EN 410
Energy Management

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Compressor modulation

Proper selection of a right combination of compressors and optimal modulation of different compressors can conserve energy.

- If all compressors are similar, the pressure setting can be adjusted such that only one compressor handles the load variation, whereas the others operate more or less at full load.
- If compressors are of different sizes, the pressure switch should be set such that only the smallest compressor is allowed to modulate (vary in flow rate).
- If different types of compressors are operated together, unload power consumptions are significant. The compressor with lowest no load power must be modulated.

Compressor modulation

- Following observation is noted for reciprocating compressors.
- How much capacity is utilized?
- Comment on the operation

Compressor Reference	Measured Capacity CMM (@ 7 kg/ cm^2)	'On' Load kW	'Unload' kW	Load Time min.	Unload Time min.
A	13.17	115.30	42.3	Full time*	Nil
B	12.32	117.20	51.8	Full time*	Nil
C	13.14	108.30	43.3	Full time*	Nil
D	12.75	104.30	29.8	Full time*	Nil
E	13.65	109.30	39.3	5.88	39.12

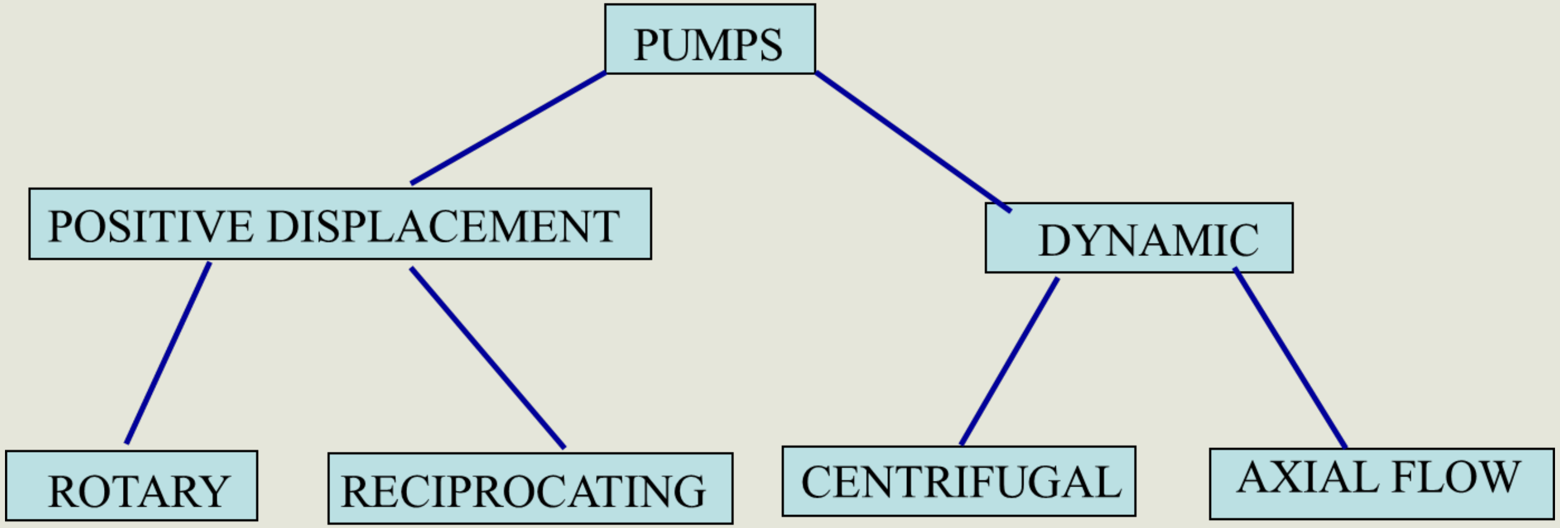
Compressor air assessment – Pump up method

- Free air delivery
- Should not deviate more than 10% as per design value
- Empty the receiver, close all the connections after receiver, and note down the time taken to reach the set pressure.

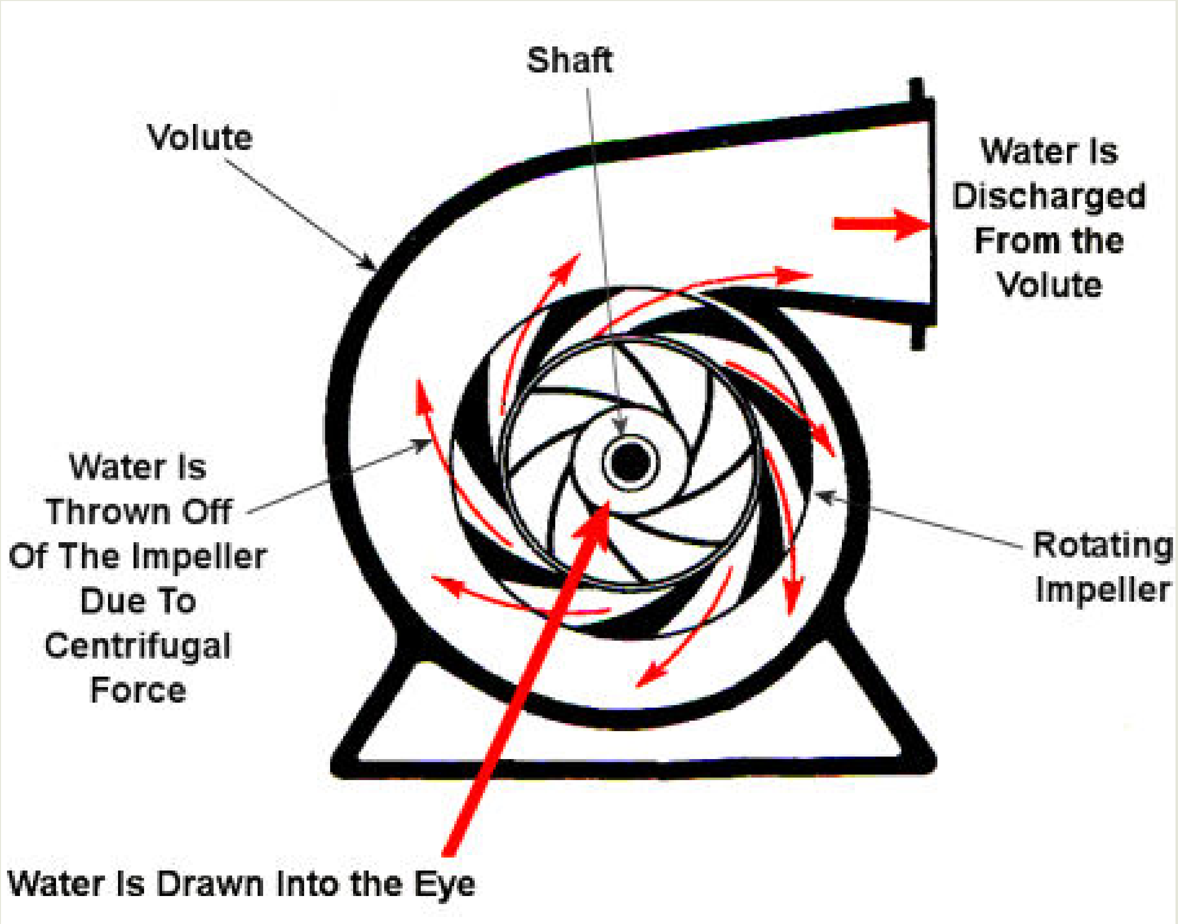
$$Q = \frac{P_2 - P_1}{P_0} \times \frac{V}{T} \ \text{m}^3/\text{min}$$

Pumps

- U.S. industrial sector - pumping systems account for 25% of the total energy consumed by electric motors and over 50 % of the electricity in pumping intensive industries
- Pump reliability is important—often critically so.
- *In cooling systems, pump failure can result in equipment overheating and catastrophic damage.*
- *In lubrication systems, inadequate pump performance can destroy equipment.*
- *In many petrochemical and power plants, pump downtime can cause a substantial loss in productivity.*

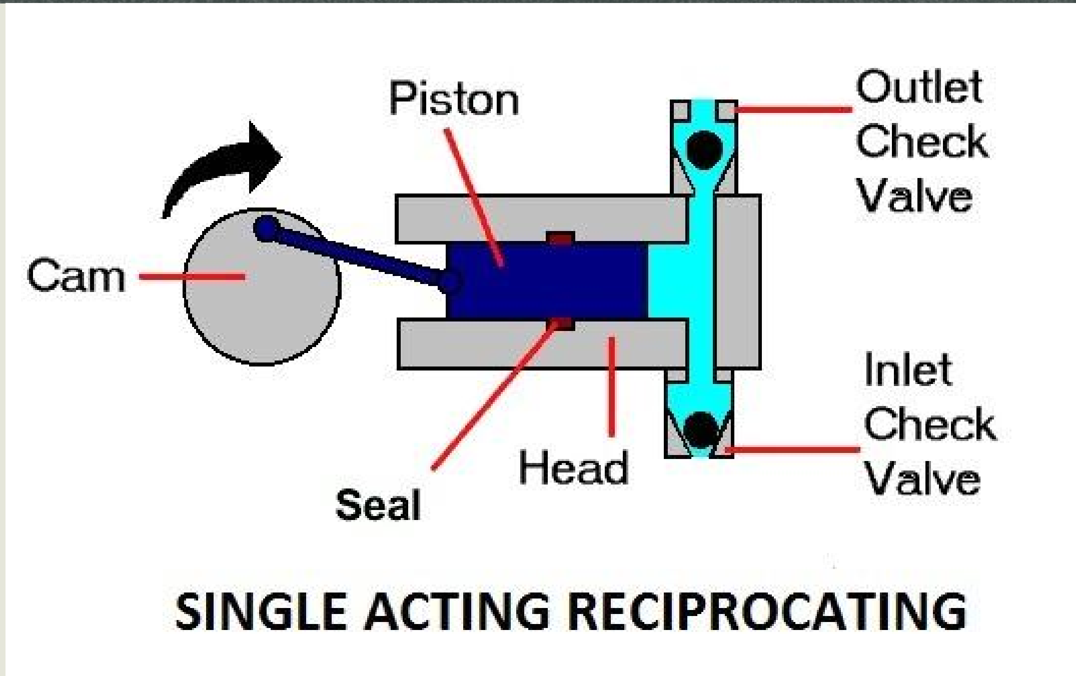


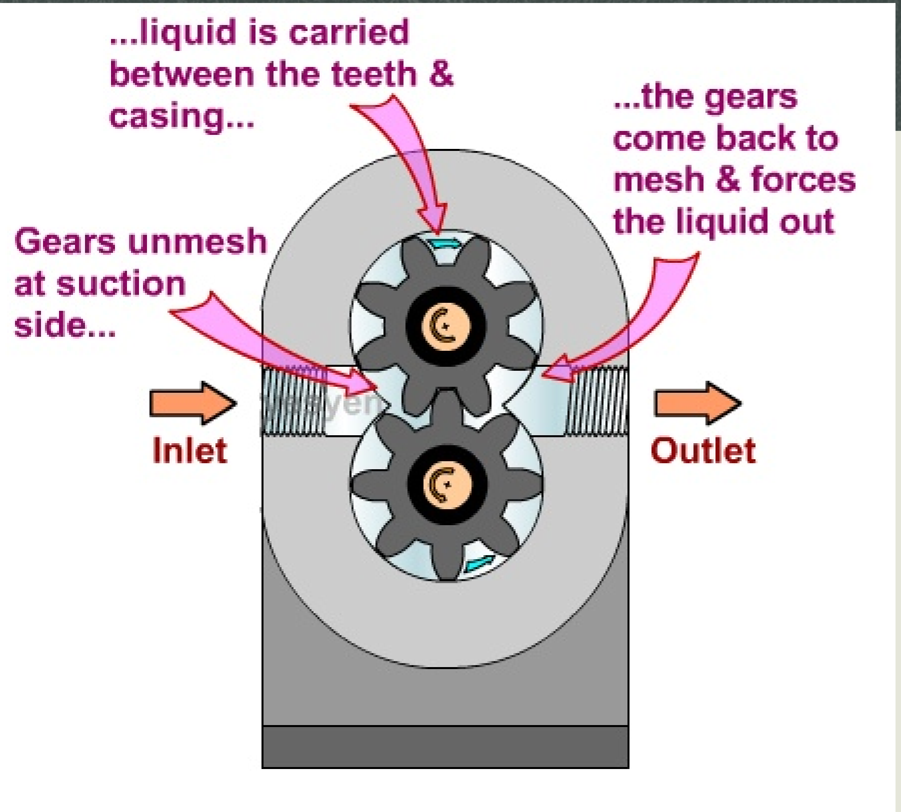
Centrifugal pumps



- Centrifugal pumps are more common –simple, safe to operate, require minimal maintenance, and have characteristically long operating lives.
- Centrifugal pumps typically suffer less wear and require fewer part replacements than positive displacement pumps.
- Packing or mechanical seals must be replaced periodically, these tasks usually require only a minor amount of downtime.

