# 1 Introduction

All machines require some type of power source and a way of transmitting this power to the point of operation. The three methods of transmitting power are:

- Mechanical
- Electrical
- Fluid

In this course we are going to deal with the third type of power transmission which is the **Fluid Power**

Fluid power is the method of using pressurized fluid to transmit energy. **Liquid** or **Gas** is referred to as a fluid. Accordingly, there are two branches of fluid power; **Pneumatics,** and **Hydraulics**.

Hydraulic systems use liquid to transfer force from one point to another. Pneumatic systems use air to transfer force from one point to another. Air is

- **Compressible:** (*This describes whether it is possible to force an object into a smaller space than it normally occupies. For example, a sponge is compressible because it can be squeezed into a smaller size*), and liquid is
- **Incompressible:** (*The opposite to compressible. When a "squeezing" force is applied to an object, it does not change to a smaller size. Liquid, for example hydraulic fluid, possesses this physical property*).

It is this difference that makes hydraulic and pneumatic systems behave in different ways. This module focuses on hydraulics.

Hydraulic systems are commonly used where mechanisms require large forces and precise control. Examples include vehicle power steering and brakes, hydraulic jacks and heavy earth moving machines.

Liquid is ideal for transferring a force from the control mechanism to the mechanism doing the work. For example transferring force from the brake pedal to the wheel brake in a car. Because liquid does not compress, it transfers all the force and enables precise movement.

# 2 Uses of hydraulics

Hydraulics plays an important role in many industries; there are a lot of hydraulic applications in manufacturing, transportation, and construction sectors. Hydraulics systems are used where large, precise forces are required.

## 2.1 Common examples of hydraulic systems include:

### 2.1.1 Vehicle brake hydraulic systems

The function of a vehicle braking system is to stop or slow down a moving vehicle.

When the brake pedal is pressed as illustrated in Fig. 1.1, the hydraulic pressure is transmitted to the piston in the brake caliper of the brakes.

The pressure forces the brake pads against the brake rotor, which is rotating with the wheel.

The friction between the brake pad and the rotor causes the wheel to slow down and then stop.

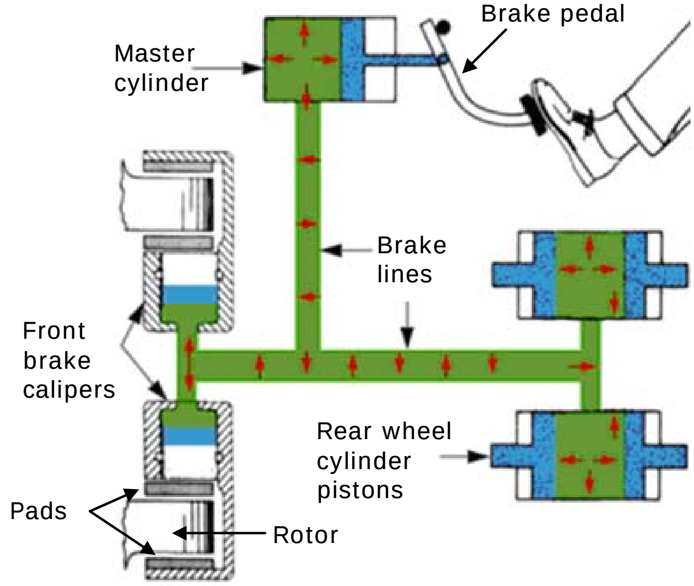



Fig.1.1: A schematic diagram of the vehicle's hydraulic brake system.

**Tip**: Watch the hydraulic brake system video.

### 2.1.2 Vehicle power steering

The vehicle power steering system uses hydraulic oil, the hydraulic pump supplies the oil through the control valves to the power cylinder as shown in Fig. 1.2. The major advantage of using this system is to turn the vehicle's wheels with less effort.

