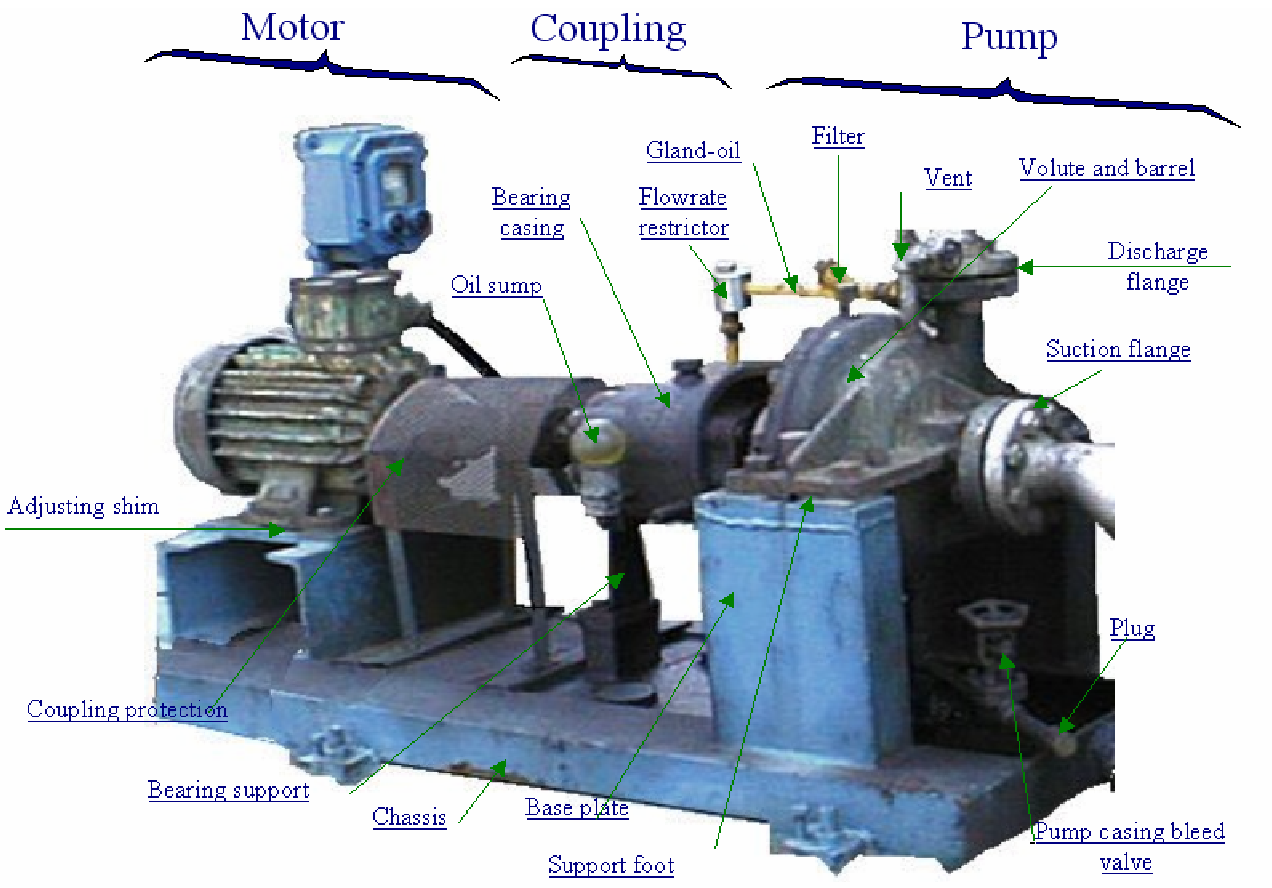


PUMPS

TRAINING MANUAL
COURSE EXP-PR-EQ070
Revision 0

EQUIPMENT

PUMPS

CONTENTS

1. THE FUNCTIONS OF PUMPS

1.1. INTRODUCTION

Pumps are mechanical devices used to convey liquids from point A to point B. In particular, they can be used to take a liquid at pressure P1 and raise it to pressure P2 (where P2 > P1).

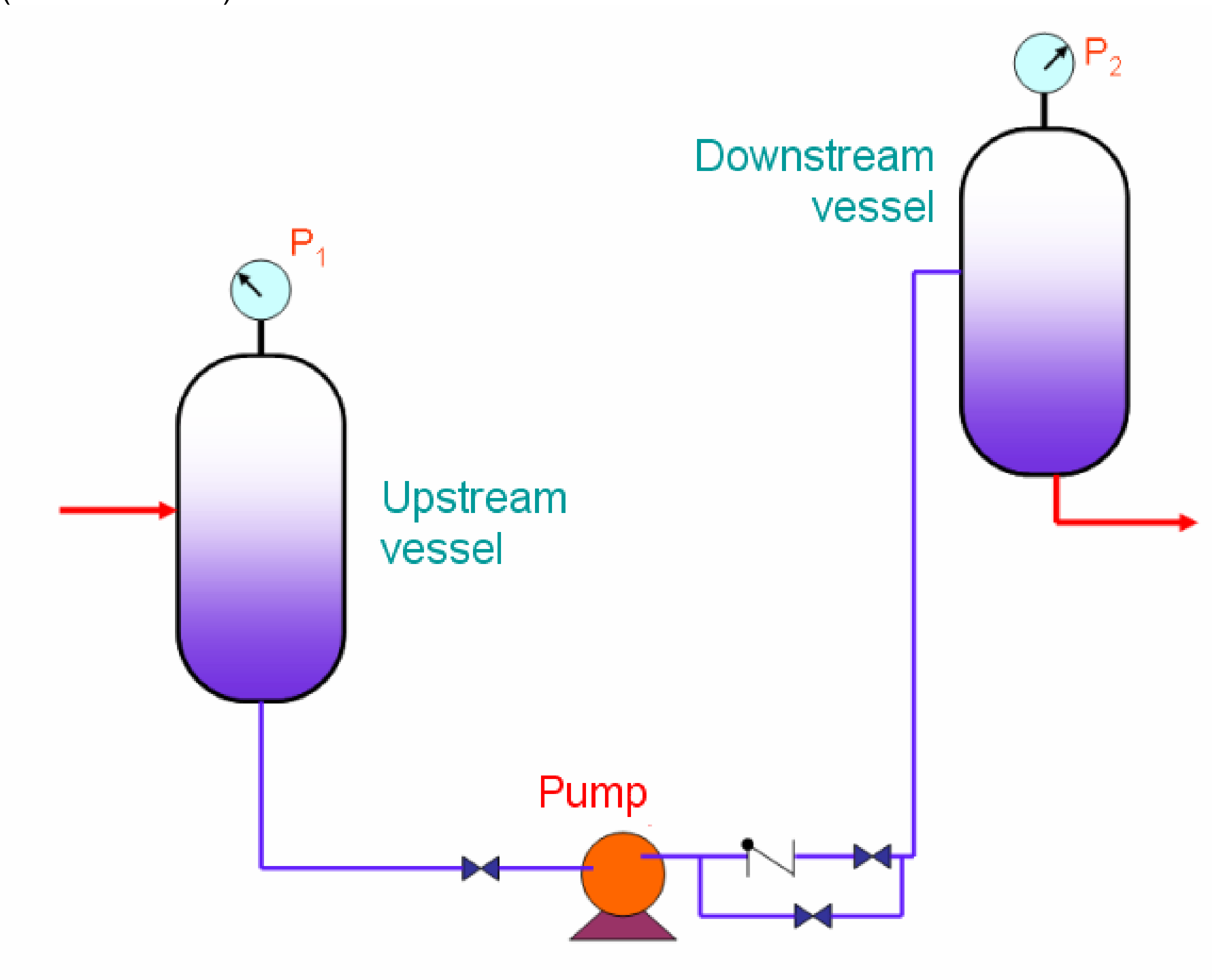


Figure 1: Schematic diagram of transfer of liquid from one vessel to another

1.2. MAIN CATEGORIES

Liquid pumps (also called liquid transfer pumps or liquid conveying pumps) pumps are divided into two main categories, which will be described in detail in the following section:

1.2.1. Centrifugal pumps

The liquid moves as a result of an energy increase derived from the centrifugal force.

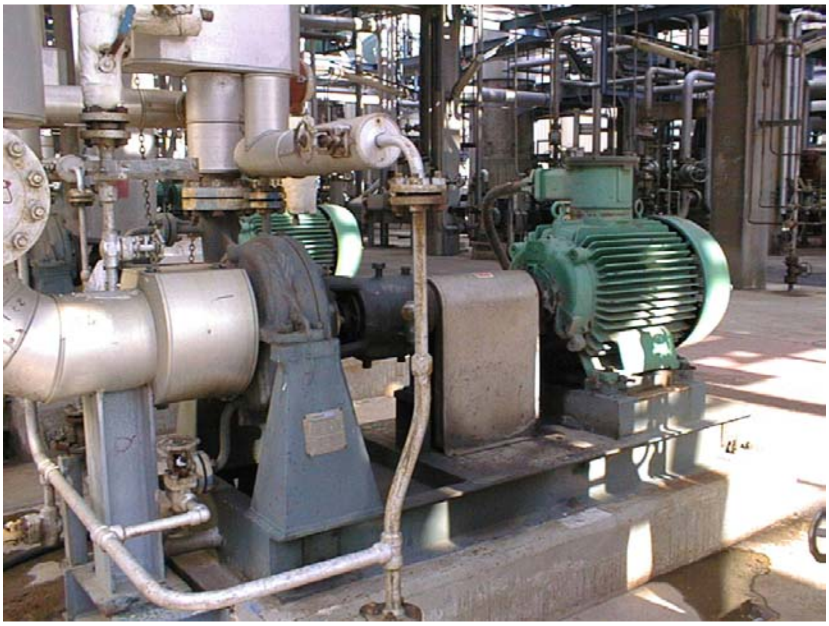


Figure 2: Example of an Axial Suction type centrifugal pump

1.2.2. Positive displacement pumps

The flow develops from the variation in the volume occupied by the liquid.