Positive displacement pumps





- The system requires high-pressure, low-flow pump performance
- The pump must be self-priming
- The working fluid must not experience high shear forces
- The flow must be metered or precisely controlled
- Disadvantage – Deadheading

Pump performance parameters

Hydraulic Power P_h = Q (m³/s) x Total Differential head, $h_d - h_s$ (m) x ρ (kg/m³) x g (m/s²) / 1000

Where h_d - discharge head, h_s – suction head, ρ - density of the liquid, g – acceleration due to gravity

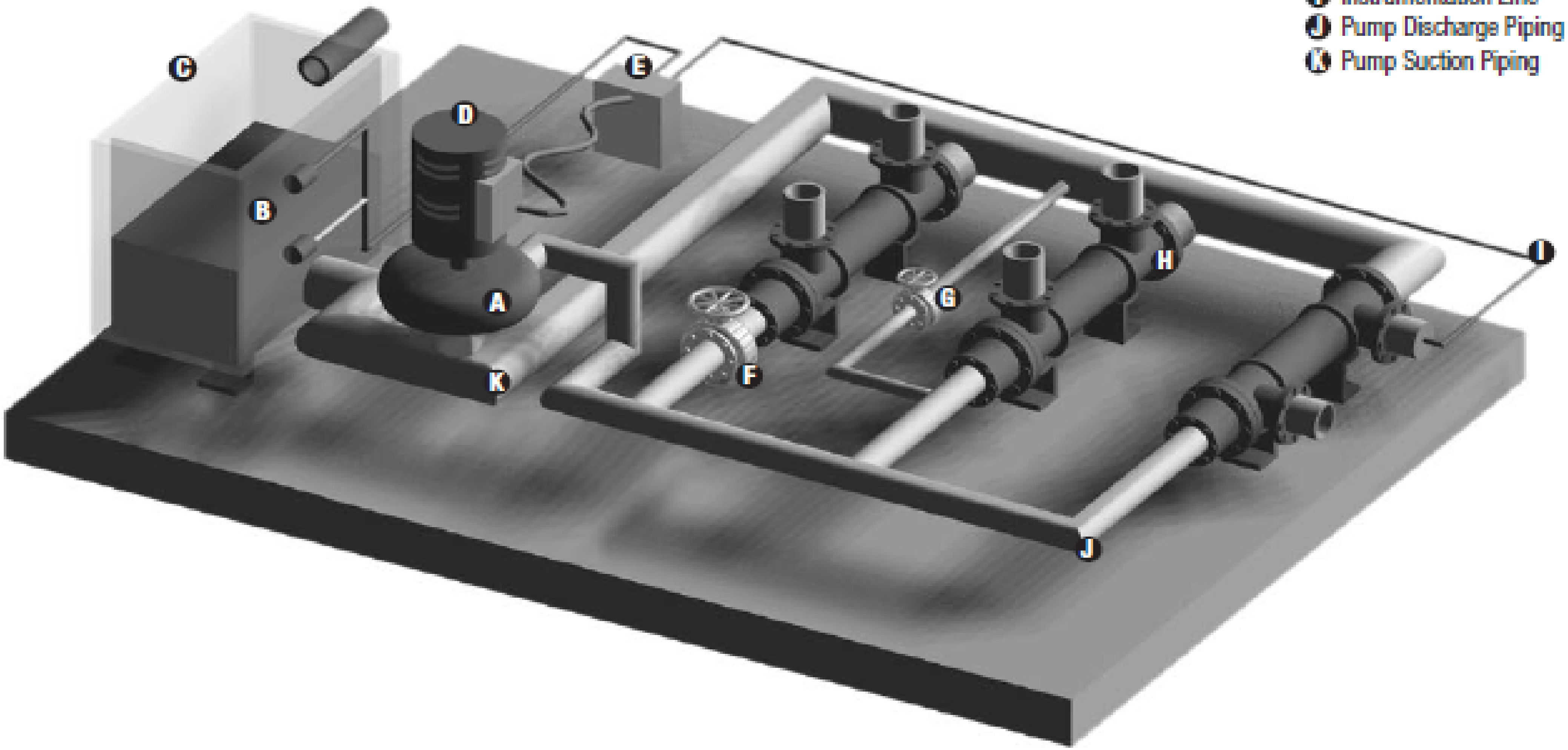
Pump Shaft Power P_s = Hydraulic power, P_h / Pump Efficiency, η_{Pump}

Motor Input Power = Pump shaft power P_s / Motor Efficiency, η_{Motor}

- Pump flow, Q = 0.40 m^3/ s
- Electrical Power supplied, P = 325 kW
- Suction head (Tower basin level), h1 = +1 m
- Delivery head, h2 = 55 m
- Motor efficiency = 88%
- Density of water = 996 kg/m^3

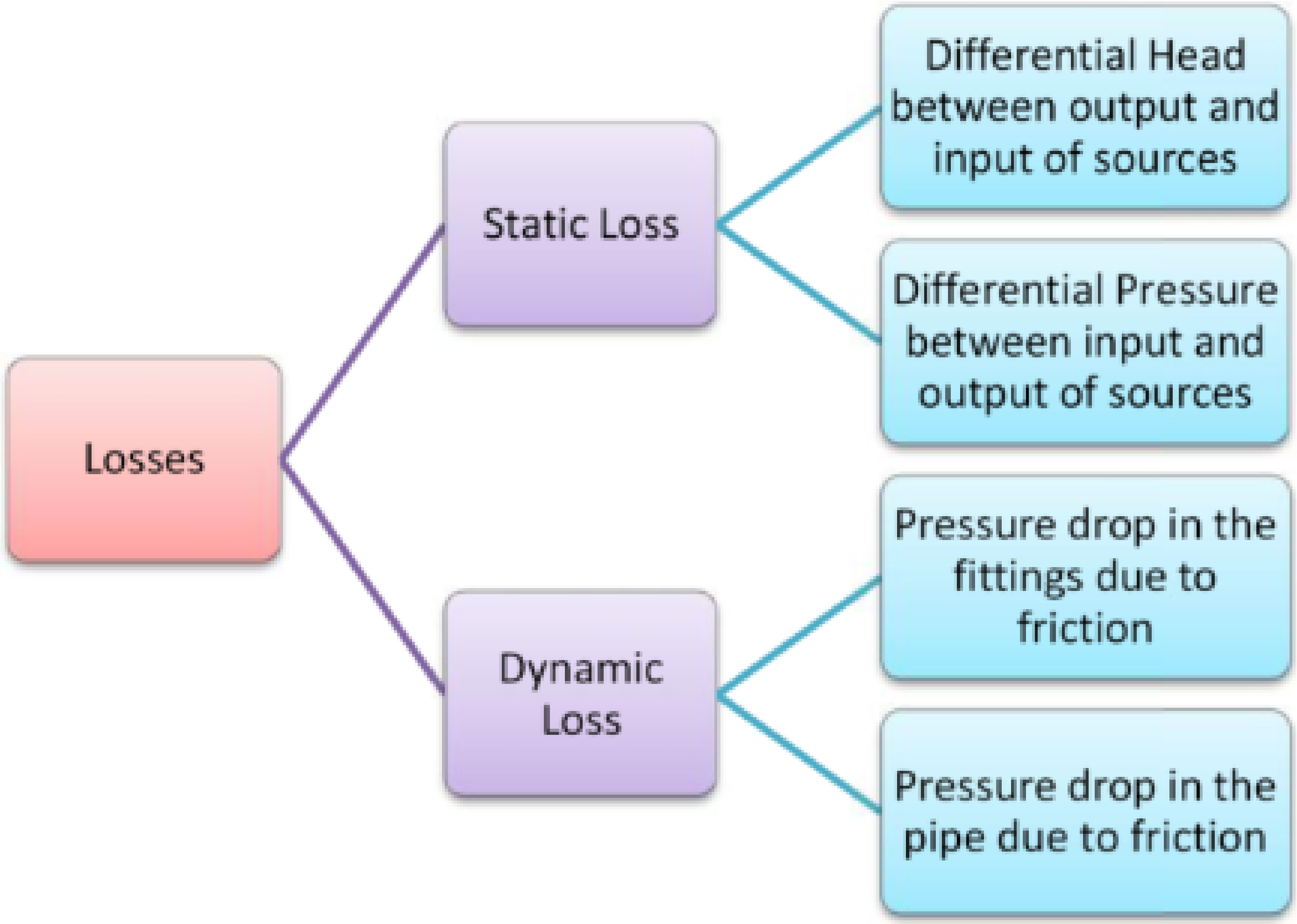
- **Net Head**
- **Hydraulic power**
- **Pump shaft power**
- **Pump efficiency**