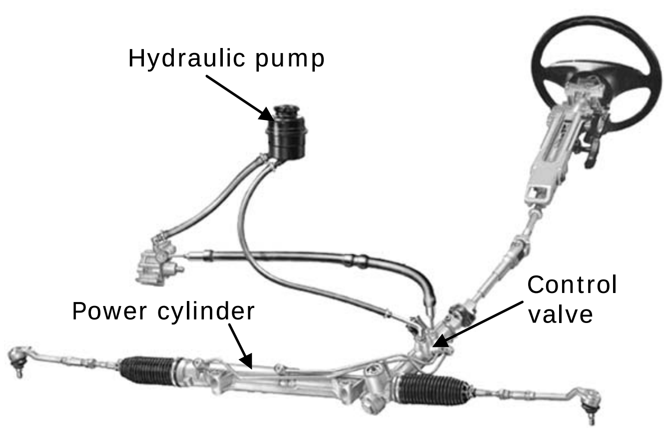


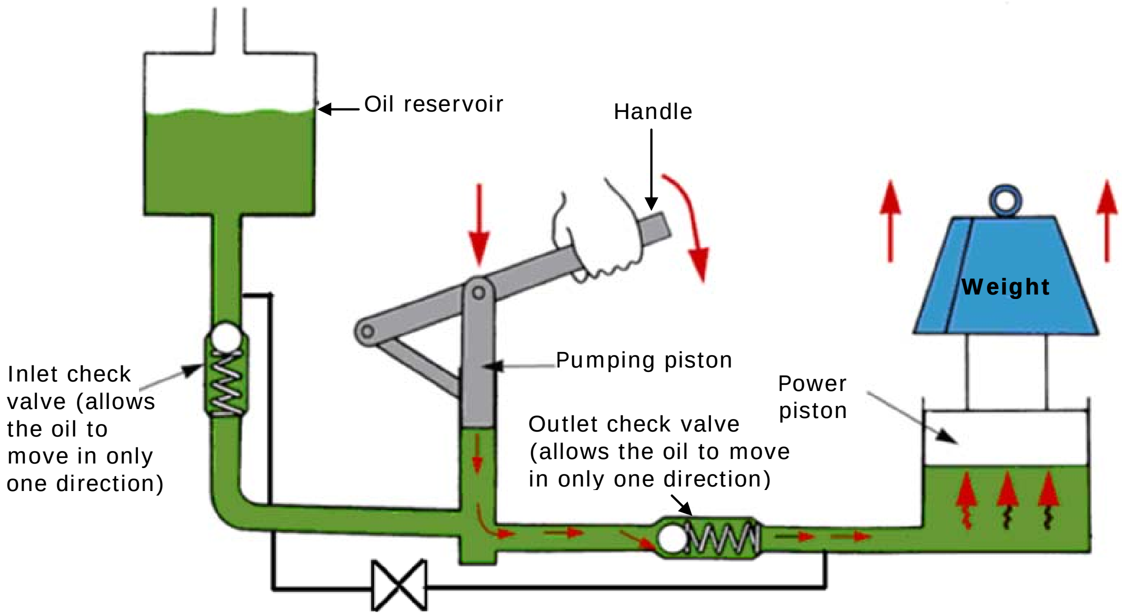

Fig.1.2:Vehicle hydraulic power steering system

### 2.1.3 Hydraulic jack

In a hydraulic jack, a small piston (pumping piston) transmits pressure through the oil to a large piston (power piston) through a check valve, resulting in the weight being lifted as shown in Fig.1.3.

**Tip**: Watch the hydraulic jack video.

(a) Hydraulic jack




(b) Hydraulic jack schematic diagram

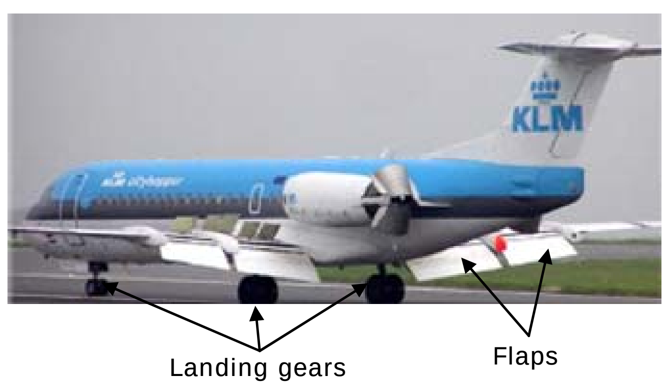
Fig.1.3: (a) hydraulic jack. (b) Schematic diagram of the hydraulic jack.