Figure 3: Example of a displacement pump with diaphragm

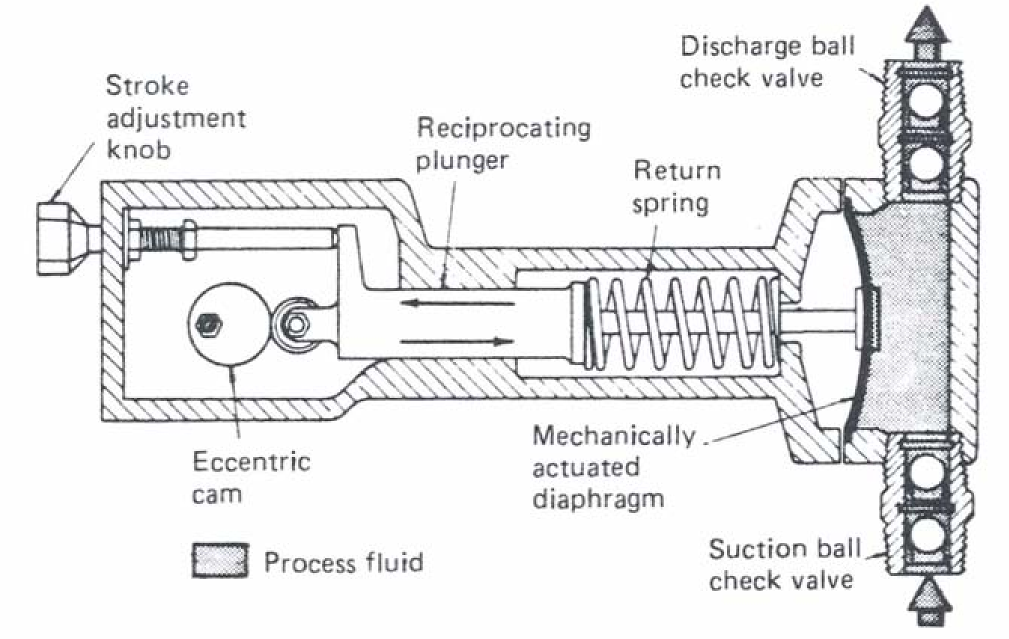


Figure 4: Cross-section of a displacement pump with diaphragm

1.3. THE VARIOUS APPLICATIONS

The simplest and most common means of conveying liquids (Crude, Oil, Water) is the centrifugal pump, and it is also the most economical means.

However, there are at least three types of applications for which centrifugal pumps lose their effectiveness:

- **Pumping viscous products**; in fact, as from a certain degree of viscosity, using a centrifugal pump would require using an oversized pump which would deliver a flowrate outside of its optimum specifications, and so make for very poor efficiency, and consequently a very high power consumption.
- The problems of **accurate instantaneous dosing**, for which using a centrifugal pump would require the facility designer to use a flowmeter to control the speed of the centrifugal pump, with the risk of the pump operating outside of its optimum specifications.
- **Pumping liquids deemed "sensitive"**, i.e. fragile, which react poorly to the internal eddies present in a centrifugal pump (milk, wine, beer, volatile liquids, etc.).

These three types of application require the use of a positive displacement pump.

The choice of design technology will primarily depend on the properties of the product to be conveyed:

- Viscosity,
- Temperature,
- Density,
- Chemical composition,
- Sensitivity
- etc.

and on the type of application:

- Transfer,
- Mixing,
- Dosing,
- Flowrate,
- Suction pressure
- Discharge pressure
- etc.

1.4. USE

Pumps, whether they are centrifugal or positive displacement, are used for conveying liquids of all types: water, hydrocarbons, more or less viscous liquids, chemicals or toxic substances such as benzene. However, vacuum pumps such as liquid-ring rotary pumps can convey gas.

As we have already seen, it is often the composition of the effluent that will determine the type of pump to use.

The example below demonstrates this.

If we look at the behaviour of a pump operating under identical conditions:

Same {
suction flowrate
suction pressure D
rotation speed

But with liquids of different densities: {
Butane dt = 0.5
Sodium hydroxide dt = 1.2
Water dt = 1

The table below gives the readings on the pressure gauges of the pump, for each liquid:

Pumped product (density)	Suction pressure (relative, bar)	Discharge pressure (relative, bar)	∆P (bar)
Butane = 0.5	10.3	14	3.7
Sodium hydroxide = 1.2	10.8	19.6	8.8
Water = 1	10.7	18.2	7.5

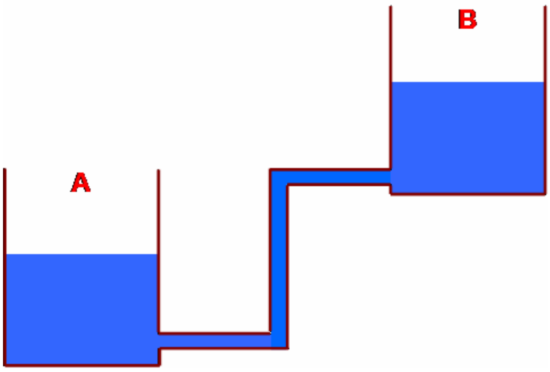
Table 1: Example of behaviour of a pump in relation to the density of the effluent

The higher the density, the greater the pump ∆P in bar

∆P expressed as the height (m) is the same regardless of the liquid pumped

1.5. EXERCISES

1. What way will the fluid flow?



❑ A to B

❑ B to A

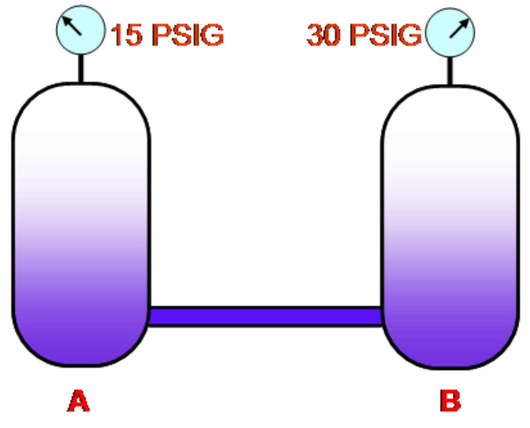
2. Why?

____

____

____

3. What way will the fluid flow?



❑ A to B

❑ B to A

❑ The liquid will not flow

4. Why?

____

____

____

5. What are pumps used for?

- ❑ Reducing the pressure of a fluid
- ❑ Increasing the pressure of a fluid from P_1 to P_2
- ❑ Conveying a fluid from point A to point B

6. What are the 2 main categories of pumps?

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7. What kind of pump is this?

- ❑ Centrifugal
- ❑ Displacement

8. What kind of pump is this?

- ❑ Centrifugal
- ❑ Displacement

9. What is the operating principle of a displacement pump?

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10. What is the operating principle of a centrifugal pump?

11. What is the most common means of conveying fluids?

- ❑ Centrifugal
- ❑ Displacement

12. What are the 3 types of application for which centrifugal pumps lose their effectiveness?

- ❑ Pumping viscous products
- ❑ Conveying liquids at a high flow rate
- ❑ Pumping liquids deemed "sensitive"
- ❑ Accurate and instantaneous dosing

13. Pumps, whether they are centrifugal or displacement, mainly convey:

- ❑ Liquid
- ❑ Gas

14. In what situation can a pump convey a gas?

15. Does the composition of the effluent affect the choice of pump to use?

- ❑ Yes
- ❑ No

2. OPERATING PRINCIPLE OF PUMPS

In this module, we will look in detail at how pumps operate, by means of their equipment, and we will review the physical principles involved.

2.1. BASIC THEORY OF CENTRIFUGAL PUMPS

2.1.1. Concept of liquid height and head

2.1.1.1. Pressure difference as liquid height

$(P_2 - P_1) / \rho . g = h$ (height in m)

P_1, P_2 = Relative pressures in Pascal
ρ = density (in kg/m³).
g = gravitational force = 9.81 (in m/s² or N/kg).
h = height of point in question in relation to a reference axis (in m).

