Objectives of Today's Lecture: Pumps

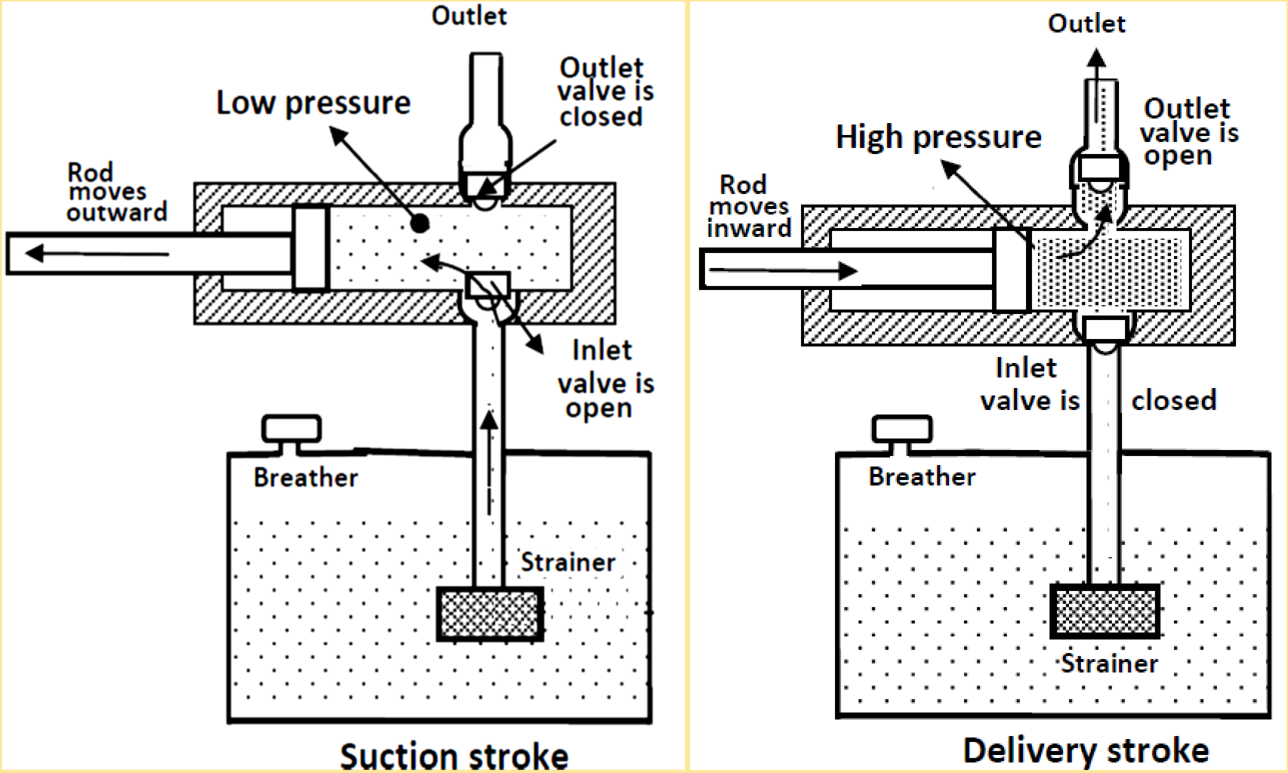
- What is a pump?
- What are its function?
- What are the types of pumps used for hydraulics system?
  - Based on Function (pressure and flow)
  - Based on Design or construction
- What are the different symbols?
- How are pump selected and rated (characteristics)?
- What are the quantities needed for pump performance; flow rate, power, pressure, etc.
- Troubles and issues with pumps

What is a pump?

- The pump is a device or machine that converts mechanical power to fluid power.
- It is a primary flow control device in any hydraulic circuit.
- A pump produces liquid movement or flow: **it does not generate pressure**.
- It produces the flow necessary for the development of pressure, which is a function of resistance to fluid flow in the system. For example, the pressure of the fluid at the pump outlet is *zero* for a pump not connected to a system (load).
- Further, for a pump delivering into a system, the pressure will rise only to the level necessary to overcome the resistance of the load.