### 2.1.4 Aircraft hydraulic systems

All modern aircraft contain hydraulic systems to operate mechanisms, such as:

- Flaps (Fig. 1.4a)
- Landing gear (Fig. 1.4a)

The hydraulic pump that is coupled to the engine provides hydraulic power as illustrated

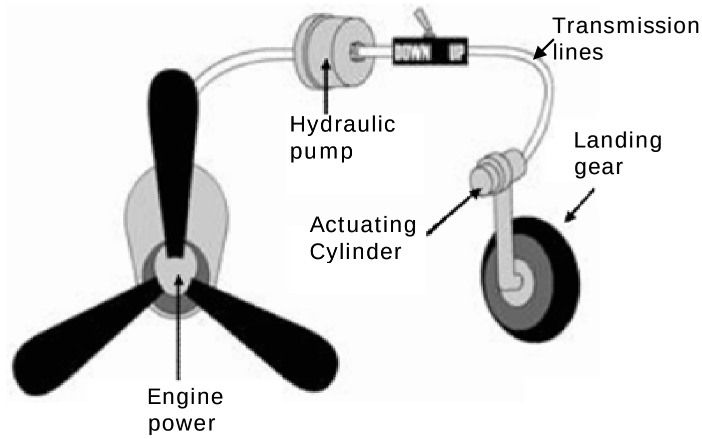



(a) Landing gears and flaps

by Fig. 1.4b.

Power is also distributed to systems through the aircraft by transmission lines.

Hydraulic power is converted to mechanical power by means of an actuating cylinder or hydraulic motor.




(b) Landing gear schematic diagram

Fig.1.4: (a) Flaps and landing gears. (b)Schematic diagram of the landing gear hydraulic system.

## 3 Hydraulic system components

All industrial hydraulic systems consist of the following basic components

1. **Power input device:** The pump and motor together are called the power input device; the pump provides power to the hydraulic system by pumping oil from the reservoir/tank. The pump's shaft is rotated by an external force which is most often an electric motor as illustrated in Fig 1.5. **Tip**: "Watch the hydraulic system video"