Notes:

- The conversion rule derives from Pascal's law: $P + \rho gh$ = constant.
- The difference between 2 relative pressures is an absolute pressure
- P (bar) = P.10^5 (Pascal) and $P_{relative}$ (gauge reading) = $P_{absolute} - P_{atmospheric}$
- $P_{atmospheric}$ = 1 atmosphere = 101325 Pa (rounded to 1 bar)

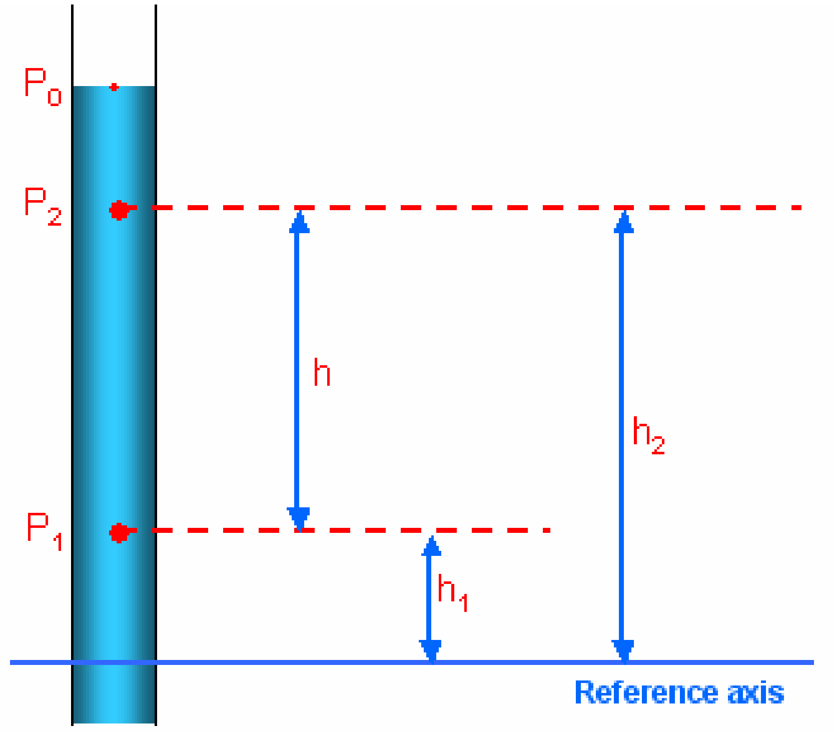


Figure 5: Pressure difference as liquid height

$P_1 + \rho .g . h_1 = P_2 + \rho .g . h_2$
$\Rightarrow P_2 - P_1 = \rho .g (h_2 - h_1) = \rho .g h$
$\Rightarrow h = (P_1 - P_2) / \rho .g$

2.1.1.2. Liquid head:

The head ht_1 of a liquid at a given point in a network corresponds to the energy possessed by the liquid at this point; this energy comes in 3 forms:

- Pressure energy,
- Kinetic energy (corresponds to the flow),
- Potential gravitational energy.

This liquid may gain head if energy is supplied by a pump, or it may lose some of its energy if its flow is subjected to friction (see head loss)

The head is expressed in mLC (m liquid column), and simply equals the energy divided by the term $\rho \cdot g$ (ρ = density and g = gravitational acceleration)

ht = sum of energies at a point, expressed in mLC

This relation between the energies is very useful, as one of the principles of physics specifies that energy is always conserved, so if one of the 3 energy components decreases, another will increase.

Mathematically, ht is expressed using the formula:
$ht\ (m) = p / \rho \cdot g + v^2 / 2g + z$

p: absolute liquid pressure in Pa
v: liquid speed in m/s
z: dimension in m from reference point

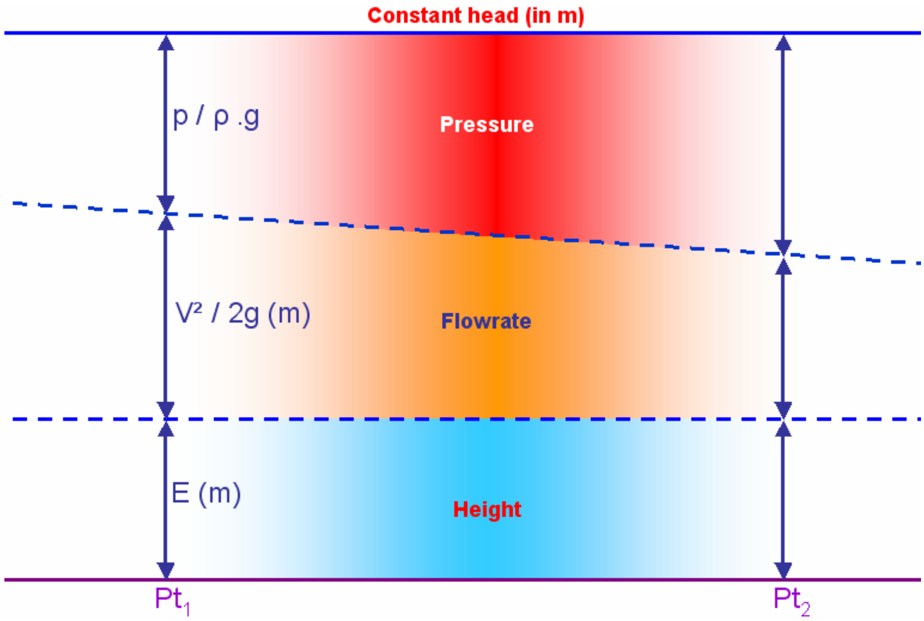


Figure 6: The head between two points remains constant

For instance, if we consider the case of a horizontal pipe where the potential energy remains constant, if the flow between points 1 and 2 decreases (kinetic energy), the pressure at point 2 must automatically be greater than at point 1.

2.1.2. Head: increasing through pumping and decreasing through friction

2.1.2.1. Using a pump: Increasing the head

We have seen that at a point pt_1 a liquid's energy comprised 3 components; if we want another point on the network, pt_2, to have for example a greater pressure while the other 2 energies remain constant (for example constant flow in a horizontal line), energy will need to be supplied between these 2 points … which is what a pump will do.

This energy that needs to be supplied to the fluid to raise its head from the value ht_1 to the value ht_2 is H (also expressed in mLc), described as follows:

$$ht_1 + H = ht_2$$

2.1.2.2. Flow friction: liquid head losses

The head loss from a fluid flowing in a pipe between 2 points pt_1 and pt_2 represents the energy lost due to friction (on the walls and between the product particles).

This lost energy is expressed (as with the other energies) in mLc, and is generally represented by the letter J.

Since the total energy between 2 points must be conserved, if between pts 1 and 2 there is a head loss due to friction J, expressed in mLc, which can be described as follows:

$$ht_1 - J = ht_2$$

So head loss can be defined in any part of a network, and in particular:

- In the suction part (between the suction point and pump inlet)
- In the discharge part (between the pump discharge and the emission point)

Head losses are dependent on the condition of the pipe's internal surface (the rougher it is, the more energy the fluid will lose), and head loss of this type is called linear head loss; all the various components of the pipe (elbow / valve / disc / ...) also cause head losses, which are known as singular head losses.

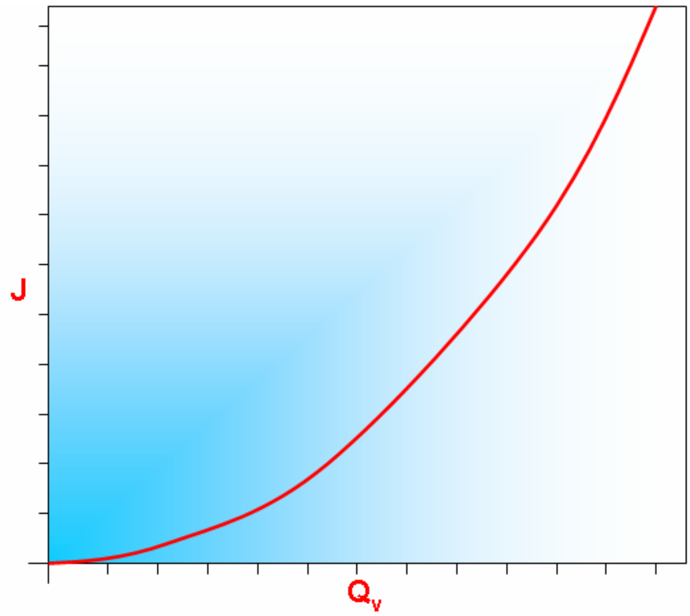


Figure 7: Head loss as a function of volume flow rate

It can be demonstrated that the head loss between 2 points is proportional to the square of the flow rate; this is represented by the curve J = f (Q_v^2).

2.1.3. Using a pump in a network with head loss

2.1.3.1. Network characteristics

We have seen that a liquid's head at a point corresponds to its energy at this point, and that between 2 points pt_1 and pt_2 there could be head loss due to friction, and a head gain by means of a pump, so a network with head losses and a pump can be expressed as follows:

$ht_1 + H - J = ht_2$

H being the head (energy) to be supplied to the liquid to raise it from point pt_1 (with starting conditions) at pt_2 (to have the requisite conditions at the distribution point), when there is an energy loss equal to J between these 2 points.

