Fluid Power

Learning Objectives

- ☐ Explain the meaning of fluid power.
- ☐ List the various applications of fluid power.
- ☐ Differentiate between fluid power and transport systems.
- ☐ List the advantages and disadvantages of fluid power.
- ☐ Explain the industrial applications of fluid power.
- ☐ List the basic components of the fluid power.
- ☐ List the basic components of the pneumatic systems.
- ☐ Differentiate between electrical, pneumatic and fluid power systems.
- ☐ Appreciate the future of fluid power in India.

Fluid Power

- Fluid power is the technology that deals with the generation, control and transmission of forces and movement of mechanical element or system with the use of pressurized fluids in a confined system.

- Both liquids and gases are considered fluids. Fluid power system includes a hydraulic system (*hydra meaning water in Greek) and a pneumatic system (pneuma meaning air in Greek).*

- *Oil hydraulic employs pressurized liquid petroleum oils and synthetic oils, and pneumatic employs compressed air that is*

Fluid power applications

- **Stationary hydraulics**

Machine tools and transfer lines.

Lifting and conveying devices.

Metal-forming presses.

Plastic machinery such as injection-molding machines.

Rolling machines.

Lifts.

Food processing machinery.

Automatic handling equipment and robots.

Fluid power applications

- **Mobile hydraulics**

□□ Automobiles, tractors, aeroplanes, missile, boats, etc.

□□ Construction machinery.

□□ Tippers, excavators and elevating platforms.

□□□ Lifting and conveying devices.

□□□ Agricultural machinery.

More applications of fluid power

Agriculture	Tractors; farm equipment such as mowers, ploughs, chemical and water sprayers, fertilizer spreaders, harvesters
Automation	Automated transfer lines, robotics
Automobiles	Power steering, power brakes, suspension systems, hydrostatic transmission
Aviation	Fluid power equipment such as landing wheels in aircraft. Helicopters, aircraft trolleys, aircraft test beds, luggage loading and unloading systems, ailerons, aircraft servicing, flight simulators
Construction industry/equipment	For metering and mixing of concrete rudders, excavators, lifts, bucket loaders, crawlers, post-hole diggers, road graders, road cleaners, road maintenance vehicles, tippers
Defense	Missile-launching systems, navigation controls

More applications of fluid power

Entertainment	Amusement park entertainment rides such as roller coasters
Fabrication industry	Hand tools such as pneumatic drills, grinders, borers, riveting machines, nut runners
Food and beverage	All types of food processing equipment, wrapping, bottling,
Foundry	Full and semi-automatic molding machines, tilting of furnaces, die-casting machines
Glass industry	Vacuum suction cups for handling
Oil industry	Off-shore oil rigs
Paper and packaging	Process control systems, special-purpose machines for rolling and packing
Pharmaceuticals	Process control systems such as bottle filling, tablet placement, packaging
Plastic industry	Automatic injection molding machines, raw material feeding, jaw closing, movement of slides of blow molder

More applications of fluid power

Hazardous gaseous areas	Hydraulic fracturing technologies: It involves pumping large volumes of water and sand into a well at high pressure to fracture shale and other tight formations, allowing hazardous oil and gas to flow into the well. However, hydraulic fracturing has serious environmental and water pollution related issues.
Instrumentation	Used to create/operate complex instruments in space rockets, gas turbines, nuclear power plants, industrial labs
Jigs and fixtures	Work holding devices, clamps, stoppers, indexers
Machine tools	Automated machine tools, numerically controlled(NC) machine tools

More applications of fluid power

Materials handling	Jacks, hoists, cranes, forklifts, conveyor systems
Medical	Medical equipment such as breathing assistors, heart assist devices, cardiac compression machines, dental drives and human patient simulator
Movies	Special-effect equipment use fluid power; movies such as Jurassic park, Jaws, Anaconda, Titanic
Mining	Rock drills, excavating equipment, ore conveyors, loaders
Newspapers and periodicals	Edge trimming, stapling, pressing, bundle wrapping

More applications of fluid power

Press tools	Heavy duty presses for bulk metal formation such as sheet metal, forging, bending, punching, etc.
Printing industry	For paper feeding, packaging
Robots	Fluid power operated robots, pneumatic systems
Ships	Stabilizing systems, unloading and loading unit, gyroscopic instruments, movement of flat forms, lifters, subsea inspection equipment
Textiles	Web tensioning devices, trolleys, process controllers
Transportation	Hydraulic elevators, winches, overhead trams
Under sea	Submarines, under sea research vehicles, marine drives and control of ships
Wood working	Tree shearers, handling huge logs, feeding clamping and saw operations

Classification of Fluid Power Systems

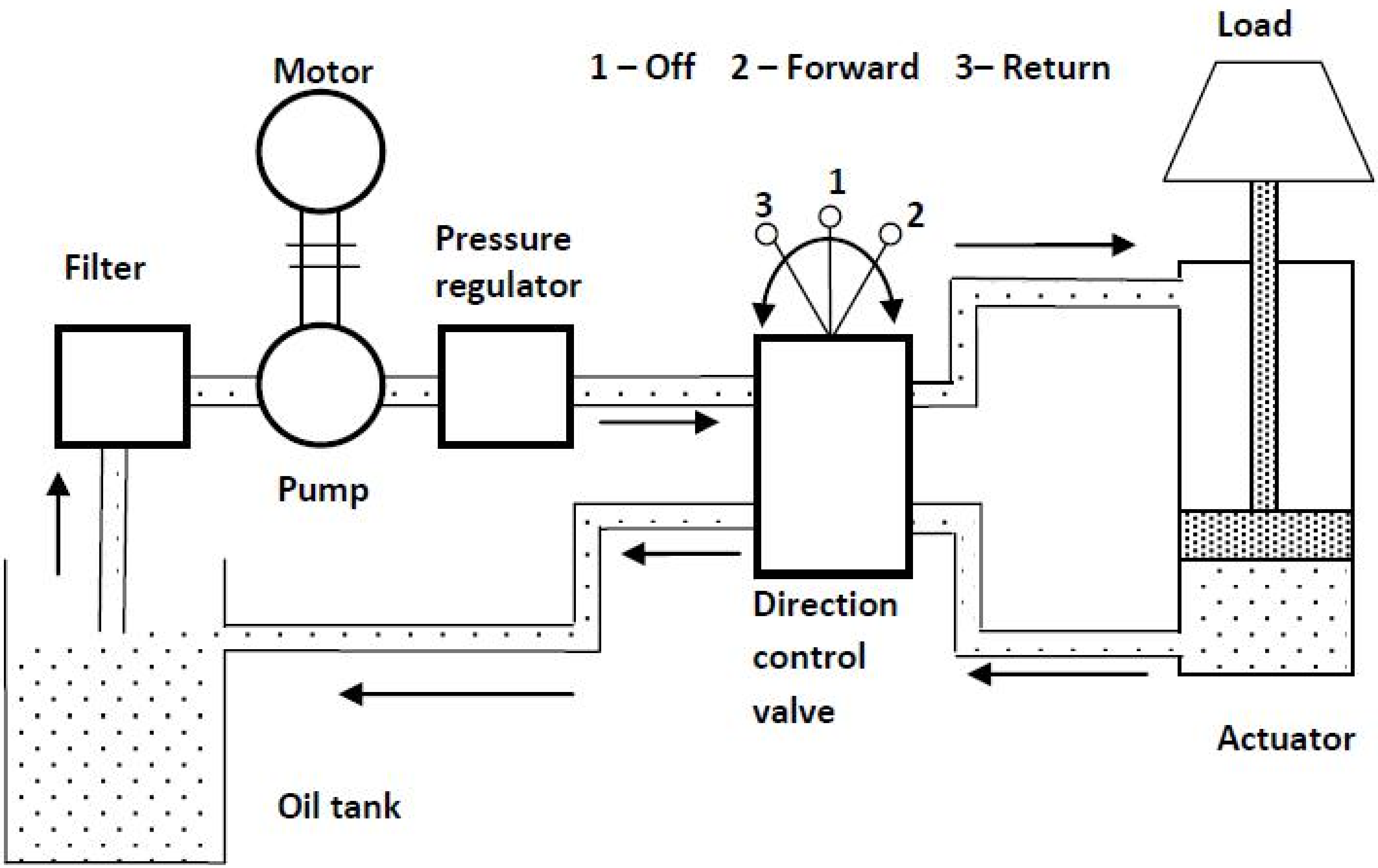
- **Based on the control system**
  - **Open-loop system**
  - **Closed-loop system**

- **Based on the type of control**
  - **Fluid logic control**
  - **Electrical control**
  - **Electronic control**

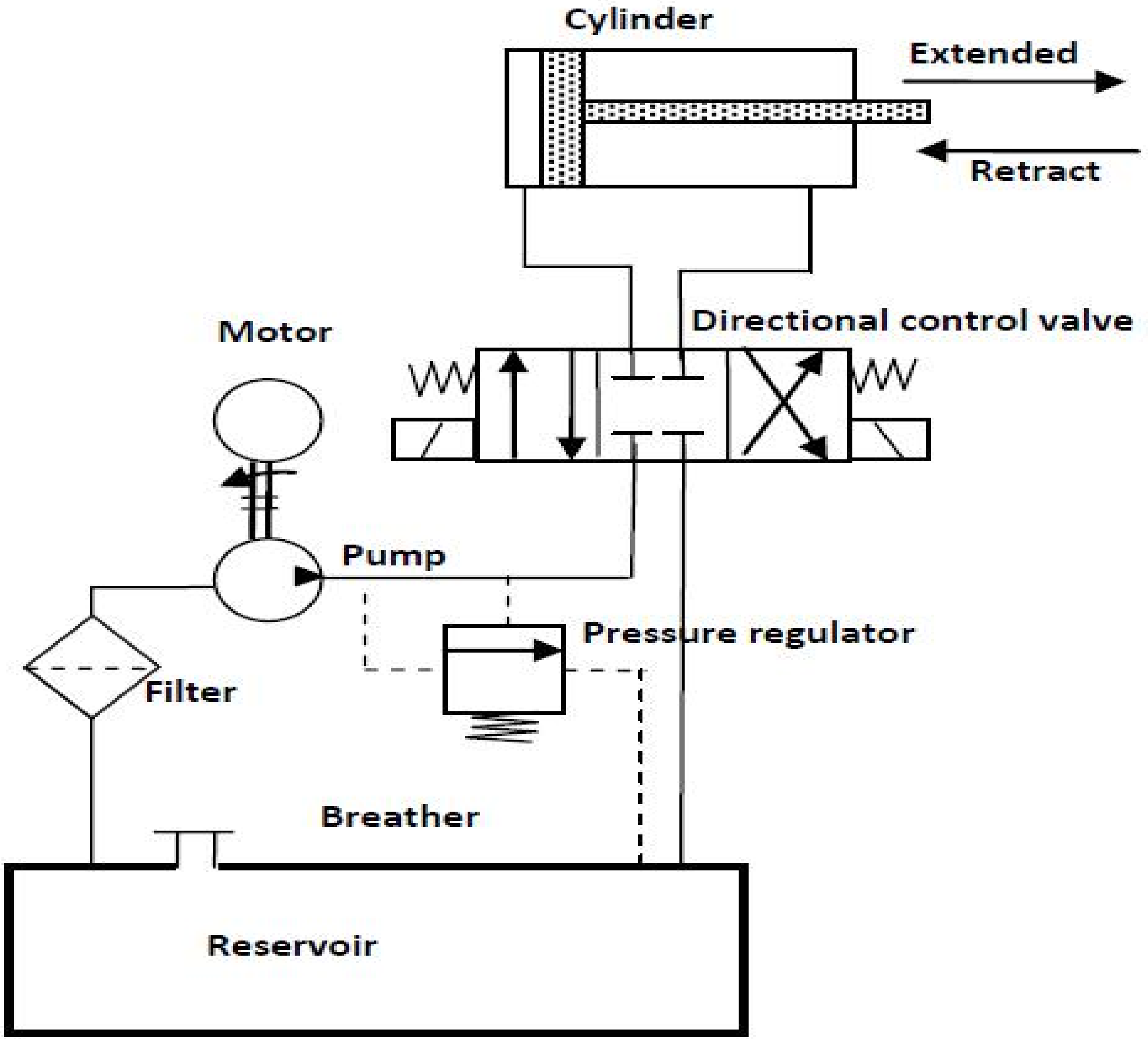
Advantages of a Fluid Power System

- Fluid power systems are simple, easy to operate and can be controlled accurately
- Multiplication and variation of forces
- Multifunction control
- Low-speed torque
- Constant force or torque
- Economical
- Low weight to power ratio
- Fluid power systems can be used where safety is of vital importance

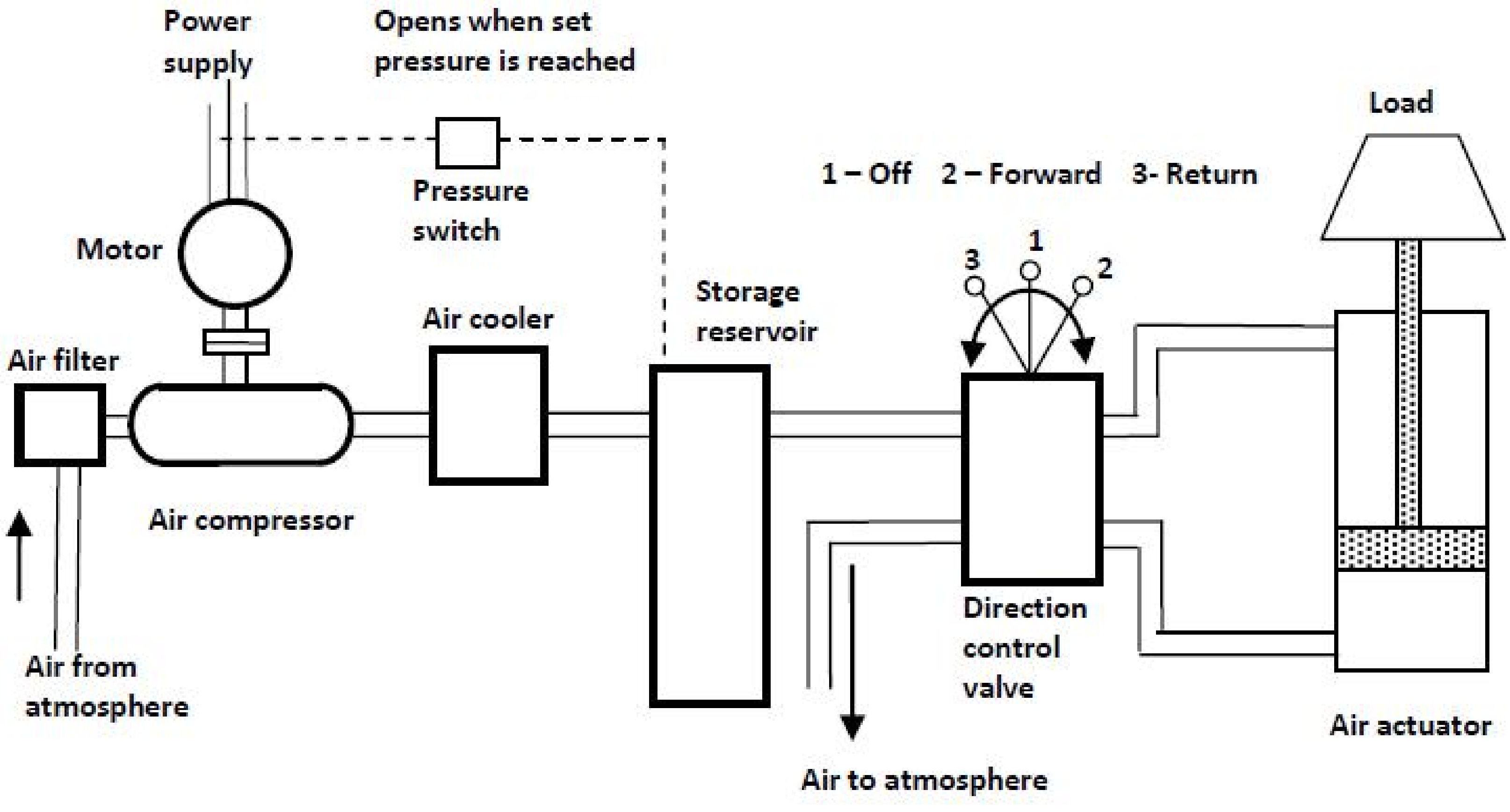
Basic Components of a Hydraulic System



Components of a hydraulic system (shown using symbols)



Basic Components of a Pneumatic System



Comparison between Hydraulic and Pneumatic

S. No.	Hydraulic System	Pneumatic System
1.	It employs a pressurized liquid as a fluid	It employs a compressed gas, usually air, as a fluid
2.	An oil hydraulic system operates at pressures up to 700 bar	A pneumatic system usually operates at 5–10 bar
3.	Generally designed as closed system	Usually designed as open system
4.	The system slows down when leakage occurs	Leakage does not affect the system much
5.	Valve operations are difficult	Valve operations are easy
6.	Heavier in weight	Lighter in weight
7.	Pumps are used to provide pressurized liquids	Compressors are used to provide compressed gases
8.	The system is unsafe to fire hazards	The system is free from fire hazards
9.	Automatic lubrication is provided	Special arrangements for lubrication are needed

Comparison of different power systems

Property	Mechanical	Electrical	Pneumatic	Hydraulic
Input energy source	I C engines Electric motor	I C engines Water/gas turbines	I C engines Pressure tank	I C engines Electric motor Air turbine
Energy transfer element	Levers, gears, shafts	Electrical cables and magnetic field	Pipes and hoses	Pipes and hoses
Energy carrier	Rigid and elastic objects	Flow of electrons	Air	Hydraulic liquids
Power-to-weight ratio	Poor	Fair	Best	Best
Torque/inertia	Poor	Fair	Good	Best
Stiffness	Good	Poor	Fair	Best
Response speed	Fair	Best	Fair	Good
Dirt sensitivity	Best	Best	Fair	Fair
Relative cost	Best	Best	Good	Fair
Control	Fair	Best	Good	Good
Motion type	Mainly rotary	Mainly rotary	Linear or rotary	Linear or rotary

Fill in the Blanks

1. Fluid power is the technology that deals with the generation, _________and transmission of forces and movement of mechanical elements or systems.

