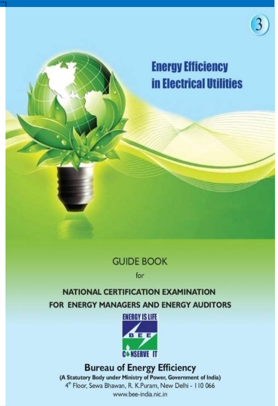
OPTC
TRAINING
COURSE

BOOK 3 – ENERGY EFFICIENCY IN ELECTRICAL UTILITIES
Brief Contents

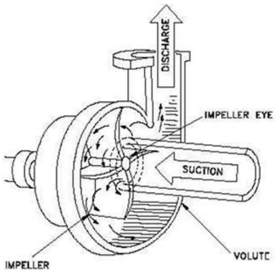


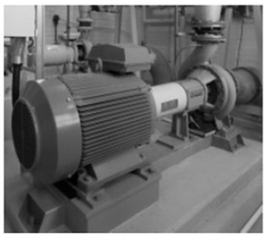
Chapter-6 Pumps and Pumping System
Contents

1. Pump Types
What are the Pumping Systems

Purpose of Pumps

- Transfer liquid from source to destination (to reservoir, tanks)
- Circulate liquid around a system (continuous circulation)





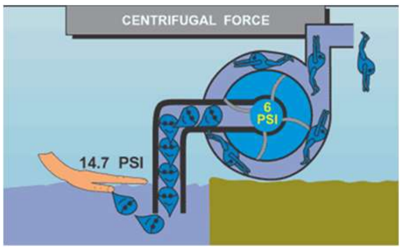
Applications : Pumps come in a variety of sizes for a wide range of applications
- Industrial ,Domestic, commercial, and agricultural
- Municipal water and wastewater services

Types: It can be classified based on operating principle as **dynamic or displacement pumps**

- Worldwide, **centrifugal pumps** account for the majority of electricity used by pumps, the focus is on centrifugal pump.

2. Centrifugal Pumps-How it Works?

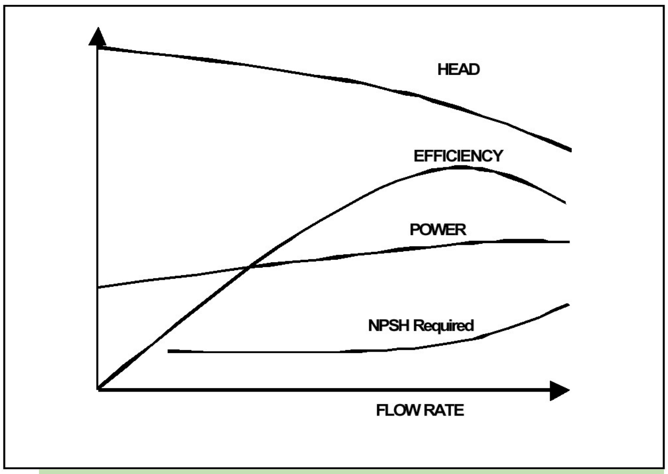
- **Impeller and the diffuser are the two main parts** in pumps and Impeller is the only moving part
- **Diffuser (volute)** houses the impeller and captures and **directs the water** off the impeller.
- Water enters the center (eye) of the impeller and exits the impeller with the help of centrifugal force.
- As water leaves the eye of the impeller a low-pressure area is created, causing more water to flow into the eye. Atmospheric pressure and centrifugal force cause this to happen.
- The water velocity is collected by the diffuser and converted to pressure that direct the flow to the discharge of the pump



- **Pump is a dynamic type**, it is convenient to consider the pressure in terms of head i.e. meters of liquid column. **The pump generates the same head of liquid whatever the density of the liquid being pumped**

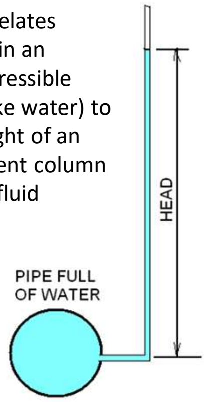
3. Pump Performance Curve-How to Read and understand?