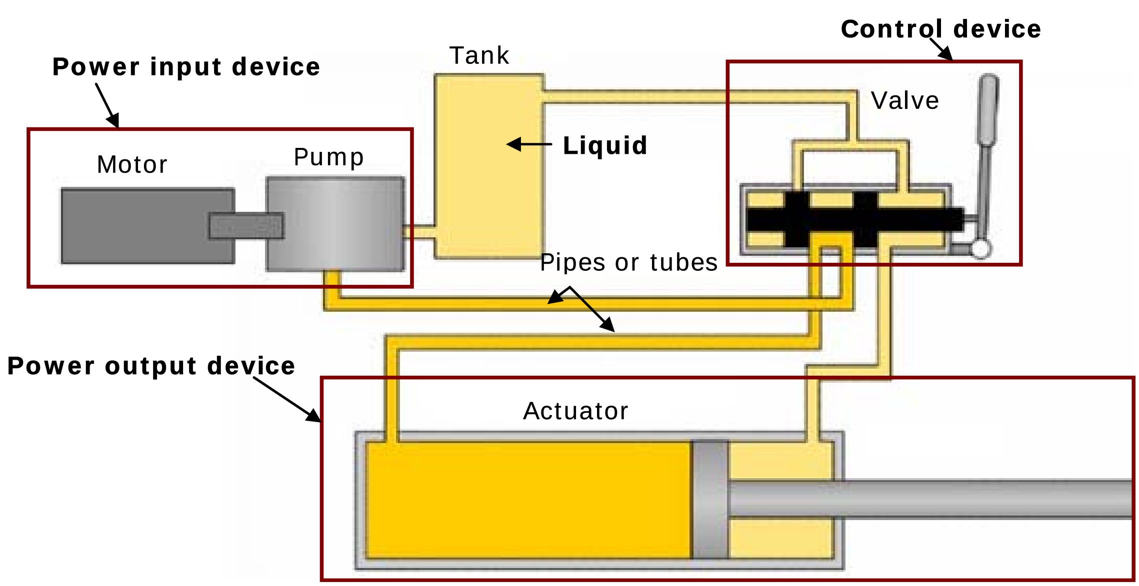



Fig.1.5: The basic components of a Hydraulic system

2. **Control device**: Valves control the direction, pressure, and flow of the hydraulic fluid from the pump to the actuator/cylinder.
3. **Power output device**: The hydraulic power is converted to mechanical power inside the power output device. The output device can be either a cylinder which produces linear motion or a motor which produces rotary motion.
4. **Liquid**: the liquid is the medium used in hydraulic systems to transmit power. The liquid is typically oil, and it is stored in a tank or reservoir.
5. **Conductors**: The conductors are the pipes or hoses needed to transmit the oil between the hydraulic components.

## 3.1 Hydraulic power pack

The hydraulic power pack combines the pump, the motor, and the tank. The hydraulic power pack unit provides the energy required for the hydraulic system. The parts of the hydraulic power pack unit are shown in Fig. 1.6.

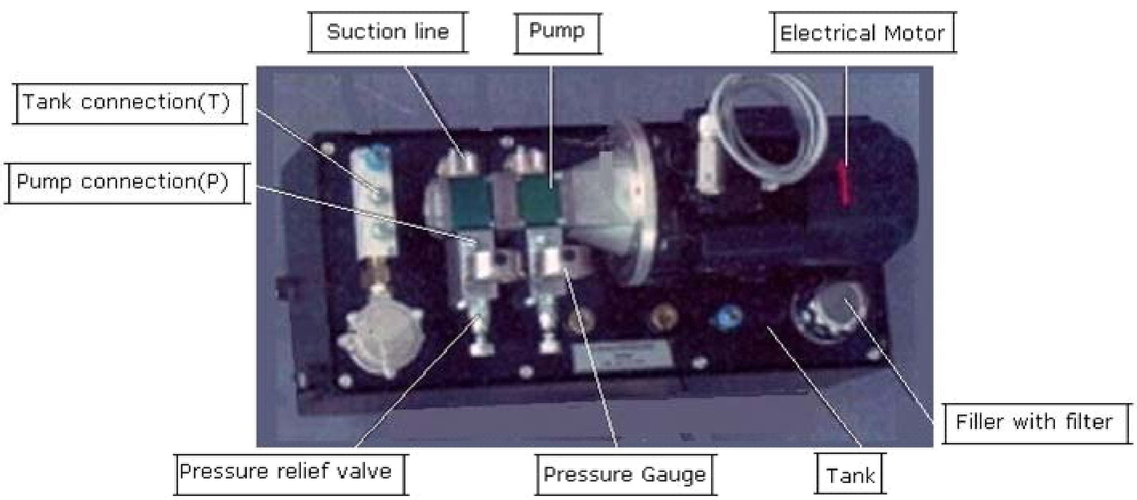



Fig.1.6: The main parts of the hydraulic power pack

## 3.2 Activity 1: Hydraulic station component identification

In this activity, you will identify the components of the Festo Hydraulic work station in your lab:

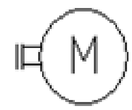
1. Locate the power pack unit and identify its parts.
2. Locate the out put device (actuators).
3. Locate the control devices (valves).
4. Locate the conductors (hoses).