2. The main objective of fluid transport systems is to deliver a fluid from one location to another, whereas fluid power systems are designed to perform _________.

3. There are three basic methods of transmitting power: Electrical, mechanical and _________.

4. Only _________are capable of providing constant force or torque regardless of speed changes.

5. The weight-to-power ratio of a hydraulic system is comparatively _________than that of an electromechanical system.

State True or False

1. Hydraulic lines can burst and pose serious problems.

2. Power losses and leakages are less in pneumatic systems.

3. Pneumatic system is not free from fire hazards.

4. Hydraulic power is especially useful when performing heavy work.

5. Water is a good functional hydraulic fluid.

Answers

Fill in the Blanks

1. Control
2. Work
3. Fluid power
4. Fluid power systems
5. Less

State True or False

1. True
2. True
3. False
4. True
5. False

Functions of Hydraulic Fluids

Power transmission: To transmit power, which is the primary function.

Lubrication: To lubricate various parts, so as to avoid metal-to-metal contact and reduce friction, wear and heat generation.

Sealing: To seal the moving elements to avoid leakage.

Cooling: To carry away the heat generated in the system and to dissipate the heat through a reservoir or a heat exchanger.

Contaminant removal: To carry along the contaminations to the tank, where they can be removed through filters.

Various properties required for an ideal hydraulic fluid

1. Ideal viscosity.
2. Good lubrication capability.
3. Demulsibility.
4. Good chemical and environmental stability.
5. Incompressibility.
6. Fire resistance.
7. Low flammability.
8. Foam resistance.
9. Low volatility.
10. Good heat dissipation.
11. Low density.
12. System compatibility.

Ideal Viscosity

High viscosity:

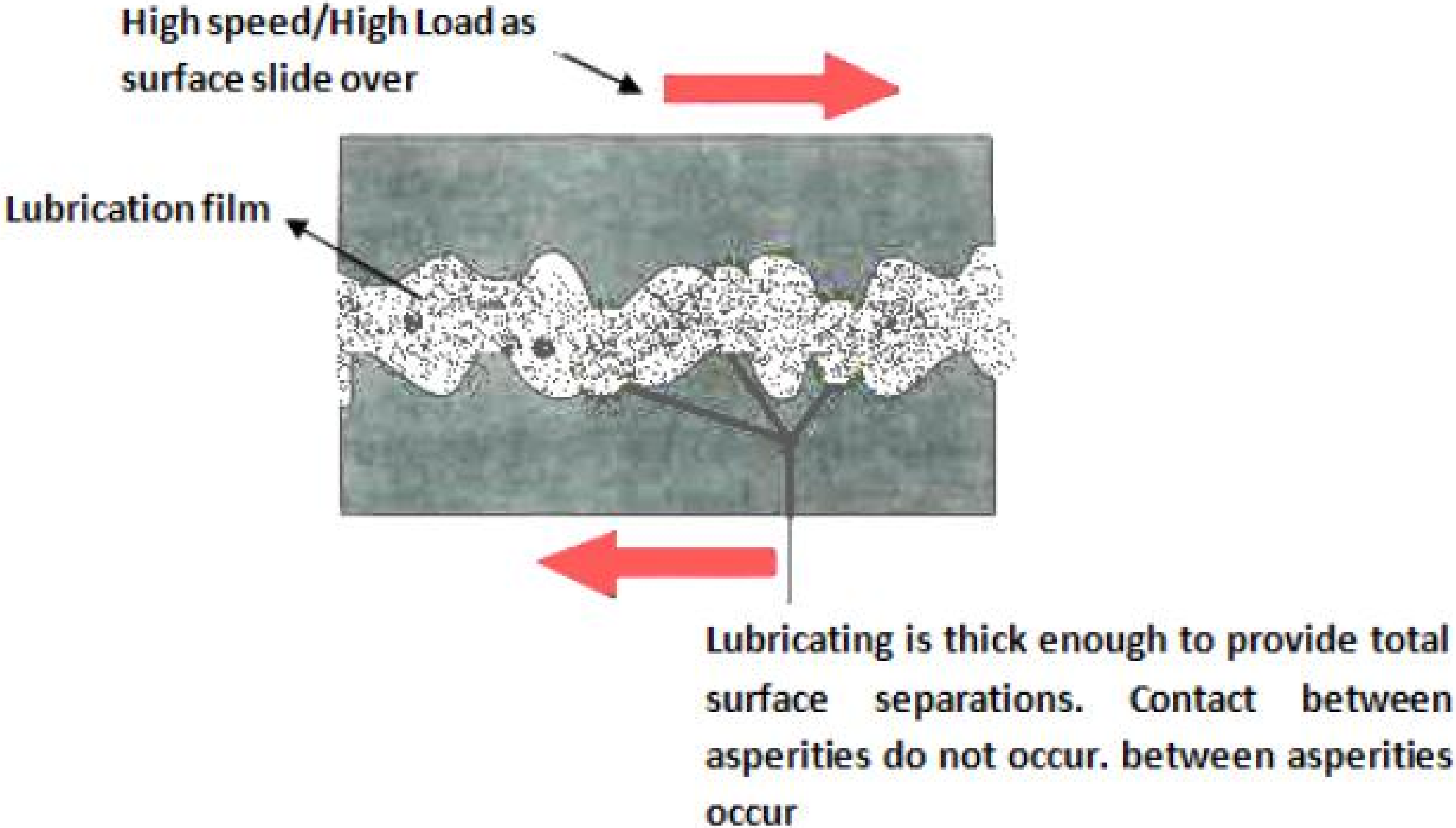
- High resistance to flow.
- Increased power consumption due to frictional loss.
- High temperature caused by friction.
- Increased pressure drop because of the resistance.
- Possibility of sluggish or slow operation.
- Difficulty in separating air from oil in a reservoir.
- Greater vacuum at the pump inlet, causing cavitation.
- Higher system noise level.

Ideal Viscosity

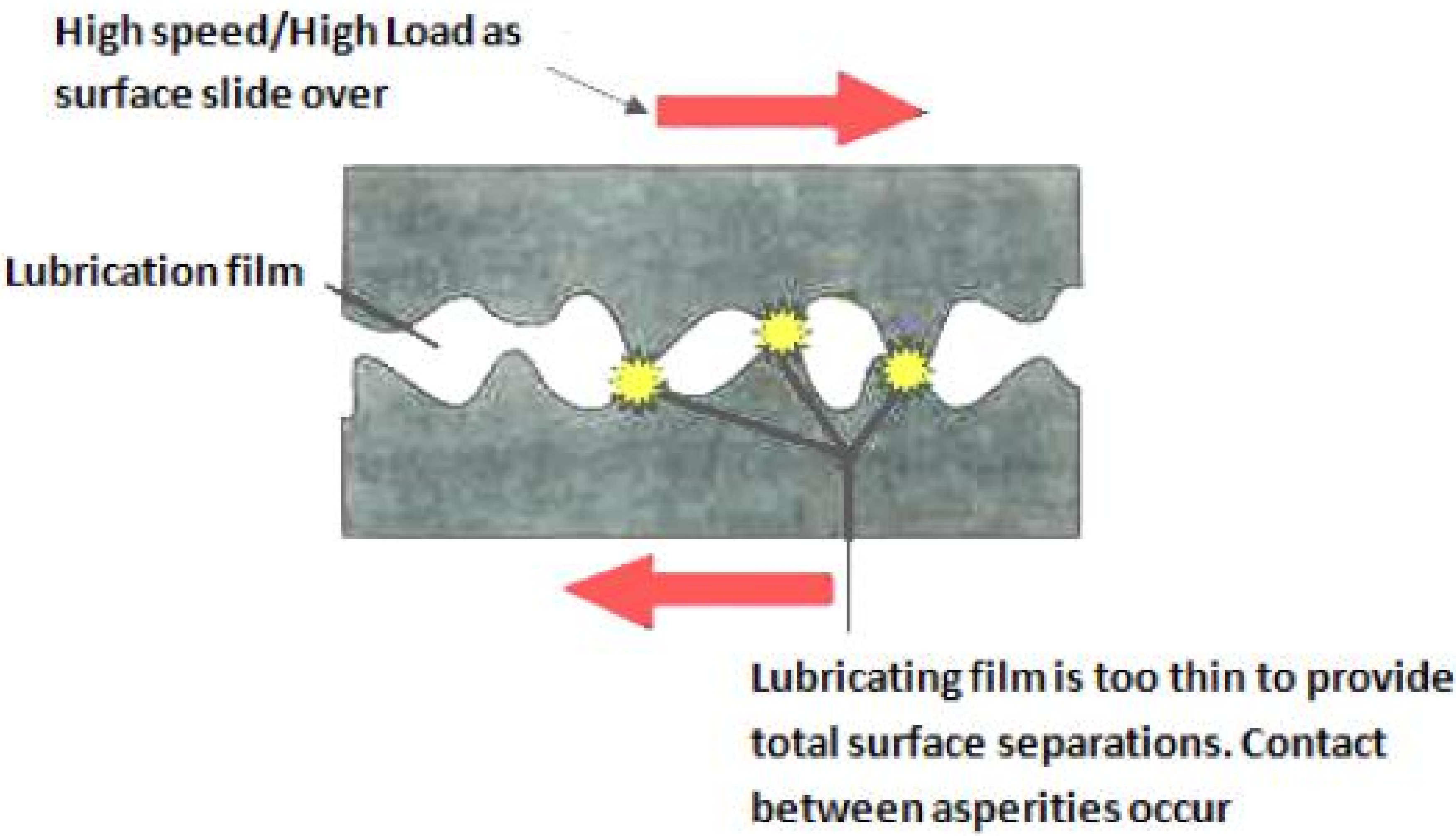
Low viscosity:

- ☐ Increased internal leakage.
- ☐ Excessive water.
- ☐ Possibility of decreased pump efficiency, causing slower operation of the actuator.
- ☐ Increased temperature resulting from leakage losses.

Lubrication Capability



Lubrication Capability



Demulsibility

- The ability of a hydraulic fluid to separate rapidly from moisture and successfully resist emulsification is known as “demulsibility.”
- If an oil emulsifies with water, the emulsion promotes the destruction of lubricating and sealant properties.
- Highly refined oils are basically water resistant by nature.

FireResistance

Flash point: The temperature at which an oil surface gives off sufficient vapors to ignite when a flame is passed over the surface.

Fire point: The temperature at which an oil releases sufficient vapors to support combustion continuously for 5 s when a flame is passed over the surface.

Autogenously ignition temperature: The temperature at which ignition occurs spontaneously.

Good Heat Dissipation

If the fluid overheats, it may cause the

1. Give off vapor and cause cavitation of the pump.
2. Increase the rate of oxidation causing its rapid deterioration by producing sledges, varnishes, etc., thus shortening its useful life.
3. Reduce viscosity of the fluid resulting in increased leakage, both internal and external.
4. Cause thermal distortion in components.
5. Damage seals and packaging owing to embrittlement.

Additives in Hydraulic Fluids

- **Pour point depressant**
- **Viscosity index improvers**
- **Defoamers(anti-foam additives)**
- **Oxidation inhibitors**
- **Corrosion inhibitors**
- **Anti-wear additives**
- **Load-carrying capacity**

Types of Hydraulic Fluids

- **Petroleum-based fluids**

Excellent lubricity.

Higher demulsibility.

More oxidation resistance.

Higher viscosity index.

Protection against rust.

Good sealing characteristics.

Easy dissipation of heat.

Easy cleaning by filtration.

Most of the desirable properties of the fluid, if not already present in the crude oil, can be incorporated through refining or adding additives.

Types of Hydraulic Fluids

- **Emulsions**
  - Emulsions are a mixture of two fluids that do not chemically react with others. Emulsions of petroleum-based oil and water are commonly used. An emulsifier is normally added to the emulsion, which keeps liquid as small droplets and remains suspended in the other liquid.

  – **Oil-in-water emulsions**

  – **Water-in-oil emulsions**

Types of Hydraulic Fluids

Water glycol

- Water glycol is another nonflammable fluid commonly used in aircraft hydraulic systems.
- It generally has a low lubrication ability as compared to mineral oils and is not suitable for high-temperature applications.
- It has water and glycol in the ratio of 1:1.
- Because of its aqueous nature and presence of air, it is prone to oxidation and related problems. It needs to be added with oxidation inhibitors.
- Enough care is essential in using this fluid as it is toxic and corrosive toward certain metals such as zinc, magnesium and aluminum.
- Again, it is not suitable for high-temperature operations as the water may evaporate.
- However, it is very good for low-temperature applications as it possesses high antifreeze characteristics.

Types of Hydraulic Fluids

- **Synthetic fluids**
  - Synthetic fluid, based on phosphate ester, is another popular fire-resistant fluid.
  - It is suitable for high-temperature applications, since it exhibits good viscosity and lubrication characteristics.
  - It is not suitable for low-temperature applications.
  - It is not compatible with common sealing materials such as nitrile.
  - Basically being expensive, it requires expensive sealing materials (viton).
  - In addition, phosphate ester is not an environmental-friendly fluid.
  - It also attacks aluminum and paints.

Types of Hydraulic Fluids

- **Vegetable oils**
  - Vegetable-based oils are biodegradable and are environmental safe.
  - They have good lubrication properties, moderate viscosity and are less expensive.
  - They can be formulated to have good fire resistance characteristics with certain additives.
  - Vegetable oils have a tendency to easily oxidize and absorb moisture.
  - The acidity, sludge formation and corrosion problems are more severe in vegetable oils than in mineral oils.
  - Hence, vegetable oils need good inhibitors to minimize oxidation problems.

Types of Hydraulic Fluids

- **Biodegradable hydraulic fluids**
- As more and more organizations are understanding their social responsibility and are turning toward eco-friendly machinery and work regime, a biodegradable hydraulic fluid is too becoming a sought after product in the dawn of an environmentalist era.
- Biodegradable hydraulic fluids, alternatively known as bio-based hydraulic fluids
- Bio-based hydraulic fluids use sunflower, rapeseed, soybean, etc., as the base oil and hence cause less pollution in the case of oil leaks or hydraulic hose failures.
- These fluids carry similar properties as that of a mineral oil–based anti-wear hydraulic fluid

Factors Influencing the Selection of a Fluid

1. Operating pressure of the system.
2. Operating temperature of the system and its variation.
3. Material of the system and its compatibility with oil used.
4. Speed of operation.
5. Availability of replacement fluid.
6. Cost of transmission lines.
7. Contamination possibilities.
8. Environmental condition (fire proneness, extreme atmosphere like in mining, etc.).
9. Lubricity.
10. Safety to operator.
11. Expected service life.