Pumping system

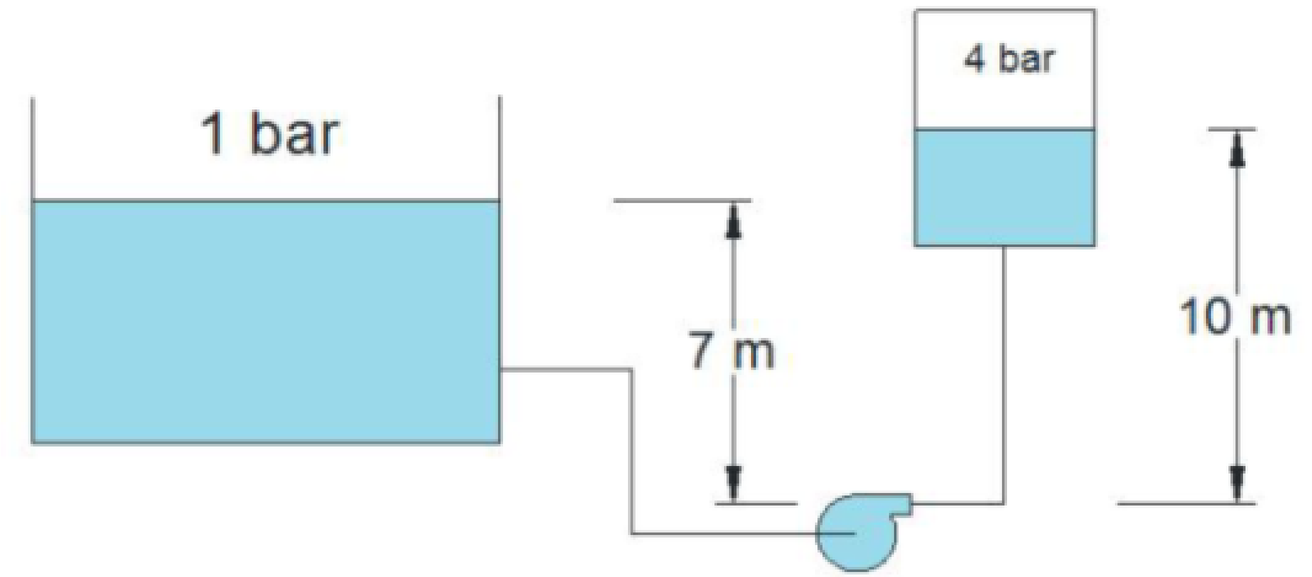


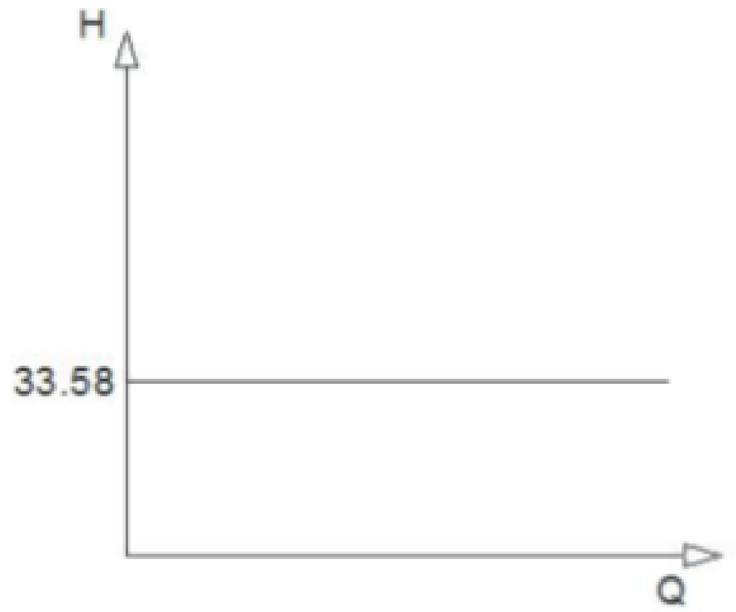
Ⓐ Pump
Ⓑ Level Indicators
Ⓒ Tank, Liquid Supply
Ⓓ Pump Motor
Ⓔ Motor Controller
Ⓕ Throttle Valve
Ⓖ Bypass Valve
Ⓗ Heat Exchangers *(End-Use Equipment)*
Ⓘ Instrumentation Line
Ⓙ Pump Discharge Piping
Ⓚ Pump Suction Piping

Pumping system losses



Static loss





$P = \rho \times g \times h = 3 \text{ bar} \times 10^5 = 1000 \times 9.81 \times h$ $\qquad h = 30.58 \text{ m}$