Pump function

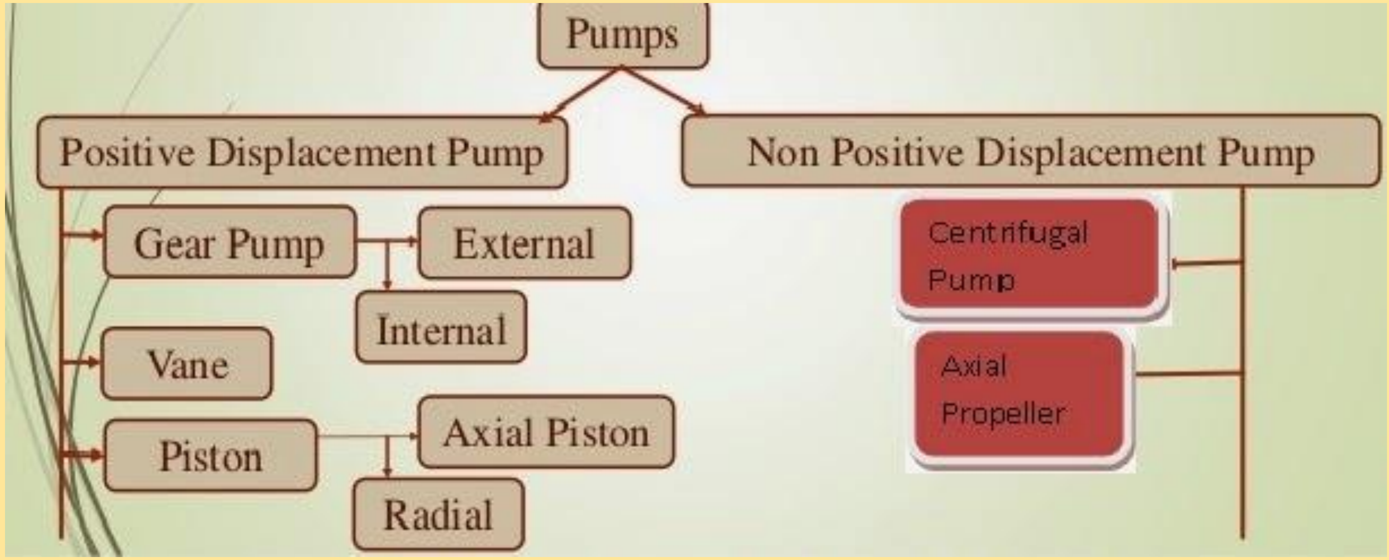
- The function of a pump is to convert mechanical energy into hydraulic energy.
- Mechanical energy is delivered to the pump using a prime mover such as an electric motor.
- Partial vacuum is created at the inlet due to the mechanical motion (rotation or reciprocation) of pump shaft.
- Vacuum permits atmospheric pressure to force the fluid through the inlet line and into the pump.
- The pump then pushes the fluid mechanically into the fluid power actuated devices such as a motor or a cylinder.



Pump classifications

Pumps are classified into three different ways;

- **based on displacement (volume):**
  - Non-positive displacement pumps (hydrodynamic)
  - Positive displacement pumps (hydrostatic)
- **based on delivery:**
  - Constant delivery pumps
  - Variable delivery pumps
- **based on motion:**
  - Rotary pump
  - Reciprocating pump



<u>Based on displacement:</u> Non-Positive Displacement Pumps

- The two most common types of non-positive displacement (hydrodynamic) pumps are;
  - The centrifugal
  - The axial flow propeller
- These types of pumps are primarily used for transporting fluids such as water, petroleum, etc., from one location to another considerable apart location.
- Non-positive displacement pumps are primarily velocity-type units that have a great deal of clearance between rotating and stationary parts.
- Non-displacement pumps are characterized by a high slip that increases as the back pressure increases, so that the outlet may be completely closed without damage to the pump or system.
- Non-positive pumps do not develop a high pressure but move a large volume of fluid at low pressures.

Based on displacement: Non-Positive Displacement Pumps

- The displacement between the inlet and the outlet is **not positive**. Therefore, the volume of fluid delivered by a pump depends on the **speed** at which the pump is operated and the **resistance** at the discharge side.
- These pumps are not self-priming because of large clearance space.
- As the resistance builds up at the discharge side, the fluid slips back into the clearance spaces, or in other words, follows the path of least resistance.
- When the resistance gets to a certain value, no fluid gets delivered to the system and the volumetric efficiency of the pump drops to zero for a given speed.
- These pumps are not used in fluid power industry as they are not capable of withstanding high pressure. Their maximum capacity is limited to 17–20 bar.

Based on displacement: Positive Displacement Pumps

Positive displacement pumps;

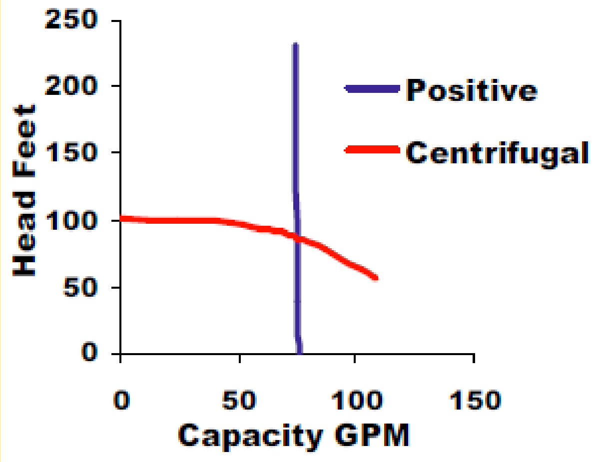
- Have a very close clearance between rotating and stationary parts and hence are self-priming
- Pump against very high pressures
- Discharge a fixed amount of fluid into the hydraulic system per revolution of the pump shaft
- Are capable of overcoming the pressure resulting from mechanical loads on the system as well as the resistance of flow due to friction
- Must always be protected by relief valves to prevent damage to the pump or system

By far, a majority of fluid power pumps fall in this category, including gear, vane and piston pumps.