Fill in the Blanks

- 1. The ability of a hydraulic fluid to separate rapidly from moisture and successfully resist emulsification is known as __________ .
- 2. The neutralization number is a measure of the _________of hydraulic oil.
- 3. Emulsions are a mixture of two fluids which _________chemically react with others.
- 4. Rust is a chemical reaction between iron or steel and __________.
- 5. The incompressibility of a fluid is a measure of its __________.

State True or False

1. Synthetic fluids can have a relative density greater than 1.
2. Viscosity index improvers are short–chain polymers.
3. Viscosity index is the arbitrary measure of a fluid resistance to viscosity change with temperature changes.
4. Mineral oils or petroleum-based oils easily react with oxygen.
5. Rust is a chemical reaction between a metal and an acid.

Answers

Fill in the Blanks

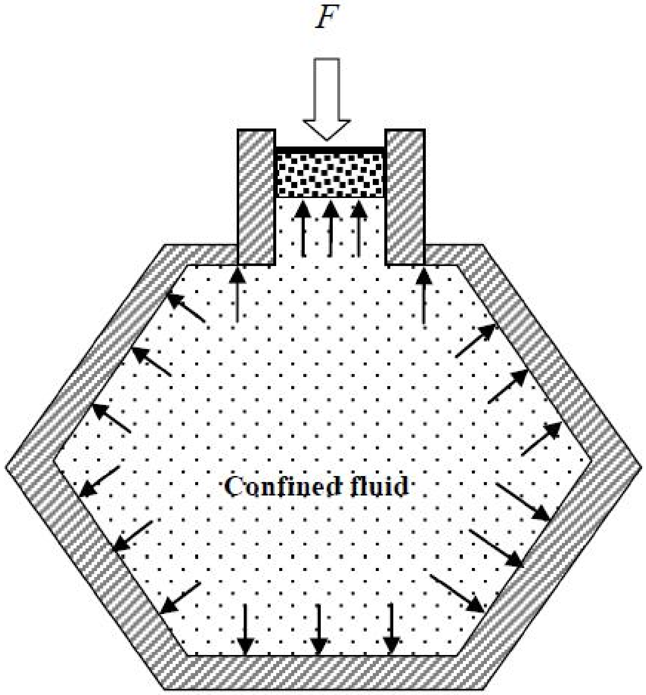
1.Demulsibility
2. Acidity or alkalinity
3. Does not
4. Oxygen
5. Stiffness

State True or False

1. True
2. False
3. True
4. True
5. False

Pascal’s Law

- Pascal’s law states that the pressure exerted on a confined fluid is transmitted undiminished in all directions and acts with equal force on equal areas and at right angles to the containing surfaces.



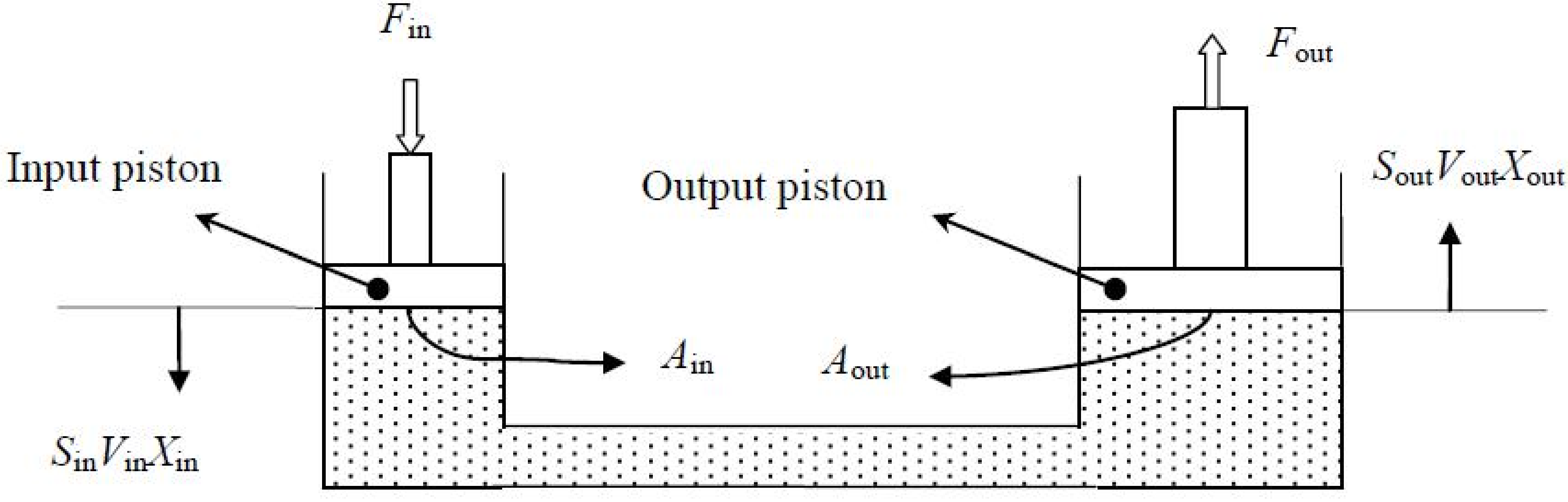
In Fig, a force is being applied to a piston, which in turn exerts a pressure on the confined fluid. The pressure is equal everywhere and acts at right angles to the containing surfaces. Pressure is defined as

$$\text{Pressure} = \frac{F}{A}$$

where F is the force acting on the piston, A is the area of the piston and p is the pressure on the fluid.

Multiplication of Force

- The most useful feature of fluid power is the ease with which it is able to multiply force. This is accomplished by using an output



$$P = \frac{F_{out}}{A_{out}}$$

$$\Rightarrow F_{out} = PA_{out} = \frac{F_{in}}{A_{in}} A_{out} = \frac{A_{out}}{A_{in}} F_{in}$$

$$A = \pi d^2 / 4$$

Hence, the above equation can be written as

$$F_{out} = \frac{d_{out}^2}{d_{in}^2} F_{in}$$

$$\Rightarrow \frac{F_{out}}{F_{in}} = \frac{d_{out}^2}{d_{in}^2}$$

Force displacement relation

- A hydrauli[c ... is as]sumed to be incompressible; hence, the volume displaced by the piston is equal to the volume [...]ced at the output piston.

$$V_{in} = V_{out}$$

- Since the volume of a cylinder equals the product of its cross-sectional area a[...], we have

$$A_{in} S_{in} = A_{out} S_{out}$$

- Where S_{in} *is the downward displacement of t[...] piston and* S_{out} *is the upward [...]ment of the output piston:*

$$\frac{S_{in}}{S_{out}} = \frac{A_{out}}{A_{in}}$$

- Comp[...]

$$\frac{F_{out}}{F_{in}} = \frac{A_{out}}{A_{in}} = \frac{S_{in}}{S_{out}} \qquad (1.1)$$

Force power relation

- A hydraulic oil is assumed to be incompressible; hence, the quantity of oil displaced by the input piston is equal to the quantity of oil gained and displaced at the output piston:
- Flow rate is the product of area and volume of fluid displaced in a

$$Q_{in} = Q_{out}$$

$$\Rightarrow A_{in} V_{in} = A_{out} V_{out}$$

$$\Rightarrow \frac{A_{out}}{A_{in}} = \frac{V_{in}}{V_{out}} \qquad (1.2)$$

Force power relation

- Comparing Equations. (1.1) and (1.2)

.

$$\frac{A_{out}}{A_{in}} = \frac{V_{in}}{V_{out}} = \frac{F_{out}}{F_{in}} = \frac{S_{in}}{S_{out}}$$

From the above equation, we get

$$F_{in} S_{in} = F_{out} S_{out}$$

or

$$(\text{Work done})_{in} = (\text{Work done})_{out}$$

We know that

$$\text{Power} = \text{Force x Velocity}$$

$$\Rightarrow F_{in} v_{in} = F_{out} v_{out}$$

or

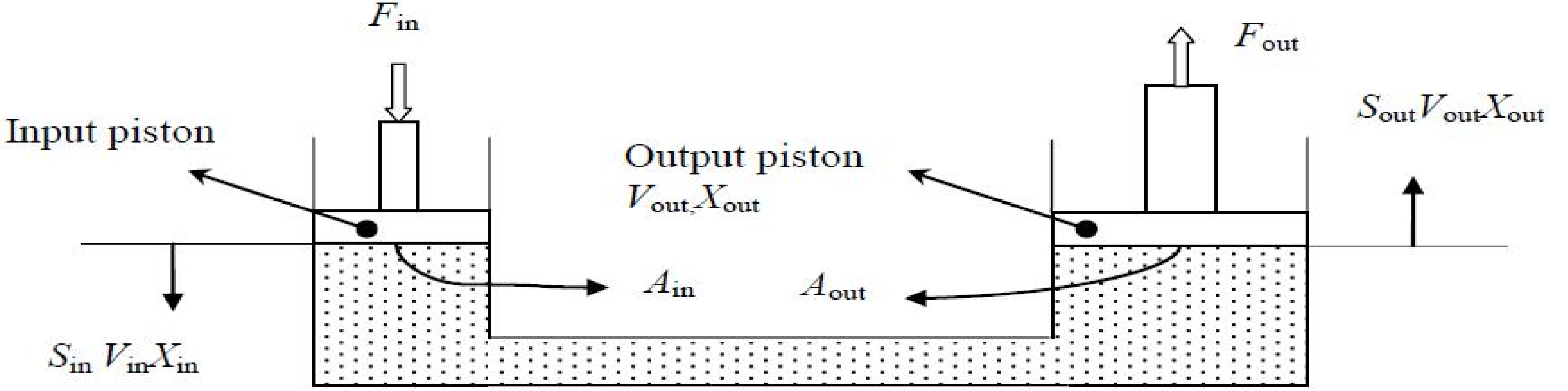
$$(\text{Power})_{in} = (\text{Power})_{out}$$

Examples

An input cylinder with a diameter of 30 mm is connected to an output cylinder with a diameter of 80 mm (Fig. 1.3). A force of 1000 N is applied to the input cylinder.

(a) What is the output force?

(b) How far do we need to move the input cylinder to move the output cylinder 100



- Since the volume of a cylinder equals the product of its cross-sectional area and it $A_{in}X_{in} = A_{out}X_{out}$ we have , where X_{in} *is the downward movement of the input piston and* X_{out} *is the*

$$\frac{X_{out}}{X_{in}} = \frac{A_{in}}{A_{out}}$$

The piston stroke ratio X_{out} / X_{in} equals the piston area ratio A_{in} / A_{out}. For a piston area of 10, the output force F_{out} increases by a factor of 10, but the output motion decreases by a factor of 10.

Thus, the output force is greater than the input force, but the output movement is less than the input force and the output movement is less than the input movement. Hence, we can write by combining equations

$$A_{in}X_{in} = A_{out}X_{out} \text{ and } \frac{X_{out}}{X_{in}} = \frac{A_{in}}{A_{out}}$$

that

$$\frac{F_{out}}{F_{in}} = \frac{X_{in}}{X_{out}}$$

$$\Rightarrow W_{in} = W_{out}$$

Hence, the input work equals the output work.
Given $F_{in} = 1000$ N, $A_1 = 0.7854 \times 30^2$ mm^2 and $A_2 = 0.7854 \times 80^2$ mm^2, $S_{out} = 1000$ mm.
To calculate S_{in}andF_2.

(a) **Force on the large piston F_2:**By Pascal's law, we have

$$\frac{F_1}{F_2} = \frac{A_1}{A_2}$$

$$\Rightarrow F_2 = \frac{A_2 \times F_1}{A_1} = \frac{1000\,\text{N}}{0.7854 \times 30^2} \times 0.7854 \times 80^2$$

$$\Rightarrow F_2 = 7111.1\text{N}$$

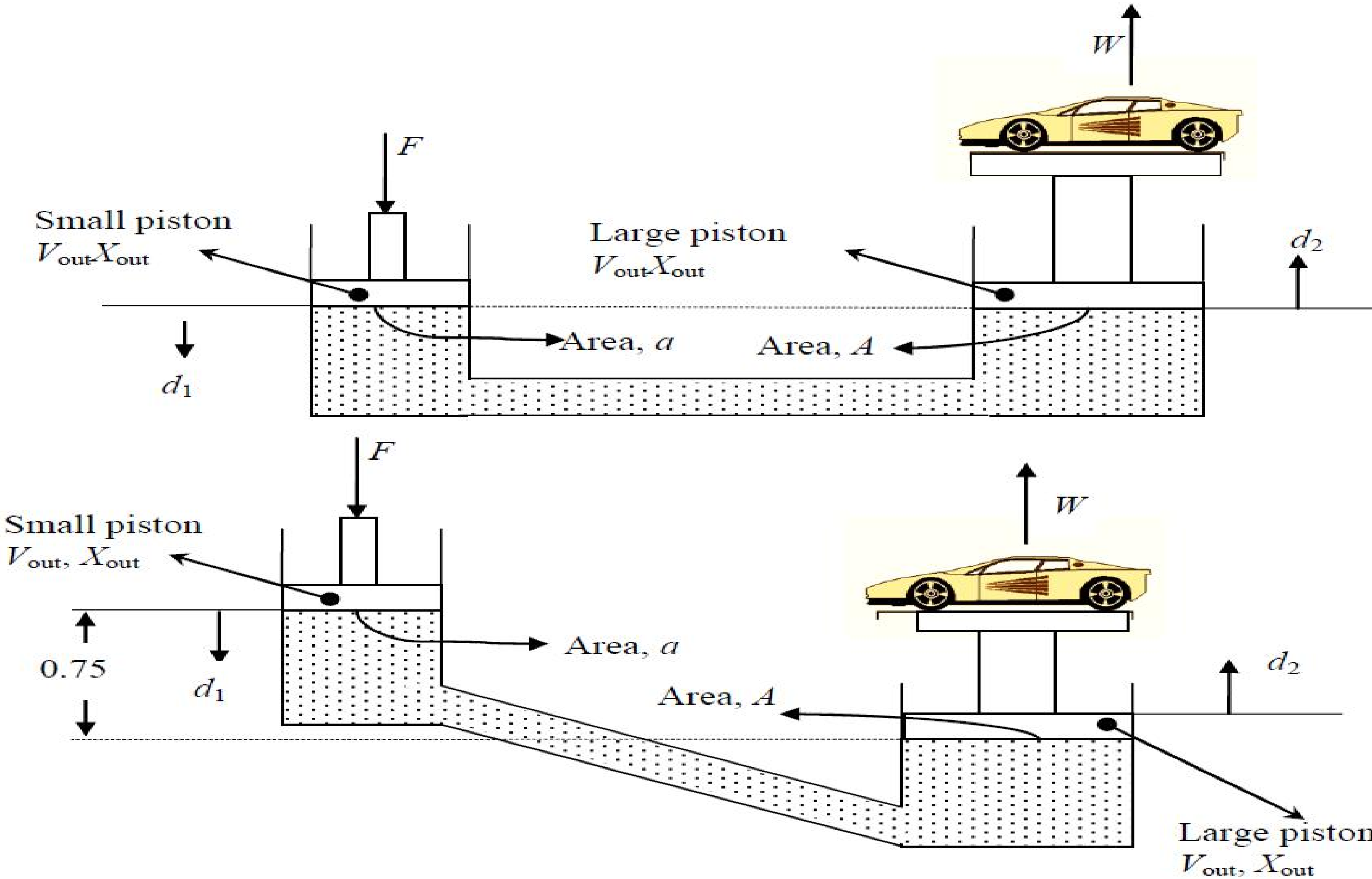
(b) **Distance moved by the large piston S_{out}:**We also know by the conversation of energy that

$$\frac{F_1}{F_2} = \frac{S_{out}}{S_{in}}$$

$$\Rightarrow S_{in} = \frac{S_{out} \times F_2}{F_1} = \frac{1000 \times 7111.1}{1000}$$

$$\Rightarrow S_{in} = 7111.11 \text{ mm}$$

A force of $P = 850$ N is applied to the smaller cylinder of a hydraulic jack (Fig.1.4). The area a of the small piston is 15 cm^2 and the area A of the larger piston is 150 cm^2. What load W can be lifted on the larger piston (a) if the pistons are at the same level, (b) if the large piston is 0.75 m below the smaller one? The mass density ρ of the liquid in the jack is 103 kg /m^3.



