

# **FLUID POWER**

## **TUTORIAL – HYDRAULIC PUMPS**

This work covers outcome 2 of the Edexcel standard module:

### **UNIT 21746P APPLIED PNEUMATICS AND HYDRAULICS**

The material needed for outcome 2 is very extensive so the tutorial is presented as a series.

<b>OUTCOME 2</b>  Investigate the construction and operation of pneumatic and hydraulic components, equipment and plant.	<ul style="list-style-type: none"><li>• Identify and describe the features of pneumatic and hydraulic equipment.</li><li>• Analyse the performance characteristics of pneumatic and hydraulic equipment.</li></ul>
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The series of tutorials provides an extensive overview of fluid power for students at all levels seeking a good knowledge of fluid power equipment.

On completion of this tutorial you should be able to do the following.

- Revise the basic units and quantities.
- Explain the working principles of a range of hydraulic pumps.
- Explain the symbols for hydraulic pumps.
- Define Shaft Power.
- Define Fluid power
- Define volumetric efficiency.
- Define overall efficiency.

You should attempt worksheets 1 and 2 on completion. These are obtained from the home page for fluid power.

## 1. BASIC UNITS

Many of you will not be familiar with the quantities used in fluid power so we must start by revising them.

### PRESSURE

Pressure is the force per unit area exerted by a compressed fluid on a surface.

The force  $F$  due to pressure  $p$  acting on a surface of area  $A$  is hence  $F = pA$

The basic unit of  $p$  is the  $\text{N/m}^2$  or Pascal. The following multiples are used.

$$1 \text{ kPa} = 10^3 \text{ N/m}^2 \qquad 1 \text{ MPa} = 10^6 \text{ N/m}^2 \qquad 1 \text{ bar} = 10^5 \text{ N/m}^2$$

Most pressure gauges read zero when open to atmosphere. Any subsequent reading is a pressure more than atmospheric pressure and the reading is called gauge pressure. Sometimes it is necessary to use the true or absolute pressure of a fluid and this is found by adding atmospheric pressure to the gauge reading. Standard atmospheric pressure is 1.013 bar.

### VOLUMES

The metric units of volume always cause confusion so you must understand them. The basic unit of volume is the  $\text{m}^3$  or cubic metre. In the SI system we adopt multiples of 1000. Since a  $\text{m}^3$  is very large we do not use large multiples but sub-multiples. Think of a cube with each side 1 m long. The volume is  $1\text{m}^3$ . Now think of a cube with each side 1/10 of a metre long or 1 dm long. The dm is not used for length because it is not 1/1000 of a metre. However the volume is 1/1000 of a  $\text{m}^3$  or  $1 (\text{dm})^3$ . We do not normally use a bracket so remember  $1 \text{ dm}^3$  means a cubic decimetre. A  $\text{dm}^3$  is also called a litre.

A cube with a side 1 cm long has a volume of 1 cubic centimetre ( $1 \text{ cm}^3$ ) and is  $10^{-6}$  of a cubic metre. We do not normally use cm for length but we do use  $\text{cm}^3$  for volume. A  $\text{cm}^3$  is also called a milli litre. A cube of side 1 mm has a volume of  $1 \text{ mm}^3$  or  $10^{-9} \text{ m}^3$ . Summarising, the units of volume are

$$1 \text{ m}^3 = 10^3 \text{ dm}^3 (\text{litre}) = 10^6 \text{ cm}^3 (\text{millilitre}) = 10^9 \text{ mm}^3.$$

### STANDARDS

The following are some of the standards that apply to fluid power.

BS2917/ISO 1219-1 SYMBOLS FOR HYDRAULIC & PNEUMATIC COMPONENTS.