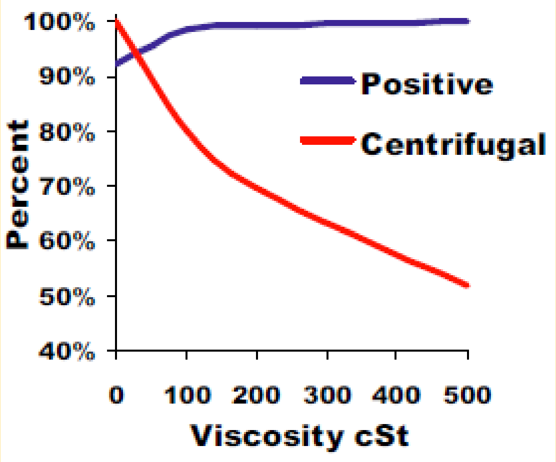
Classification of Positive displacement pumps

- **Type of motion of pumping element:** Based on the type of motion of pumping element, positive displacement pumps are classified as follows:
  - Rotary pumps, for example, gear pumps and vane pumps.
  - Reciprocating pumps, for example, piston pumps.
- **Displacement characteristics:** Based on displacement characteristics, positive displacement pumps are classified as follows:
  - Fixed displacement pumps.
  - Variable displacement pumps.
- **Type of pumping element**.

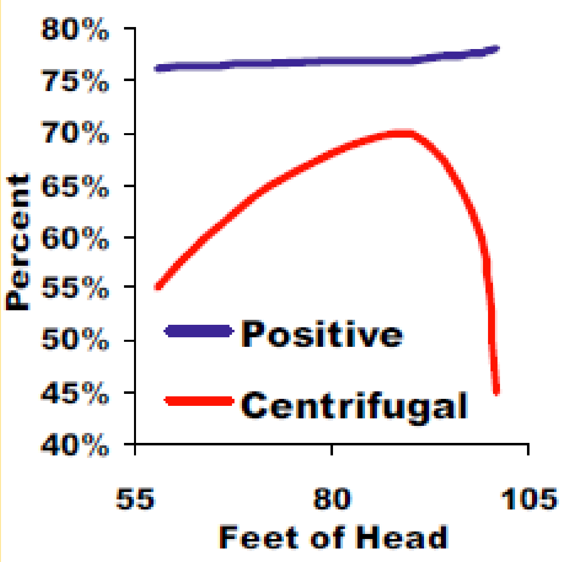
Performance of positive & non-positive pump



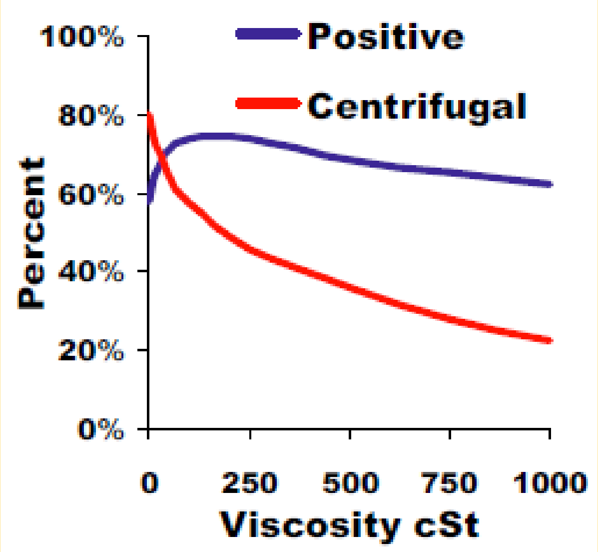
Flow rate versus pressure



Flow rate versus viscosity



Efficiency versus pressure



Efficiency versus viscosity

<u>Based on delivery:</u> Constant Delivery Pumps

- Constant volume pumps always deliver the same quantity of fluid in a given time at the operating speed and temperature.

- These pumps are generally used with relatively simple machines, such as saws or drill presses or where a group of machines is operated with no specific relationship among their relative speeds.

- Power for reciprocating actuators is most often provided by constant volume pumps.

Based on delivery: Variable Delivery Pumps

- The output of variable volume pumps may be varied either manually or automatically with no change in the input speed to the pump.

- Variable volume pumps are frequently used for rewinds, constant tension devices or where a group of separate drives has an integrated speed relationship such as a conveyor system or continuous processing equipment.

Classification Based on Motion:

This classification concerns the motion that may be either;

- *rotary*
- *reciprocating*

Present-day reciprocating pumps differ very little from rotary pumps in either external appearance or the flow characteristics.