$H_{total} = 3 + 30.58 = 33.58 \text{ m}$

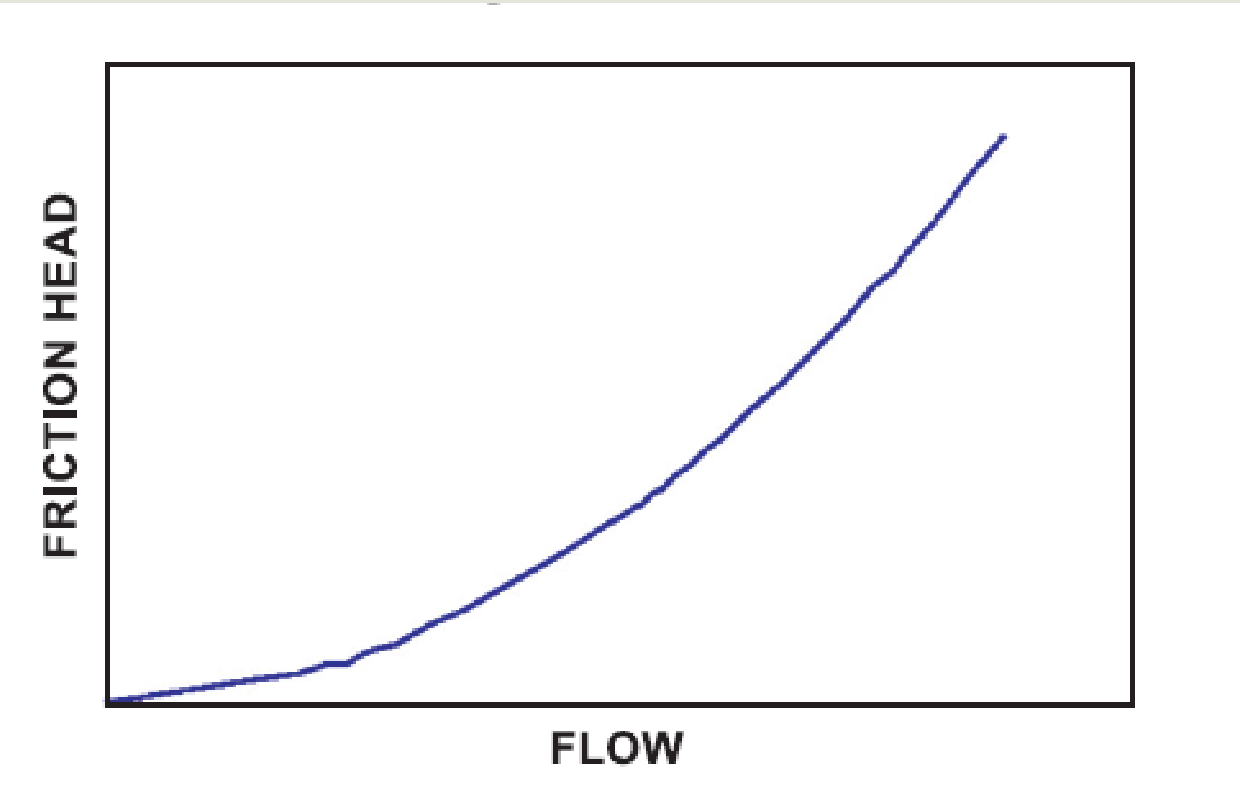
Dynamic losses

Valves fittings, entry, exit

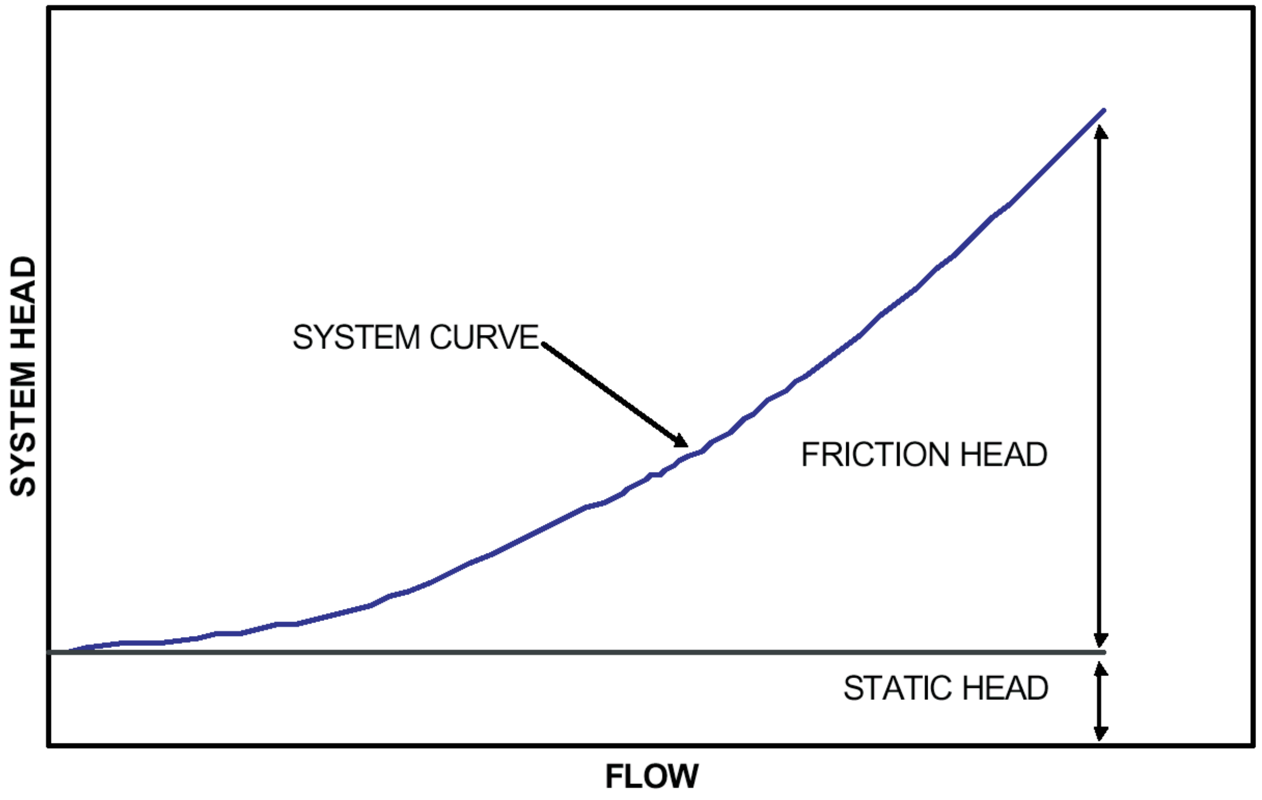
$$h_f = k\frac{V^2}{2g}$$

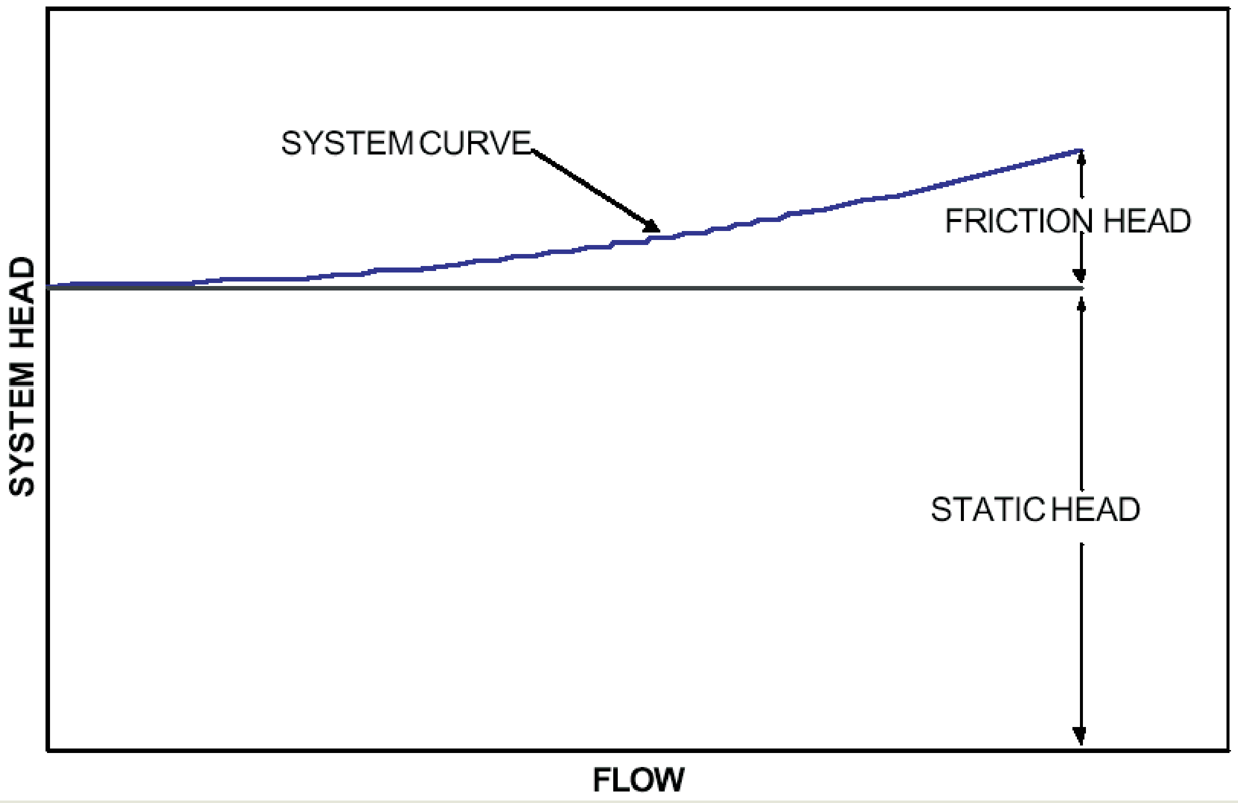
Due to pipe friction

$$H_f = f\,\frac{L}{D}\,\frac{v^2}{2\,g}$$

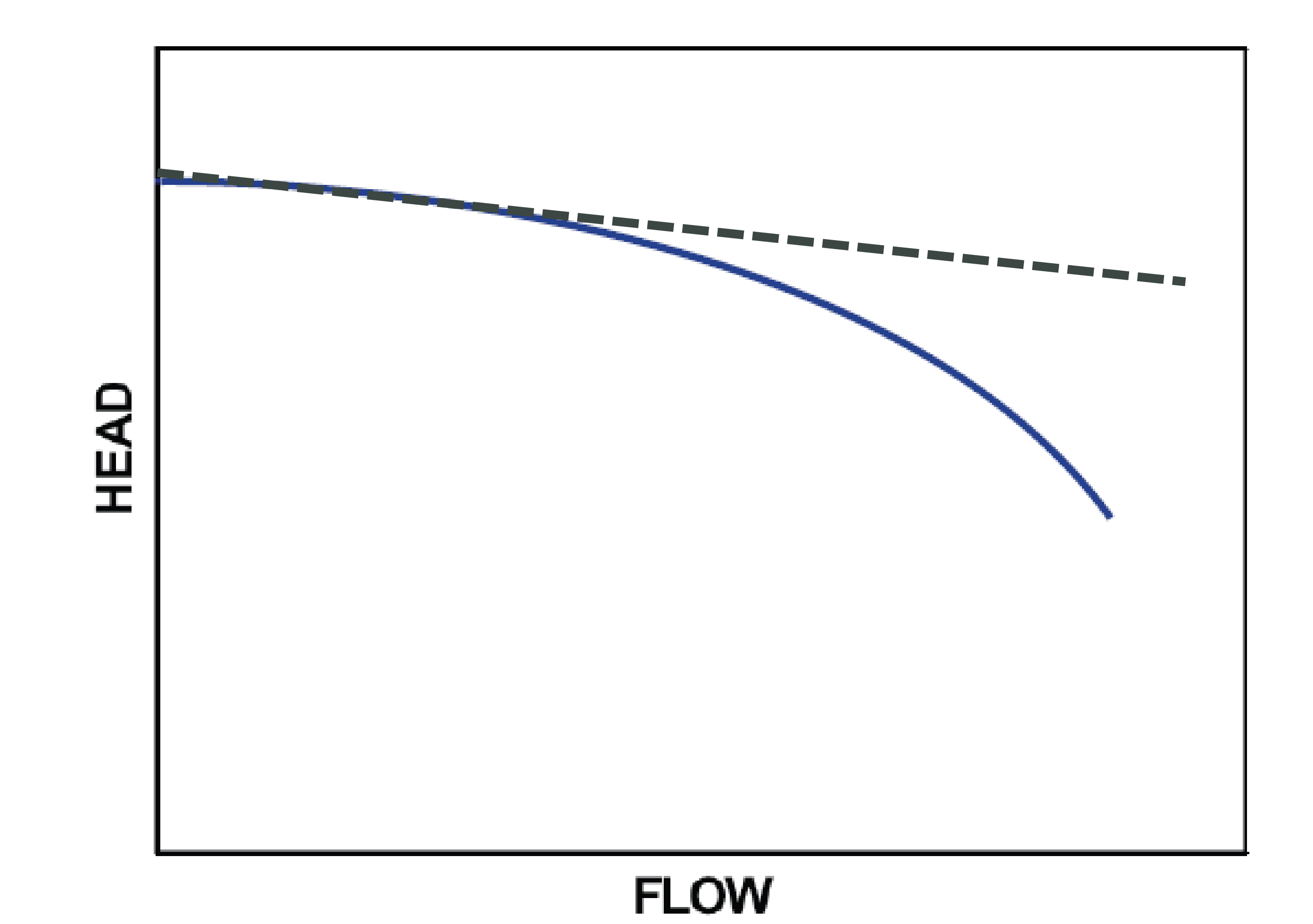


System curve



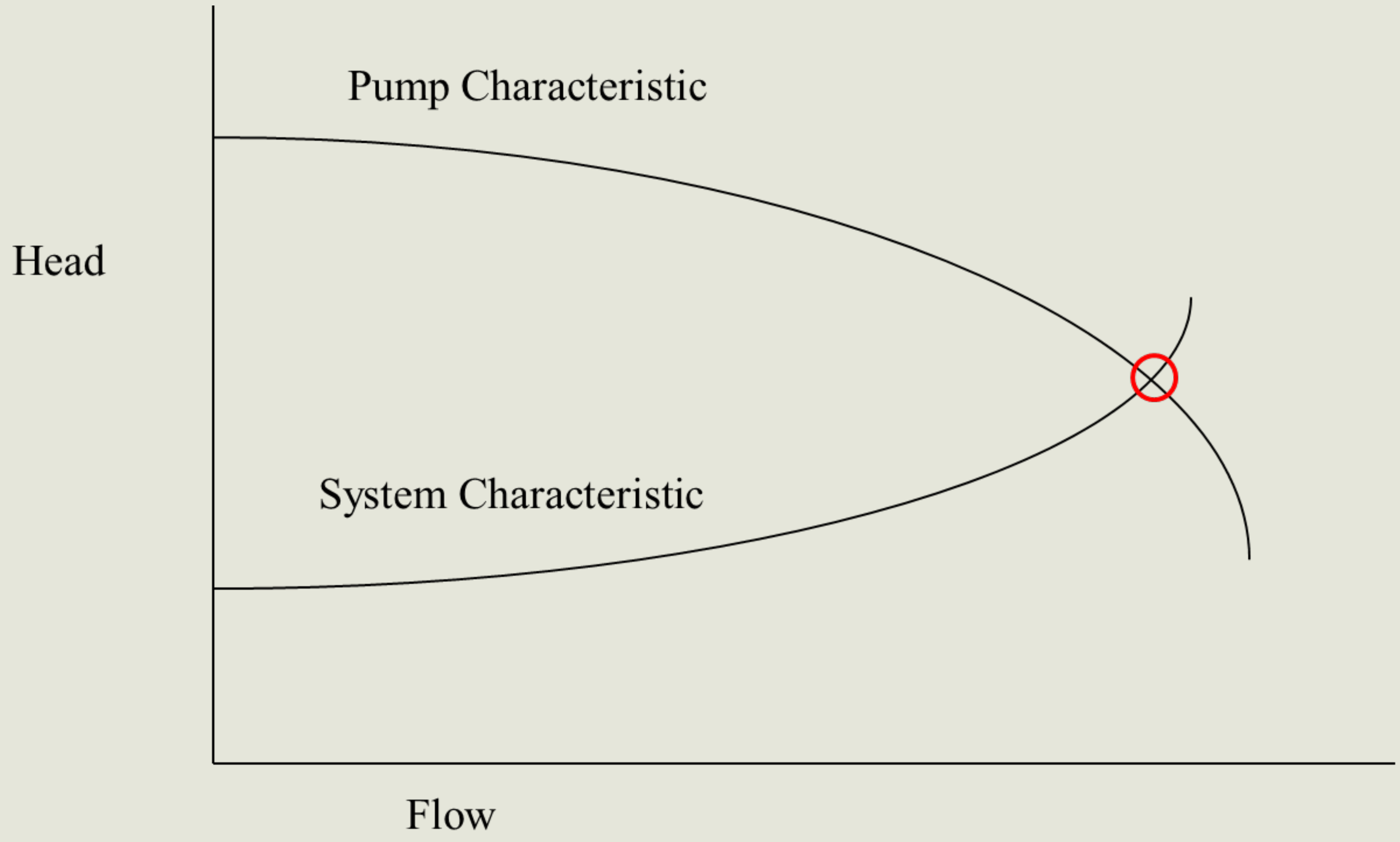


Pump curve

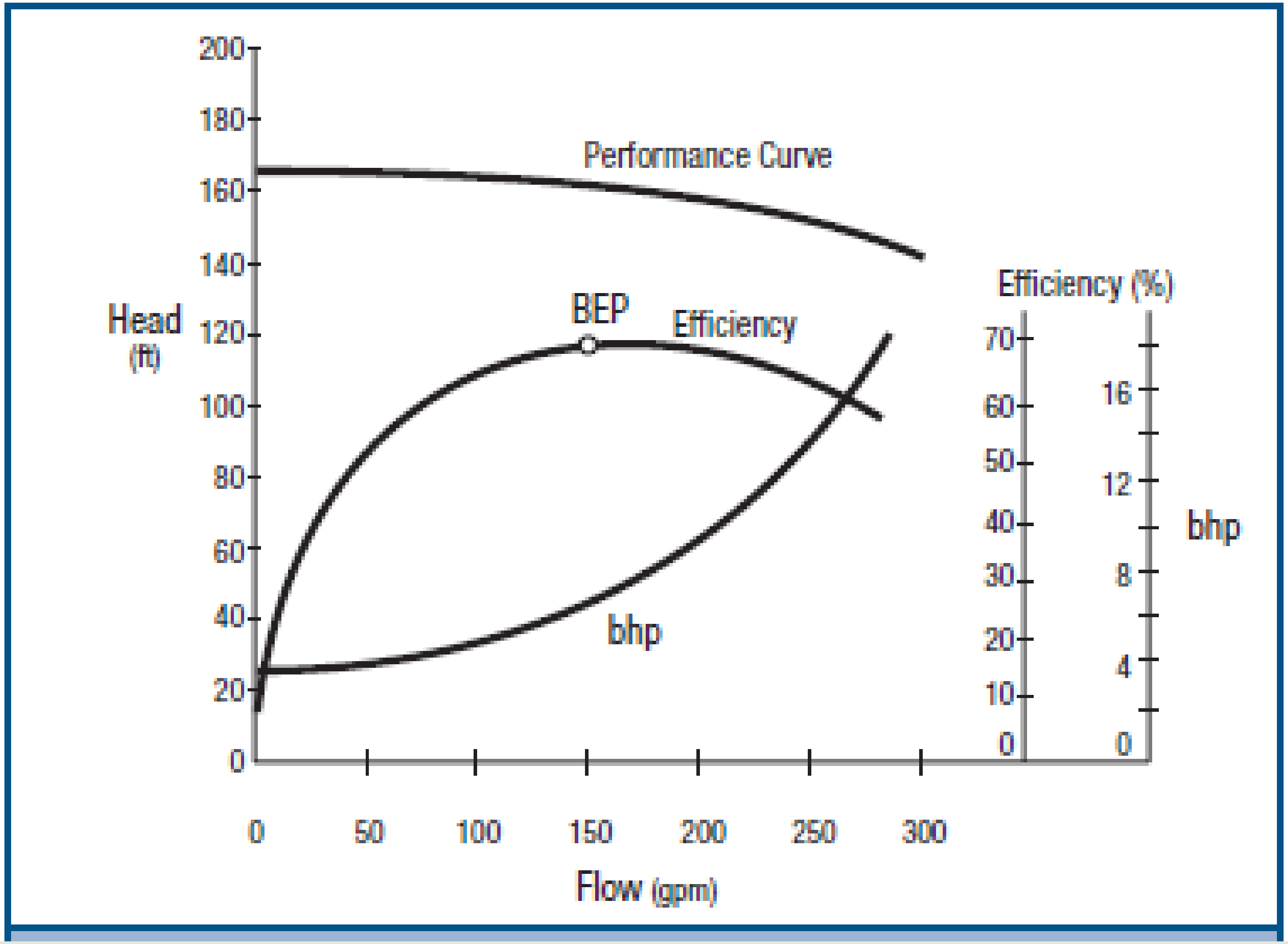


- Decreasing (but flat) due to eddy and shock losses
- Further decreasing (become parabolic) due to frictional losses