ISO 9461 ISO 5599 CETOP RP68P PORT IDENTIFICATION

ISO 1219-2 RULES FOR LAYOUT OF CIRCUIT DIAGRAMS

## HYDRAULIC PUMPS

The pump is the heart of a hydraulic system. The simple system shown shows how a pump sucks oil out of the tank and pushes it through a directional control valve to the cylinder and the piston is forced down. The oil expelled from the bottom of the cylinder is guided back to the tank by the valve. If the valve is operated the piston in the cylinder moves up. At all times the flow of oil and the energy required to move the piston is supplied by the pump.

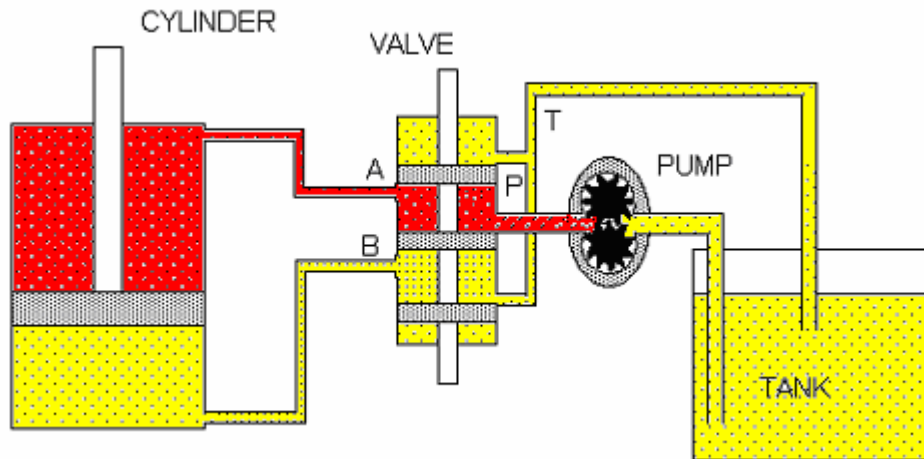


Figure 1

Pumps are divided into two categories **NON POSITIVE DISPLACEMENT TYPES**  
**POSITIVE DISPLACEMENT TYPES**

### 1. NON POSITIVE DISPLACEMENT TYPES

The two main types in this category are **CENTRIFUGAL** and **AXIAL**

In both cases a continuous flow is produced by a rotating impeller. There is no positive seal between the inlet and outlet and if the impeller was stopped, flow could be forced through it. When the pressure rises on the outlet, flow may slip back from the outlet to the inlet and the output flow rate is reduced. For example it is possible to shut the outlet valve on a centrifugal pump and the rotor will spin but no output flow is produced. Because of internal slippage, the relationship between pressure and flow rate of such a pump is typically as shown.

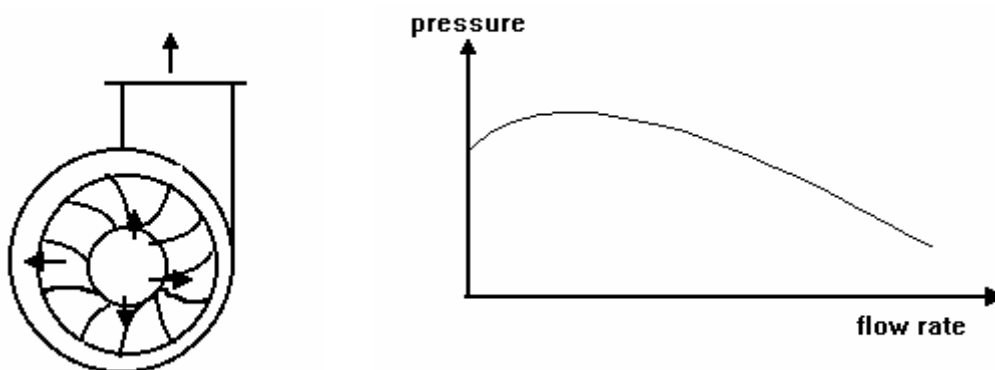
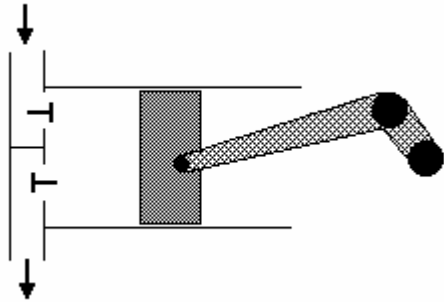