Advantages/Disadvantages of displacement pumps

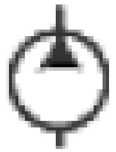
Non-Positive		**Positive**
Advantages	Disadvantages	Advantages
1. These have fewer moving parts. 2. Initial and maintenance cost is low. 3. They give smooth continuous flow. 4. They are suitable for handling almost all types of fluids including slurries and sledges. 5. Their operation is simple and reliable.	1. Non-displacement pumps are not self-priming and hence they must be positioned below the fluid level. 2. Discharge is a function of output resistance. 3. Low volumetric efficiency.	1. They can operate at very high pressures of up to 800 bar (used for lifting oils from very deep oil wells) 2. They can achieve a high volumetric efficiency of up to 98% 3. They are highly efficient and almost constant throughout the designed pressure range 4. They can obtain a smooth and precisely controlled motion 5. By proper application and control, they produce only the amount of flow required to move the load at the desired velocity.

Differences between positive displacement pumps and non-positive displacement pumps

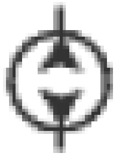
POSITIVE DISPLACEMENT PUMPS	NON-POSITIVE DISPLACEMENT PUMPS
The flow rate does not change with head	The flow rate decreases with head
The flow rate is not much affected by the viscosity of fluid	The flow rate decreases with the viscosity
Efficiency is almost constant with head	Efficiency increases with head at first and then decreases

Pumps: Symbol

Fixed Displacement hydraulic pump



- unidirectional



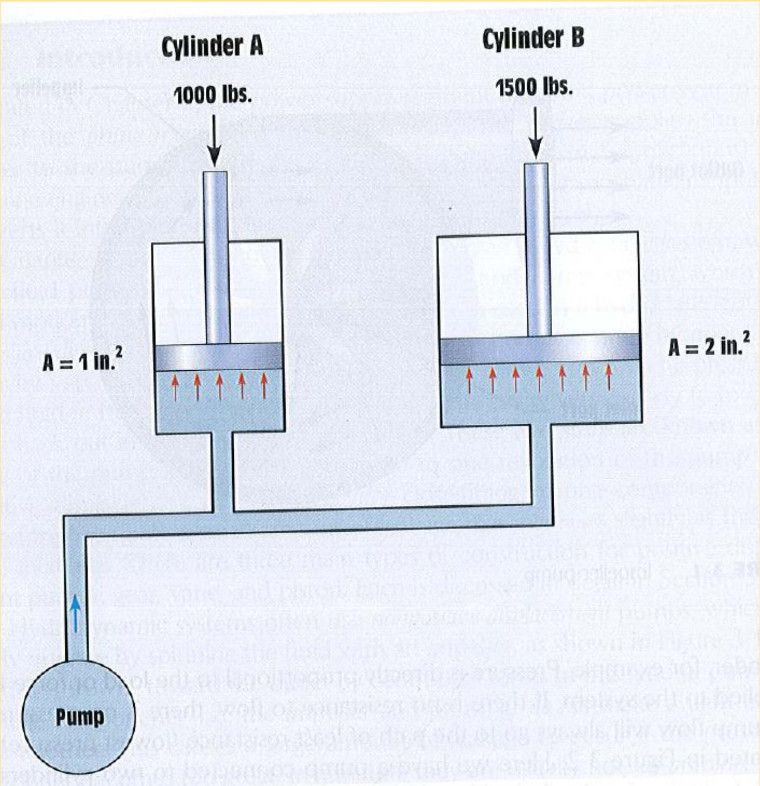
- bidirectional

Variable displacement hydraulic pump

- unidirectional

- bidirectional

Pump flow and pressure



- As it is clear that purpose of the pump is to create flow but not pressure. However, the pressure is generated when the flow is resisted (by putting a load on the cylinder).
- Pump flow will always follow (first) the path of least resistance (like electrical current).
- How can it be clarified?
- Consider the example of a two cylinders ***A*** & ***B*** loaded with ***1000 lbs*** & ***1500 lbs***, connected to a pump, having area of ***1 in²*** and ***2 in²*** respectively.
- Pressure needed to lift the Cylinder A; $P_A = \frac{F_A}{A_A} = \frac{1000\ \text{lb}}{1\ \text{in}^2} = 1000\ \text{psi}$
- Pressure needed to lift the Cylinder B; $P_B = \frac{F_B}{A_B} = \frac{1500\ \text{lb}}{2\ \text{in}^2} = 750\ \text{psi}$
- Therefore, the flow will go to first in Cylinder B which is a least resistance flow path and then to Cylinder A

Quantification of Hydraulics Pumps

- In general, positive displacement pumps are used for hydraulic applications.
- The volume of fluid that is discharged or transported per revolution of the rotating shaft is called the **displacement** (one complete revolution is known as one cycle).
- Units of displacement in SI system are usually, **cm^3/rev** and in US system are **in^3/rev**.
- Similarly, **delivery or output** of the pump is the volume of fluid that it outputs per unit time. It is also known as the flow rate of the pump.
- Flow rate is determined by the displacement of the pump and how fast the pump is driven.
- The drive speed of the pump is expressed in revolution per minute and is written as **rpm** or **rev/min**
- Most common drive speeds of the hydraulic pumps are 1200 rpm & 1800 rpm

PD-Pumps Used for Hydraulics (Design-wise)

- Three types of PD pumps are normally used in hydraulics;

1. **Piston pumps**
    - Radial piston
    - Axial piston
        - Bent-axis-type piston pump.
        - Swash-plate-type piston pump.
2. **Gear pumps**
    - External Gear pumps
    - Internal Gear pumps
    - Gerotor pumps
    - Lobe pumps
    - Screw pumps
3. **Vane pumps**
    - Unbalanced Vane pumps
        - Unbalanced vane pump with fixed delivery.
        - Unbalanced vane pump with pressure-compensated variable delivery
    - Balanced Vane pump

Comparison of Hydraulic Pumps

Pump selection is important decision in circuit design. Designer must compare the various options available and then choose the optimum pump. Following table gives a typical comparison of all pumps.