Solution: A diagram of a hydraulic jack is shown in Fig. 1.4.A force F is applied to the piston of the small cylinder which forces oil or water into the large cylinder thus raising the piston supporting the load W. The force F acting on the area a produces a pressure p_1 that is transmitted equally in all directions through the liquid. If the pistons are at the same level, the pressure p_2 acting on the larger piston must equal $p_1$as per Pascal's law

Figure 1.4 (a) Pistons are at same level. (b) Pistons are at different level.

We know that

$$p_1 = \frac{F}{a} \text{ and } p_2 = \frac{W}{A}$$

If $p_1 = p_2$, a small force can raise a larger load W. The jack has a mechanical advantage of A/a.

(a) Now $P = 850\,\text{N}, a = 15/1000\ \text{m}^2, A = 150/10000\ \text{m}^2$. Using Pascal's law we can write

$$p_1 = p_2$$

$$\Rightarrow \frac{F}{a} = \frac{W}{A}$$

$$\Rightarrow W = \frac{F \times A}{a} = \frac{850 \times 1.5}{0.15} = 8500\,\text{N}$$

Now

$$\text{Mass lifted} = \frac{W}{g} = \frac{8500}{9.81} = 868\,\text{kg}$$

(b) If the larger piston is a distance h below the smaller, the pressure p_2 is greater than p_1, due to the head h, by an amount ρg where ρ is the mass density of the liquid:

$$p_2 = p_1 + \rho g h$$

Now

$$p_1 = \frac{F}{a} = \frac{850}{15 \times 10^{-4}} = 56.7 \times 10^4 \text{ N/m}^2$$

$$\rho = 103 \text{kg/m}^3$$

$$h = 0.75 \text{m}$$

So

$$p_2 = 56.7 \times 104 + (103 \times 9.81) \times 0.75$$

$$= 57.44 \times 104 \text{ N/m}^2$$

Now

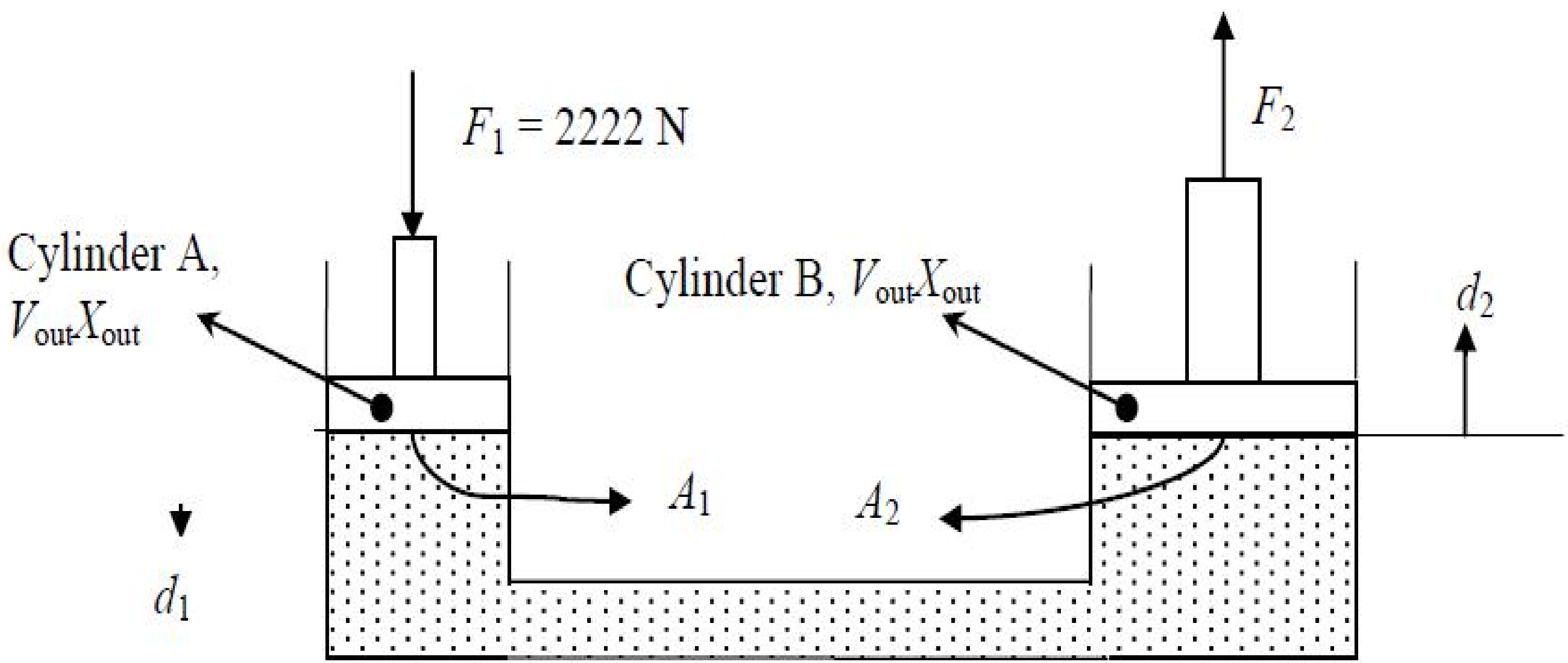
$$W = p_2 A = 57.44 \times 104 \times 150 \times 10^{-4} = 8650 \text{ N}$$

Therefore

$$\text{Mass lifted} = \frac{W}{g} = 883 \text{kg}$$

Two hydraulic cylinders are connected at their piston ends (cap ends rather than rod ends) by a single pipe (Fig. 1.5). Cylinder A has a diameter of 50 mm and cylinder B has a diameter of 100 mm. A retraction force of 2222 N is applied to the piston rod of cylinder A. Determine the following:

(a) Pressure at cylinder A.
(b) Pressure at cylinder B.
(c) Pressure in the connection pipe.
(d) Output force of cylinder B.



Area of the piston of cylinder A is

$$\frac{\pi}{4}(50)^2 = 1963.5\,\text{mm}^2$$

Area of the piston of cylinder B is

$$\frac{\pi}{4}(100)^2 = 7853.8\,\text{mm}^2$$

(a) Pressure in cylinder A is given by $\frac{\text{Force}}{\text{Area}} = \frac{2222}{1963.5} = 1.132\frac{\text{N}}{\text{mm}^2} = 1.132\,\text{MPa}$

(b) By Pascal's law, pressure in cylinder A = pressure in cylinder B = 1.132 MPa

(c) By Pascal's law, pressure in cylinder A = pressure in cylinder B = pressure in the pipe line = 1.132 MPa

(d) Force on the large piston (cylinder B) F_2: By Pascal's law, we have

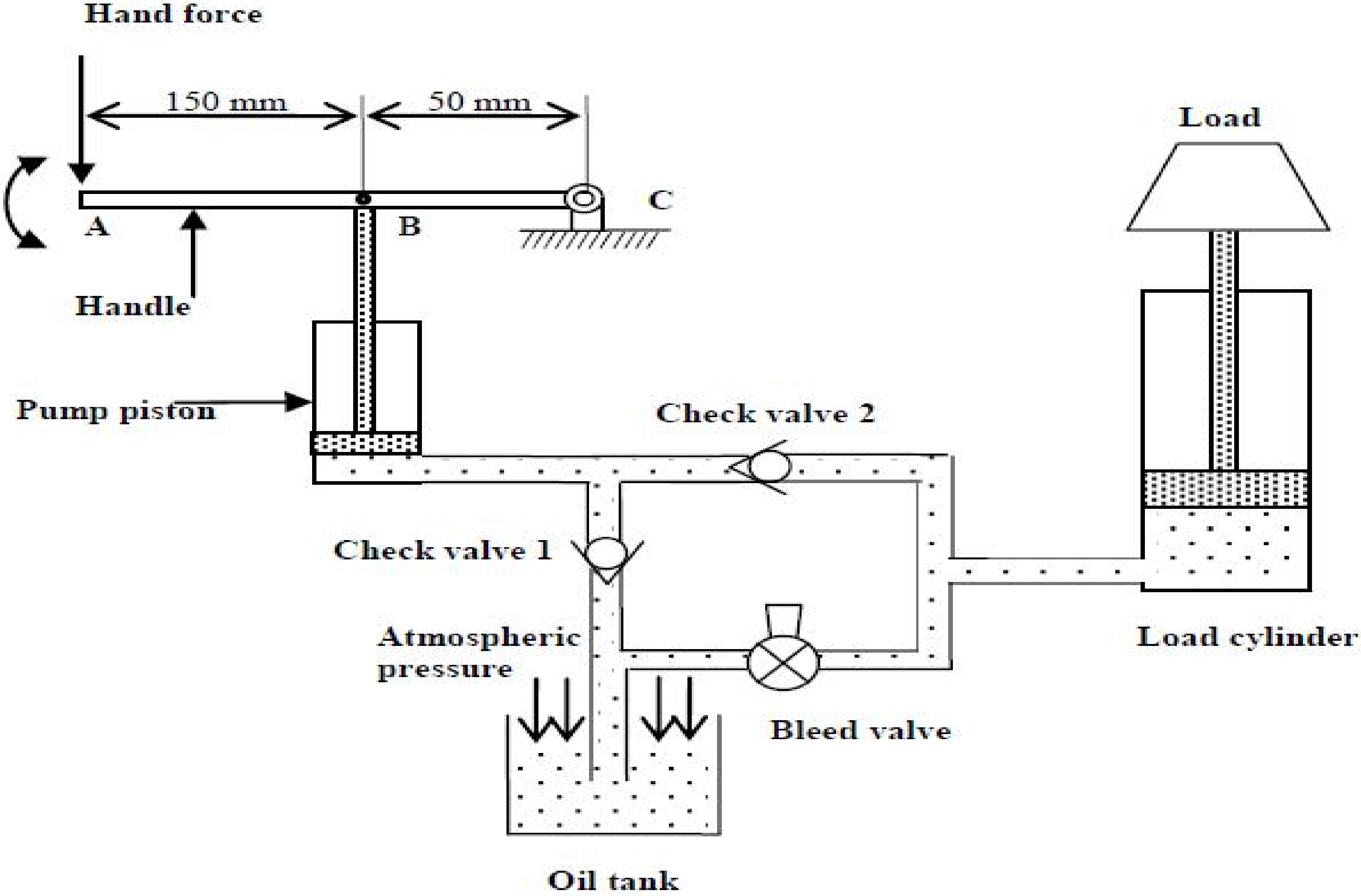
$$\frac{F_1}{F_2} = \frac{A_1}{A_2}$$

$$\Rightarrow F_2 = \frac{A_2 \times F_1}{A_1} = \frac{2222\,\text{N}}{1963.5\,\text{mm}^2} \times 7853.8\,\text{mm}^2 = 8888\,\text{N}$$

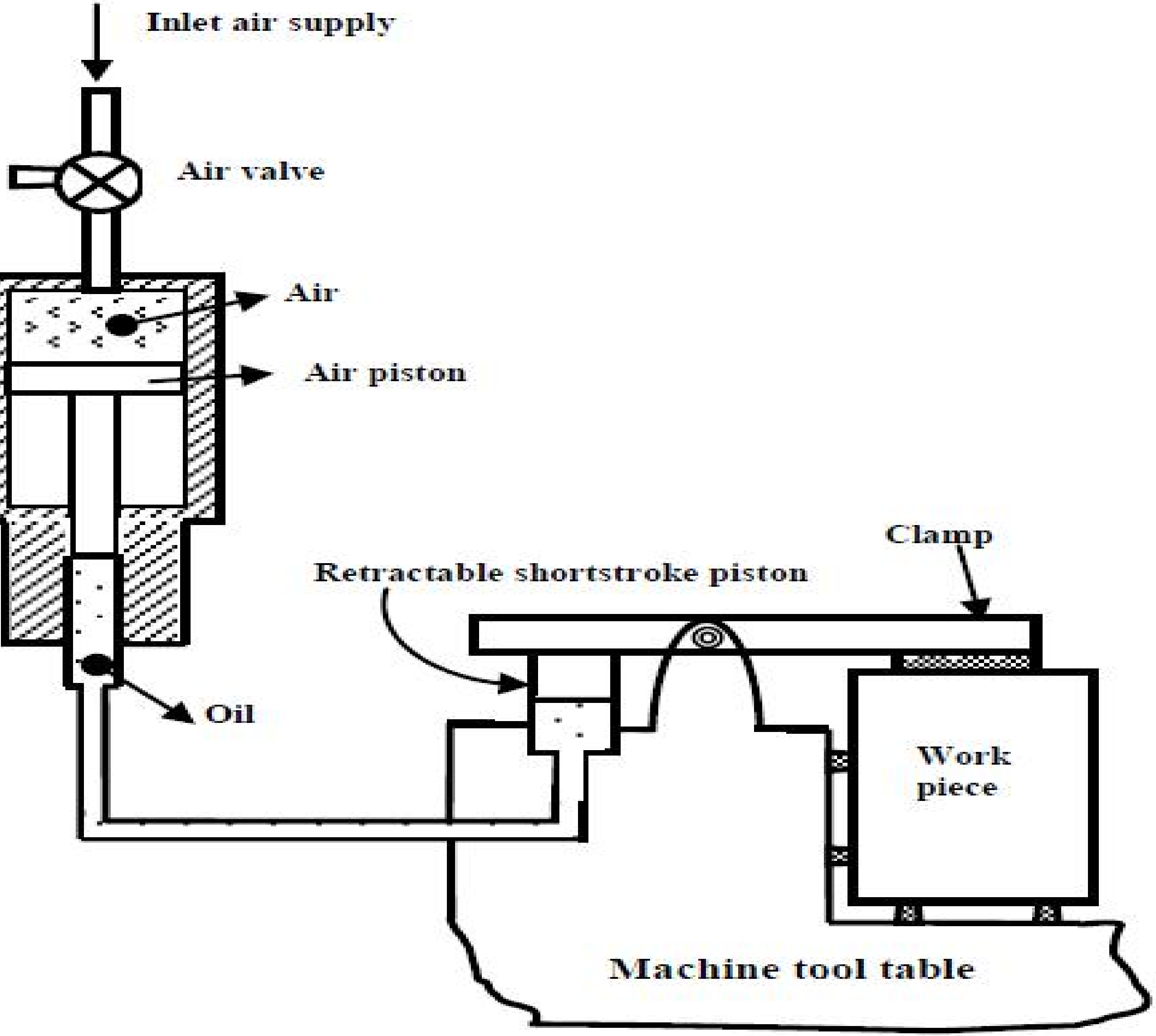
Practical Applications of Pascal's Law

- The practical applications of Pascal's law are numerous. In this section, two applications of Pascal's law are presented:
  - (a) The hand-operated hydraulic jack and
  - (b) the air-to-hydraulic pressure booster.