Figure 2

## 2 POSITIVE DISPLACEMENT PUMPS



Nearly all power hydraulic systems use positive displacement pumps. In such pumps, there is ideally no internal slippage and the amount of liquid pumped is the same for each revolution regardless of the pressure. The piston pump illustrated is a good example of this. The piston sucks in and pushes out a fixed volume for every revolution of the shaft. This is called the **NOMINAL DISPLACEMENT**.

Figure 3

It follows that

$$\text{Flow Rate} = \text{Nominal Displacement} \times \text{Shaft Speed.}$$

In reality the mating components are not a perfect fit and so small leaks may occur past the valves and pistons. The crank area would have to be drained in order to stop it filling and pressurising. The leakage increases with pressure and a graph of flow against pressure is as shown.

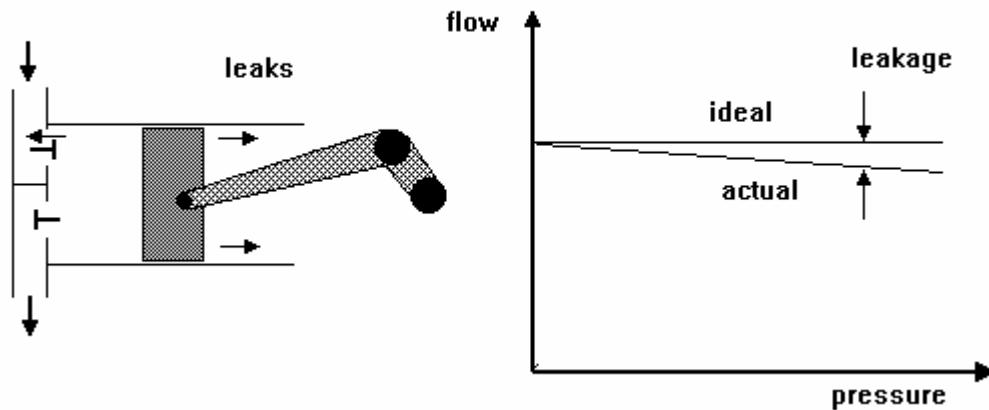


Figure 4

The volumetric efficiency is defined as  $\eta_{vol} = \text{actual flow rate} / \text{ideal flow rate}$

The leakage is the difference between the ideal and actual flow rates.

The piston pump illustrated is only one example of positive displacement pumps and the following sheets show the principles of some other types which include Vane Pump, Lobe Pump, Gear Pump, Axial Piston Pump, Radial Piston Pump, Deri Sine Pump and so on. There are variants of these types and this is shown on the selection chart.

### 3. SHAFT POWER

The shaft power of a pump is the mechanical power transmitted to it by the shaft. The formulae is the product of speed and torque such that:

$$S.P. = \omega T$$

$\omega$  is the angular speed of the shaft in radians/s and T is the torque transmitted in Nm. Since speed is more usually measured in rev/min the alternative formula is:

$$S.P. = 2\pi NT/60$$

N is the speed in rev/min

### 4. FLUID POWER

Fluid power is the energy per second carried in the fluid in the form of pressure and quantity. Fluid power is defined as

$$F.P. = Q \Delta p$$

Q is the flow rate in m<sup>3</sup>/s and  $\Delta p$  the change in pressure over the pump in N/m<sup>2</sup>.

### 5. OVERALL EFFICIENCY

The overall efficiency is the ratio of output power (Fluid Power) to input power (Shaft Power). Because of friction and internal leakage, the power input to a pump is larger than the fluid power (added to the fluid). The overall efficiency of the pump is hence:

$$\eta = F.P./S.P.$$

### 6. PUMP SYMBOLS

The basic symbol is a circle with a black triangular arrow head showing the direction of flow.