## 3.3 Hydraulic symbols

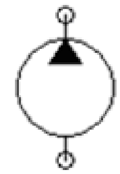
The way hydraulic components direct and control liquid around a circuit can be complex. This would cause difficulty for one engineer explaining to another engineer how the circuit works. A common form of representing components and circuits is used to more easily explain what is happening. This form of representation uses common symbols to represent components and the ways in which they are connected to form circuits. Fig. 1.7 shows some of the components' symbols used in hydraulics.

The symbols don't show the component construction, or size, however, it is a standard form that is used by all engineers to represent that specific component.

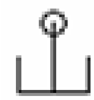
The simplified and detailed symbols of the hydraulic power pack are shown in Fig. 1.8.



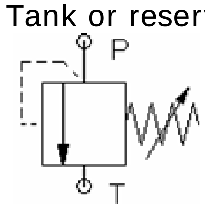

(a) Electric motor



(b) Hydraulic pump

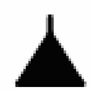


(c) Tank or reservoir

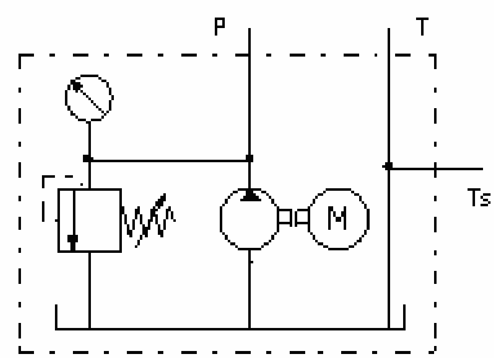



(d)Pressure relief valve

Fig.1.7: (a) Electric motor. (b) Hydraulic pump. (c) Tank or reservoir. (d) Pressure relief valve.



(a) Simplified




(b) Detailed

Fig.1.8: (a) Simplified symbol of the hydraulic power pack. (b) Detailed symbol of the hydraulic power pack.

## 4 Fundamental laws of Hydraulics

All hydraulic systems operate following a defined relationship between area, force and pressure. Laws have been established to explain the behavior of hydraulic systems. Hydraulic systems use the ability of a fluid to distribute an applied force to a desired location.

### 4.1 Pressure

When a force (F) is applied on an area (A) of an enclosed liquid, a pressure (P) is produced as shown in Fig. 1.9.

Pressure is the distribution of a given force over a certain area. Pressure can be quoted in bar, pounds per square inch (PSI) or Pascal (Pa)

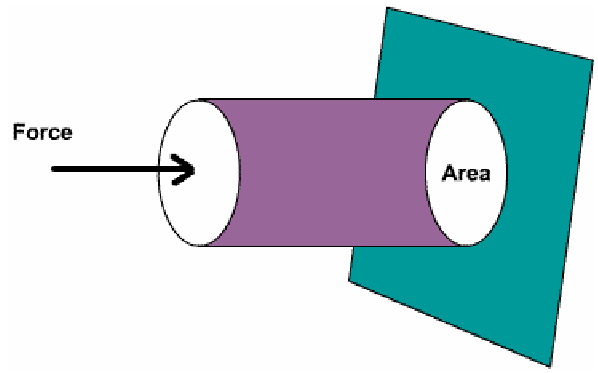



Fig. 1.9: Illustration of pressure definition

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

Where force is in newtons (N) and area is in square meters ($m^2$).

1 Pascal (Pa) =1 $N/m^2$.

1 bar= 100,000 Pa= $10^5$ Pa.

10 bar= 1 MPa (mega Pascals)

In hydraulic systems, the engineer often has the force in newtons and the area in square millimeters.