Pump performance curves

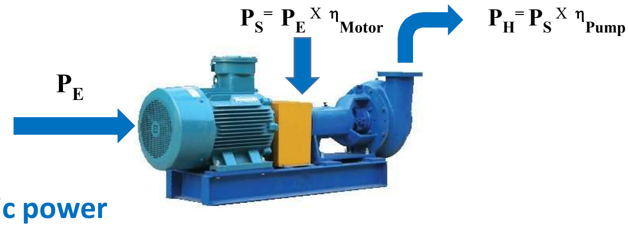


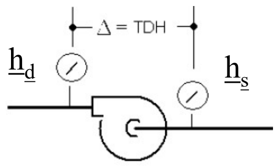
- The standard pump performance curves
- Flow on the horizontal axis and Head generated on the vertical axis.
- Efficiency, Power & NPSH Required, are shown on the vertical axis

Head-Relates energy in an incompressible fluid (like water) to the height of an equivalent column of that fluid



Hydraulic power, pump shaft power and electrical input power





- **Hydraulic power**
- $P_h = \dfrac{Q(m^3/s) \text{x Total head,} (h_d - h_s)(m) \text{x } \rho(kg/m^3) \text{x} g\ (m/s^2)}{1000}$

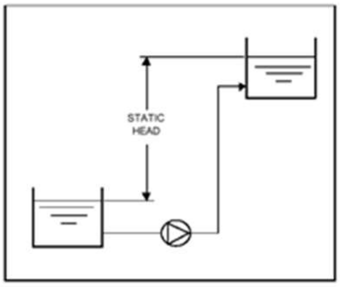
  Where h_d - discharge head, h_s – suction head, ρ - density of the fluid, g – acceleration due to gravity

- **Pump shaft power P_s** = $\dfrac{\text{Hydraulic power, } P_h}{\text{pump efficiency, } \eta_{Pump}}$

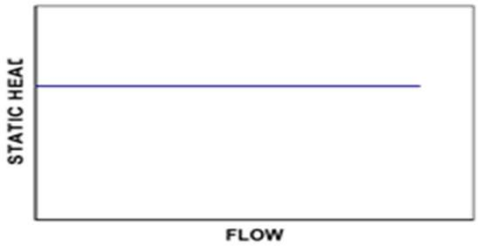
- **Electrical input power** = $\dfrac{\text{Pump shaft power P}}{\eta_{Motor}}$

System Characteristics

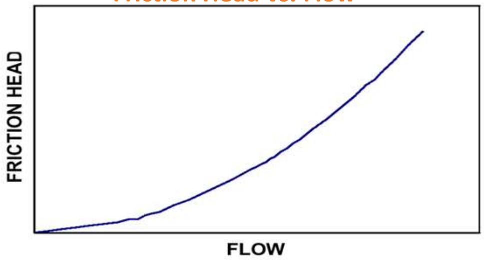
Static Head



Static Head vs. Flow



Friction Head vs. Flow

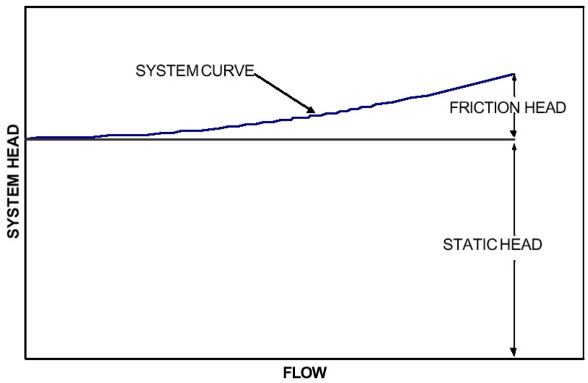


Dynamic (Friction) Head

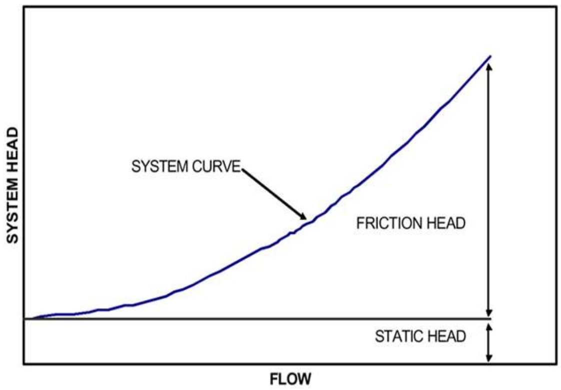
A closed loop circulating system without a surface open to atmospheric pressure, would exhibit only friction losses and system friction head loss vs. flow curve as Figure

