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Chapter 7
CENTRIFUGAL PUMPS IN PIPELINES
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Learning Outcomes

Upon completing this chapter, the students are expected to be able to:
1) *Identify the components of a centrifugal pump.*
2) *Identify the characteristics of multistage pumps.*
3) *Illustrate the characteristics of a centrifugal pump.*
4) *List the affinity laws of a centrifugal pump.*
5) *Calculate the specific speed of a pump.*
6) *Determine the operating point of a pump connected in pipeline system.*

7.1) Introduction

- Pumps are hydraulic machines that convert mechanical energy to fluid energy. On the other hand, turbines convert fluid energy to mechanical energy.
- There are several types of pumps used in civil engineering project. The most popular one is centrifugal pump.

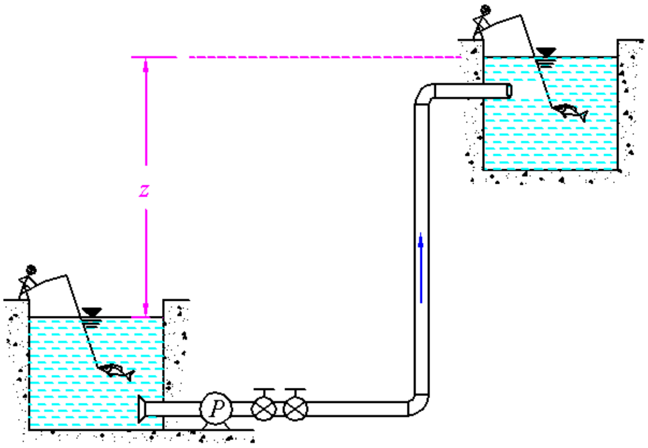
7.2) Centrifugal Pumps

- The fluid enters the pump chamber along the axis of the impeller and is discharged radially by centrifugal action.
- A foot valve is installed in the suction pipe to prevent water from leaving the pump when it is stopped.
- A check valve is installed in the discharge pipe to prevent backflow if there is power failure.
- The size of the suction pipe should never be smaller than the delivery pipe.

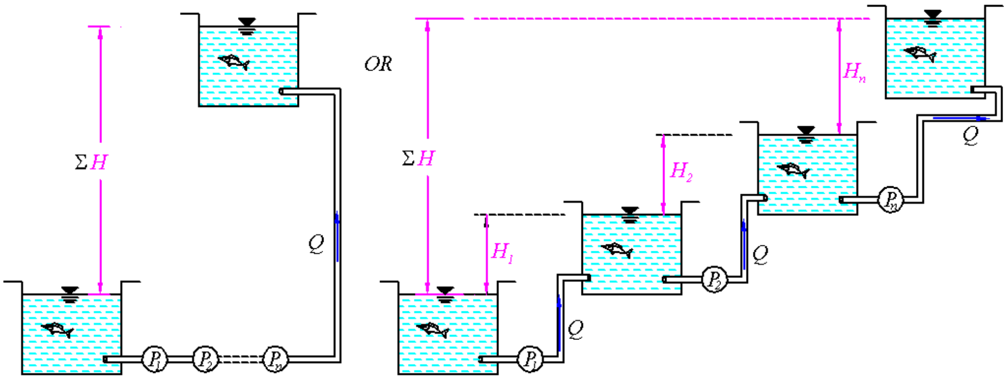
7.3) Multistage Centrifugal Pumps

More than one pump can be installed whether in Series or in Parallel.

7.3.1) Single Stage Pump



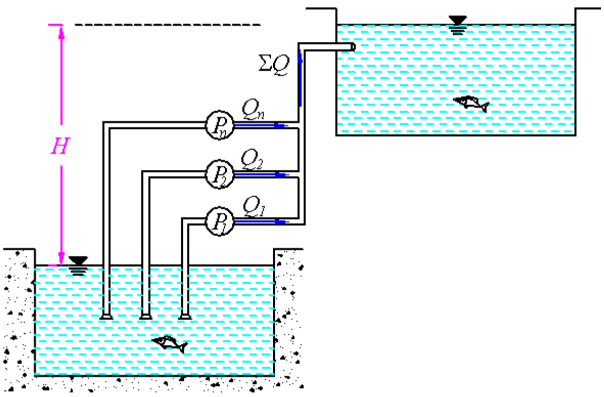
7.3.2) Pumps in Series



- Single suction pipe – to increase head if one pump is insufficient for the same flow rate.
- If all pumps are identical: Q is the same for each pump

$$H_{total} = \sum_{i=1}^{n} H_i$$

7.3.3) Pumps in Parallel

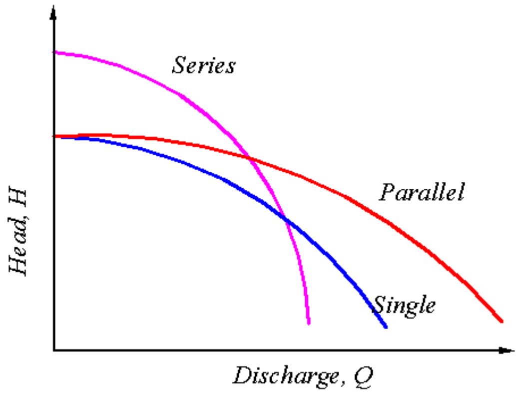


- To increase flow rate if one pump is insufficient for the same head.