1 $N/mm^2$ = 1 MPa = 10 bar

If the pressure is calculated using a force in newtons, and area in square millimeters, the pressure in bar can be calculated.

$$P = \frac{F}{A} = \frac{1000\,N}{3000\,mm^2} = 0.33\,N/mm^2 = 0.33\,MPa = 3.3\,bar$$

**Note:** To convert from $N/mm^2$ to bar, multiply by 10, and to convert from bar to $N/mm^2$, divide by 10.

**Example 1-1.**

A cylinder is supplied with 100 bar pressure; its effective piston surface is equal to 700 $mm^2$. Find the maximum force which can be attained.

$$P = 100 \text{ bar} = 100/10 = 10 \text{ N/mm}^2.$$

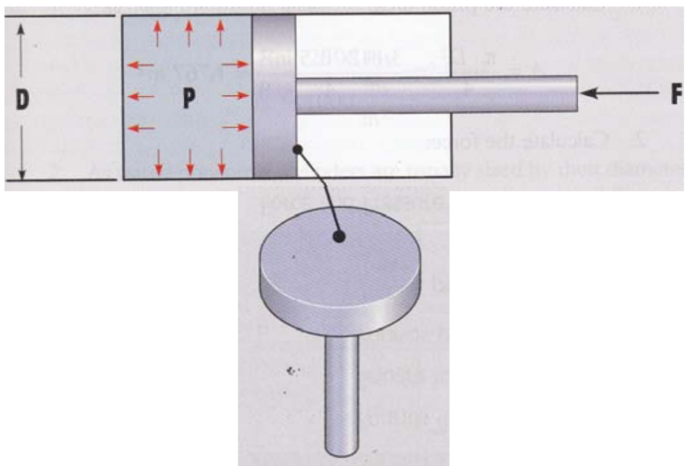
$$A = 700 \text{ mm}^2.$$

$$F = P.A = 10X700 = 7000 \text{ N} = 7 \text{ kN}$$

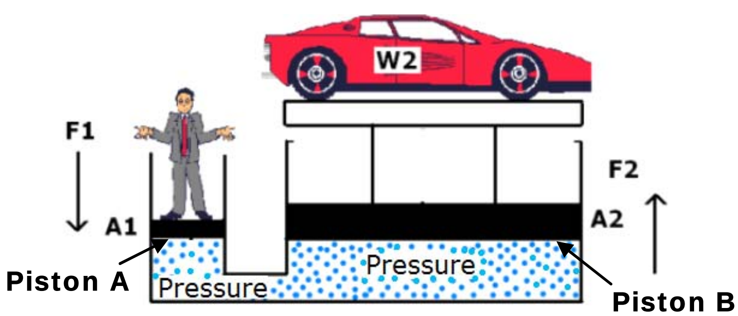
## 4.2 Pascal's Law

Pascal's law states that: "***The pressure in a confined fluid is transmitted equally to the whole surface of its container***" Accordingly, the pressure at any point in a body of fluid is the same in any direction as shown in Fig. 1.10a.

Fig.1.10b shows that, if a downward force is applied to piston A, it will be transmitted through the system to piston B. According to Pascal's law, the pressure at piston A (P1) equals the pressure at piston B (P2)




(a) Pascal's law




(b)Power transmission

Fig.1.10: (a) Pascal's law. (b) Power transmission in an enclosed system.

$$P_1 = P_2$$

Fluid pressure is measured in terms of the force exerted per unit area.

$$P = \frac{F}{A}$$

$$P_1 = \frac{F_1}{A_1}$$

$$P_2 = \frac{F_2}{A_2}$$

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

The values F1, A2 can be calculated using the following formula:

$$F_1 = \frac{A_1 \times F_2}{A_2}, \text{ and } A_2 = \frac{A_1 \times F_2}{F_1}$$

**Example 1-2.**

In Fig.11, find the weight of the car in N, if the area of piston A is 600 $mm^2$, the area of piston B is 10500 $mm^2$, and the force applied on piston A is 500 N.

**Solution:**

$$P_1 = P_2$$

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

$$F_2 = \frac{F1 \times A_2}{A_1}$$

$$F_2 = \frac{500 \times 10500}{600}$$

$$F_2 = 8750\ N = 8.75\ kN$$

**Example 1-3.**

In Fig 1.11, if the weight of the car is 10,000 N, the diameter of piston A is 10 mm, and the force applied on piston A is 250 N. Calculate the radius of piston B.