	Pressure (Bar)	Discharge(LPM)	MaximumSpeed (RPM)	Overall Efficiency
Gear pump	20–175	7–570	1800–7000	75–90
Vane pump	20–175	2–950	2000–4000	75–90
Axial piston pump	70–350	2–1700	600–6000	85–95
Radial piston pump	50–250	20–700	600–1800	80–92

"The major factor in adopting a pump to a particular system is the system's overall needs. It would be wrong to use a pump with high delivery in a system that requires only a low delivery rate. Also, using a pump that must produce at its maximum continuously just to meet the minimum requirements of the system is equally wrong. Making either of these mistakes produces a poor system due to excessive initial pump costs or maintenance cost."

Pump Performance: Volumetric efficiency (η_v)

The performance of a pump is determined by the following efficiencies:

- **Volumetric efficiency (η_v):** It is the ratio of actual flow rate of the pump to the theoretical flow rate of the pump. This is expressed as follows:

$$\text{Volumetric efficiency } (\eta_v) = \frac{\text{Actual flow rate of the pump}}{\text{Theoretical flow rate of the pump}} = \frac{Q_A}{Q_T}$$

Volumetric efficiency (η_v) indicates the amount of leakage that takes place within the pump. This is due to manufacture tolerances and bending of the pump casing under designed pressure operating conditions.

For gear pumps, $\eta_v = 80\%–90\%$.

For vane pumps, $\eta_v = 92\%$.

For piston pumps, $\eta_v = 90\%–98\%$.

Pump Performance: Mechanical efficiency (η_m)

- **Mechanical efficiency (η_m):** It is the ratio of the pump output power assuming no leakage to actual power delivered to the pump:

$$\text{Mechanical efficiency } (\eta_m) = \frac{\text{Pump output power assuming no leakages}}{\text{Actual power delivered to the pump}}$$

$$\eta_m = \frac{p\,Q_T}{T_A N}$$

Where
p is the pump discharge pressure in Pa or N/m^2,
$\boldsymbol{Q_T}$ is the theoretical flow rate of the pump in m^3/s,
$\boldsymbol{T_A}$ is the actual torque delivered to the pump in N-m
N is the speed of the pump in rad/s.

Mechanical efficiency(η_m) indicates the amount of energy losses that occur for reasons other than leakage. For example;

- Friction in bearings and between mating parts.
- Energy losses due to fluid turbulence.

Mechanical efficiencies are about 90%–95%.

Overall efficiency (η_o)

It is defined as the ratio of actual power delivered by the pump to actual power delivered to the pump.

$$\text{Overall efficiency } (\eta_o) = \frac{\text{Actual power delivered by the pump}}{\text{Actual power delivered to the pump}}$$

Overall efficiency (η_o) considers all energy losses and can be represented mathematically as follows:

$$\text{Overall efficiency } (\eta_o) = \eta_v \, \eta_m$$

$$\eta_o = \frac{Q_A}{Q_T} \times \frac{pQ_T}{T_A N}$$

Pump Selection

The main parameters affecting the selection of a particular type of pump are as follows:

1. Maximum operating pressure.
2. Maximum delivery.
3. Type of control.
4. Pump drive speed.
5. Type of fluid.
6. Pump contamination tolerance.
7. Pump noise.
8. Size and weight of a pump.
9. Pump efficiency.
10. Cost.
11. Availability and interchangeability.
12. Maintenance and spares.

Problem solving session on Pump

- Review of equations
  - Theoretical flow rate of the pump;

$$Q_T = V_p \cdot N$$

where: Q_T = theoretical flow rate of the pump $\left(\frac{in^3}{min}, \frac{cm^3}{min}\right)$

V_p = pump displacement $\left(\frac{in^3}{rev}, \frac{cm^3}{rev}\right)$

N = drive speed $\left(\frac{rev}{min}\right)$

  - Theoretical flow rate of the pump in gallons per min (US units);

$$Q_T = \frac{V_p \cdot N}{231}$$

V_p in in³/rev, N in rpm, and Q_T in gpm.

  - Theoretical flow rate of the pump in metric (SI) units;

$$Q_T = \frac{V_p \cdot N}{1000}$$

V_p in cm³/rev, N in rpm, and Q_T in lpm.