Hand-Operated Hydraulic Jack



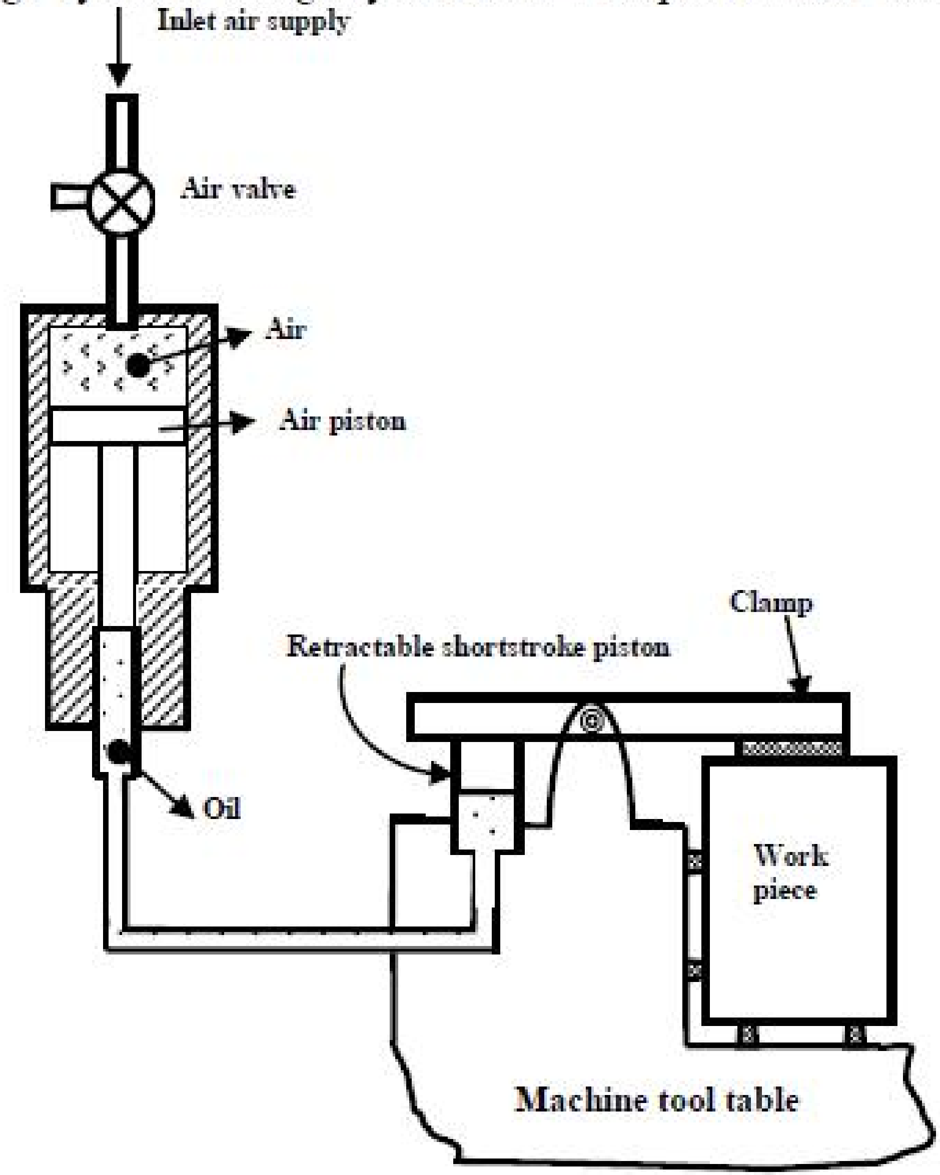
Air-to-Hydraulic Pressure Booster



Air-to-Hydraulic Pressure Booster

- This device is used for converting shop air into higher hydraulic pressure needed for operating hydraulic cylinders requiring small to medium volumes of higher pressure oil.
- It consists of a cylinder containing a large-diameter air piston driving a small-diameter hydraulic piston that is actually a long rod connected to the piston.
- Any shop equipped with an airline can obtain smooth, efficient hydraulic power from an air-to-hydraulic pressure booster hooked into the air line.
- The alternative would be a complete hydraulic system including expensive pumps and high-pressure valves.
- Other benefits include space savings and low

Figure 1.13 shows an application where an air-to-hydraulic pressure booster supplies high-pressure oil to a hydraulic cylinder whose short stroke piston is used to clamp a workpiece to a machine tool table. Since shop air pressure normally operates at 100 psi, a pneumatically operated clamp would require an excessively large cylinder to rigidly hold the workpiece while it is being machined.



The air-to-hydraulic pressure booster operates as follows. Let us assume that the air piston has 10 cm^2 area and is subjected to a 10 bar air pressure. This produces a 1000 N force on the booster's hydraulic piston. Thus, if the area of the booster's hydraulic piston is 1 cm^2, the hydraulic oil pressure is 100 bar. As per Pascal's law, this produces 100 bar oil at the short stroke piston of the hydraulic clamping cylinder mounted on the machine tool table.

The pressure ratio of an air-to-hydraulic pressure booster can be found by using the following equation:

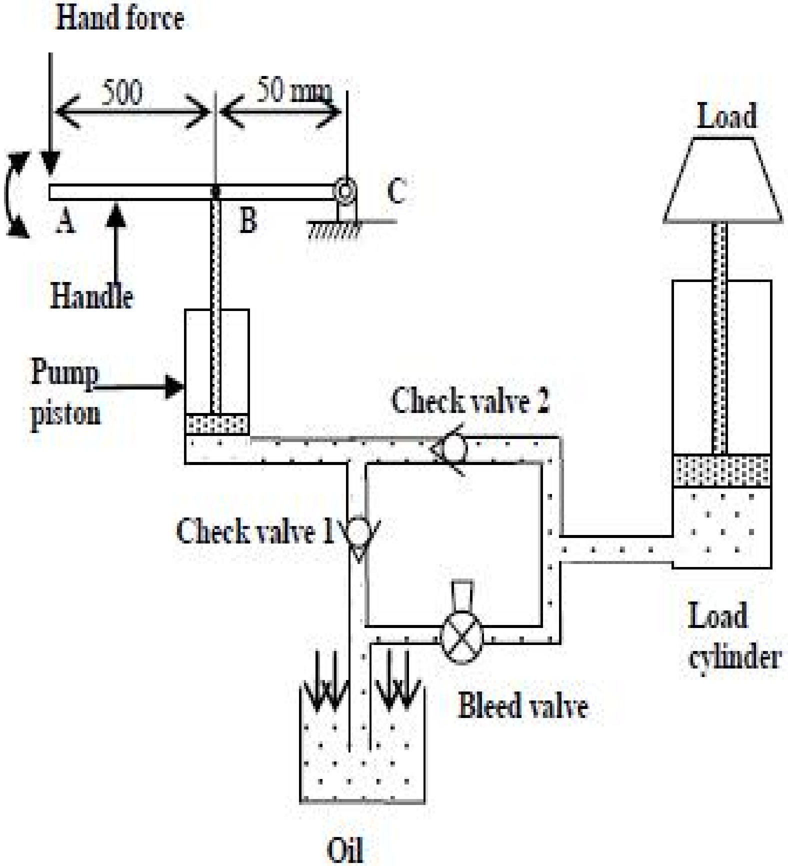
$$\text{Pressure ratio} = \frac{\text{Output oil pressure}}{\text{Input oil pressure}}$$

$$= \frac{\text{Area of air piston}}{\text{Area of hydraulic piston}}$$

Substituting into the above equation for the earlier mentioned pressure booster, we have

$$\text{Pressure ratio} = \frac{10000\ \text{kPa}}{1000\ \text{kPa}} = \frac{10\,\text{cm}^2}{1\ \text{cm}^2}$$

For a clamping cylinder piston area of 0.5 cm^2, the clamping force equals 1000 $N/cm^2 \times 0.5\ cm^2$ or 500 N. To provide the same clamping force of 500 N without booster requires a clamping cylinder piston area of 5 cm^2, assuming 10 bar air pressure. Air-to-hydraulic pressure boosters are available in a wide range of pressure ratios and can provide hydraulic pressures up to 1000 bar using approximately 7 bar shop air.



An operator makes 15 complete cycles in 15 s interval using the hand pump shown in Fig. 1.14. Each complete cycle consists of two pump strokes (intake and power). The pump has a piston of diameter 30 mm and the load cylinder has a piston of diameter 150 mm. The average hand force is 100 N during each power stroke.

(a) How much load can be lifted?

(b) How many cycles are required to lift the load by 500 mm, assuming no oil leakage? The pump piston has 20 mm stroke.

(c) What is the output power assuming 80% efficiency?

Solution: Given: pump diameter $d = 30\,\text{mm}$, load cylinder diameter $D = 150\,\text{mm}$, hand force $f = 100\,\text{N}$, number of cycles $n = 15$ strokes/s, pump piston force

$$F_1 = \frac{100 \times 550}{50} = 1100\ \text{N}$$

(a) **Load capacity:** Now since the pressure remains undiminished throughout, we have $p_1 = p_2$. Therefore,

$$\frac{F_1}{A_1} = \frac{F_2}{A_2}$$

$$\Rightarrow F_2 = \frac{\pi D^2/4}{\pi d^2/4} F_1 = \frac{150^2}{30^2} \times 1100 = 27500\,\text{N} = 27.5\,\text{kN}$$

(b) **Number of cycles:** Stroke length $l = 20$ mm. Let the number of strokes be N. Then assuming no leakage, we get

$$Q_1 = Q_2$$

where

Q_1 = Total volume of fluid displaced by pump piston
= (Area × Stroke) × Number of strokes = $N \times A_1 l$
Q_2 = Flow rate of load cylinder = (Area × Stroke of load cylinder)
= $A_2 \times 500$

So we get

$$N \times A_1 l = A_2 \times 500$$

$$\Rightarrow N = \frac{150^2}{20 \times 30^2} \times 500 = 625$$

Hence, the number of cycles required is 625.

(c) **Output power:**

Input power = $F_1 \times l \times n$

Output power = $\eta \times F_1 \times l \times n = 0.8 \times 1100 \times 0.02 \times 15 = 264\,\text{W}$

Example 1.12

For the pressure booster of Fig. 1.15, the following data are given:

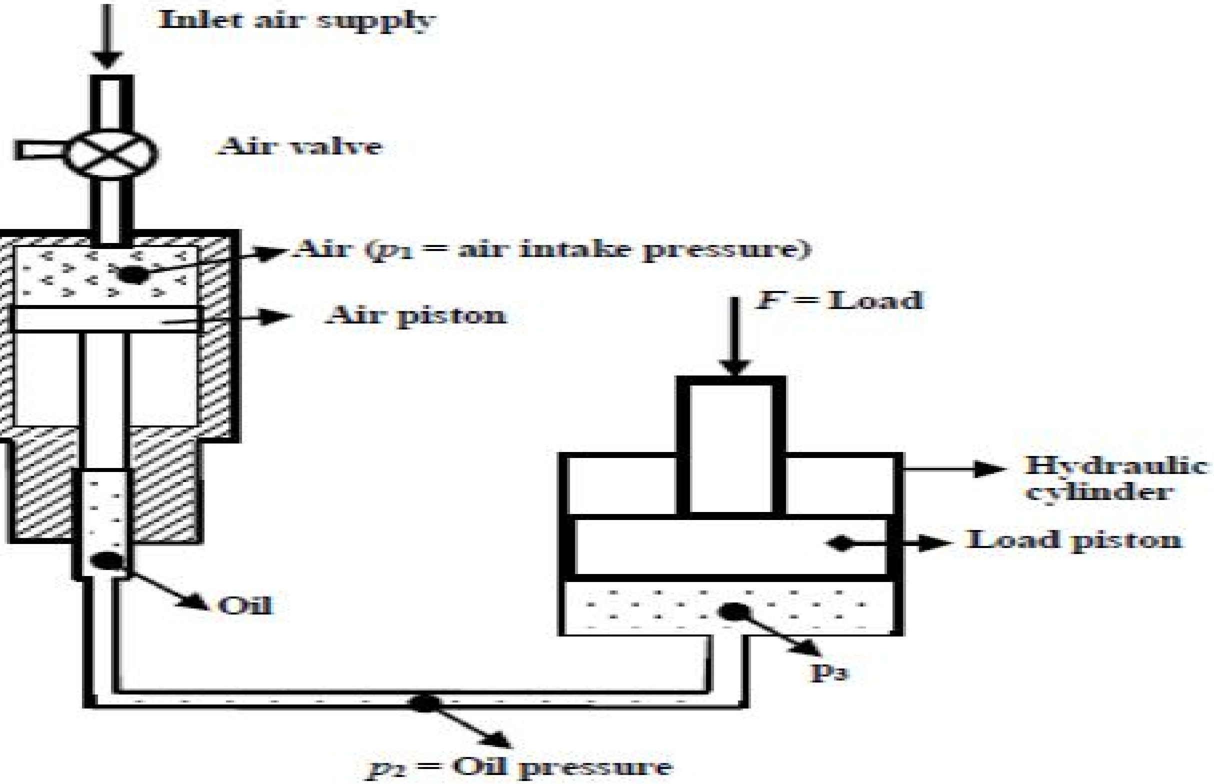
Inlet oil pressure (p_1) = 1 MPa

Air piston area (A_1) = 0.02 m^2

Oil piston area (A_2) = 0.001 m^2

Load carrying capacity = 300000 N

Find the load required on load piston area A_3.



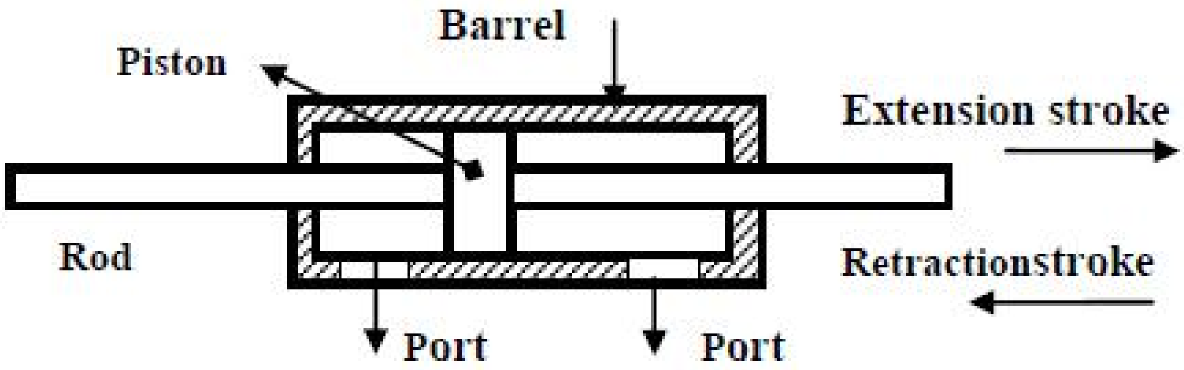
Solution: We know that

$$p_2 = \frac{p_1 A_1}{A_2} = \frac{1\,\text{MPa} \times 0.02\,\text{m}^2}{0.001\,\text{m}^2} = 20\,\text{MPa}$$

Also $p_3 = p_2 = 20\,\text{MPa}$. So

$$A_3 = \frac{F}{p_3} = \frac{300000\,\text{N}}{20 \times 10^6\,\text{N/m}^2} = 0.015\,\text{m}^2$$

A double-rod cylinder is one in which a rod extends out of the cylinder at both ends (Fig. 1.19). Such a cylinder with a piston of diameter 75 mm and a rod of diameter 50 mm cycles through 254 mm stroke at 60 cycles/min. What LPM size pump is required?



$$A_{\text{Annulus}} = \frac{\pi(75^2 - 50^2)}{4} = 2454 \text{ mm}^2$$

Volume of oil displaced per minute (m³/s) is

Area × Stroke length × No. of cycles per second

Now

$$Q = \frac{\pi(75^2 - 50^2)\text{mm}^2}{4} \times 10^{-6} \text{ m}^2 \times \left\{\frac{254}{1000} \times 2\right\} (\text{m}) \times \frac{60}{60} (\text{s})$$

$$= 0.001296 \text{ m}^3/\text{s} = 77.8 \text{ LPM}$$

We can select 80 LPM pump.

A cylinder with a piston of diameter 8 cm and a rod of diameter 3 cm receives fluid at 30 LPM. If the cylinder has a stroke of 35 cm, what is the maximum cycle rate that can be accomplished?

Solution: We know that

Volume of oil displaced per minute (m^3/min) = Area × Stroke length × No. of cycles per minute

So

$$Q = \frac{\pi(0.08^2)\,m^2}{4} \times \left\{\frac{35}{100}\right\}(m) \times N\,(cycles/min) + \frac{\pi(0.08^2 - 0.03^2)\,m^2}{4} \times \left\{\frac{35}{100}\right\}(m) \times N\,(cycles/min)$$

$$= 0.03\,m^3/min$$

$$\Rightarrow 0.030 = 0.00176 + 0.0015 \times N$$

$$\Rightarrow N = 9.2 \text{ cycles/min}$$

A hydraulic pump delivers a fluid at 50 LPM and 10000 kPa. How much hydraulic power does the pump produce?

Solution: We have

$$Q = 50\ \text{LPM} = \frac{50}{60 \times 10^{3}} = 0.833 \times 10^{-3}\,\text{m}^3/\text{s}$$

Now

$$1\ \text{L} = 1000\ \text{cc} = 1000 \times 10^{-6}\ \text{m}^3 = 10^{-3}\,\text{m}^3$$

So

$$\text{Power (kW)} = p\ (\text{kPa}) \times Q\ (\text{m}^3/\text{s})$$

$$= 10000 \times\ 0.833 \times 10^{-3}$$

$$= 8.33\ \text{kW}\ = 8330\ \text{W}$$

HYDRAULIC PUMPS

1. **Classification based on displacement:**
   - Positive displacement pump (hydrostatic pump).
   - Non-positive displacement pump (hydrodynamic pump).

2. **Classification based on delivery:**
   - Constant delivery pumps.
   - Variable delivery pumps.