**Solution:**

1. Calculate the area of piston A, the piston shape is circular as shown in Fig. 1.10a, accordingly the area will be calculated using the following formula.

$$A_1 = \pi \frac{D^2}{4} = 3.14 \times \frac{(10)^2}{4} = 78.5\,\text{mm}^2,$$

$$F_1 = 250\,N\,,\ F_2 = 10{,}000\,N$$

2. Apply Pascal's law

$$P_1 = P_2$$

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

3. Use Pascal's law to calculate the area of piston B

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

$$A_2 = \frac{78.5 \times 10{,}000}{250} = 3140\,\text{mm}^2$$

$$A_2 = \pi \times \frac{(D_2)^2}{4} = 3140\,\text{mm}^2$$

4. Find the diameter of piston B

$$\frac{(D_2)^2}{4} = \frac{A_2}{\pi} = \frac{3140}{314}$$

$$D_2 = \sqrt{\frac{4 \times A_2}{\pi}} = \sqrt{\frac{4 \times 3140}{3.14}} = 6.33\,\text{mm}$$

## 4.3 Liquid flow

### 4.3.1 Flow rate versus flow velocity

The **flow rate** is the volume of fluid that moves through the system in a given period of time. Flow rates determine the speed at which the output device (e.g., a cylinder) will operate. The **flow velocity** of a fluid is the distance the fluid travels in a given period of time. These two quantities are often confused, so care should be taken to note the distinction. The following equation relates the flow rate and flow velocity of a liquid to the size (area) of the conductors (pipe, tube or hose) through which it flows.

$$Q = V \times A$$

Where: Q= flow rate ($\frac{m^3}{Sec}$)

V= flow velocity ($\frac{m}{Sec}$)

A= area ($m^2$)

This is shown graphically in Fig. 1.11. Arrows are used to represent the fluid flow. It is important to note that the area of the pipe or tube being used.

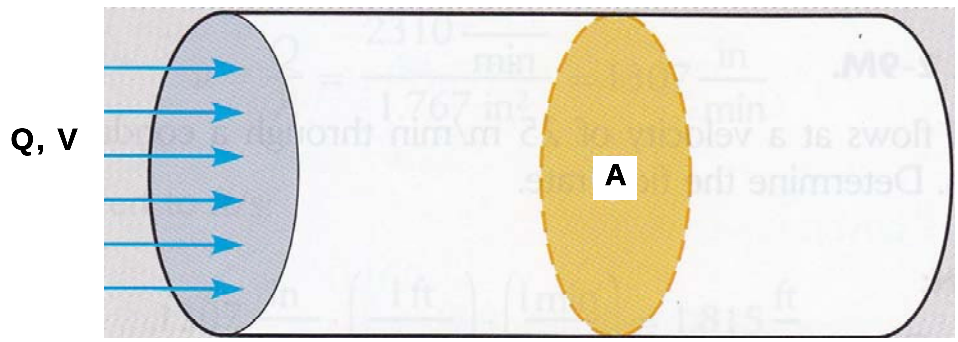



Fig.1.11: Flow velocity and flow rate

**Example 1-4.**

A fluid flows at a velocity of 2 m/s through a pipe with a diameter of 0.2 m. Determine the flow rate.

**Solution:**

1. Calculate the pipe area

$$A = \pi \frac{D^2}{4} = 3.14 \times \frac{(0.2)^2}{4} = 0.0314\,\mathrm{mm}^2$$

2. Calculate the flow rate

$$Q = V \times A$$

$$Q = 2 \times 0.0314 = 0.0628\ \frac{\mathrm{m}^3}{\mathrm{Sec}}$$

**Example 1-5.**

A pipe size needs to be determined for a system in which the flow rate will be 100 liter/ min. Determine the pipe diameter if the flow velocity is not to exceed 6 m/sec.