Head to be supplied $H = (ht_2 - ht_1) + J = hG + J$

$H = hG + J$: this is the energy expressed in mLc to be supplied to the liquid to raise it from pt_1 to pt_2

The term hG is the network's geometric height, which, as a reminder, is the difference in head between 2 points, i.e. not necessarily the difference in the height:

If $P_1 = P_2$ we get $hG = Z_2 - Z_1$
If P_1 is different from P_2 we get:
$hG = (Z_2 - Z_1) + (P_2 - P1) / \rho g$

So we can see that in fact the energy to be supplied will serve on the one hand to raise the head from ht_1 to ht_2 and also to compensate for head losses J = f (Q_v^2)

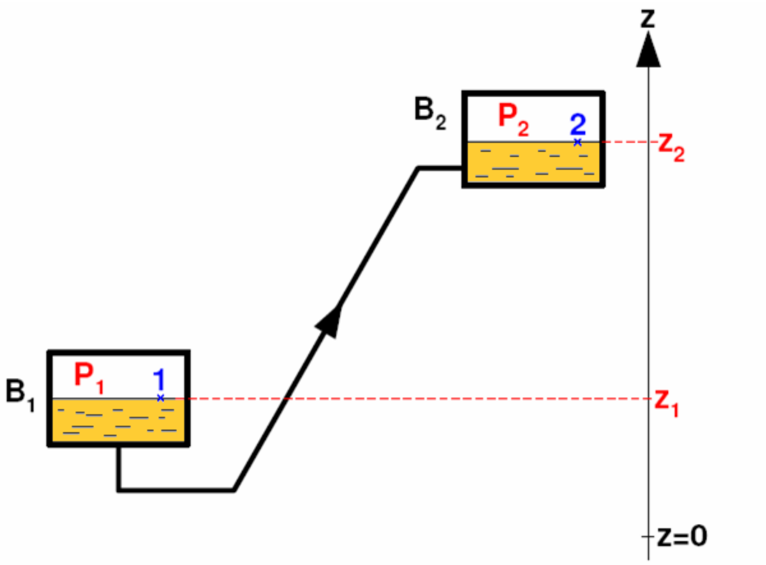


Figure 8: Transfer using a pump from vessel B_1 to vessel B_2

Let us consider the network below:

The prevailing pressure in vessel 1 is P_1 = 3.6 bar, and the prevailing pressure in vessel 2 is P_2 = 1.4 bar. The distance between the liquid levels in the two vessels is 12 m.

The water level in vessel 1 is taken as the elevation reference.

So this gives:
z_1 = 0 m - z_2 = 12 m

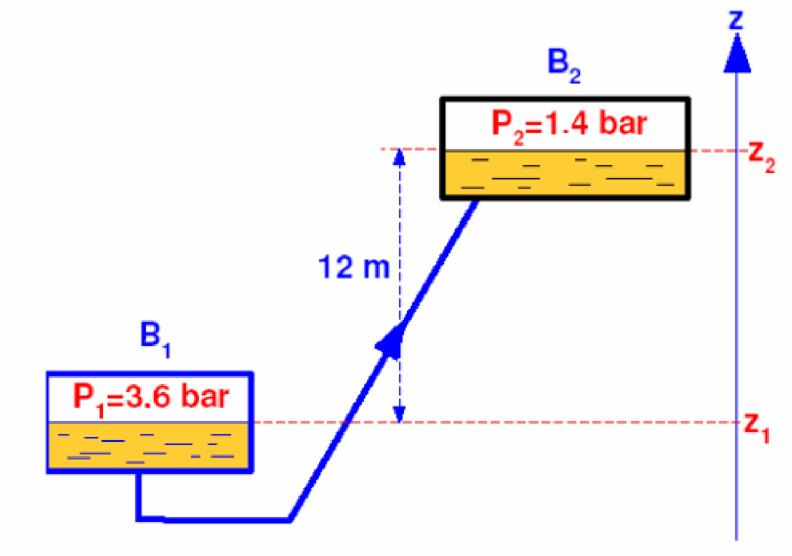
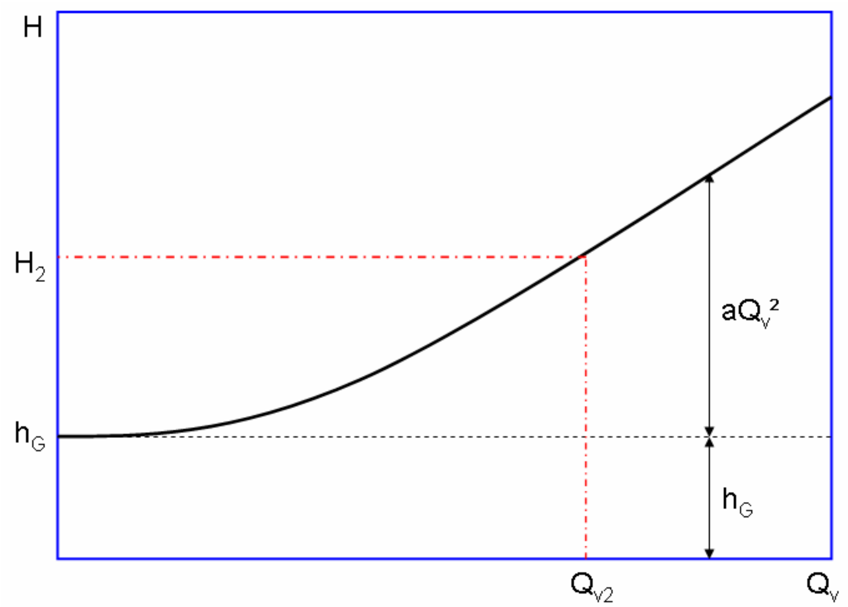


Figure 9: Example of a head difference calculation

In addition we will assume that the vessels are operating at constant level: $u_1 = u_2 = 0$

So we then get:

$hG = (P_2 / \rho \cdot g + z_2) - (P_1 / \rho \cdot g + z_1) = (3.6 \cdot 10^5 / 1000 \cdot 9.81 + 12) - (1.4 \cdot 10^5 / 1000 \cdot 9.81 + 0)$ = 34.4 m



For a given network and with known/desired conditions, we can therefore plot the curve $H = hG + a Q_v^2$ as a function of flow rate.

hG actually represents the energy that the pump needs to supply (expressed in mLc) for a flowrate of zero; if we want the pump to deliver a flow rate Q_{v2} at pt_2, the pump will have to supply the energy H_2

Figure 10: Curve of a network

So the network curve is the expression in mLc of the energy which needs to be supplied to the system to raise the given liquid from its starting point (P_1, Z_1) to the end point (P_2, Z_2) as a function of flow rate Q_v (Q_v is only involved in developed head loss).

So the pump selection process consists in finding the pump that will supply the energy required to provide the desired flow rate in the network, i.e. supply the energy required to meet:

- the static height requirement (which depends only on the heights and pressures of the starting and end points (from P_1 to P_2 and from Z_1 to Z_2)
- the head loss requirement (dynamic height)

If the energy of the pump is also represented in mLc as a function of the flowrate Q_v, the intersection point of this pump (capacity) and the network curve (requirement) will therefore be the operating (or duty) point of the network / pump assembly.

A pump can only be selected if the network curve has been correctly determined (or at least well estimated).

2.1.3.2. Pump characteristics

Centrifugal pumps are devices that will supply the liquid energy in the form of height differential, which is known as the pump manometric height (or the pump total manometric height, TMH, or manometric delivery head).

The TMH value represents the height of liquid which may be obtained in the discharge pipe in relation to the suction liquid level.

Experience tells us that the pump TMH is a function of the flow rate; this relation is given by the manufacturer's curve TMH= f (Q_v), which means that for a given flow rate Q_{v1}, the pump will provide a given discharge pressure that will be used to "raise" the liquid to a given height TMH_1.

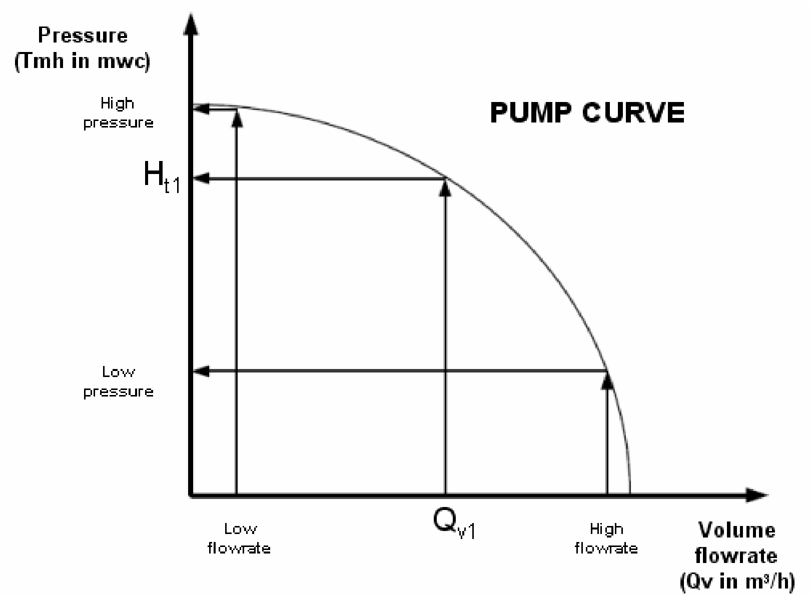


Figure 11: Pump curve

If we assume that P_a is the pressure reading (in absolute bar) at the pump suction, and that P_r is the discharge reading, the pump TMH expressed in mLc can be more simply defined by:

TMH = (Pr-Pa)/ρg

This mLc value can be represented schematically in the diagram below, in which the liquid at the discharge point has reached a maximum level (zero flow) with the pump in operation:

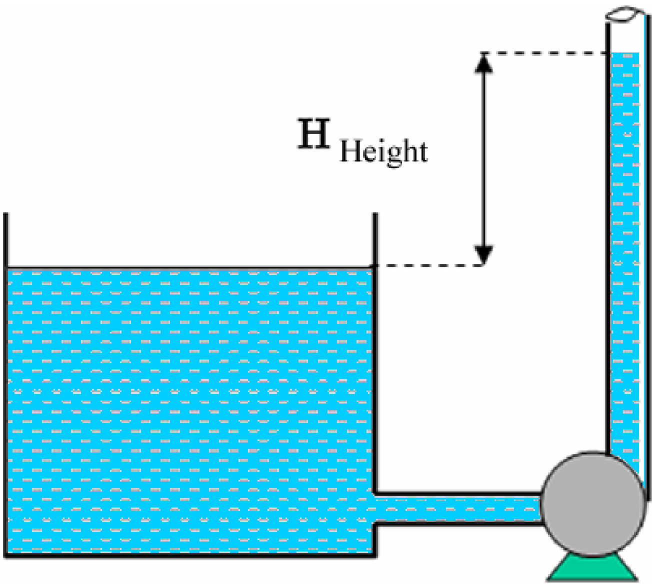


Figure 12: TMH of a pump

Since the pressures are proportional to the term ρ · g (manometric height h at a point is such that $p = \rho \cdot g \cdot h$), the TMH of a centrifugal pump expressed in mLc is independent of the density of the product.