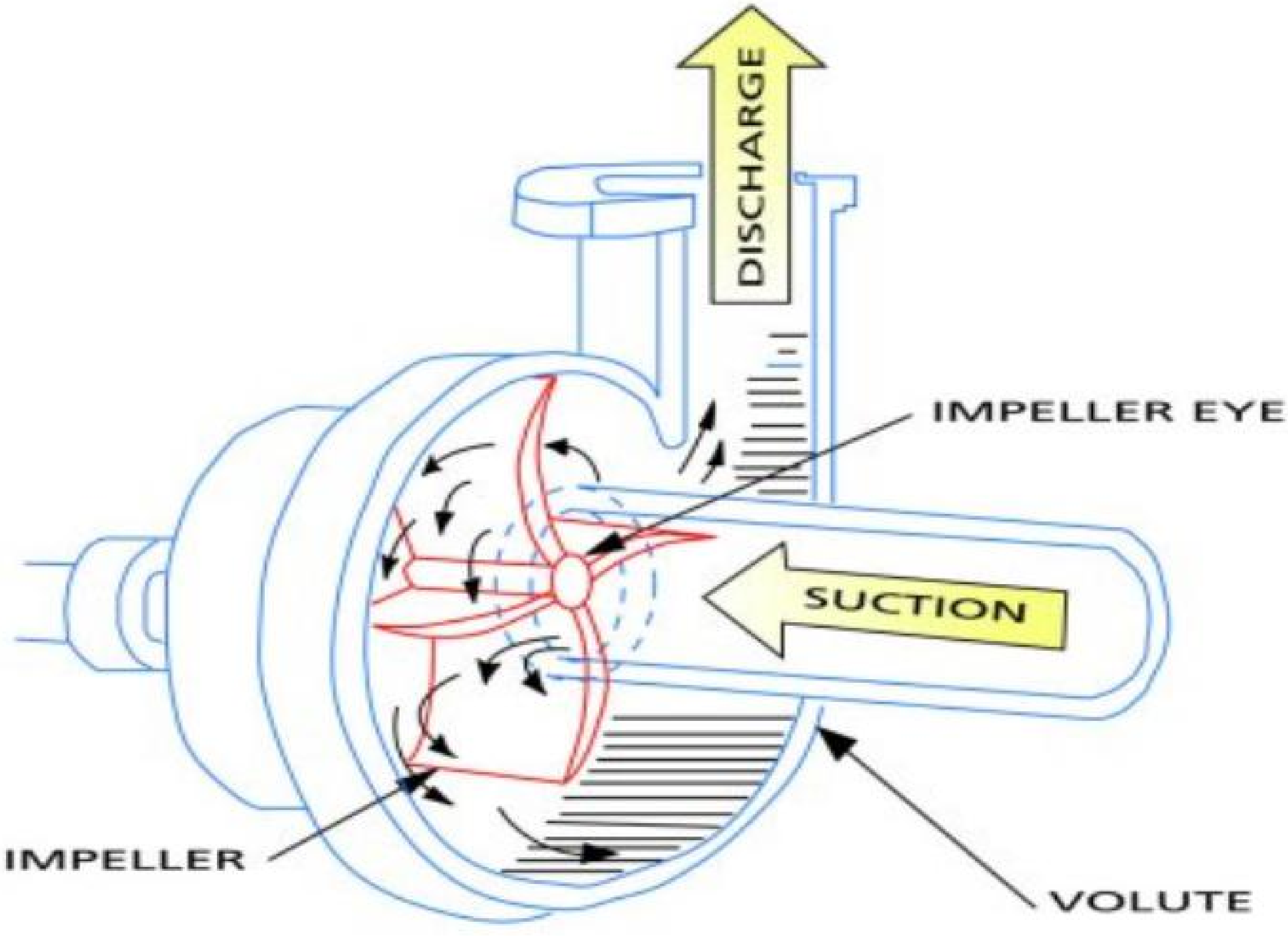
3. **Classification based on motion:**
   - Rotary pump.
   - Reciprocating pump.

Displacement
Non-Positive Displacement Pumps

- 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.
- They have essentially no suction lift. Because of large clearance space, these pumps are not self priming. In other words,

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.
- 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.
- These types of pumps are primarily used for transporting fluids such as water, petroleum, etc., from one location to another considerable apart location.
- The two most common types of hydrodynamic pumps are the centrifugal and the axial flow propeller pumps.



DISCHARGE
IMPELLER EYE
SUCTION
IMPELLER
VOLUTE

Advantages of Non-positive displacement pumps

1. Non-displacement pumps 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.

Disadvantages of Non-positive displacement pumps

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.

Positive Displacement Pumps

- Positive displacement pumps, in contrast, have very little slips, are self-priming and pump against very high pressures, but their volumetric capacity is low.
- Positive displacement pumps have a very close clearance between rotating and stationary parts and hence are self-priming.
- Positive displacement pumps eject a fixed amount of fluid into the hydraulic system per revolution of the pump shaft.
- Such pumps are capable of overcoming the pressure resulting from mechanical loads on the system as well as the resistance of flow due to friction.
- This equipment must always be protected by relief valves to prevent damage to the pump or system.

Classification - PDP

1. 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.

2. Displacement characteristics: Based on displacement characteristics, positive displacement pumps are classified as follows:

- Fixed displacement pumps.
- Variable displacement pumps.

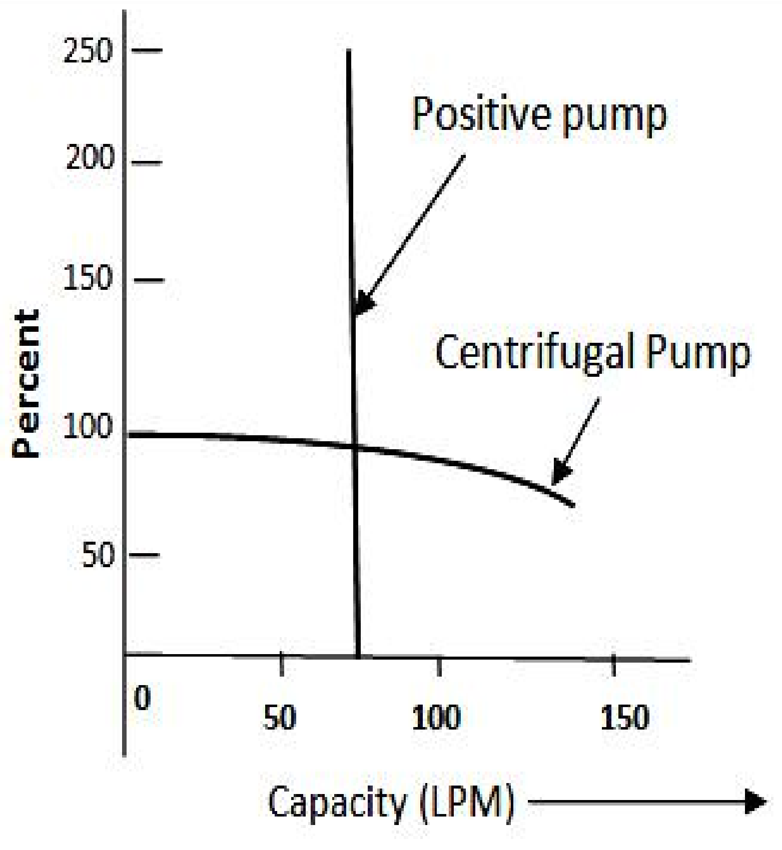
Advantages of PDP over NPD

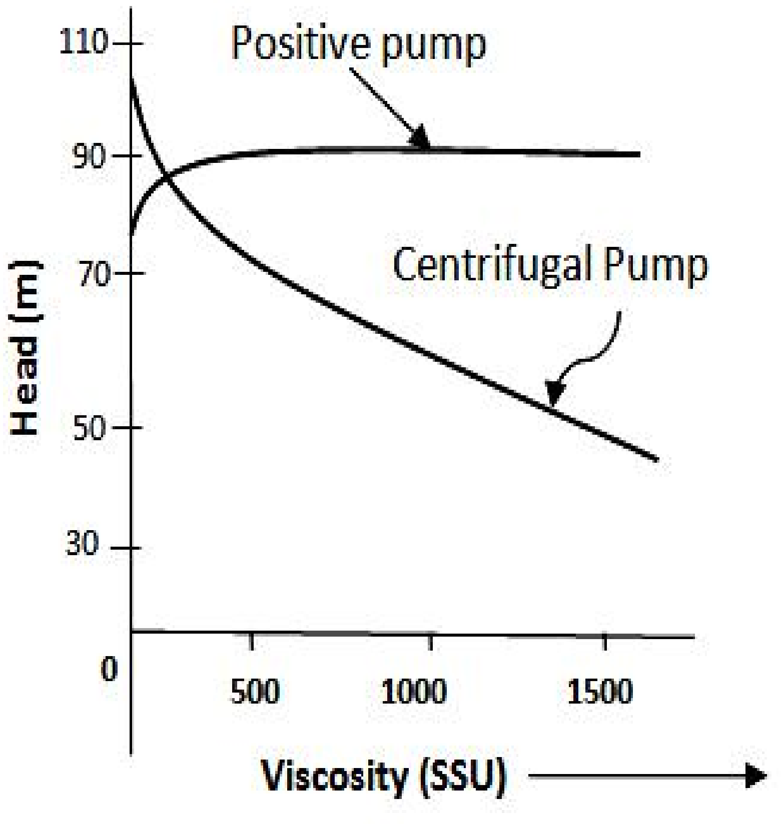
1. They can operate at very high pressures of up to 800 bar (used for lifting oils from very deep oil wells).
2. They can achieve a high volumetric efficiency of up to 98%.
3. They are highly efficient and almost constant throughout the designed pressure range.
4. They are a compact unit, having a high power-to-weight ratio.
5. They can obtain a smooth and precisely controlled motion.
6. By proper application and control, they produce only the amount of flow required to move the load at the desired velocity.
7. They have a great flexibility of performance. They can be made to operate over a wide range

Difference between PDP and NPD

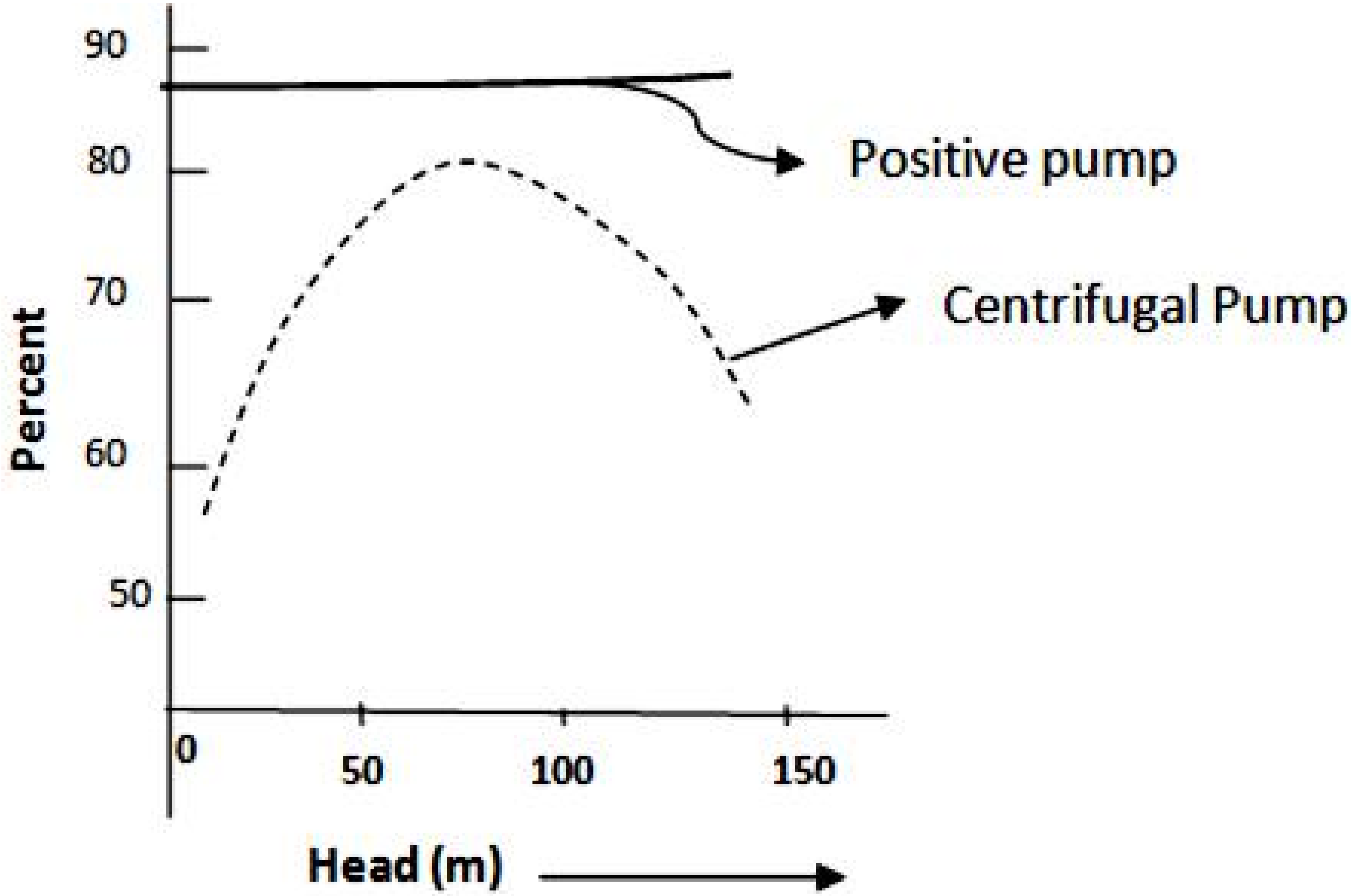
Positive Displacement Pumps	Non-positive Displacement Pumps
The flow rate does not change with head	The flow rate decreases with head
The flow rate is not much affected by the viscosity of fluid	The flow rate decreases with the viscosity
Efficiency is almost constant with head	Efficiency increases with head at first and then decreases