In real cases,most systems have a combination of static and friction head and the system curves as below

System with high static head

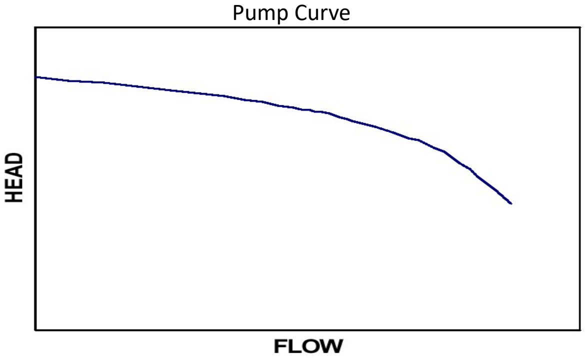


System with low static head

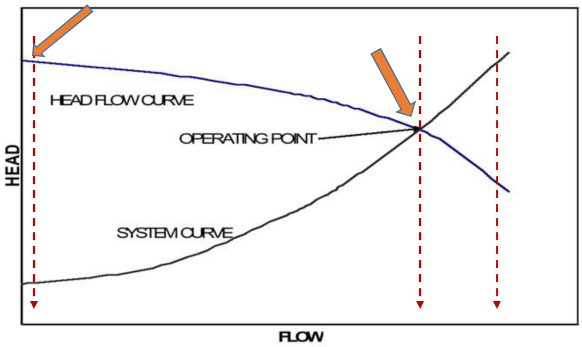


4 Pump curves

Pump Curve



Head- Flow Curve



Pump operating point

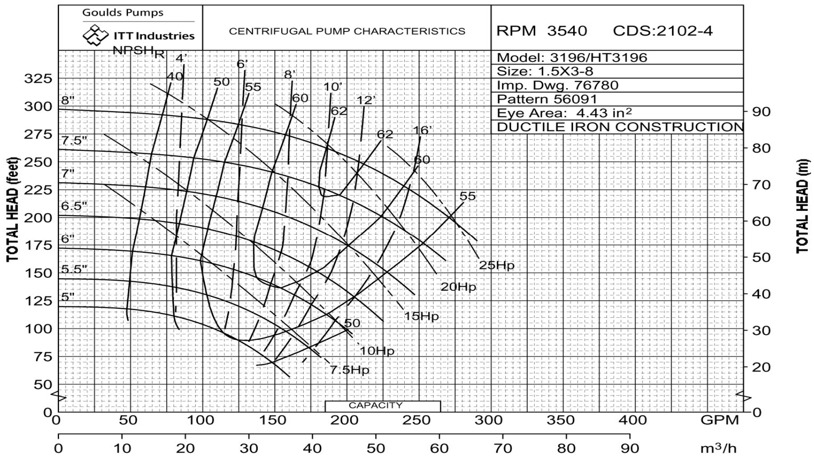
oversized pump will operate at an excessive flow rate or in a throttled condition, which increases energy use and reduces pump life.