When the density of the product varies, TMH remains the same, only the pressure difference $P_r - P_a$ (expressed in bar) will vary; and the greater the density, the greater the △p.

For example, if we consider a pump conveying 3 different products at the same flowrate, we see that the TMH remains the same, whereas △p varies.
(Ref. Table, Chap 2.4)

Pumped product (density)	Suction pressure (relative, bar)	Discharge pressure (relative, bar)	ΔP (bar)
Butane = 0.5	10.3	14	3.7
Sodium hydroxide = 1.2	10.8	19.6	8.8
Water = 1	10.7	18.2	7.5

For each flowrate Q_v desired for a given circuit, the pump will supply the TMH required, which is defined by the intersection of the pump curve (TMH = f (Q_v)) with the network characteristic curve (H = f (Q_v)).

2.1.3.3. Operating point

We have seen that the network curve defined the requirement - I have a liquid (defined by its density) at a pressure P_1 at a level Z_1 which I want to transfer to a level Z_2 at pressure P_2, and this network experiences head losses represented by J = f (Q_v^2).

If I want the flowrate to be Q_v*, the energy that the pump will need to supply, expressed in mLc, is the point corresponding to H*.

We have seen that a pump supplied energy, and TMH was expressed in mLc as a function of the flow rate Q_v as per the manufacturer's curve; so we need only find a pump which at the target flowrate Q_v* provides the energy TMH* equal to the required energy H*.

So the operating point is the intersection of these 2 curves.

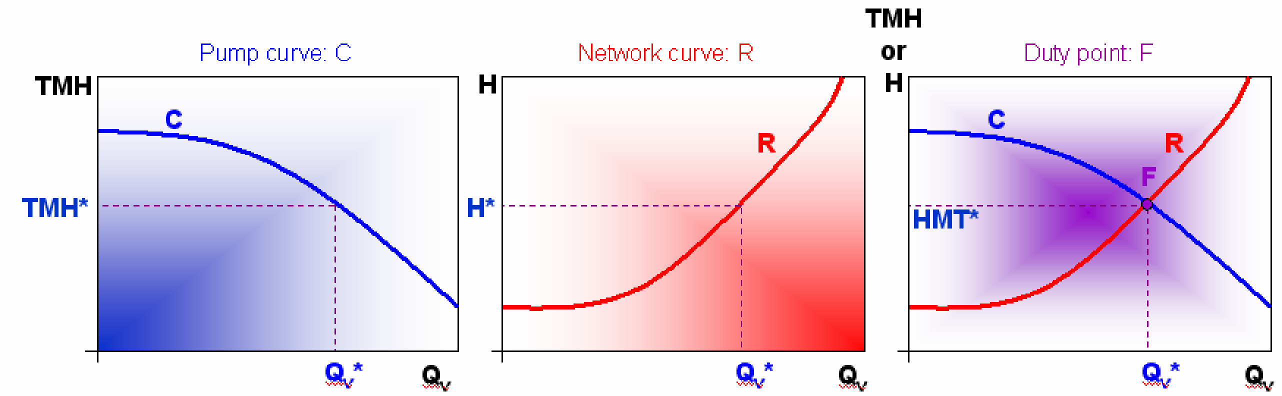


Figure 13: Operating (or duty) point of a pump

2.1.4. Additional considerations

2.1.4.1. Vapour pressure: source of cavitation

For a given temperature any liquid has a definite boiling pressure known as the vapour pressure P_v. So with any liquid, when the vapour pressure P_v is reached, the liquid will start to vaporise or boil (for example at sea level water boils at 100°C, whereas at the top of a high mountain, water boils before reaching 100°C since the pressure is lower than at sea level.

If we take the case of water for example, we know that water at atmospheric pressure boils at a temperature of 100°C. However, if the prevailing pressure above the liquid is different from atmospheric pressure, the boiling point temperature will be altered.

So when the pressure rises, so does the boiling point temperature (and when the pressure drops, so does the boiling point temperature). The table below gives the boiling point temperature of water at different pressures.

We can see that if water at 20°C undergoes a pressure drop below a value of 0.023 bar, then it will start to boil.

Pressure (bar)	Boiling point temperature (ºC)
50	264
6	159
2	120
1	100
0.5	81
0.023	20
0.2	17.5

Table 2: Boiling point temperature of water as a function of pressure

2.1.4.2. Cavitation: equality between the pressure of the pumped liquid and its P_v

Centrifugal pumps are designed in such a way that the pressure is lowest at the wheel (impeller) inlet.

This is due to the fact that the incoming liquid tends to be propelled towards the tip of the vanes, thereby generating a negative pressure at the impeller inlet.

If the pressure becomes = P_v of the pumped liquid, this liquid will partially vaporise, the gas bubbles will be carried along with the liquid to zones where the pressure is higher (the further we go from the axis), and the gas bubbles will then rise above P_v and condense, imploding near the walls; this is the phenomenon called cavitation which, depending on its magnitude, manifests itself as noise, vibrations, operating instability, power losses and possibly erosion of the metal ...

To prevent the phenomenon of cavitation, the liquid needs only arrive at the pump inlet with enough pressure to maintain the pressure at the wheel inlet >P_v (when the pump is running).

Now let us consider the following network:

We can describe the total head for the part of the network located upstream of the pump:
$h_{t1} - J = h_{tA}$,where h_{t1} is the total head of the fluid in the vessel, h_{tA} the total head of the fluid at the pump inlet and J the fluid's head loss between the vessel and the pump.

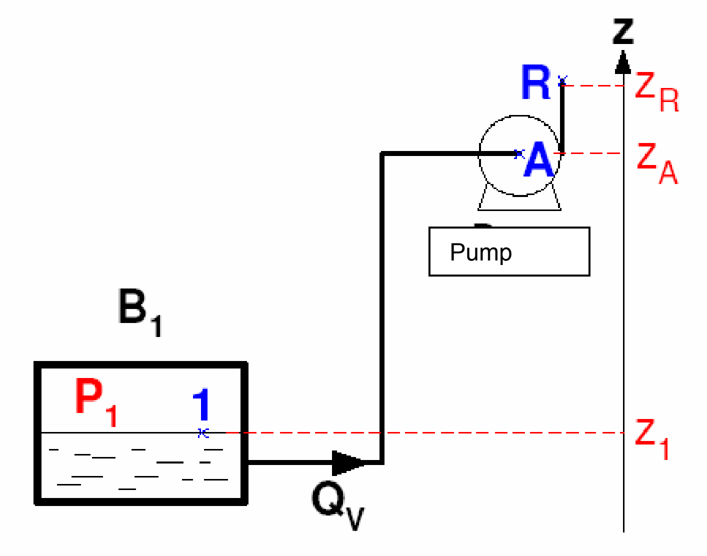


Figure 14: Total head

Thus we can deduce $P_A = P_1 - \rho \cdot g \cdot (Z_A – Z_1) - J$
We can see that, in view of the terms which are deducted, the pressure P_A may be very low. In particular, it may equal the saturation vapour pressure of the liquid. Partial vaporisation of the liquid then occurs, similar to boiling, generating bubbles of vapour. This is the phenomenon of cavitation.

So we can see that whether or not cavitation will occur depends on how and where the pump is installed. So in our example, the pump suction point is well above the level of the liquid in vessel B_1, and consequently the term $z_S - z_1$ is positive. The further the pump is above the liquid, the lower the suction pressure P_A will be, and the greater the risk of cavitation. Similarly, the greater the head loss J in the pump suction network, the lower P_A will be, and the greater the risk of cavitation in this case too.

So the user needs to know, according to the layout of the pump system, what is the risk of seeing cavitation appear. This is the role of NPSH.

Specifically, to prevent cavitation, when possible

- Favour set-ups with primed pumps.
- Limit the fluid temperatures (at the same pressure, a hot liquid vaporises more quickly than when cold)
- Prevent suction head loss
- Avoid pumping from a reservoir at low pressure

2.1.4.3. NPSH - Net Positive Suction Head

NPSH is the abbreviation for "Net Positive Suction Head" over vapour pressure.

More specifically, this represents the pressure at the pump suction point, due to the network and pumped liquid only (regardless of the pump used).

Definition of NPSH: It is the total pressure in m liquid column pumped, determined at the pump's suction flange, minus the Pv of the liquid at operating temperature.