Difference between PDP and NPD

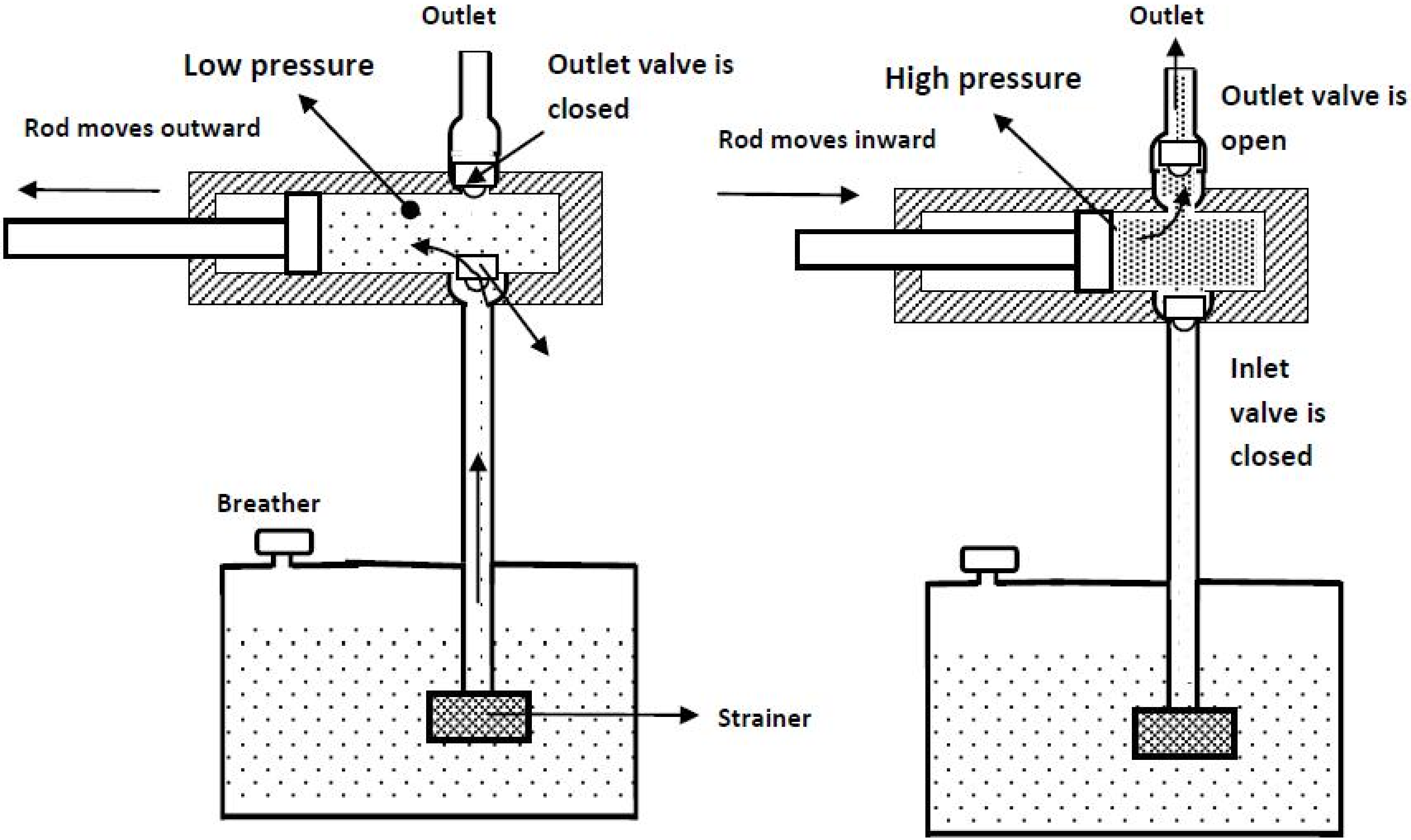




Difference between PDP and NPD



Pumping Theory



Suction stroke

Delivery stroke

Gear Pumps

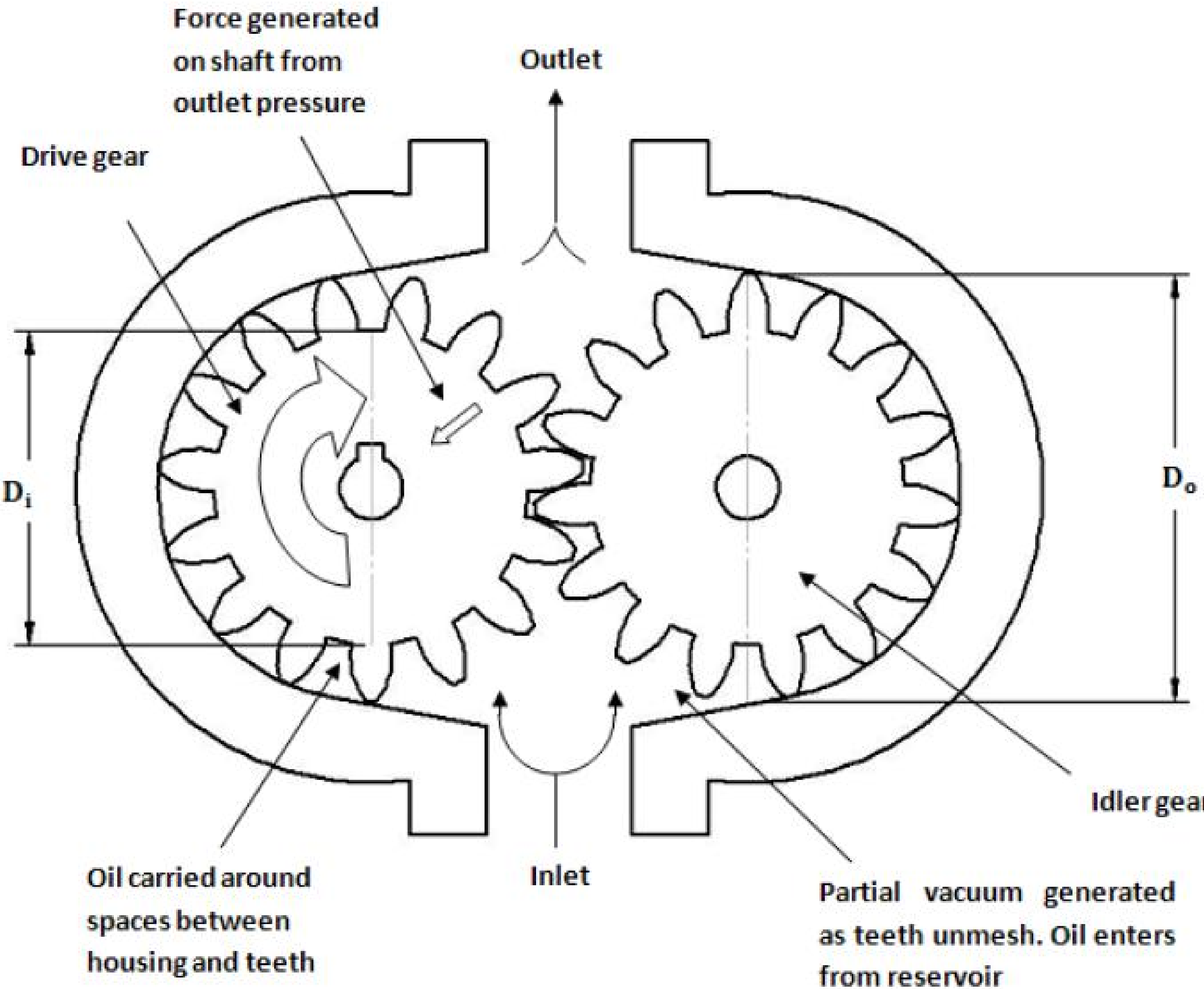
- Gear pumps are less expensive but limited to pressures below 140 bar.
- It is noisy in operation than either vane or piston pumps.
- Gear pumps are invariably of fixed displacement type, which means that the amount of fluid displaced for each revolution of the drive shaft is theoretically constant.

Advantages of gear pumps

1. They are self-priming.
2. They give constant delivery for a given speed.
3. They are compact and light in weight.
4. Volumetric efficiency is high.

Disadvantages of gear pumps

1. The liquid to be pumped must be clean, otherwise it will damage pump.
2. Variable speed drives are required to change the delivery.
3. If they run dry, parts can be damaged because the fluid to be pumped is used as lubricant.


Force generated
on shaft from
outlet pressure
Outlet
Drive gear
D_i
D_o
Idler gear
Oil carried around
spaces between
housing and teeth
Inlet
Partial vacuum generated
as teeth unmesh. Oil enters
from reservoir

Expression for the theoretical flow rate of an external gear pump

Let

D_o =the outside diameter of gear teeth

D_i= the inside diameter of gear teeth

L =the width of gear teeth

N=the speed of pump in RPM

V_D=the displacement of pump in m/rev

M= module of gear

z=number of gear teeth

α= pressure angle

Volume displacement is

$$V_D = \frac{\pi}{4}(D_o^2 - D_i^2)L$$

$$D_i = D_o - 2(\text{Addendum} + \text{Dendendum})$$

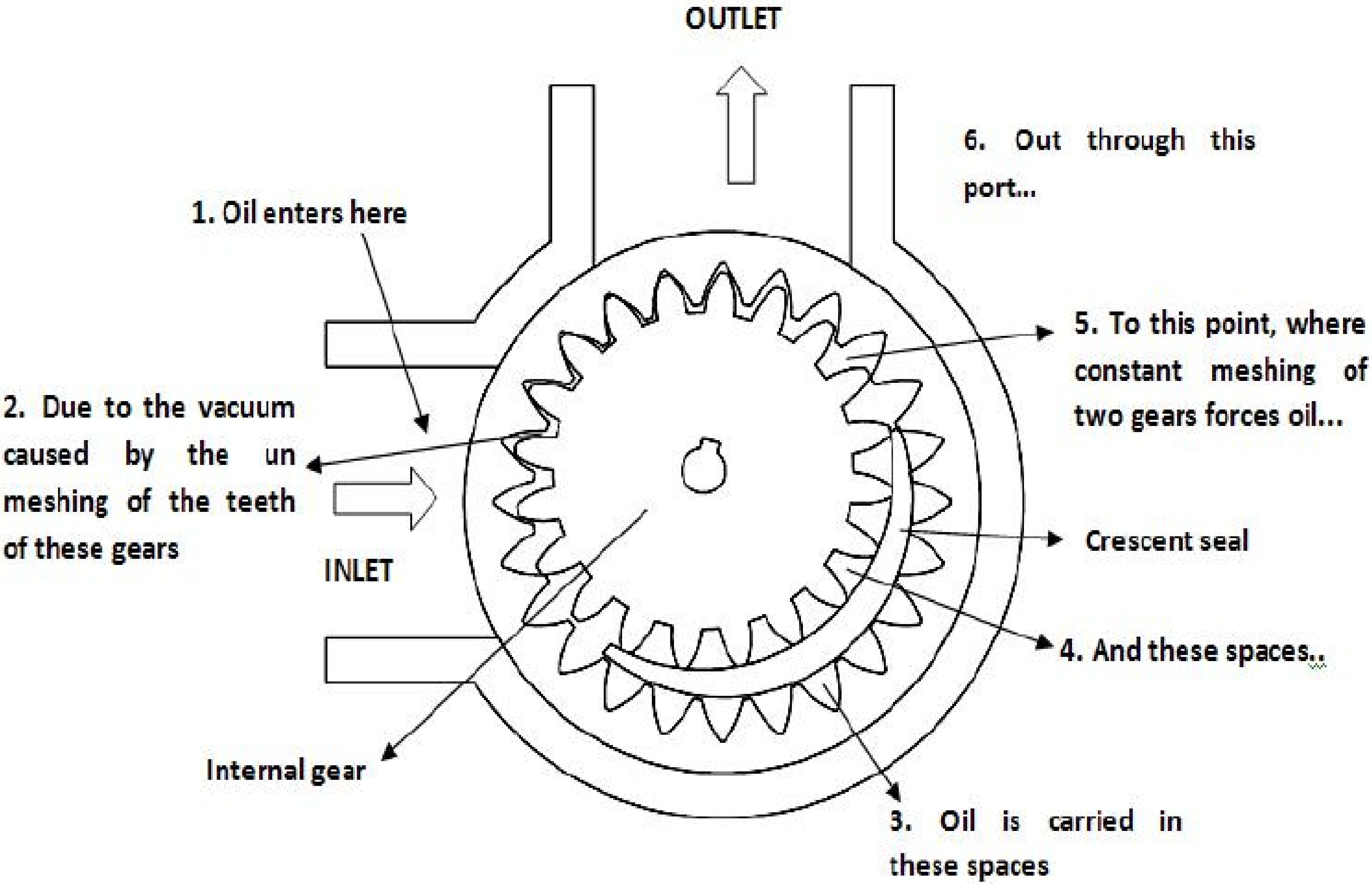
Theoretical discharge is

$$Q_T\ (\text{m}^3/\text{min}) = V_D\,(\text{m}^3/\text{rev}) \times N\ (\text{rev/min})$$

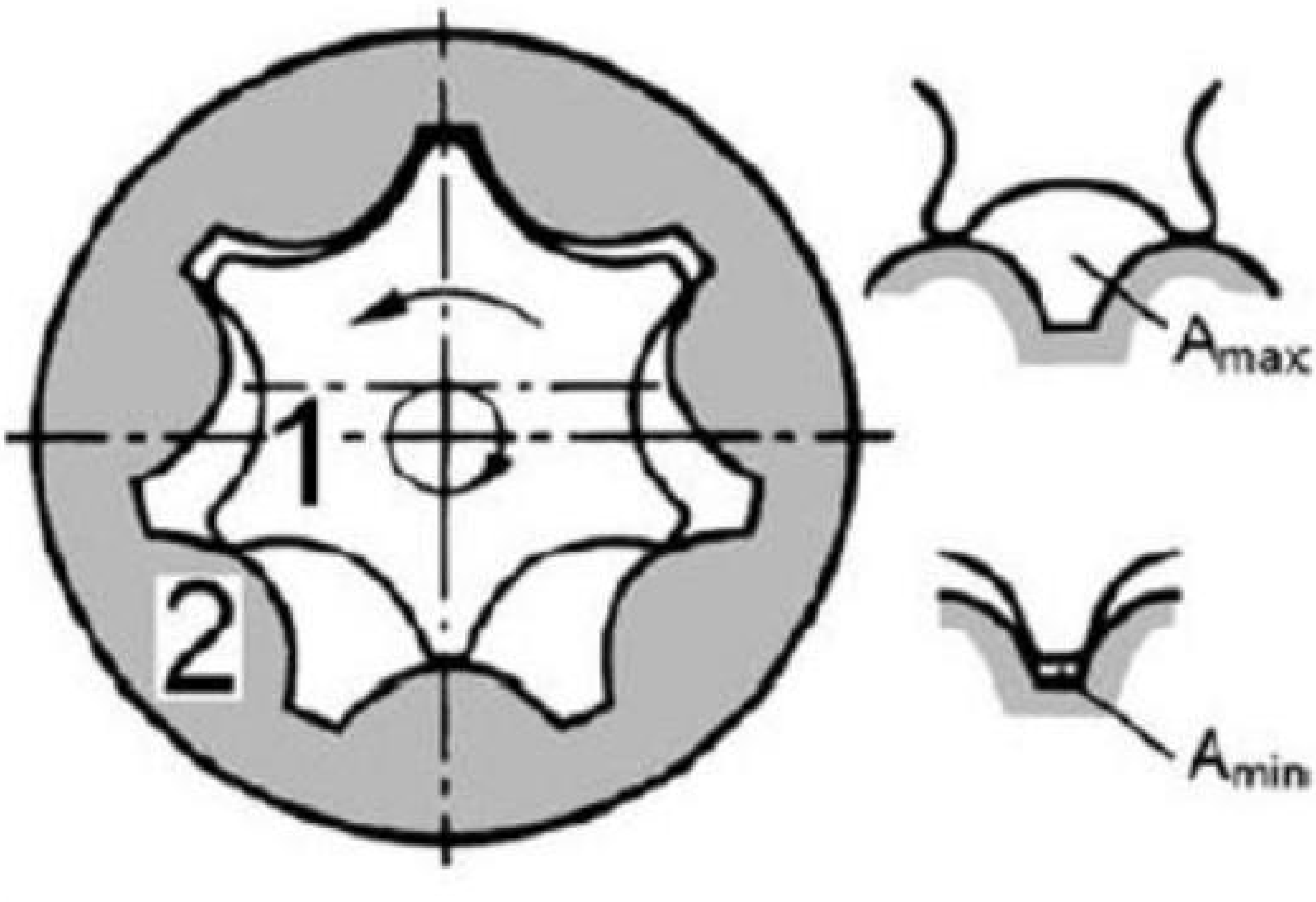
If the gear is specified by its module and number of teeth, then the theoretical discharge can be found by

$$Q_T = 2\pi L m^2 N\left[z + \left(1 + \frac{\pi^2 \cos^2 20}{12}\right)\right]\ \text{m}^3/\text{min}$$

Internal Gear Pumps



Gerotor Pumps



Example 1

- The inlet to a hydraulic pump is 0.6 m below the top surface of an oil reservoir. If the specific gravity of the oil used is 0.86, determine the static pressure at the pump inlet.

Solution: We know that

$$\text{Pressure} = \rho g h$$

The density of water is 1 g/cm^3 or 1000 kg/m^3.

Therefore, the density of oil is 0.86×1 g/cm^3 or 860kg/m^3.

Pressure at the pump inlet is

$$P = 860 \times 0.6 \text{kg/m}^2 = 516 \text{kg/m}^2 = 0.0516 \text{kg/cm}^2 = 0.0516 \times 0.981 \text{bar}$$

$$= 0.0506 \text{bar}$$

(Note: $1 \text{kg/cm}^2 = 0.981 \text{bar}$.)

Example 2

A hydraulic pump delivers 12 L of fluid per minute against a pressure of 200 bar.

(a) Calculate the hydraulic power.

(b) If the overall pump efficiency is 60%, what size of electric motor would be needed to drive the pump?

Solution:

(a) Hydraulic power is given by

$$\text{Hydraulic power (kW)} = 12\ \text{L/min} \times \frac{200\ \text{(bar)}}{600} = 4\ \text{kW}$$

(b) We have

$$\text{Electric motor power (power input)} = \frac{\text{Hydraulic power}}{\text{Overall efficiency}}$$

Substituting we get

$$\text{Electric motor power (power input)} = \frac{4}{0.6} = 6.67\,kW$$

$$\text{Electric motor power} = \frac{4}{0.6} = 6.67\ \text{kW}$$

Example 3

- A gear pump has an outside diameter of 80mm, inside diameter of 55mm and a width of 25mm. If the actual pump flow is 1600 RPM and the rated pressure is 95 LPM what is the volumetric displacement and theoretical discharge.