The centrifugal pump has a curve where the head falls gradually with increasing flow. Graphical representation performance of a pump

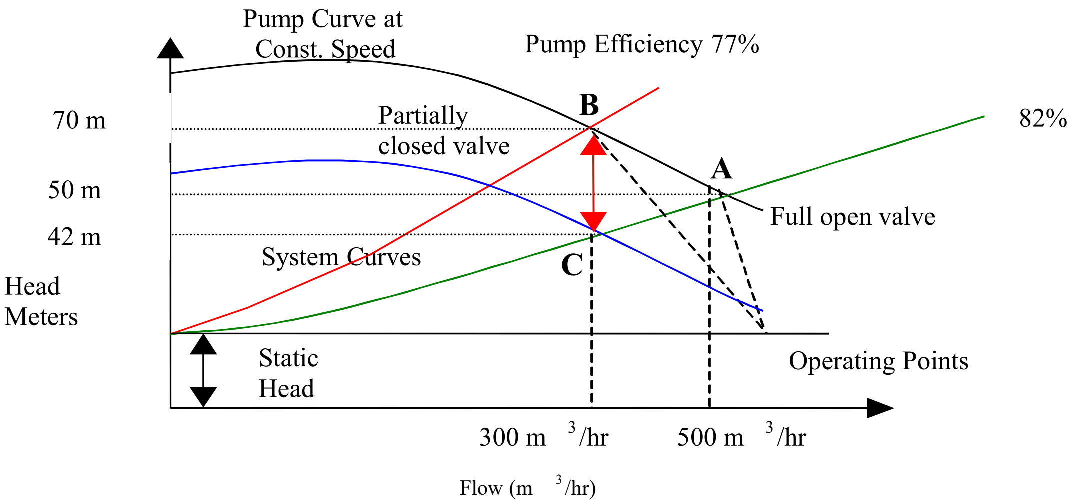
When a pump is installed in a system the effect can be shown by superimposing pump and system curves. The operating point will always be where the two curves intersect. As increasing system resistance will reduce the flow, eventually to zero, but the maximum head is limited as shown

5.Factors Affecting Pump Performance

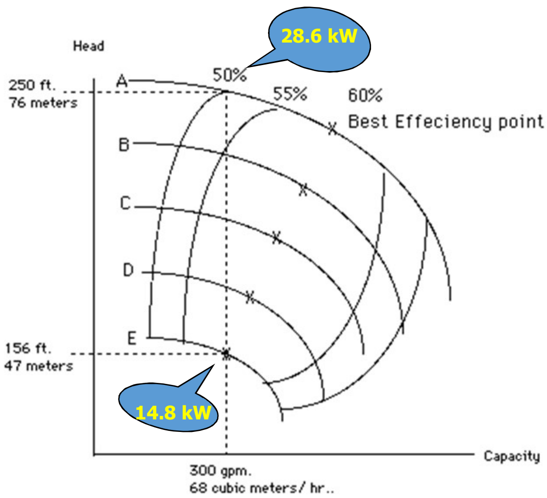
Vendor supplied pump characteristic curves



6.How to select a pumps?



7.Efficiency Curves



*If we select **E**, then the pump efficiency is **60%***

Hydraulic Power= $\frac{Q\,(m^3/s) \times \text{Total head}, h_d - h_s\,(m) \times \rho\,(kg/m^3) \times g\,(m^2/s)}{1000}$

$= \frac{(68/3600) \times 47 \times 1000 \times 9.81}{1000}$

= 8.7 kW

Shaft Power = 8.7 / 0.60 = 14.5 Kw

Motor Power = 14.8 / 0.9 = 16.1Kw

(considering a motor efficiency of 90%)

*If we select **A**, then the pump efficiency is **50%***

$$\text{Hydraulic Power} = \frac{Q\,(m^3/s) \times \text{Total head, } h_d - h_s\,(m) \times \rho\,(kg/m^3) \times g\,(m^2/s)}{1000}$$

$$= \frac{(68/3600) \times 76 \times 1000 \times 9.81}{1000}$$

$$= 14\ kW$$

Shaft Power = 14 / 0.50 = 28 Kw

Motor Power = 28 / 0.9 = 31 Kw

(considering a motor efficiency of 90%)

Using oversized pump !

As shown in the drawing, we should be using impeller "E" to do this, but we have an oversized pump so we are using the larger impeller "A" with the pump discharge valve throttled back to 68 cubic meters per hour, giving us an actual head of 76 meters.

- Hence, additional power drawn by A over E is
- = 31 –16.1 = **14.9 kW.**
- Extra energy used= 8760 hrs/yr x 14.9= 1,30,524 kw.