Problem solving session on Pump

1. **Example problem on Theoretical flow rate of the pump (in US units);**

A pump has a displacement of 2 in³/rev and is driven at 1200 rpm. What is its theoretical flow rate?

$$Q_T = \frac{V_p \cdot N}{231} = \frac{2\,\dfrac{\text{in}^3}{\text{rev}} \cdot \left(1200\,\dfrac{\text{rev}}{\text{min}}\right)}{231\,\dfrac{\text{in}^3}{\text{gal}}} = 10.4\,\frac{\text{gal}}{\text{min}}$$

2. **Example problem on Theoretical flow rate of the pump (in Metric units);**

A pump has a displacement of 30 cm³/rev and is driven at 1200 rpm. What is its theoretical flow rate?

$$Q_T = \frac{V_p \cdot N}{1000} = \frac{30\,\dfrac{\text{cm}^3}{\text{rev}} \cdot \left(1200\,\dfrac{\text{rev}}{\text{min}}\right)}{1000\,\dfrac{\text{cm}^3}{l}} = 36.0\,\frac{l}{\text{min}}$$

Problem solving session on Pump

- **Example problem on Theoretical flow rate of the pump (in US units);**

A flow rate of 8 gpm is required for a system. If we use 1800 rpm electric motor to drive a pump. What should the displacement be to achieve this flow rate? Assume 100 % efficiency.

$$V_p = \frac{231 \cdot Q_T}{N} = \frac{231 \frac{in^3}{gal} \cdot \left(8 \frac{gal}{min}\right)}{1800 \frac{rev}{min}} = 1.03 \frac{in^3}{rev}$$

Assume that you have not found a pump which can have this displacement (1.03 in^3/rev), instead you have located a pump whose displacement is 1.15 in^3/rev. What will the flow rate be with this pump?

$$Q_T = \frac{V_p \cdot N}{231} = \frac{1.15 \frac{in^3}{rev} \cdot \left(1800 \frac{rev}{min}\right)}{231 \frac{in^3}{gal}} = 8.96 \frac{gal}{min}$$

Pump Performance: Mechanical efficiency (η_m)

Mechanical Efficiency (η_m) can also be expressed/computed in terms of torque as follows:

$$\eta_{\mathrm{m}} = \frac{\text{Theoretical torque required to operate the pump}}{\text{Actual torque delivered to the pump}} = \frac{T_{\mathrm{T}}}{T_{\mathrm{A}}}$$

The theoretical torque (T_{T}) required to operate the pump is the torque that would be required if there were no leakage. The theoretical torque (T_{T}) is determined as follows;

$$T_T = \frac{p \cdot V_p}{2 \cdot \pi}$$

The actual torque (T_{A}) is determined as follows;

$$\text{Actual torque } T_{\mathrm{A}} \text{ (N m)} = \frac{P}{\omega}\left(\frac{\text{N m/s}}{\text{rad/s}}\right) = \text{N m.}$$

Where;
$\omega = 2\ \pi\ N\,/60.$
N is the speed in RPM.

Problem solving session on Pump

- Pump Drive Torque & Power

$$T = F \cdot d$$

The above equation is generally used to explain the concept of Torque, however, to calculate the required torque to overcome the generated pressure is;

$$T_T = \frac{p \cdot V_p}{2 \cdot \pi}$$

T_T is the theoretical drive torque.

In US units, each quantity in above equation is expressed as; V_P in in^3/rev, p in lbs/in^2, and T in in · lbs.

In metric units, each quantity in above equation is expressed as; V_P in m^3/rev, p in N/m^2, and T in N · m.

Displacement in the metric system, however, is usually given in cm^3/rev.

The conversion factor used to convert from cm^3/rev to m^3/rev is

$$1 \text{ m}^3 = 1{,}000{,}000 \text{ cm}^3.$$

The factor 2π is a conversion from revs to radians

Problem solving session on Pump

- **Problem on Drive Torque in US system**

A hydraulic pump with a displacement of 3 in^3/rev is selected for a system that will operate at a maximum pressure of 3000 psi. What is the required driving torque? Assume 100 % efficiency.

$$T_T = \frac{p \cdot V_p}{2 \cdot \pi} = \frac{3000 \frac{\text{lb}}{\text{in}^2} \cdot \left(3 \frac{\text{in}^3}{\text{rev}}\right)}{2 \cdot \pi} = 1432 \text{ in} \cdot \text{lbs}$$

- **Problem on Drive Torque in SI system**

A hydraulic pump with a displacement of 40 cm^3/rev is selected for a system that will operate at a maximum pressure of 20,000 kPa. What is the required driving torque? Assume 100 % efficiency.

1. Convert to m^3/rev:

$$40 \frac{\text{cm}^3}{\text{rev}} \cdot \left(\frac{1 \text{ m}^3}{1{,}000{,}000 \text{ cm}^3}\right) = 0.00004 \frac{\text{m}^3}{\text{rev}}$$

2. Calculate the drive torque:

$$T_T = \frac{p \cdot V_p}{2 \cdot \pi} = \frac{20{,}000{,}000 \frac{\text{N}}{\text{m}^2} \cdot \left(0.00004 \frac{\text{m}^3}{\text{rev}}\right)}{2 \cdot \pi} = 127.3 \text{ N} \cdot \text{m}$$

Problem solving session on Pump

- **Pump Input Power in US system of units**

The input power provided/generated by the prime mover/rotating shaft can be determined by multiplying the torque by the rotational speed as;

$$HP_I = \frac{T \cdot N}{63,025}$$

HP_I is the input horsepower to the pump. The factor 63,025 in the denominator is a combination of conversion factors that allows to use T in $in \cdot lbs$, N in $rpms$, and HP_I in hp.