Solution: We have

Outside diameter $D_o = 80\text{ mm}$

Inside diameter $D_i = 55\text{ mm}$

Width $d = 25\text{mm}$

Speed of pump $N = 1600$ RPM

Actual flow rate = 95 LPM

Now

$$Q_A = 95\,\text{LPM} = 95 \times 10^{-3}\,\text{m}^3/\text{min}$$

$$V_D = \frac{\pi}{4} \times (D_o^{\ 2} - D_i^{\ 2}) \times L$$

$$V_D = \frac{\pi}{4} \times (0.080^2 - 0.055^2) \times 0.025 = 6.627 \times 10^{-5} m^3 / rev$$

Theoretical flow rate

$$Q_T = \frac{\pi}{4} \times (D_o^{\ 2} - D_i^{\ 2}) \times L \times N$$

$$= \frac{\pi}{4} \times (0.080^2 - 0.055^2) \times 0.025 \times 1600$$

$$= 0.106\,\text{m}^3/\text{min}$$

Example 4

- Calculate the theoretical delivery of a gear pump. Module of the gear teeth is 6mm and width of gear teeth is 25mm. Number of teeth on driver gear is 18 and pressure angle of the gear is 20 . Pump speed is 1000 RPM. Volumetric efficiency is 90%.

$$Q_T = 2\pi L m^2 N\left[z + \left(1 + \frac{\pi^2 \cos\alpha}{12}\right)\right] \text{ m}^3/\text{min}$$

$$= 2\pi(0.025)(6\times10^{-3})^2 \times 1000 \times \left[18 + \left(1 + \frac{\pi^2 \cos^2 20}{12}\right)\right] \text{ m}^3/\text{min}$$

$$= 0.1118 \text{ m}^3/\text{min}$$

Example 5

- Calculate the theoretical delivery of a gear pump. Module of the gear teeth is 6mm and width of gear teeth is 65mm. Number of teeth on driver gear is 16 and pressure angle of the gear is 20 . Pump speed is 1600 RPM. Outer diameter of gear is 108 mm and Dedendum circle diameter is 81 mm. Volumetric efficiency is 88%at 7 MPa.

Solution: If the gear is specified by its module and number of teeth, then the theoretical discharge can be found by

$$Q_{\mathrm{T}} = 2\pi L m^2 N\left[z + \left(1 + \frac{\pi^2 \cos^2 20}{12}\right)\right] \mathrm{m^3/min}$$

$$= 2\pi(0.065)(6\times10^{-3})^2 \times 1600 \times \left[16 + \left(1 + \frac{\pi^2 0.939^2}{12}\right)\right] \mathrm{m^3/min}$$

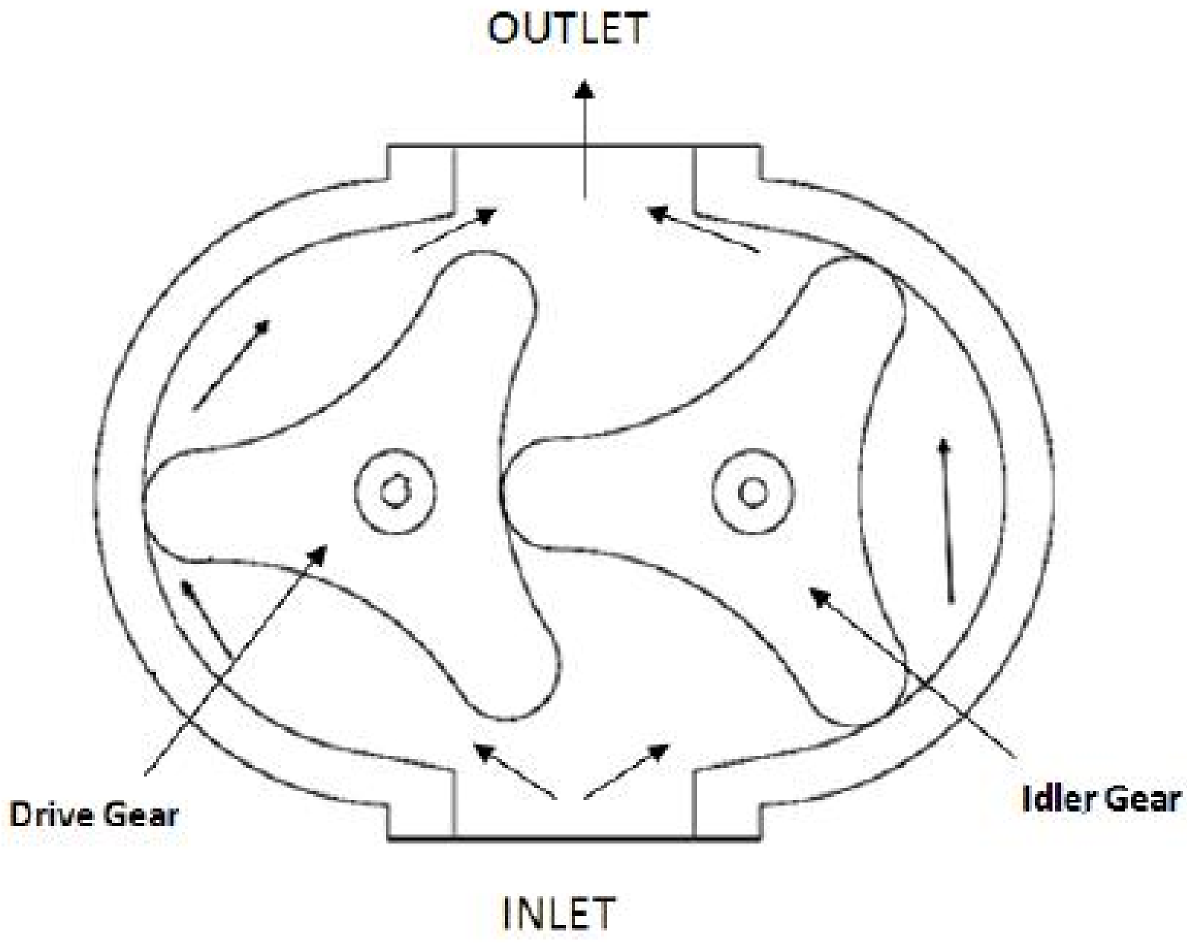
$$= 0.416\ \mathrm{m^3/min}$$

Alternatively we can use

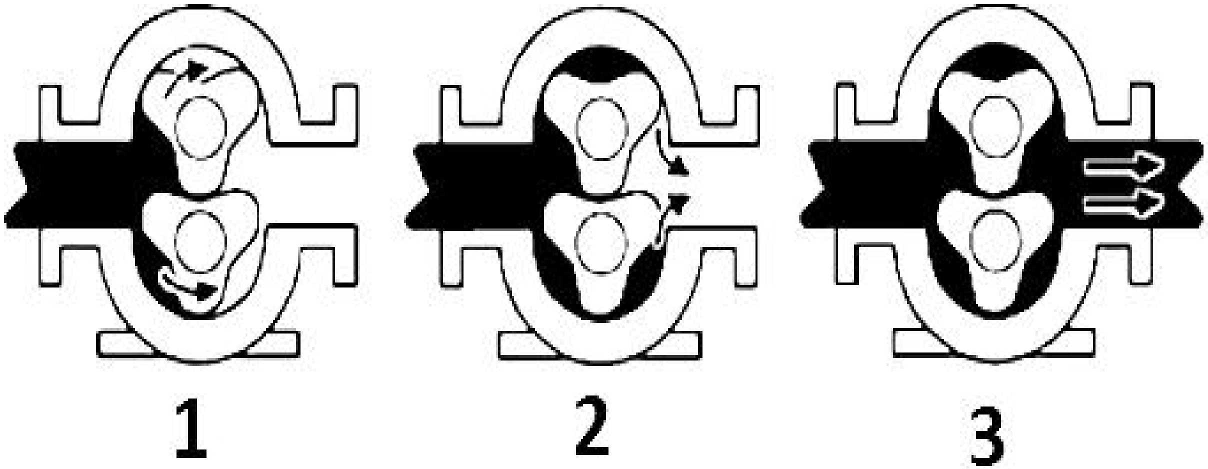
$$V_{\mathrm{D}} = \frac{\pi}{4} \times (D_{\mathrm{o}}^2 - D_{\mathrm{i}}^2) \times L$$

$$Q_{\mathrm{T}} = \frac{\pi}{4} \times (0.108^2 - 0.081^2) \times 0.065 \times 1600 = 0.416\ \ \mathrm{m^3/rev}$$

Lobe Pumps



Stages of operation of Lobe pump



1.As the lobes come out of mesh, they create expanding volume on the inlet side of the pump.Liquid flows into the cavity and is trapped by the lobes as they rotate.

2.Liquid travels around the interior of the casing in pockets between the lobes and the casing (it does not pass between the lobes).

3.Finally, the meshing of the lobes forces the liquid through the outlet port under pressure.

Lobe Pumps

- Lobe pumps are frequently used in food applications because they are good at handling solids without inflicting damage to the product.
- Solid particle size can be much larger in lobe pumps than in other positive displacement types.
- Because lobes do not make contact, and clearances are not as close as in other positive displacement pumps, this design handles low-viscosity liquids with diminished performance.
- Loading characteristics are not as good as other designs and suction ability is low.
- High-viscosity liquids require reduced speeds to achieve satisfactory performance.
- Reductions of 25% of rated speed and lower are common with high-viscosity liquids.

The advantages of lobe pumps are as follows:

1. Lobe pumps can handle solids, slurries, pastes and many liquid.
2. No metal-to-metal contact.
3. Superior CIP(Cleaning in Place) /SIP(Sterilization in Place) capabilities.
4. Long-term dry run (with lubrication to seals).
5. Non-pulsating discharge.

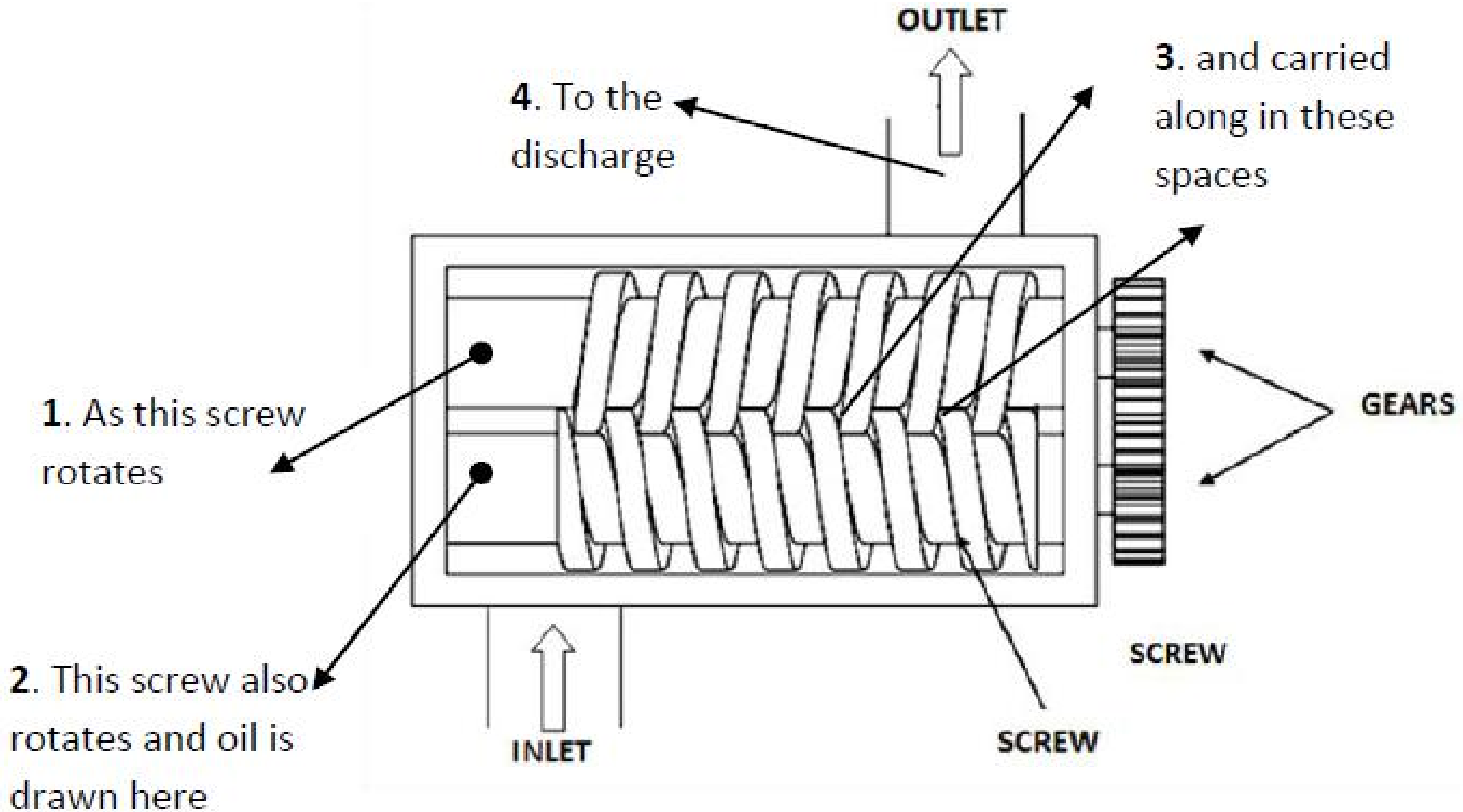
The disadvantages of lobe pumps are as follows:

1. Require timing gears.
2. Require two seals.
3. Reduced lift with thin liquids.

Applications

1. Polymers.
2. Paper coatings.
3. Soaps and surfactants.
4. Paints and dyes.
5. Rubber and adhesives.
6. Pharmaceuticals.
7. Food applications.

Screw Pumps


OUTLET
3. and carried along in these spaces
4. To the discharge
1. As this screw rotates
GEARS
2. This screw also rotates and oil is drawn here
SCREW
INLET
SCREW

Ina screw pump, a chamber is formed between thread and housing as shown in Fig.1.11. The following expression gives the volumetric displacement

$$V_{\mathrm{D}} = \frac{\pi}{4}(D^2 - d^2)s - D^2\left\{\frac{\alpha}{2} - \frac{\sin 2\alpha}{2}\right\}s$$

Heres is the stroke length and $\cos(\alpha) = \dfrac{D+d}{2D}$

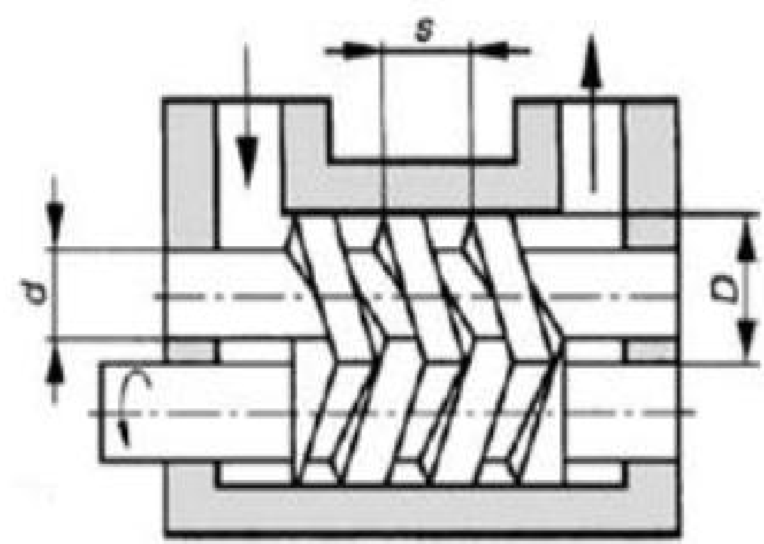


Figure 1.11 Volumetric displacement of a screw pump

Advantages of screw pump

1. They are self-priming and more reliable.
2. They are quiet due to rolling action of screw spindles.
3. They can handle liquids containing gases and vapor.
4. They have long service life.

Disadvantages of screw pump

1. They are bulky and heavy.
2. They are sensitive to viscosity changes of the fluid.
3. They have low volumetric and mechanical efficiencies.
4. Manufacturing cost of precision screw is high.