- If all pumps are identical: *H* the same for each pump

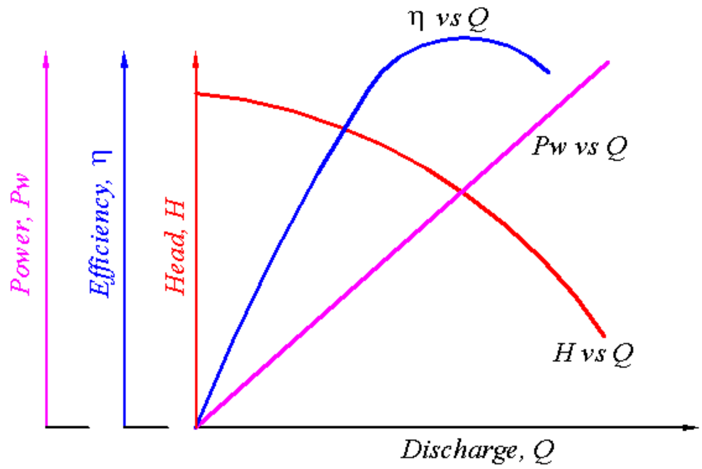
$$Q_{total} = \sum_{i=1}^{n} Q_i$$

H vs Q curves for single, pumps in series and parallel.

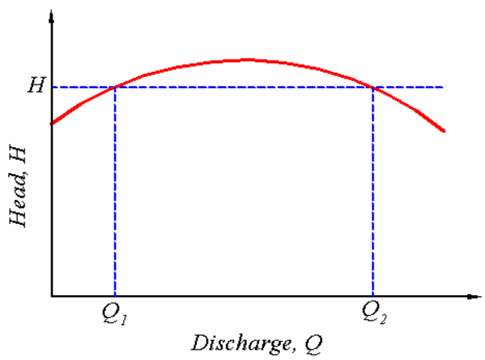


7.4) Pump Characteristics

- The pump characteristics are as shown in the figure – characteristics curve.
- For *H* vs *Q* curve – if *Q* = 0, pump is operating but the valve in the delivery pipe is closed, the head is maximum – shutoff head.



- which for one value of head H, there are two values of discharge Q.



- The pump efficiency is calculated by:

$$\eta = \frac{P_{out}}{P_{in}} \times 100\%$$

where:

P_{out} = power delivered to the fluid

$P_{out} = \rho g H Q$ *Watt*

P_{in} = power supplied to the pump shaft $P_{in} = \frac{P_{out}}{\eta} \times 100$ *Watt*

= $2\pi NT$ *Watt*

where N = pump impeller speed (revolution/minute)

T = the torque (moment) of the shaft (N.m)

7.5) Affinity Laws

- The pump impeller speed (N) and the impeller diameter (D) can be change to change the pump capacity.
- If N and D is changed, the flow rate (Q), the pump head (H) and the pump power (P) is also change according to the affinity laws:

7.5.1) *D* constant and *N* varies:

Flow rate: $$\frac{Q_2}{Q_1} = \frac{N_2}{N_1}$$

Head: $$\frac{H_2}{H_1} = \left(\frac{N_2}{N_1}\right)^2$$

Power: $$\frac{P_2}{P_1} = \left(\frac{N_2}{N_1}\right)^3$$

7.5.2) *N* constant and *D* varies:

Flow rate: $$\frac{Q_2}{Q_1} = \frac{D_2}{D_1}$$

Head: $$\frac{H_2}{H_1} = \left(\frac{D_2}{D_1}\right)^2$$

Power: $$\frac{P_2}{P_1} = \left(\frac{D_2}{D_1}\right)^3$$

7.5.3) If Both N and D varies

Flow rate: $$\frac{Q_2}{Q_1} = \left(\frac{N_2}{N_1}\right)\left(\frac{D_2}{D_1}\right)^3$$

Head: $$\frac{H_2}{H_1} = \left(\frac{N_2}{N_1}\right)^2\left(\frac{D_2}{D_1}\right)^2$$

7.5.4) More Than One Homologous Pump

In Series: $H_2 = nH_1$ ⟶ Q the same

In Parallel: $Q_2 = nQ_1$ ⟶ H the same

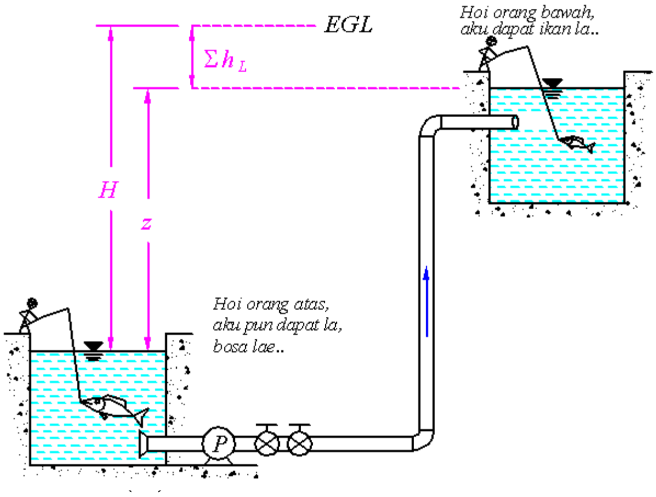
where n is the number of identical pumps.