Figure 5

Some of the pumps described have variable geometry and the nominal displacement may be changed (e.g. by altering the swash plate angle). The symbols for pumps are shown for fixed and variable geometry (delivery). Symbols may also show a shaft drain connection.

### **WORKED EXAMPLE No.1**

A pump delivers 10 dm<sup>3</sup>/min with a pressure rise of 80 bar. The shaft speed is 1420 rev/min and the nominal displacement is 8 cm<sup>3</sup>/rev. The Torque input is 11.4 Nm.

Calculate:

- i. The volumetric efficiency.
- ii. The shaft power.
- iii. The overall efficiency.

### **SOLUTION**

Idea flow rate = Nominal Displacement x Speed = 8 x 1420 = 11360 cm<sup>3</sup>/min = 11.36 dm<sup>3</sup>/min

Volumetric efficiency = Actual Flow/Ideal Flow = 10/11.36 = 0.88 or 88%

$$Q = (10 \times 10^{-3})/60 \text{ m}^3/\text{s} = 16.7 \times 10^{-6} \text{ m}^3/\text{s}$$

$$\Delta p = 80 \times 10^5 \text{ N/m}^2$$

$$\text{Fluid Power} = Q \Delta p = 16.7 \times 10^{-6} \times 80 \times 10^5 = 1333.3 \text{ Watts}$$

$$\text{Shaft Power} = 2\pi NT/60 = 2\pi \times 1420 \times 11.4 / 60 = 1695.2 \text{ Nm}$$

$$\text{Overall Efficiency} = \text{F.P./S.P.} = 1333/1695.2 = 0.787 \text{ or } 78.7\%$$

### **SELF ASSESSMENT EXERCISE No.1**

1. A pump delivers 35 dm<sup>3</sup>/min with a pressure rise of 100 bar. The overall efficiency is 87%. Calculate the shaft power.  
(Ans. 6.7 kW).
2. A pump has a nominal displacement of 50 cm<sup>3</sup>/revolution. It delivers 72.75 dm<sup>3</sup>/min at 1500 rev/min and the pressure rise is 100 bar. The shaft power is 13.57 kW. Calculate the volumetric and overall efficiencies.  
(Ans. 97% and 90 %)

## 7. PUMP PROTECTION

Positive displacement pumps should in theory deliver the same volume of fluid no matter how much the outlet is restricted. If the flow from the pump becomes blocked, the pressure will rise to enormous levels and damage the pump. The shaft seal might blow out or the case might crack. This would happen for example when a cylinder reaches the end of its stroke and the moil can no longer enter it.

The first line of protection would be a pressure relief valve on the pump outlet. Another method is to use a pressure switch on the pump outlet to switch off the motor. Some pumps are designed so that the build up in pressure on the outlet changes the geometry of the pump and makes it pump less oil.

## 8. TYPES OF HYDRAULIC PUMPS

### 8.1 SIMPLE VANE PUMP

The rotor has a permanent offset or eccentricity so that as it turns, the space between the vanes gets larger and then smaller. When the space is getting larger, oil is drawn in. When the space gets smaller, oil is pushed out.