Mathematically NPSH = $Pa / \rho \cdot g + ua^2 / 2g – Tv / \rho \cdot g$ (Za = 0 suction height)

In the study of pump systems, two types of NPSH can be defined.

- $NPSH_a$ (available)
- $NPSH_r$ (required)

The NPSH available is a network characteristic independent of the pump, which the user must define to correctly choose a pump.

2.1.4.4. Calculating NSPH available

Depending on the installation configuration and the product conveyed, there is a pressure P_a at the pump suction. Therefore, only the pressure quantity above P_v will be useful (if this pressure reaches P_v there will be gas at the pump inlet).

$NPSH_a = P_1 / \rho \cdot g + z_1 – J - T_v / \rho \cdot g$

If these values are expressed in mLc, they can be described as follows:

$NPSH_a = P_1$ (mLc) – P_v (mLc) + z_1 (mLc) – suction head loss (mLc)

However, the position of point z_1 relative to the reference point – the pump suction point - needs to be taken into consideration.

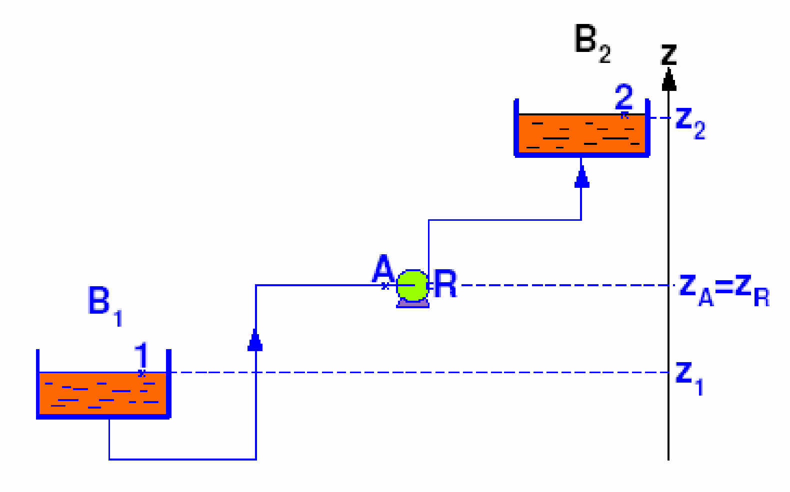
So, there are 2 possible pump installation scenarios, which are examined in detail in example 3.1.5 (Study of a simple scenario).

The NPSH can be calculated either from the pump suction data, or from vessel suction data.

Practical example of verification of NPSH available:

The pumped liquid is water at 20 °C.

At this temperature, the saturation vapour pressure of water is P_v = 0.023 bar.



Once the pump has been installed, a suction pressure of P_A = 0.6 bar is measured, with flowrate Q_V = 23 m³/h.

The suction pipe has a diameter D = 32 mm.

Figure 15: Calculating NPSH available in a network

The NPSH available must be calculated using the formula:

$NPSH_a = P_A / \rho \cdot g + u_A^2 / 2 \cdot g - T_v / \rho \cdot g$

The speed at the suction point u_A may be calculated using the volume flowrate:
$u_A = Q_V / \pi \cdot D^2 / 4 = (23 / 3600) / (\pi \cdot 0.032^2 / 4) = 7.9$ m/s

Which gives us:
$NPSH_a = 0.6 \cdot 10^5 / 1000 \cdot 9.81 + 7.9^2 / 2 \cdot 9.81 - 0.023 \cdot 10^5 / 1000 \cdot 9.81 = 9.27$ mwc

So the NPSH available on this facility is 9.27 mwc.

2.1.4.5. NPSH required

For every pump, there is a minimum NPSH below which cavitation will appear.

This is known as the NPSH required. It is denoted $NPSH_r$.
Every pump manufacturer determines the NPSH required of its pumps by forced cavitation tests.

By experiment, as shown in the figure below, the NPSH required increases with the flowrate Q_V. The pump manufacturer provides the $NPSH_r$ curve as a function of Q_V.

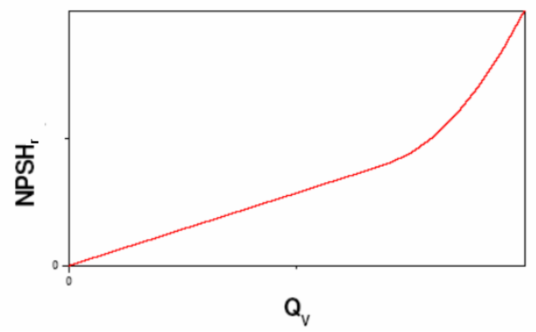


Figure 16: Variation of NPSH required with the flow circulated by the pump

In practice, for a pump to be able to run normally (without cavitation), you need to calculate the NPSH available and verify that it is greater than the NPSH required (which has been determined using the curve supplied by the manufacturer).

The greater the difference $NPSH_a - NPSH_r$, the better the pump's operating suction conditions. It is considered that a safety margin of at least 0.5 mLc should be reserved, so as to have: $NPSH_a > NPSH_r + 0.5$

2.1.4.6. Efficiency considerations

A pump's efficiency, R, is the ratio between the power consumption of the pump P_a (supplied by the drive motor) and the energy actually transmitted by the pump to the liquid, the hydraulic power P_h (In fact there will be losses in the pumps due to friction / turbulence / internal leaks).

Efficiency is equal to the ratio of these two powers:

$R = P_h / P_a$

For centrifugal pumps, efficiency has a maximum value as a function of flowrate Qv: this curve supplied by the manufacturer must be taken into consideration when choosing a pump, so that the operating point is in a maximum efficiency zone for the pump.

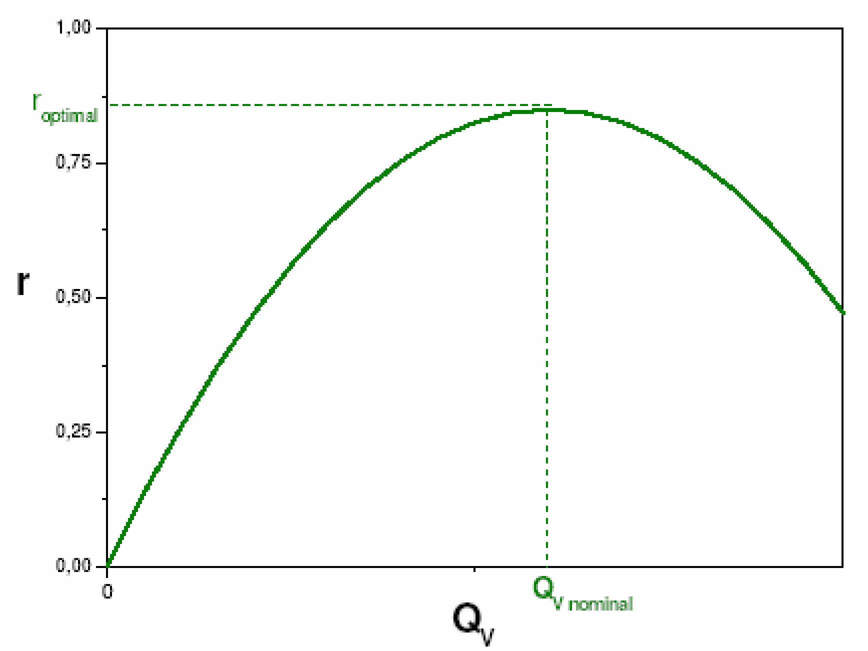


Figure 17: Efficiency as a function of flowrate

2.1.4.7. Adapting the process to the pump

When trying to choose a pump (which can supply the desired flowrate, convey the product to a point Z with pressure P, and in an operating zone where efficiency is optimal), we may realise that the pump we are looking does not exist for such specific parameters.

So we select a pump with a greater capacity (TMH), and the head loss is artificially increased by installing an automatic valve on the discharge (valve 100% open => additional head loss from network= 0, the more the valve closes the more the head loss increases), so we can always obtain the chosen operating point.

2.1.4.8. Process variation considerations

Though a pump's curve is an unvarying characteristic (for a given pump at a given speed), the operating conditions may change over time, in particular the vessel levels (suction and discharge).
So the most extreme negative scenarios must be analysed on an individual basis before making the choice of pump.

- Lowest pressure at pump suction point following a possible pressure drop in the vessel and/or min level in this vessel

- Highest pump discharge pressure following a pressure increase in the inlet vessel and/or the top level in this vessel.

Besides these process considerations we will see that clogging of filters, ageing of lines, recycling and modifications are changes that alter the network curve and therefore change the pump's operating point: so we will generally adopt a safety margin (of around 20%) to compensate for these possible variations.

2.1.5. Study of a simple scenario

- Pump in suction mode: the pump is installed above the level of the liquid to be pumped, in this case the pump must raise this liquid to the suction point before expelling it at the discharge point.

