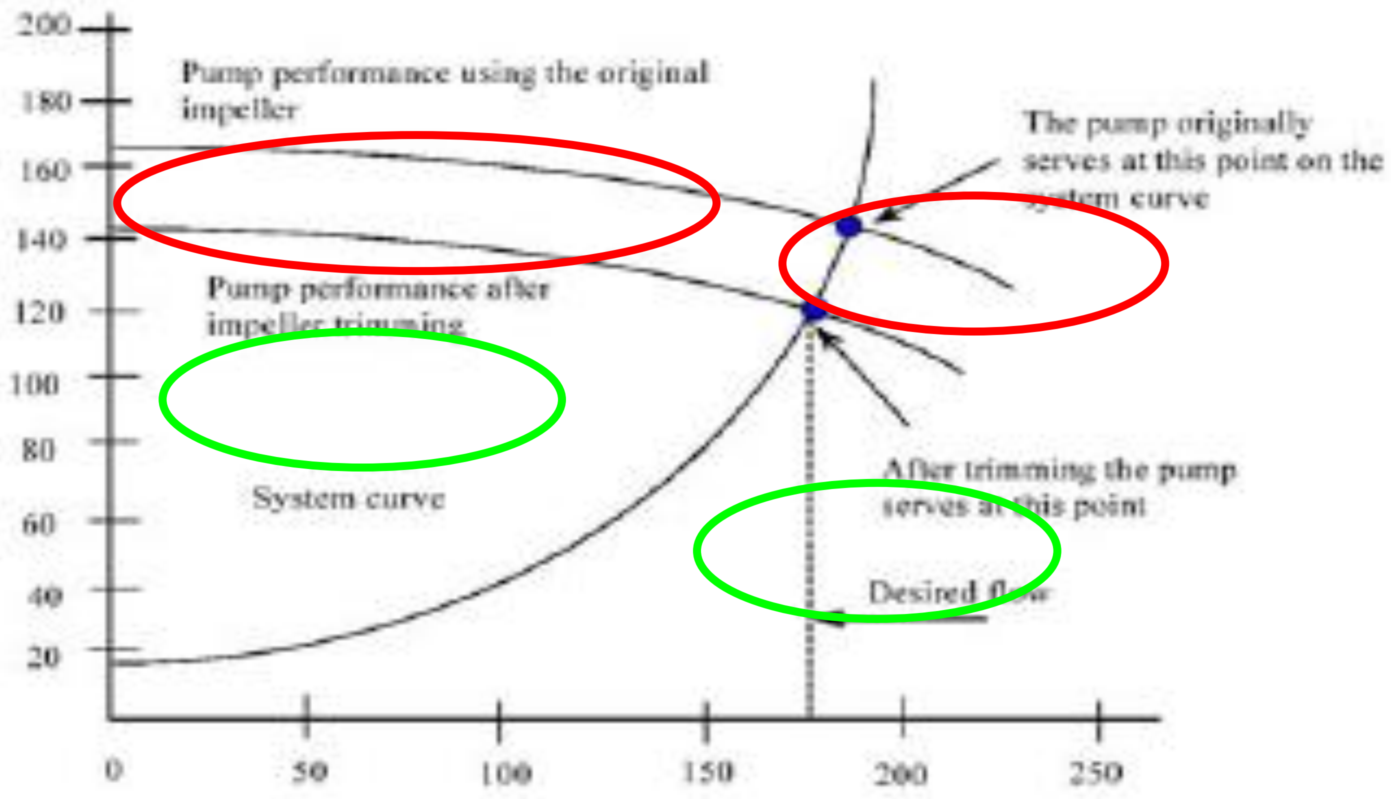
Example:

$5/P2 = 1750^3 / 3500^3$

$P2 = 40$

7. Impeller Trimming

Impeller trimming and centrifugal pump performance



Comparing Energy Efficiency Options

Parameter	Change control valve	Trim impeller	VFD
Impeller diameter	430 mm	375 mm	430 mm
Pump head	71.7 m	42 m	34.5 m
Pump efficiency	75.1%	72.1%	77%
Rate of flow	80 m^3/hr	80 m^3/hr	80 m^3/hr
Power consumed	23.1 kW	14 kW	11.6 kW

THANK YOU

for your attention

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