= Rs. 5,22,096/annum

In this example, the extra cost of the electricity is more than the cost of purchasing a new pump.

8. Efficient Pumping System Operation

Symptoms that Indicate Potential for Energy Savings		
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

9. Effect of speed variation

Flow vs Speed

If the speed of the impeller is increased from N_1 to N_2 rpm, the flow rate will increase from Q_1 to Q_2 as per the given formula:

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

The affinity law for a centrifugal pump with the impeller diameter held constant and the speed changed:

Flow:

Q1 / Q2 = N1 / N2

Example: 100 / Q_2 = 1750/3500

Q_2 = 200 m^3/hr

The head developed(H) will be proportional to the square of the quantity discharged, so that

$$\frac{H_1}{H_2} = \frac{Q_1^2}{Q_2^2} = \frac{N_1^2}{N_2^2}$$

Head:

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

Example:100 /H_2 = 1750 2 / 3500

H_2 = 400 m

Power Vs Speed

The power consumed(W) will be the product of H and Q, and, therefore

$$\frac{W_1}{W_2} = \frac{Q_1^3}{Q_2^3} = \frac{N_1^3}{N_2^3}$$

Power(kW):

kW1 / kW2 = ($N1^3$) / ($N2^3$)

Example: 5/kW_2 = 17503 / 35003

kW_2 = 40

$Q \propto N$

$H \propto N^2$

$P \propto N^3$

The affinity law for a centrifugal pump with the speed held constant and the impeller diameter changed

Flow:

Q1 / Q2 = D1 / D2

Example: 100 / Q2 = 8/6

Q2 = 75 m^3/hr

Head:

H1/H2 = (D1) x (D1) / (D2) x (D2)

Example: 100 /H2 = 8 x 8 / 6 x 6

H2 = 56.25 m

Horsepower(BHP):

kW1 / kW2 = (D1) x (D1) x (D1) / (D2) x (D2) x (D2)

Example: 5/kW2 = 8 x 8 x 8 / 6 x 6 x 6

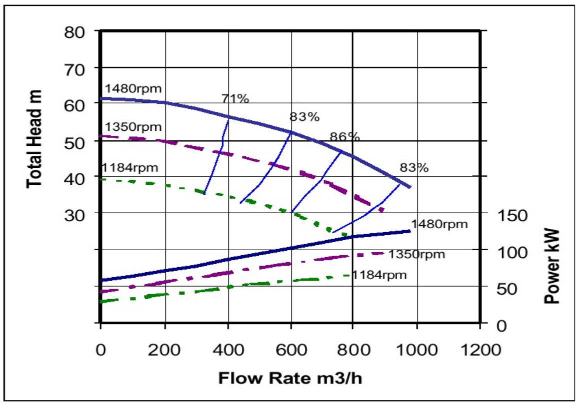
kW2 = 2.1 kW

$Q \propto D$

$H \propto D^2$

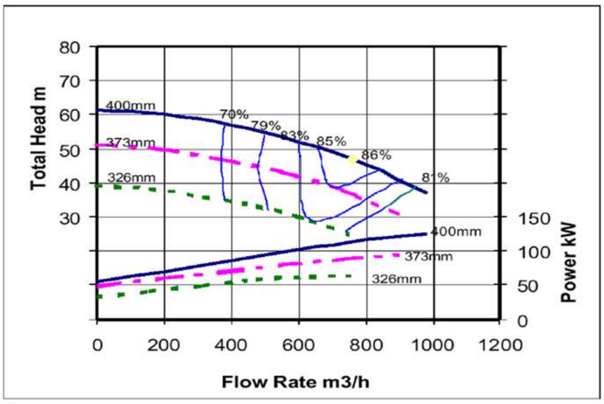
$P \propto D^3$

Effect of speed variation



Example of Speed Variation Effecting Centrifugal Pump Performance

Impeller Diameter Reduction on Centrifugal Pump Performance



Example: Impeller Diameter Reduction on Centrifugal Pump Performance

10. Pump suction performance (NPSH)

- ❑Net Positive Suction Head Available – (NPSHA)
- ❑NPSH Required – (NPSHR)
- ❑Cavitation

$Q \propto N$

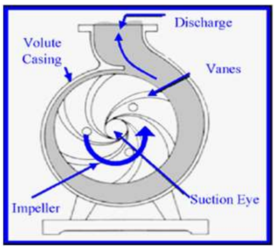
$NPSHR \propto N^2$

- NPSHR increases as the flow through the pump increases. As flow increases in the suction pipework, friction losses also increase, giving a lower NPSHA at the pump suction, both of which give a greater chance that cavitation will occur .