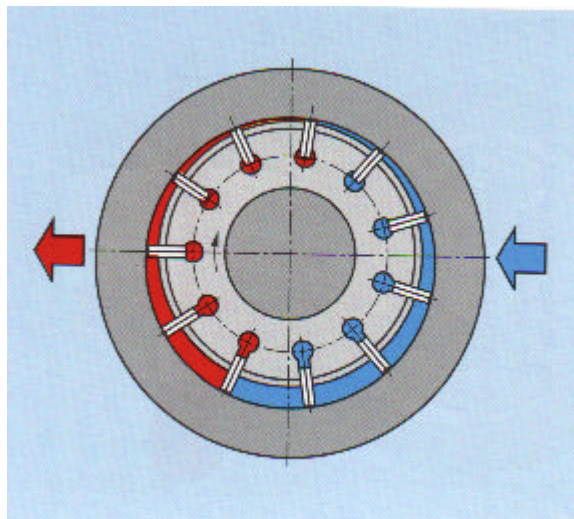


Figure 6

## 8.2 VARIABLE DELIVERY VANE PUMP

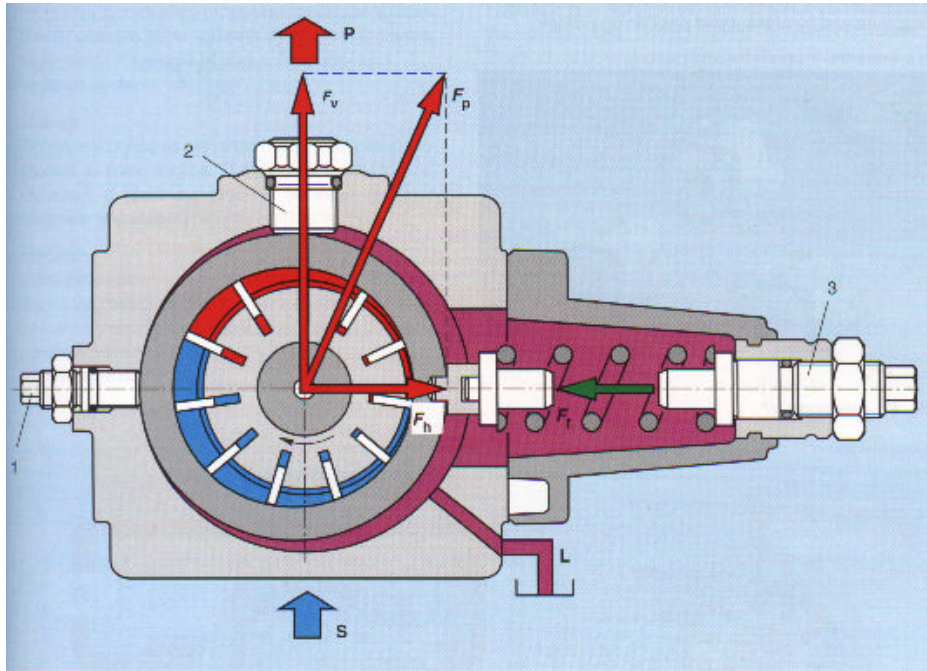
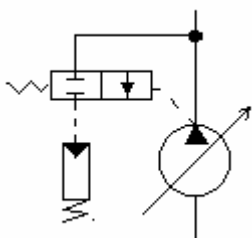
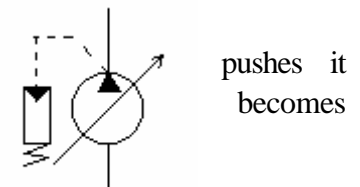


Figure 7

The principles are the same but adjusting items (1) and (3) on the diagram can change the eccentricity of the ring relative to the rotor. This enables the quantity of oil being pumped to be set to a required value. The pump can be designed so that as the pressure increases beyond a set limit, it forces the ring to a concentric position and reduces the flow to zero thus protecting the pump.

Pumps with variable delivery such as the eccentric ring vane pump, may be designed to reduce their flow as the pressure rises.

The symbol indicates that the outlet pressure acts on the eccentric ring and against an opposing spring so that as the pressure rises the ring gradually becomes concentric and the flow is reduced.



In many systems we do not want the flow to decrease with pressure until a dangerous pressure is reached. In this case a simple pilot operated valve is used which opens at a preset pressure and allows the ring to be centralised. The symbol for such a system is shown below.