- **Pump Input Power in SI system of units**

The following equation can be used when calculating the required input power in kilowatts (metric units)

$$kW_I = \frac{T \cdot N}{9550}$$

The factor 9550 in the denominator is a combination of conversion factor that allows to use ***T*** in **N . m,** ***N*** in ***rpm*** and kW_1 in **kW**

Problem solving session on Pump

- **Power input to Pump in US system**

An electrical motor drives a pump at 1800 rpm with a torque of 350 in . lbs. What is the power input to this pump?

$$HP_I = \frac{T \cdot N}{63,025} = \frac{350 \text{ in} \cdot \text{lbs} \cdot (1800 \text{ rpm})}{63,025} = 10.0 \text{ hp}$$

- **Power input to Pump in SI system**

An electrical motor drives a pump at 1800 rpm with a torque of 40 N . m. What is the power input to this pump?

$$kW_I = \frac{T \cdot N}{9550} = \frac{40 \text{ N} \cdot \text{m} \cdot (1800 \text{ rpm})}{9550} = 7.54 \text{ kW}$$

Problem solving session on Pump

- **Pump output Power in US system of units**

The hydraulic power of a fluid flowing under pressure can be calculated as;

$$HP_H = \frac{p \cdot Q}{1714}$$

The factor 1714 in the denominator is a combination of conversion factor that allows to use ***p*** in **psi, *Q*** in ***gpm*** and $\boldsymbol{HP_H}$ in **hp**

- **Pump output Power in SI system of units**

The following equation can be used when calculating the required input power in kilowatts (metric units)

$$kW_H = \frac{p \cdot Q}{60{,}000}$$

The factor 60,000 in the denominator is a combination of conversion factor that allows to use ***p*** in **kPa, *Q*** in ***lpm*** and $\boldsymbol{kW_H}$ in **kW**

Problem solving session on Pump

- **Power output by the Pump in US system**

A hydraulic pump has a flow rate of 20 gpm and is rated for a maximum pressure of 2500 psi. What is the maximum power output of this pump?

$$HP_H = \frac{p \cdot Q}{1714} = \frac{2500 \text{ psi} \cdot (20 \text{ gpm})}{1714} = 29.2 \text{ hp}$$

- **Power output by the Pump in SI system**

A hydraulic pump has a flow rate of 75 lpm and is rated for a maximum pressure of 20,000 kPa. What is the maximum power output of this pump?

$$kW_H = \frac{p \cdot Q}{60,000} = \frac{20,000 \text{ kPa} \cdot (75 \text{ lpm})}{60,000} = 25 \text{ kW}$$

Problem solving session on Pump

- Homework (do it yourself)

A hydraulic power unit (electric motor and pump) produces a flow rate of 15 gpm and has a maximum power rating of 25 hp. What is the maximum pressure at which this unit can operate? Assume 100% efficiency.

Problem solving session on Pump

- **Pump volumetric efficiency (η_v):** It is the ratio of actual flow rate of the pump to the theoretical flow rate of the pump. This is expressed as follows:

$$\eta_V = \frac{Q_A}{Q_T}$$

where: η_v = the Greek letter eta = volumetric efficiency (no units)
Q_A = actual flow rate (gpm, lpm)
Q_T = theoretical flow rate (gpm, lpm)

- **Pump actual flow rate Q_A *(in US system)***

$$Q_A = \eta_V \cdot \frac{V_p \cdot N}{231}$$

Where, $\boldsymbol{V_p}$ in in^3/rev, $\boldsymbol{Q_A}$ in ***gpm*** and N in **rpm**

- **Pump actual flow rate Q_A *(in SI system)***

$$Q_A = \eta_V \cdot \frac{V_p \cdot N}{1000}$$

Where, $\boldsymbol{V_p}$ in cm^3/rev, $\boldsymbol{Q_A}$ in ***lpm*** and N in **rpm**

Problem solving session on Pump

A pump has a displacement of 2 in³/rev and a volumetric efficiency of 0.92. If it is driven at 1200 rpm, what will its actual flow rate be?

SOLUTION:

$$Q_A = \eta_V \cdot \frac{V_p \cdot N}{231} = 0.92 \cdot \frac{2\,\frac{in^3}{rev} \cdot \left(1200\,\frac{rev}{min}\right)}{231\,\frac{in^3}{gal}} = 9.56\,\frac{gal}{min}$$

A pump has a displacement of 50 cm³/rev and a volumetric efficiency of 0.90. If it is driven at 1200 rpm, what will its actual flow rate be?