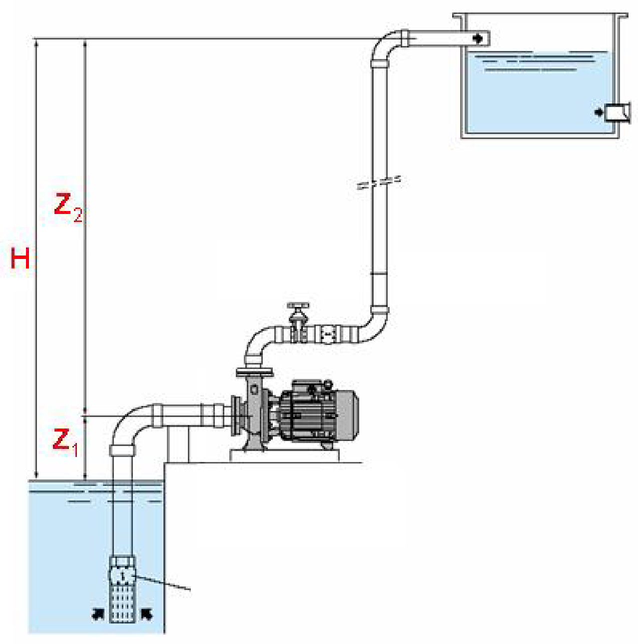


Figure 18: Suction mode

Example: On the facility above where we have measured z_1 = 3.5 m and z_2 = 39 m relative to the suction axis, there is a head loss of 0.8 mwc at the suction point and of 7.2 mwc at the discharge point. We are aiming to select a pump to obtain a flowrate of 42 m³/h of water.

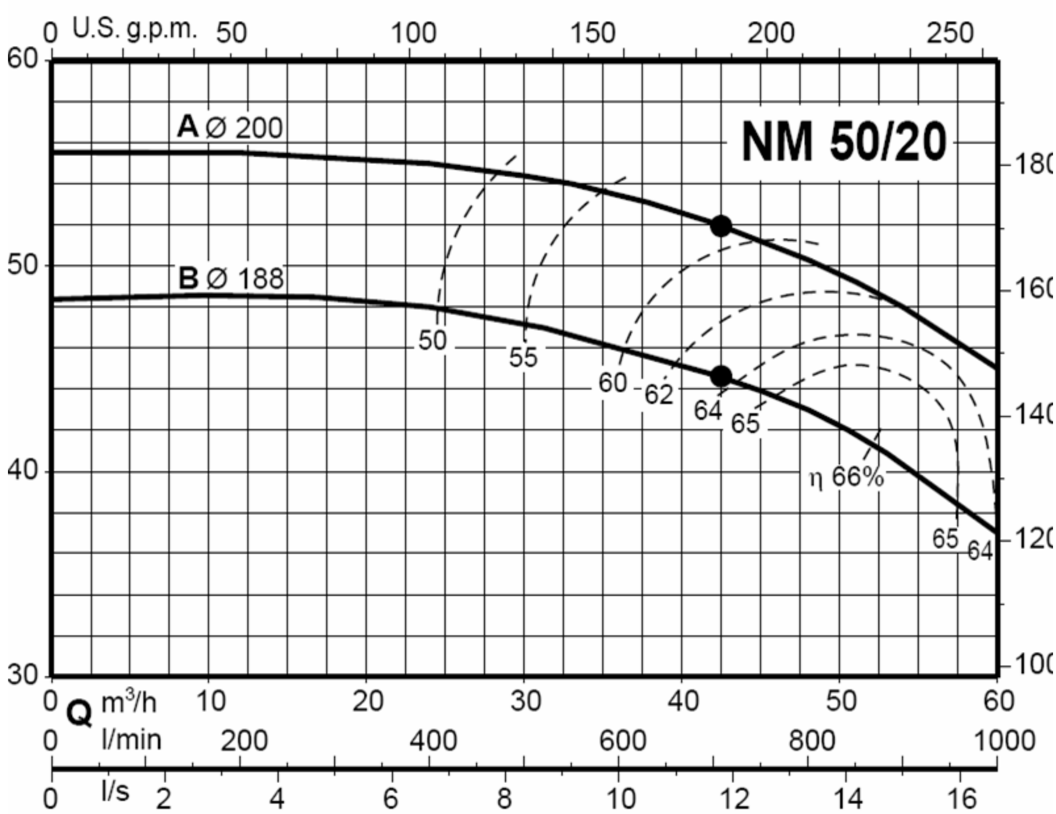


Figure 19: TMH as a function of flowrate (pump A and pump B)

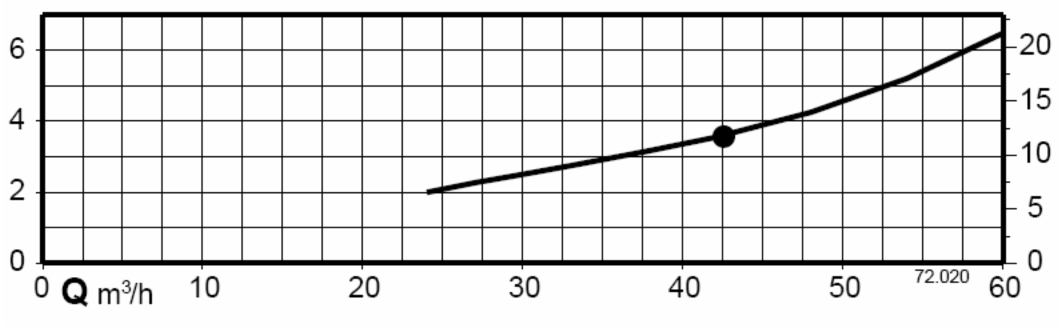


Figure 20: NPSH required as a function of flowrate for both pumps

The total energy expressed as head: h_{t1} + TMH – Head loss = h_{t2}

TMH = $h_{t2} - h_{t1}$ + Head loss = $P_2 / \rho . g + ½ u_2^2 / g + z_2 - (P_1 / \rho . g + ½ u_1^2 / g - z_1)$ + Head loss

$P_1 = P_2 = P_{atm}$, $u_1 = u_2 = 0$ (constant level), -z1 since the reference level is the axis of the pump.

So TMH = $z_2 + z_1$ + Head loss = 3.5 + 39 + (0.8 + 7.2) = 50.5 (mwc).

We can see that the pump in curve B does not have enough capacity since with a flowrate of 42 m³/h it only supplies a TMH of 45 mwc.
The pump in curve A, which can supply up to 57 mwc, will be adopted if the NPSH condition is observed ($NPSH_a > NPSH_r + 0.5$ mwc).

For this pump at this flowrate the $NPSH_r$ (required) is 3.5 mwc

NPSHa = Patm – Suct. head loss – z1 = Patm – 0.8 – 3.5
Patm = 101325 Pa and 1 mwc = 9810 Pa so Patm = 10.33 mwc
NPSHa = 10.33 – 4.3 = 6.03 mwc, so we do have NPSHa > NPSHr + 0.5

- Pump primed: the pump is installed below the level of the liquid to be pumped, in this case the liquid in the suction pipe produces a "useful" pressure for which the pump will not need to compensate

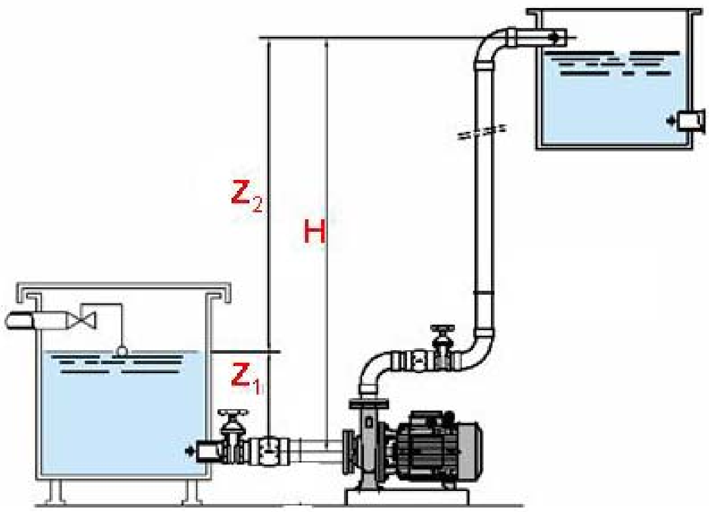


Figure 21: Primed operation

Example: On the following facility, we have measurements relative to the suction axis of z_1 = 3.5 m and z_2 = 39 m. There is a head loss of 0.8 mwc at suction and of 7.2 mwc at discharge.

We are aiming to select a pump to obtain a flowrate of 42 m³/h of water.

Total energy expressed using head: h_{t1} + TMH – Head loss = h_{t2}

TMH = $h_{t2} - h_{t1}$ + Head loss = $P_2 / \rho . g + ½ u_2^2 / g + z_2 – (P_1 / \rho . g + ½ u_1^2 / g + z_1)$ + Head loss
$P_1 = P_2 = P_{atm}$, $u_1 = u_2 = 0$ (constant level), +z1 since the reference level is the axis of the pump.

So TMH = $z_2 - z_1$ + Head loss = 39 - 3.5 + (0.8 + 7.2) = 43.5 (mwc).

We can see that the pump in curve B has sufficient capacity, since for a flowrate of 42 m³/h it supplies a TMH of 45 mwc.

This pump will be adopted if the NPSH condition is observed ($NPSH_a > NPSH_r + 0.5$ mwc).

For this pump at this flowrate, the $NPSH_r$ (required) is 3.5 mwc

NPSHa = Patm – Suct. head loss + z1 = Patm – 0.8 + 3.5
Patm = 101325 Pa and 1 mwc = 9810 Pa so Patm = 10.33 mwc
NPSHa = 10.33 + 2.7 = 13.03 mwc, so we do have NPSHa > NPSHr + 0.5

Note: is there a max dimension for a pump in suction mode?