Operating point



Best efficiency point (BEP)



Pump selection curve

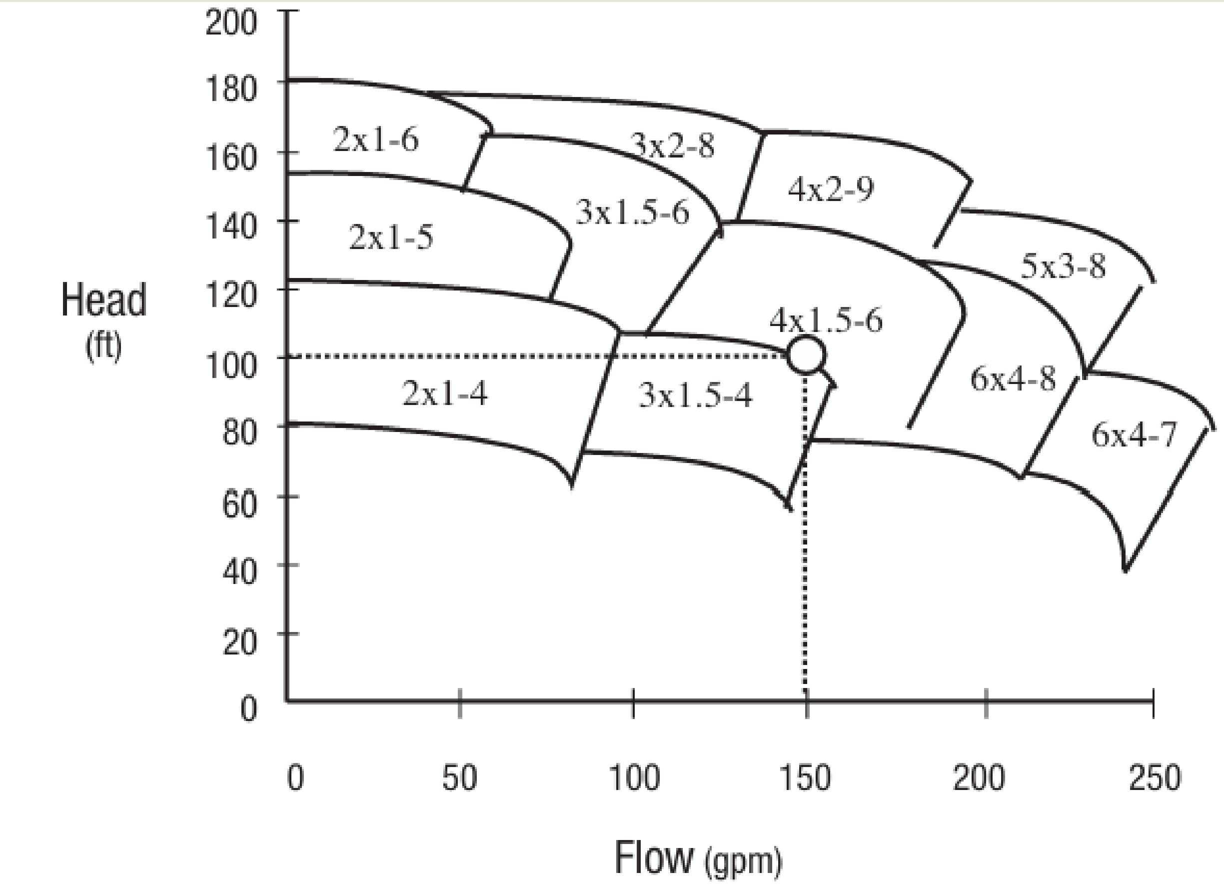


Figure 11. Family of Pump Performance Curves

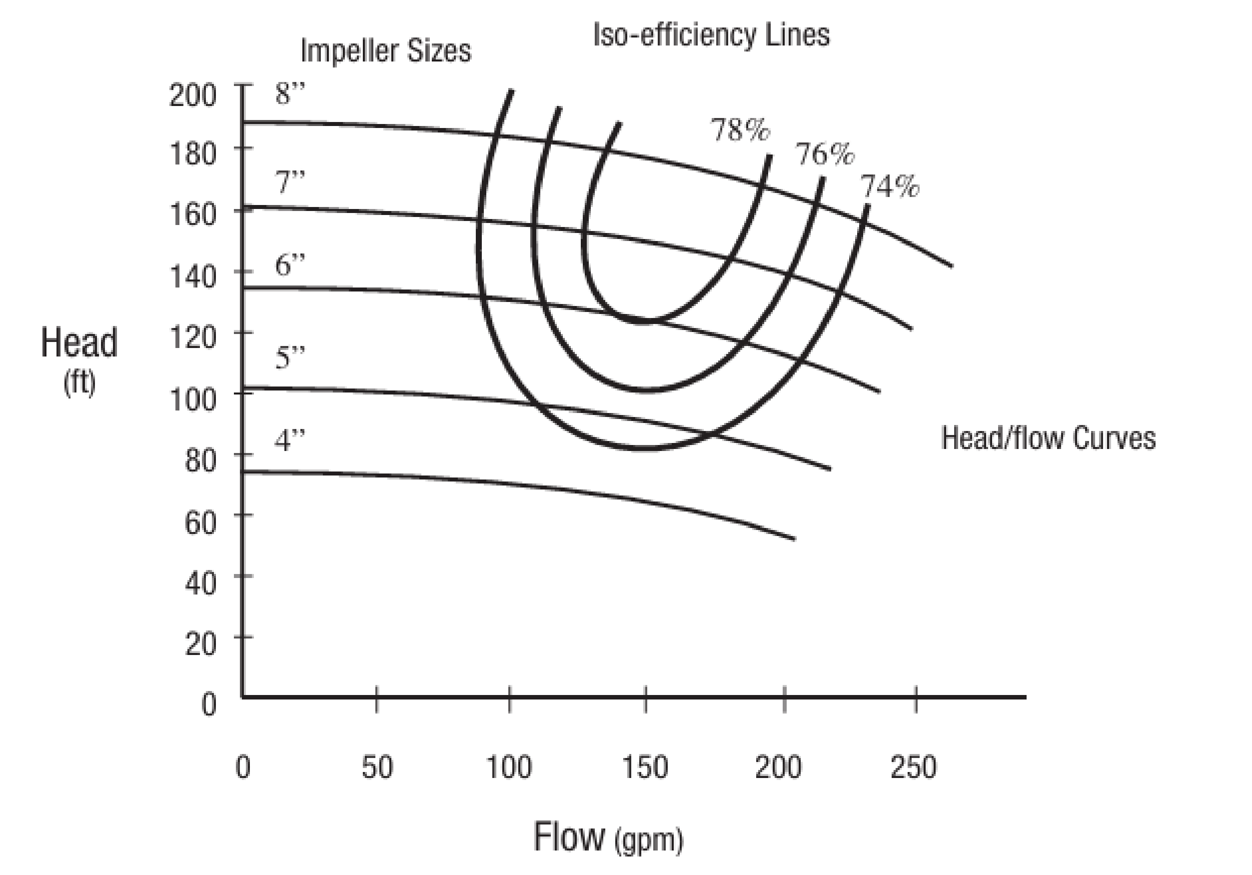
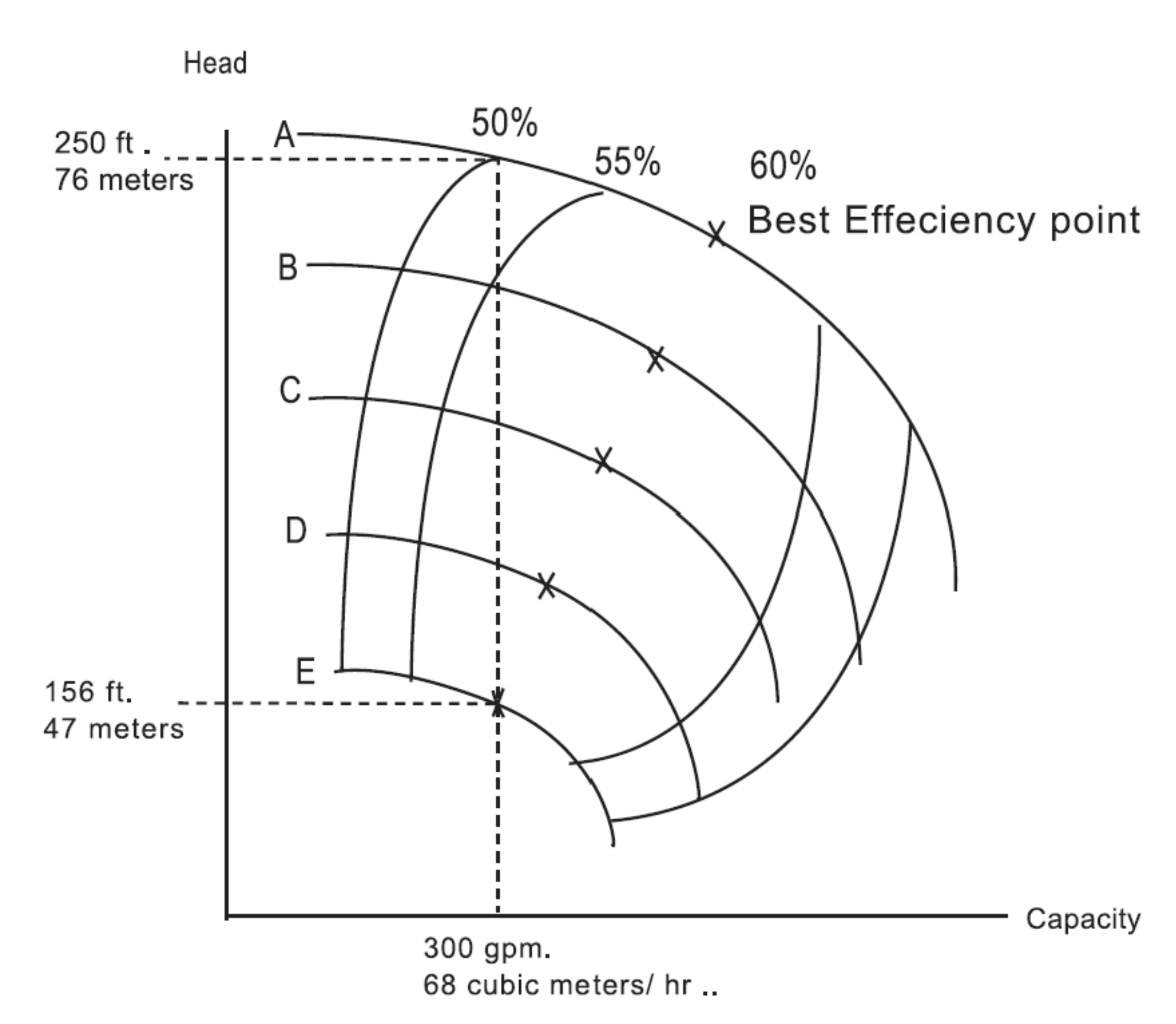