### 8.3 RADIAL PISTON PUMP

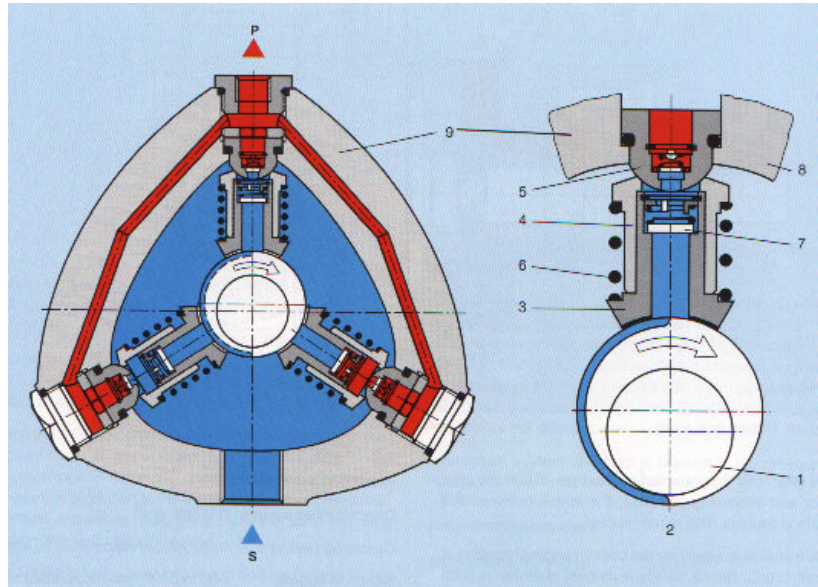


Figure 8

There are many designs for radial piston pumps. The design shown below has three pistons (3) arranged around an eccentric cam (2). The cam is part of the main shaft (1) and when it rotates the pistons are made to reciprocate inside cylinders (4) which lay on a radial line. When the piston moves inwards the space in the cylinder fills with oil through the suction valve (7) and the suction port (s). When the piston moves outwards, the oil is trapped inside and forced out to the pressure port (p).

### 8.4 GEAR PUMP

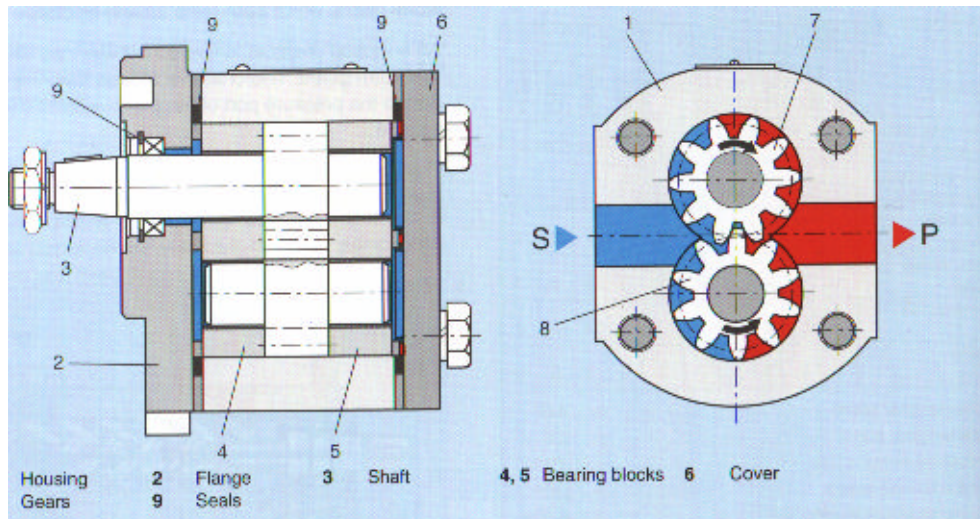


Figure 9

These are very common and have only two moving parts. The input shaft (3) carries the driving gear (7) that turns the idler gear (8). Oil from the suction port is carried around in the space between the gears and at the pressure port the gears mesh and form a barrier so the oil is forced out.

## SELF ASSESSMENT EXERCISE No.2

Figures A to D show pictures of 4 different types of hydraulic pumps. Identify which picture is:

- i. an eccentric ring vane pump.
- ii. a radial piston pump.
- iii. a gear pump.