SOLUTION:

$$Q_A = \eta_V \cdot \frac{V_p \cdot N}{1000} = 0.90 \cdot \frac{50\,\frac{cm^3}{rev} \cdot \left(1200\,\frac{rev}{min}\right)}{1000\,\frac{cm^3}{1}} = 54.0\ \text{lpm}$$

Homework

- Problem 1 (first part)

A flow of 5 gpm is required in a new system. The pump type chosen has a volumetric efficiency of 0.88 and will be driven at 1200 rpm. What size (displacement) should we select?

- Problem 1 (2nd part)

Assume that you have not found a pump which can have the displacement calculated in first part of the problem, instead you have located a pump whose displacement is 1.15 in^3/rev. What will the flow rate be with this pump?

Mechanical Efficiency

- Other than leakage losses (volumetric losses), pumps have losses due to mechanical forces such as friction. These losses are measured by mechanical efficiency. Mechanical Efficiency (η_m) can also be expressed/computed in terms of torque as follows:

$$\eta_m = \frac{\text{Theoretical torque required to operate the pump}}{\text{Actual torque delivered to the pump}} = \frac{T_T}{T_A}$$

Mechanical efficiency

Example:

A pump that has a mechanical efficiency of 0.90 and a displacement of 4 in^3/rev is to be used in a system with a maximum operating pressure of 2500 psi. What is the required drive torque?

SOLUTION:

1. Calculate the theoretical drive torque:

$$T_T = \frac{p \cdot V_p}{2 \cdot \pi} = \frac{2500 \text{ psi} \cdot \left(4 \frac{\text{in}^3}{\text{rev}}\right)}{2 \cdot \pi} = 1592 \text{ in} \cdot \text{lbs}$$

2. Calculate the actual drive torque:

$$T_A = \frac{T_T}{\eta_M} = \frac{1592 \text{ in} \cdot \text{lbs}}{0.90} = 1769 \text{ in} \cdot \text{lbs}$$

Mechanical efficiency

- **Example (SI units):**

A pump that has a mechanical efficiency of 0.92 and a displacement of 20 cm³/rev is to be used in a system with a maximum operating pressure of 15,000 kPa. What is the required drive torque?

Solution

1. Convert to m³/rev:

$$20\,\frac{\text{cm}^3}{\text{rev}} \cdot \left(\frac{1\ \text{m}^3}{1{,}000{,}000\ \text{cm}^3}\right) = 0.00002\,\frac{\text{m}^3}{\text{rev}}$$

2. Calculate T_T:

$$T_T = \frac{p \cdot V_p}{2 \cdot \pi} = \frac{15{,}000{,}000\,\frac{\text{N}}{\text{m}^2} \cdot \left(0.00002\,\frac{\text{m}^3}{\text{rev}}\right)}{2 \cdot \pi} = 47.75\ \text{N} \cdot \text{m}$$

3. Calculate T_A:

$$T_A = \frac{T_T}{\eta_M} = \frac{47.75\ \text{N} \cdot \text{m}}{0.92} = 51.90\ \text{N} \cdot \text{m}$$

Overall efficiency

The total power loss incurred by a pump is measured by the *overall efficiency*, which is the ratio of a pump's input power to output power. This quantity includes losses due to leakage and mechanical losses due to friction.

The overall efficiency is then given by the following equations:

In US system:

$$\eta_O = \frac{HP_H}{HP_I}$$

In SI system:

$$\eta_O = \frac{kW_H}{kW_I}$$

The overall efficiency can also be expressed as a combination of volumetric and mechanical efficiencies;

$$\eta_O = \eta_M \cdot \eta_V$$

Overall efficiency

In US system:

A pump that has an overall efficiency of 0.85 and a flow rate of 6 gpm is to be used in a system that has a maximum operating pressure of 2500 psi. What input horsepower is required?

SOLUTION:

1. Calculate the hydraulic horsepower:

$$HP_H = \frac{p \cdot Q}{1714} = \frac{2{,}500 \text{ psi} \cdot (6 \text{ gpm})}{1714} = 8.75 \text{ hp}$$

2. Calculate the input horsepower:

$$HP_I = \frac{HP_H}{\eta_O} = \frac{8.75 \text{ hp}}{0.85} = 10.3 \text{ hp}$$

In SI system:

A pump that has an overall efficiency of 0.87 and a flow rate of 45 lpm is to be used in a system that has a maximum operating pressure of 25,000 kPa. What input horsepower is required?

SOLUTION:

1. Calculate the hydraulic power:

$$kW_H = \frac{p \cdot Q}{60{,}000} = \frac{25{,}000 \text{ kPa} \cdot (45 \text{ lpm})}{60{,}000} = 18.75 \text{ kW}$$

2. Calculate the input power:

$$kW_I = \frac{kW_H}{\eta_O} = \frac{18.75 \text{ kW}}{0.87} = 2155 \text{ kW}$$

Homework:

A power unit consists of a pump with an overall efficiency of 0.82 and an electric motor with a maximum power rating of 15 hp. What is the maximum hydraulic power output for this system?

Assume that the pump produces a flow rate of 5 gpm. What is the maximum pressure this system can operate at?