7.6) Specific Speed, N_s

- N_s is the pump speed that can deliver a unit of volume per second of liquid at a unit of head, that is

$$N_s = \frac{NQ^{1/2}}{H^{3/4}}$$

7.7) Pump Operating Point



z = st

The head required by the pump to deliver water at static head z is:
Bernoulli's equation 1 to2:

$$\cancelto{0}{\frac{P_1}{\rho g}} + \cancelto{0}{\frac{v_1^2}{2g}} + z_1 + H_P = \cancelto{0}{\frac{P_2}{\rho g}} + \cancelto{0}{\frac{v_2^2}{2g}} + z_2 + \sum h_L$$

$H_p = z + \sum h_L$

$$\sum h_L = \sum k\frac{v^2}{2g} = \sum KQ^n$$

Note that ***k*** is NOT THE SAME as ***K***

- Head Loss (in meter): general formula $h_L = k\frac{v^2}{2g}$ or $h_L = KQ^n$

- What are coefficient *k*, *K* and *n*? Two formula can be adapted:

To derive the formula for ***K*** and ***n***:

(i) Darcy Weisbach:

$$h_L = \frac{4fL}{d}\frac{v^2}{2g} \longleftarrow k = \frac{4fL}{d}$$

$$h_L = \frac{4fL}{d}\frac{Q^2}{2gA^2} = \frac{4fL}{d\,2g\left(\frac{\pi d^2}{4}\right)^2}Q^2$$

$$h_L = \frac{fL}{3d^5}Q^2 \longleftarrow \boxed{K = \frac{fL}{3d^5}} \quad \text{and} \quad \boxed{n = 2}$$

(ii) Hazen-William:

$$h_L = \frac{133.9L}{C^{1.85}d^{1.17}v^{0.15}}\frac{v^2}{2g} \longleftarrow k = \frac{133.9L}{C^{1.85}d^{1.17}v^{0.15}}$$

$$h_L = \frac{133.9L}{C^{1.85}d^{1.17}}\frac{v^{1.85}}{2g} = \frac{133.9LQ^{1.85}}{C^{1.85}d^{1.17}\,2gA^{1.85}} = \frac{133.9L}{C^{1.85}d^{1.17}\,2g\left(\frac{\pi d^2}{4}\right)^{1.85}}Q^{1.85}$$

$$h_L = \frac{10.67L}{C^{1.85}d^{4.87}}Q^{1.85} \longleftarrow \boxed{K = \frac{10.67L}{C^{1.85}d^{4.87}}} \quad \text{and} \quad \boxed{n = 1.85}$$

where *C* is the Hazen Williams coefficient.

<u>Conclusion:</u>

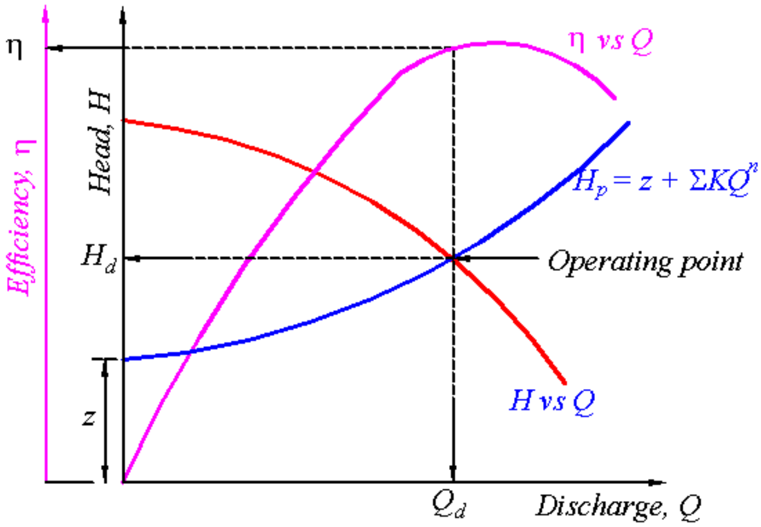
Darcy-Weisbach: $K = \frac{fL}{3d^5}$ and $n = 2$

Hazen-Williams: $K = \frac{10.67L}{C^{1.85}d^{4.87}}$ and $n = 1.85$

Therefore, the total head required by a pump is:

$$H_p = z + \sum KQ^n$$

The intersection between the characteristics curve of the pump (H vs Q) and the $H_p = z + \sum KQ^n$ curve is the **operating point** of the pump.



The pump characteristics curve or pump function curve or pump performance curve is to be provided by the pump manufacturer. The pipe system curve should be from the piping system installed or connected to the pump.

From the location of the Operating Point, determine the operating flow and head as well as the operating efficiency.