(NPSHA). It is the characteristic of the system design:
The value, by which the liquid pressure at the eye exceeds the liquid vapour pressure called as Net Positive Suction Head Available
(NPSHR). It is the characteristic of the pump design:
The value of NPSH needed at the pump suction to prevent the pump from cavitation is known as NPSH Required

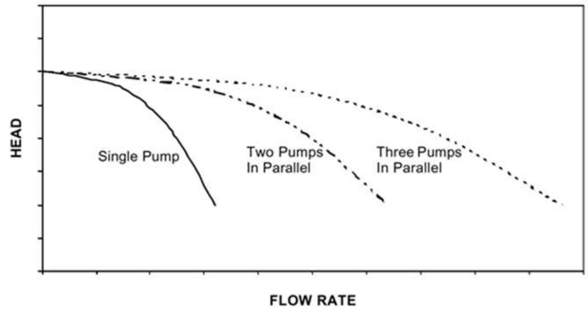
Cavitation has three undesirable effects:

1. Collapsing cavitation bubbles can erode the vane surface,
2. Noise and vibration are increased, shortened seal and bearing life.
3. Cavity areas will partially choke the impeller passages and loss of pump developed head occurs.

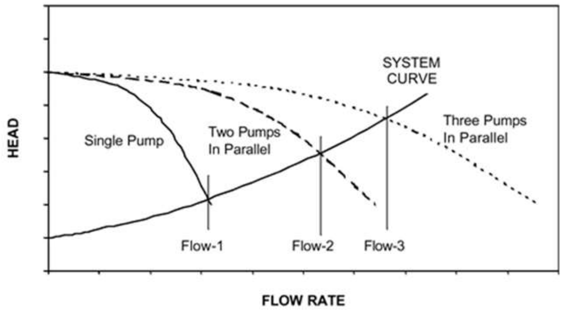


11. Flow Control Strategies

Pumps in parallel switched to meet demand



Pumps in parallel with system curve



12.Boiler Feed Water Pumps (BFP)

Boiler Feed Pump Control with VFD

There are several ways of controlling the pump

- **One pump, one boiler, no feed water regulating valve**
- In this the pump speed is varied according to the level of water in the boiler. The level control system used for the feed water admission valve transmits its signal directly to the pump VFD controller.
- **Constant discharge pressure control**
- The feed pump is controlled to a predetermined pressure setting irrespective of plant load.
- **Constant differential pressure control**
- Feed pump pressure is controlled to produce a predetermined pressure drop across the feed water regulating valve, usually approximately 3.5 – 5.5 kg/cm^2, thus allowing the boiler feed pump to follow plant demand.

Optimizing Boiler Feed Water Pump Capacity - Case

- A waste heat boiler has two feed water pumps, each of 6 stages and having a capacity of 35 m^3/hr. The pumps are designed to generate a head of 276 m, normally one pump is operated
- The actual steam demand is 28 TPH at 15 kg/cm^2. The capacity of the feed water pumps is far in excess of the requirement. This results in throttling of pump discharge leading to energy loss. To save energy in the BFW pumps, it was suggested to **remove two impeller stages of the pump** to effectively regulate the pressure developed in the pumps.

Power Drawn Before and After	
Operation of pumps	
With 6 stages (impellers)	53 kW
With 4 stages (impellers)	35 kW
Actual power savings achieved	18 kW

13.Municipal Water Pumping System

- Municipal water pumps are predominantly centrifugal pumps and vertical turbine pumps.
- The capacity of a water pumping station is normally specified in Million Liters per Day (**MLD**) of water handled.