Figure 12. Performance Curves for Different Impeller Sizes

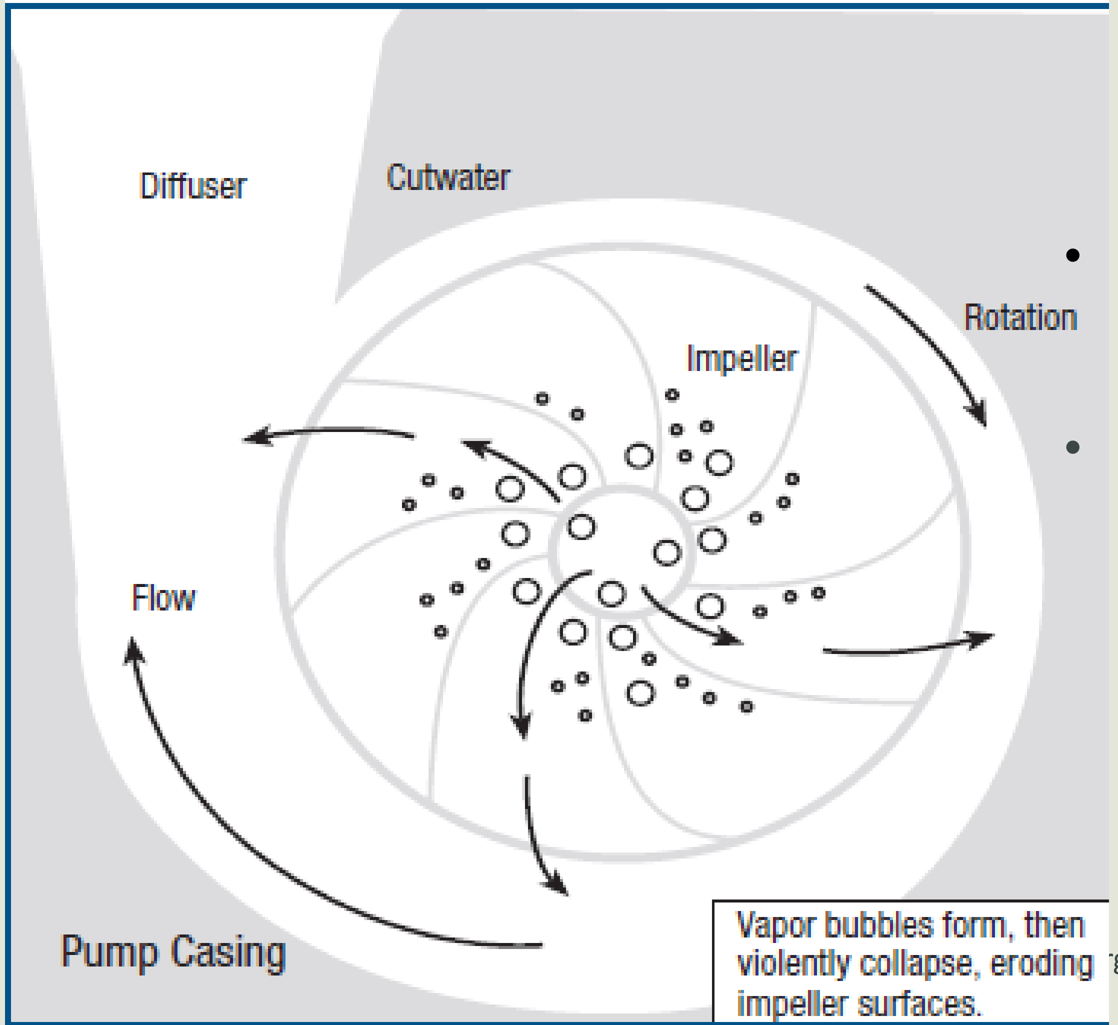
Effect of oversized pump



What happened if we select A instead of E?

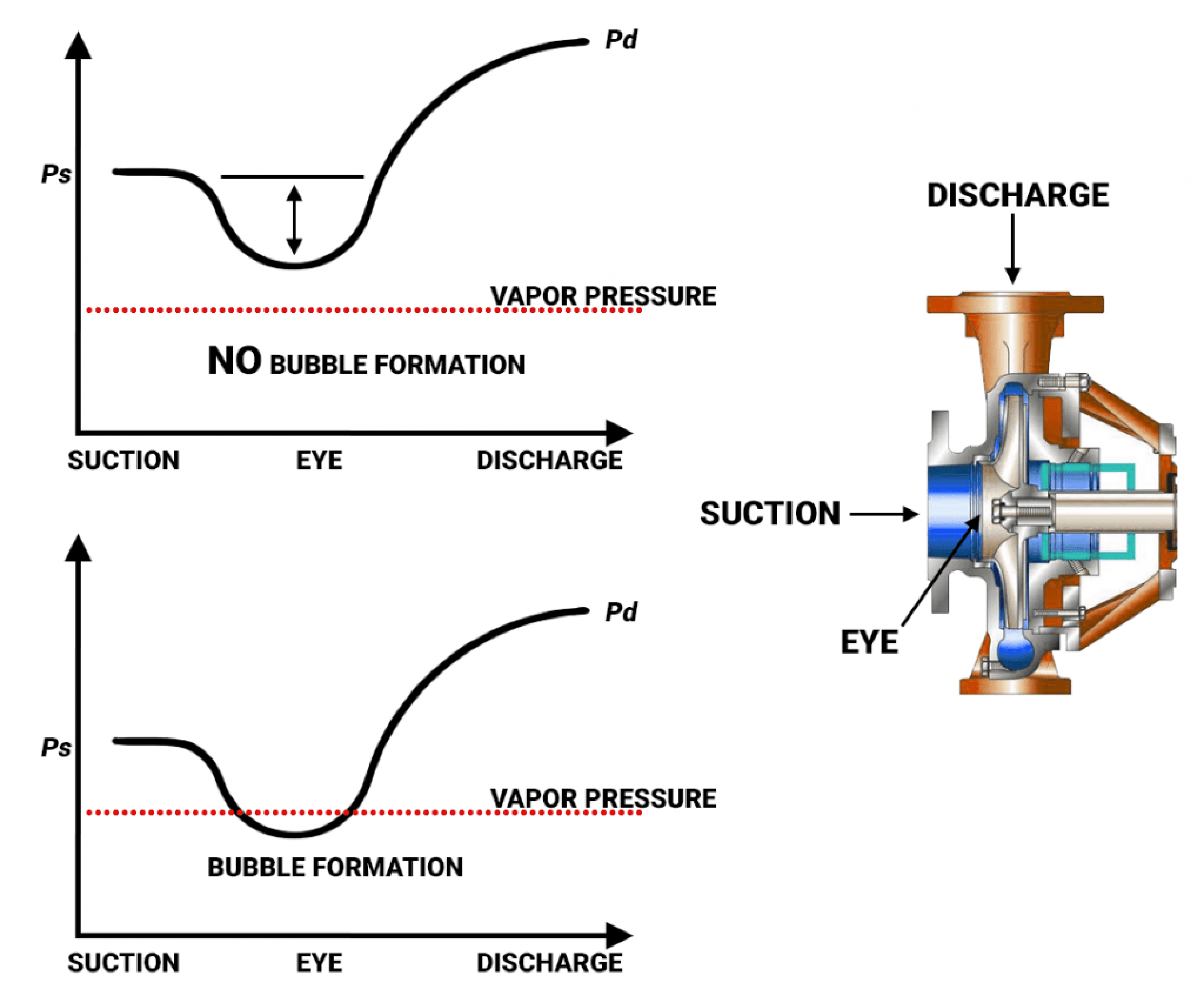
- Pump cost of E is INR 300000
- Operating hours = 8000 hrs./year
- Utility rate = INR 5.5/kWh
- Motor efficiency = 90%
- Density of water = 1000 kg/m^3

Cavitation



- Crackling and popping noises that often sound like marbles passing through the pump
- For applications in which cavitation is to some extent unavoidable, high-tensile-strength materials should be specified for the impeller

Net positive suction head



Pump Control Strategies

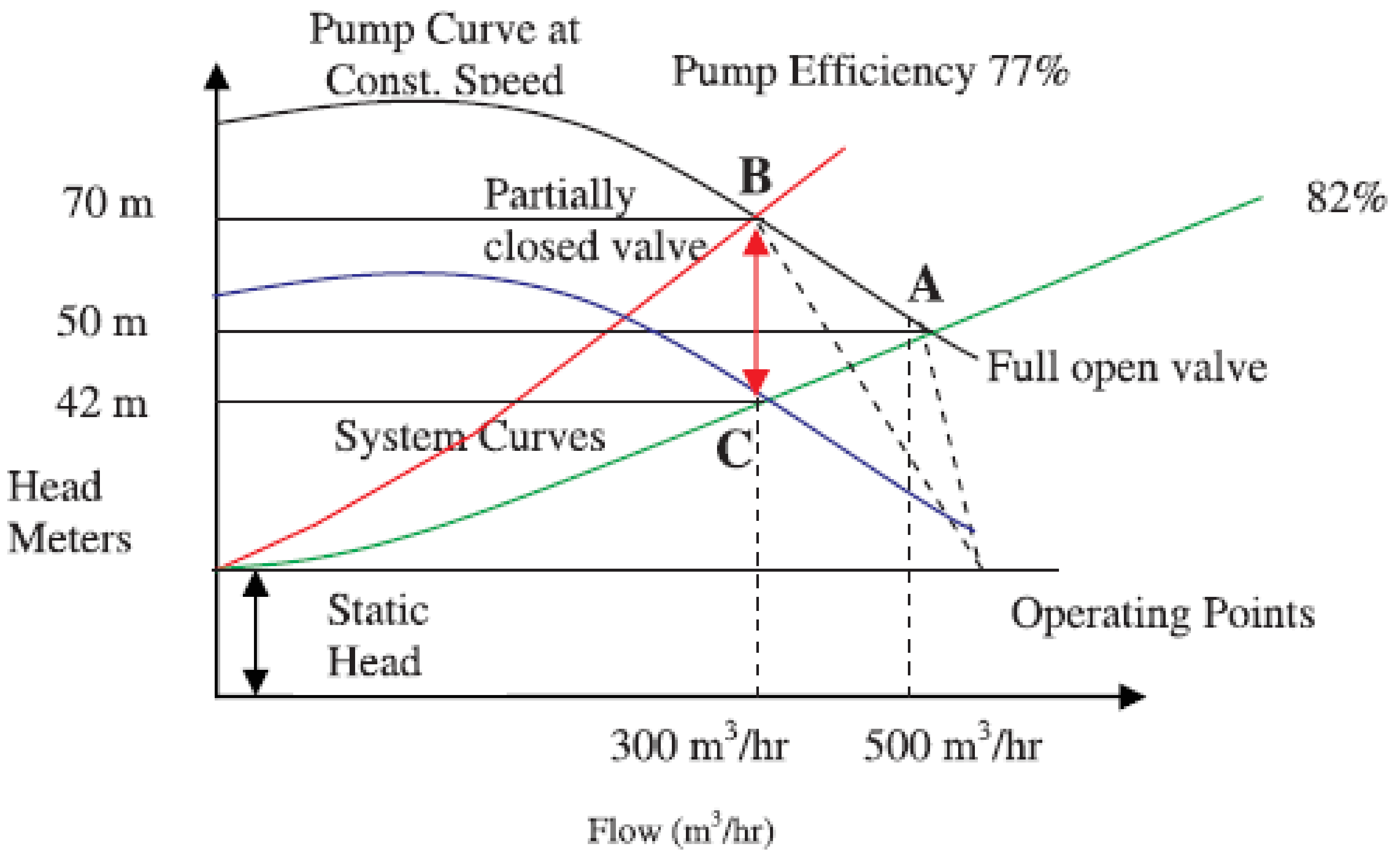
Often Oversizing – Does not operate at Design point

- Bypass Control
- Throttling
- Variable Speed Drives
- Trimming Impeller (reducing Diameter)

Bypass control

- Pump runs continuously at the maximum process demand level, with a permanent bypass line attached to the outlet.
- When a lower flow is required, the surplus liquid is bypassed and returned to the supply source.