**Solution:**

1. Convert the unit of the flow rate from liter/min to m$^3$/sec.

$$Q = 100\frac{liter}{\min} = 100 \times \frac{dm^3}{\min} = 100 \times \frac{10^{-3}}{60}\frac{m^3}{s}$$

$$Q = 1.66 \times 10^{-3}\ \frac{m^3}{s}$$

2. Calculate the pipe area

$$Q = V \times A$$

$$A = \frac{Q}{V} = \frac{1.66 \times 10^{-3}}{6} = 2.76 \times 10^{-4}\ m^2$$

3. Calculate the diameter of the pipe

$$A = \pi \times \frac{D^2}{4} = 2.76 \times 10^{-4}\ m^2$$

$$\frac{D^2}{4} = \frac{A}{\pi} = \frac{2.76 \times 10^{-4}}{3.14} = 8.78 \times 10^{-5}$$

$$D^2 = 3.5 \times 10^{-4}$$

$$D = \sqrt{3.5 \times 10^{-4}} = 0.059\, m$$

### 4.3.2 The continuity equation

Hydraulic systems commonly have a pump that produces a constant flow rate. If we assume that the fluid is incompressible (oil), this situation is referred to as steady flow. This simply means that whatever volume of fluid flows through one section of the system must also flow through any other section. Fig. 1.12 shows a system where flow is constant and the diameter varies.

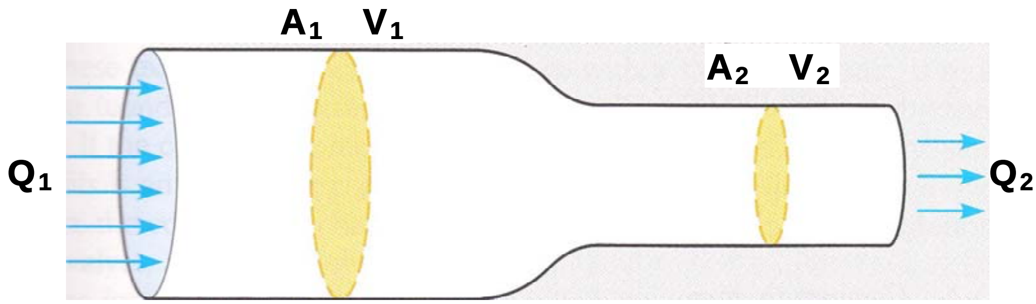



Fig.1.12: Continuity of flow.

The following equation applies in this system:

$$Q_1 = Q_2$$

Therefore,

$$V_1 \times A_1 = V_2 \times A_2$$

The following example illustrates the significance of the continuity equation shown above.

**Example 1-5.**

A fluid flows at a velocity of 0.2 m/s at point 1 in the system shown in Fig. 1.12. The diameter at point 1 is 50mm and the diameter at point 2 is 30 mm. Determine the flow velocity at point 2. Also determine the flow rate in m/s.

1. Calculate the areas

$$A_1 = \pi \times \frac{D_1{}^2}{4} = \frac{(50 \times 10^{-3})^2}{4} = 6.25 \times 10^{-4}\, m^2$$

$$A_2 = \pi \times \frac{D_2{}^2}{4} = \frac{(30 \times 10^{-3})^2}{4} = 2.25 \times 10^{-4}\, m^2$$

2. Calculate the velocity at point 2

$$Q_1 = Q_2$$

Therefore, $V_1 \times A_1 = V_2 \times A_2$

$$V_2 = V_1 \times \frac{A_1}{A_2} = 0.2 \times \frac{6.25 \times 10^{-4}}{2.25 \times 10^{-4}} = 0.55 m/s$$

3. Calculate the flow rate in m/s

$$Q_1 = V_1 \times A_1 = 0.2 \times 6.25 \times 10^{-4} = 1.25 \times 10^{-4}\, m^3/s$$

The example shows that in a system with a steady flow rate, a reduction in area (pipe size) corresponds to an increase in flow velocity by the same factor. If the pipe diameter increases, the flow velocity is reduced by the same factor. This is an important concept to understand because in an actual hydraulic system, the pipe size changes repeatedly as the fluid flows through hoses, fittings, valves, and other devices.