Municipal water sub systems:

a) Raw water pump house, intake pumps at water source/river

b) Pure water pump house and filtration plant

c) Booster station as per the requirement

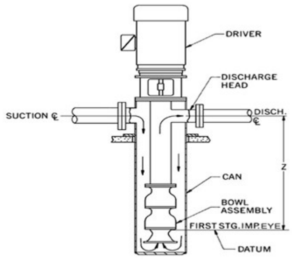
d) Elevated Storage Reservoirs in the distribution system

Vertical turbine pump is vertical axis centrifugal or mixed flow type pump comprising of stages which accommodate rotating impellers and stationary bowls possessing guide vanes.

Construction:

1. Pump Element
2. Discharge Column
3. Discharge head

Submersible Pump:A vertical turbine pump close coupled to a small diameter submersible electric motor is termed as “submersible pump”. The pump element and the motor operate under submerged condition. It can be used in very deep tube well where a long shaft would not be practical.



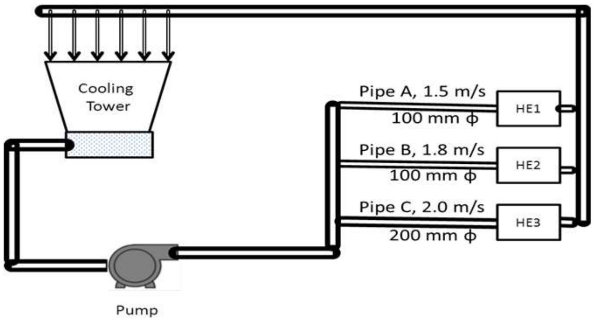
Vertical Turbine Pump

14.Energy Conservation Opportunities in Pumping Systems

1. Ensure adequate NPSH at site of installation
2. Operate pumps near best efficiency point.
3. Modify pumping system/pumps losses to minimize throttling.
4. Adapt to wide load variation with variable speed drives
5. Stop running multiple pumps - add an auto-start for an on-line spare or add a booster pump in the problem area.
6. Conduct water balance to minimise water consumption
7. Replace old pumps by energy efficient pumps

Solved Example:

The cooling water circuit of a process industry is depicted in the figure below. Cooling water is pumped to three heat exchangers via pipes A, B and C where flow is throttled depending upon the requirement. The diameter of pipes and measured velocities with non-contact ultrasonic flow meter in each pipe are indicated in the figure.



The following are the other data:
Measured motor power : 50.7 kW
Motor efficiency at operating load: 90%
Pump discharge pressure : 3.4 kg/cm^2
Suction head : 2 meters
Determine the efficiency of the pump.

Flow in pipe A	22/7 x $(0.1)^2$/4 x 1.5
	0.011786 m^3/s
Flow in pipe B	22/7 x $(0.1)^2$/4 x 1.8
	0.014143 m^3/s
Flow in pipe C	22/7 x $(0.2)^2$/4 x 2.0
	0.062857 m^3/s
Total flow	0.088786 m^3/s
Total head	34 m – 2 m = 32 m
Pump hydraulic power	0.088786 x 32 x 9.81=27.9 kW
Pump efficiency	27.9 x 100/50.7 x 0.9=61 %

QUESTIONS	
Objective Type Questions	
1.	What is the impact on flow and pressure when the impeller of a pump is trimmed? a) flow decreases with increased pressure b) both flow and pressure increases c) both pressure and flow decreases d) none of the above
2.	The most efficient method of flow control in a pumping system is______________. a) throttling the flow b) speed control c) impeller trimming d) bypass control
3.	In case of centrifugal pumps, impeller diameter changes are generally limited to reducing the diameter to about _____ of maximum size. a) 75% b) 50% c) 25% d) none of the above
4.	Generally water pipe lines are designed with water velocity of a) < 1m/s b) up to 2 m/s c) > 2 m/s d) None of the above
5.	The head generated by a centrifugal pump is a) Independent of the density of the liquid being pumped. b) Directly proportional to the density of the liquid being pumped. c) Inversely proportional to the density of the liquid being pumped. d) Proportional to the square of the density of the liquid being pumped.

Thank You

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