Valve control method



The Affinity Laws

$$Q_2 = \left[\frac{N_2}{N_1}\right] Q_1$$

$$H_2 = \left[\frac{N_2}{N_1}\right]^2 H_1$$

$$P_2 = \left[\frac{N_2}{N_1}\right]^3 P_1$$

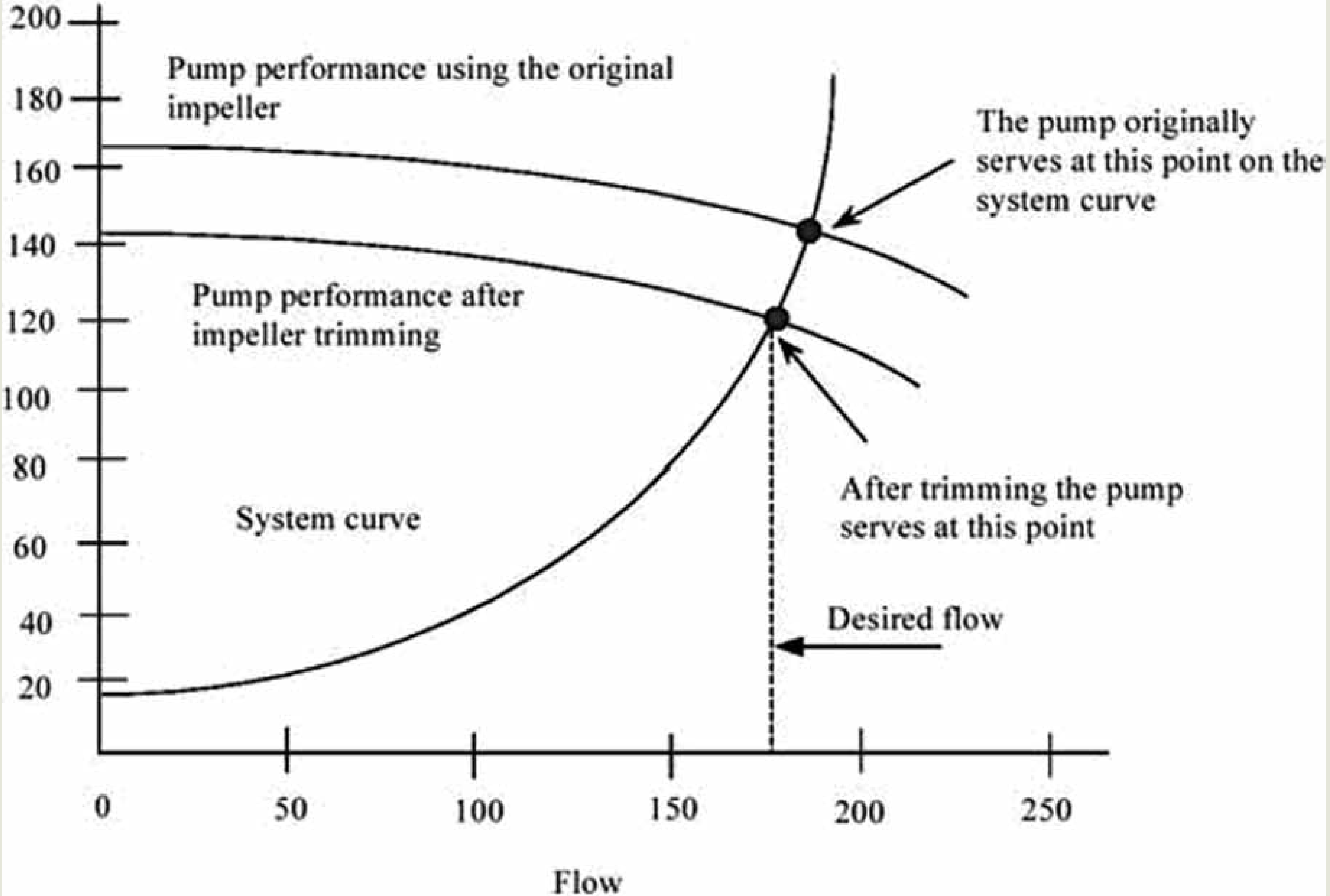
$$Q_2 = \left[\frac{D_2}{D_1}\right] Q_1 Q_2$$

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

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

Impeller trimming to reduce flow

- Permanent changes
- Impeller diameters are rarely reduced below 70% of their original size



Speed Control

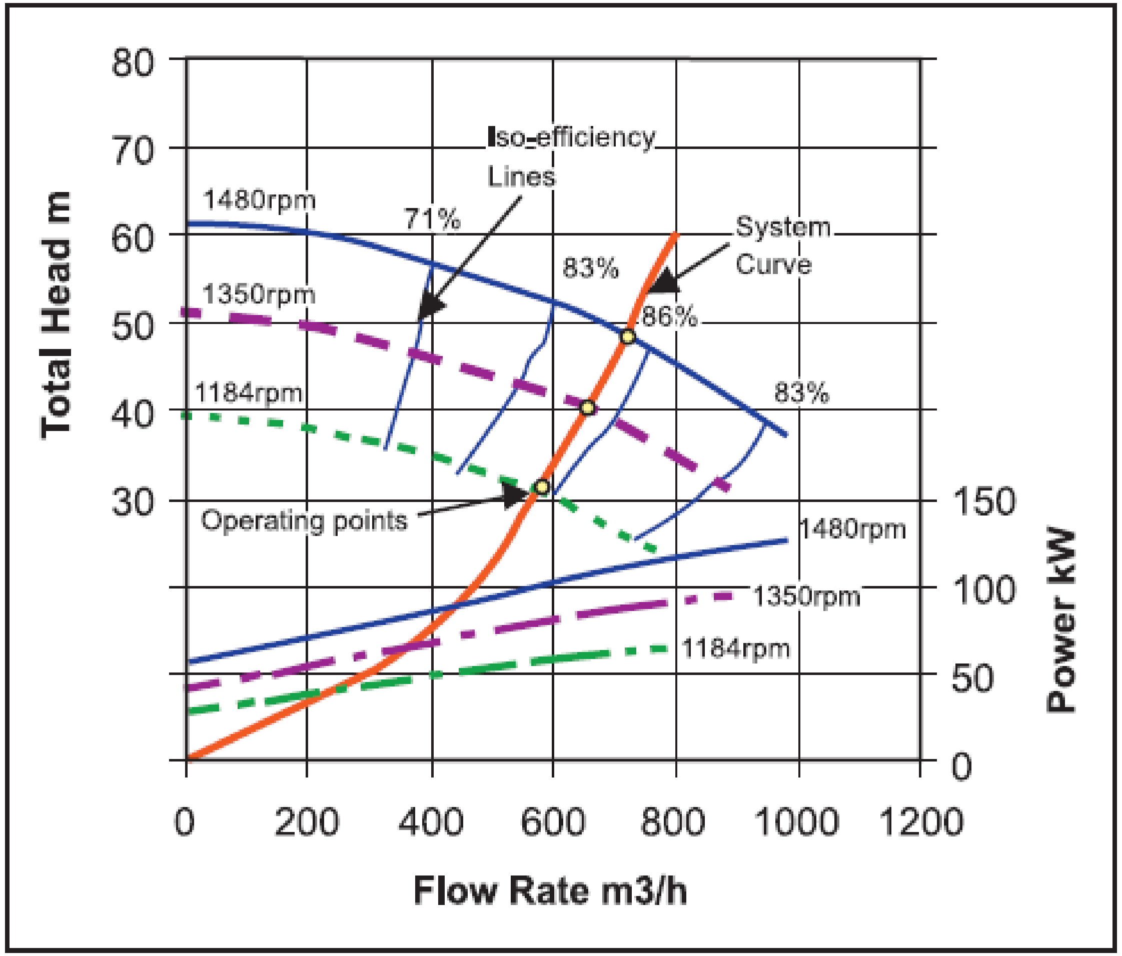


Figure 6.15 Example of the Effect of Pump Speed Change in a System with Only Friction Loss

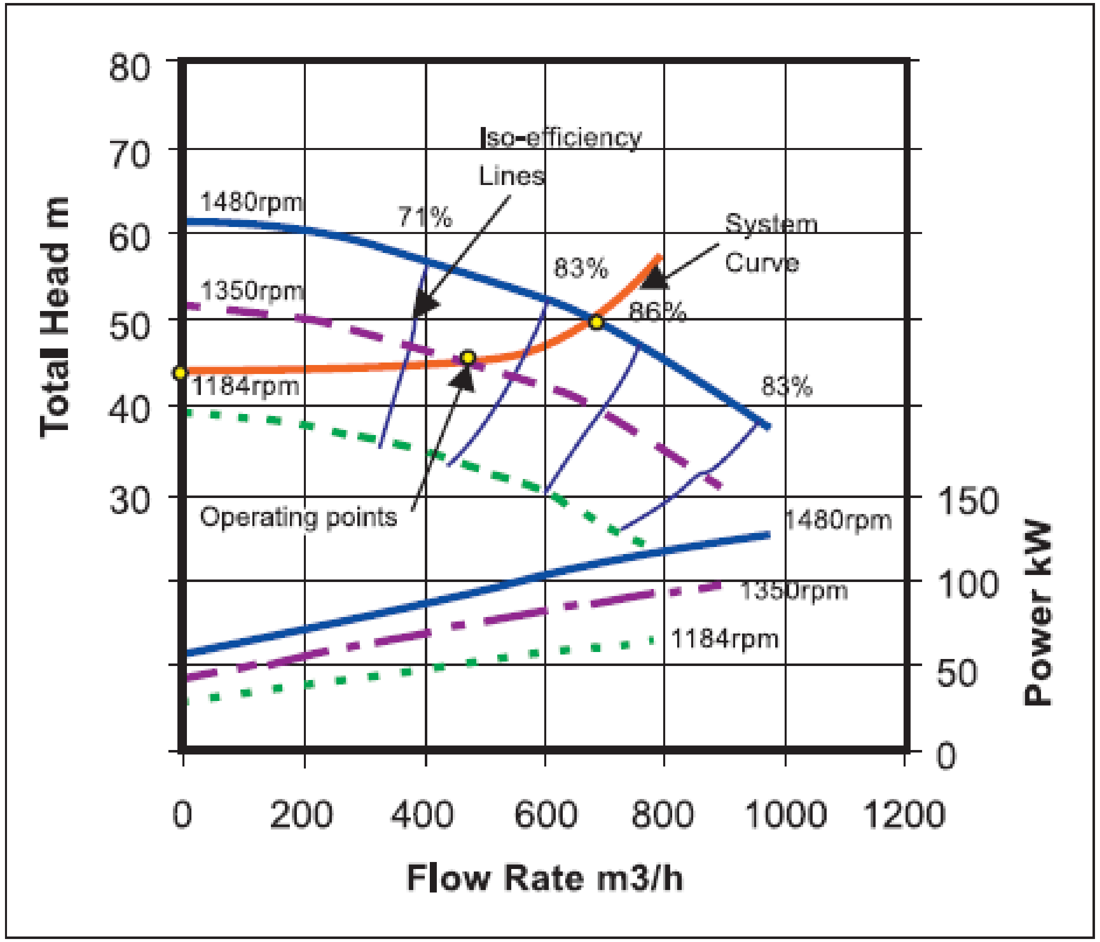


Figure 6.16 Example for the Effect of Pump Speed Change with a System with High Static Head

Pump speed adjustments

- Multiple-speed pump motors and variable speed drives (VSDs)
- Multiple-speed motors: different set of windings for each motor speed
  - Expensive, less efficient, discrete speeds
- Mechanical VSDs: hydraulic clutches, fluid couplings, and adjustable belts and pulleys.
- Electrical VSDs: eddy current clutches, wound-rotor motor controllers, and variable frequency drives (VFDs)

Speed control

- A centrifugal pump, pumping water operates at 35 m^3/h and at 1440 RPM. The pump operating efficiency is 68% and motor efficiency is 90%. The discharge pressure gauge shows 4.4 kg/cm^2. The suction is 2 m below the pump centerline. If the speed of the pump is reduced by 50% estimate the new flow, head and power.