State which pump is the most likely to have the following features.

- i. Self-pressure regulation.
- ii. Variable delivery.
- iii. The highest noise level.
- iv. The highest range of operating pressure.

State two possible reasons for cavitation to occur in a pump.

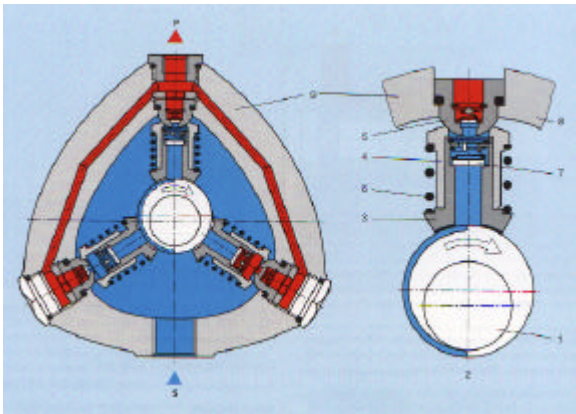


Figure 10A

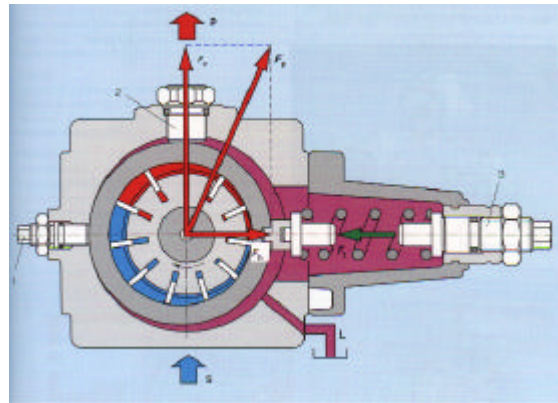


Figure 10B

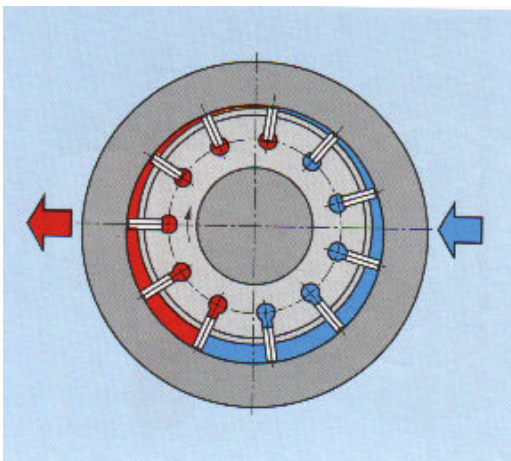


Figure 10C

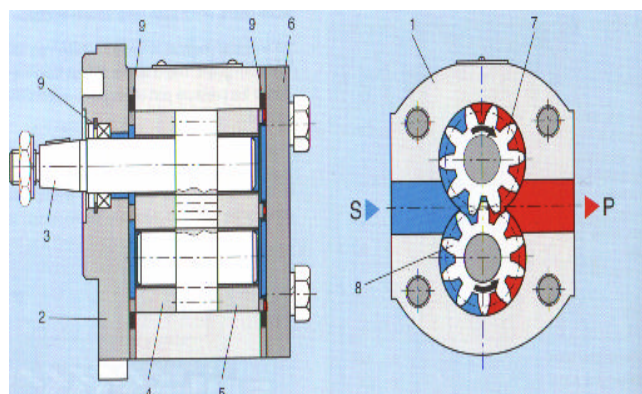


Figure 10D

## ANSWERS

- i. B and C are eccentric ring vane pumps.
- ii. A is a radial piston pump.
- iii. D is gear pump

- i. Eccentric ring vane type.
- ii. Eccentric ring vane type.
- iii. Gear Pump.
- iv. Piston Pump.

Excessive suction due a blocked filter.

Excessive suction due to poor pipe design.