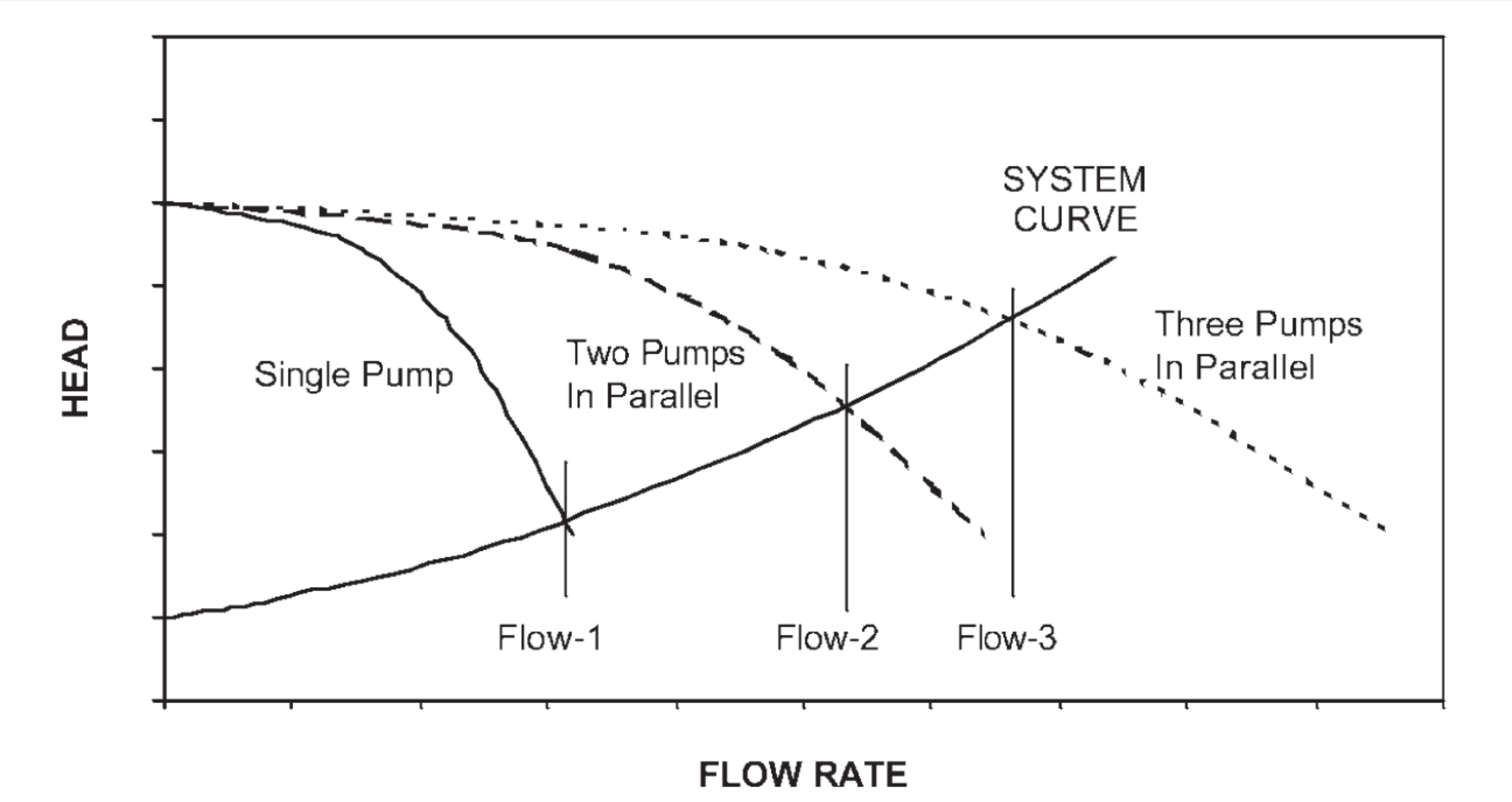
- **Original** **Modified**
  - **flow:**
  - **head:**
  - **power:**

Speed control

- A centrifugal pump, pumping water operates at 35 m^3/h and at 1440 RPM. The pump operating efficiency is 68% and motor efficiency is 90%. The discharge pressure gauge shows 4.4 kg/cm^2. The suction is 2 m below the pump centerline. If the speed of the pump is reduced by 50% estimate the new flow, head and power.

Original	**Modified**
flow: 35 m^3/h	**17.5 m^3/h**
head: 46m	**11.5 m**
power: 7.17kW	**0.9kW**

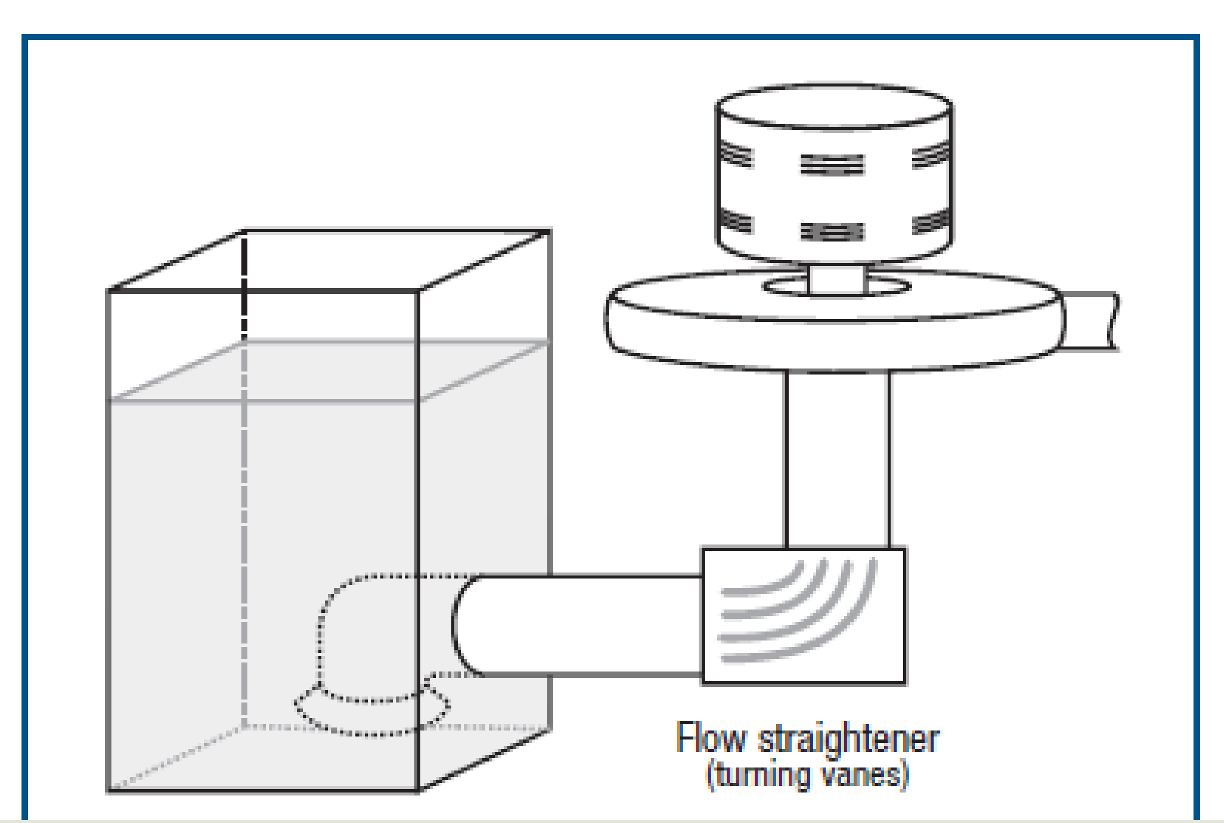
Pumps in Parallel

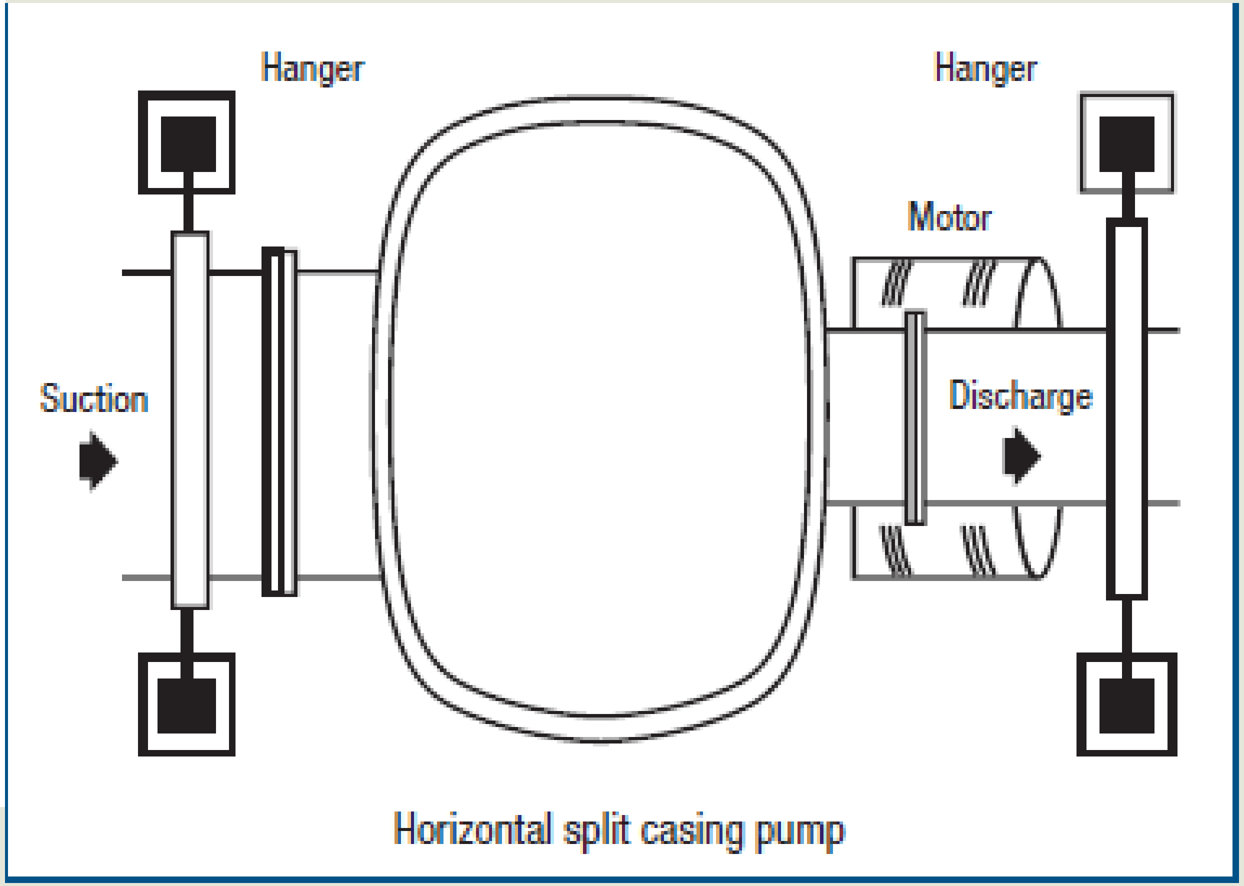


Symptoms for energy efficient operation

Symptom	Likely Reason	Best Solutions
Throttle valve-controlled systems	Oversized pump	Trim impeller, smaller impeller, variable speed drive, two speed drive, lower RPM
Bypass line (partially or completely) open	Oversized pump	Trim impeller, smaller impeller, variable speed drive, two speed drive, lower RPM
Multiple parallel pump system with the same number of pumps always operating	Pump use not monitored or controlled	Install controls
Constant pump operation in a batch environment	Wrong system design	On-off controls
High maintenance cost (seals, bearings)	Pump operated far away from BEP	Match pump capacity with system requirement

Piping arrangements





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