P_v water = 0.1252 mwc (at 10°C)

For a pump in suction mode: $NPSH_a = P_{atm} - \triangle h - P_v$ – suction head loss

If we assume that there is no suction head loss: $NPSHa = P_{atm} - \triangle h - T_v$

For pumping to be possible, we require $NPSH_a > NPSH_r$ i.e. > 0

I.e. $P_{atm} - \triangle h - T_v > 0$
=> $\triangle h < P_{atm} - T_v < 1013 * 10^5$ Pa (to be converted into mwc) – 0.1252m

$\triangle h < 10.2$ mwc – 0.1252 m, so we can say that water suction is impossible if the suction point is more than 10 m below the pump.

In fact, problems start at around 8 m (when suction head loss takes effect).

2.2. CENTRIFUGAL PUMPS

A centrifugal pump comprises:

- a vaned wheel (also called vaned rotor or impeller) rotating on its axis
- a distributor in the wheel axis
- a spiral-shaped manifold with increasing cross-section, known as the volute.

The liquid flows in along the axis of the pump via the distributor and the centrifugal force generated by the vaned wheel's rotation drives it toward the outside of the wheel. It acquires high kinetic energy, which is converted into pressure energy in the manifold, where the cross-section increases.

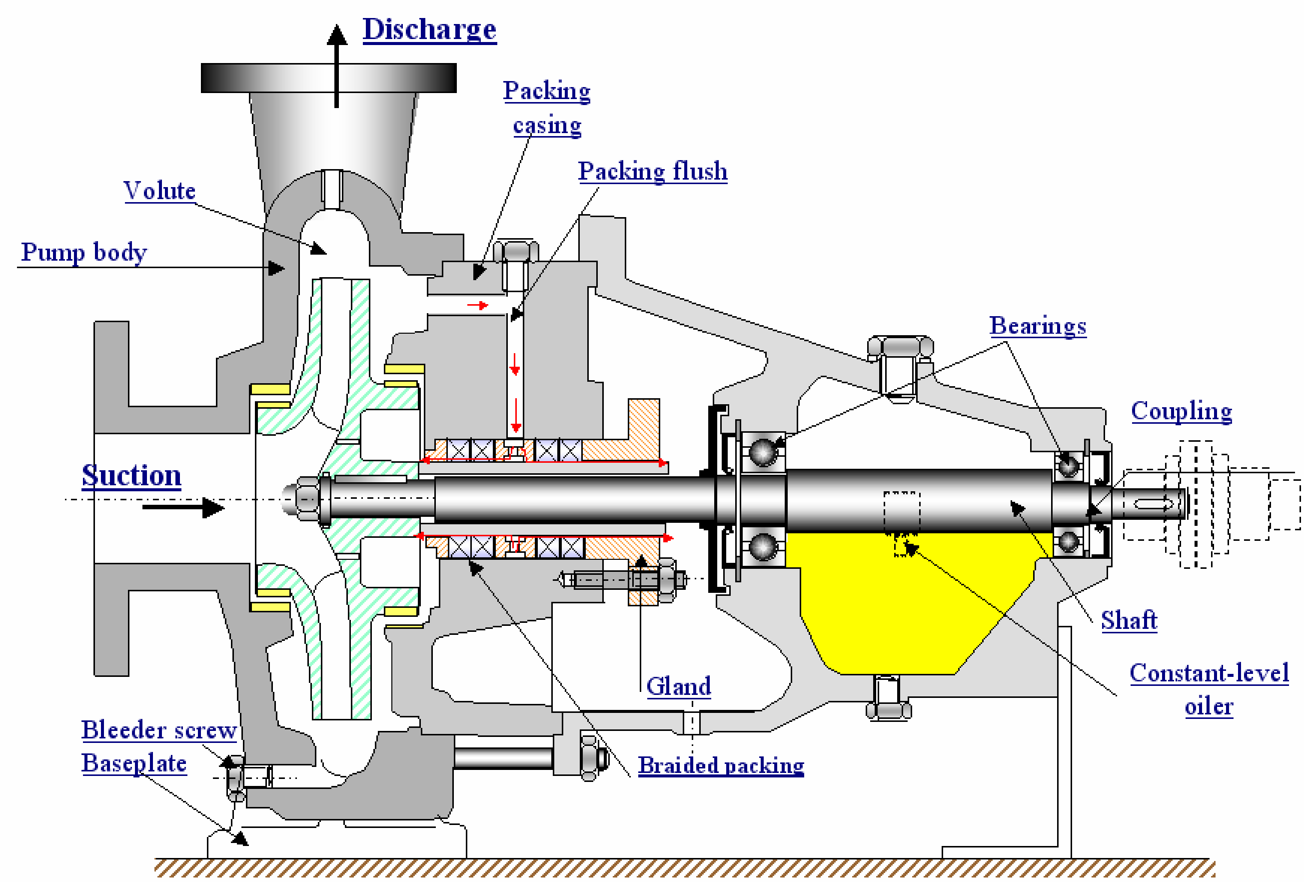


Figure 22: Overhanging single-stage centrifugal pump

Using a diffuser (stator vane impeller) on the edge of the mobile wheel can reduce the energy loss.

So why increase the speed of the water stream in the impeller only to slow it down immediately in the diffuser and the volute?

- Increasing the speed of a fluid stream imparts an energy gain, **kinetic energy**. So the vaned rotor transmits kinetic energy to the fluid.
- Slowing a fluid stream means reducing its speed, thereby making it lose kinetic energy. This lost energy must convert itself into another form of energy, **potential energy**, which is manifested as a pressure increase.

By examining the cross-section of an Overhung Single-stage Pump and its environment, we can locate the various component parts according to their function.

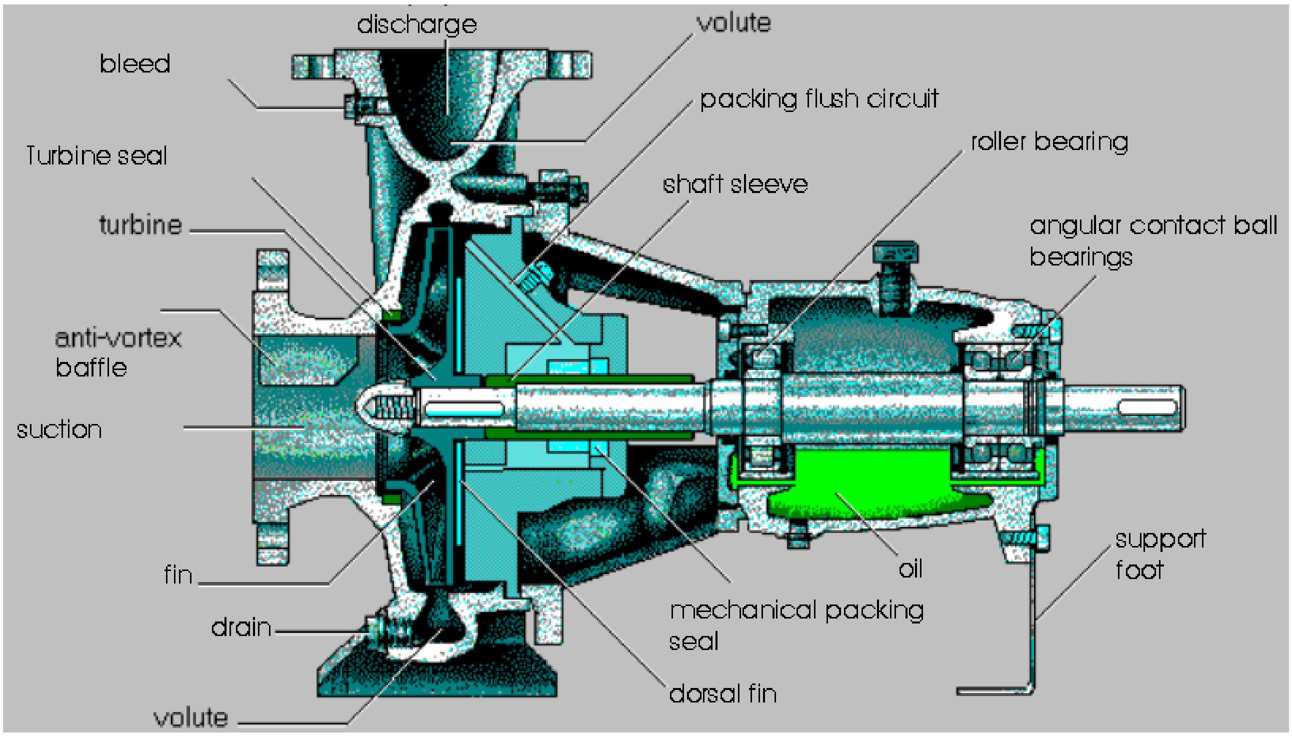


Figure 23: Cutaway view of a single-stage pump

This enables us to differentiate:

- The components involved in pumping fluid: **Hydraulic Function**
- The components contributing to the maintenance of the rotating parts: **Rotor rotation guide function and axial displacement guide function**.
- **Lubrication Function**
- Devices for limiting leaks: **Sealing Function**.

- Cooling of certain parts: **Cooling Function**.
- and finally in structure: **Assembly Function**

2.2.1. Hydraulic Function

The pumped fluid enters the pump via the **suction nozzle** and comes to the **eye** of the **wheel**.

It is guided into the wheel by **side plates**, between which the **vanes** are set.

At the outlet it is driven into the **Volute** with increasing cross-section, which converts part of the velocity energy acquired in the wheel into pressure.

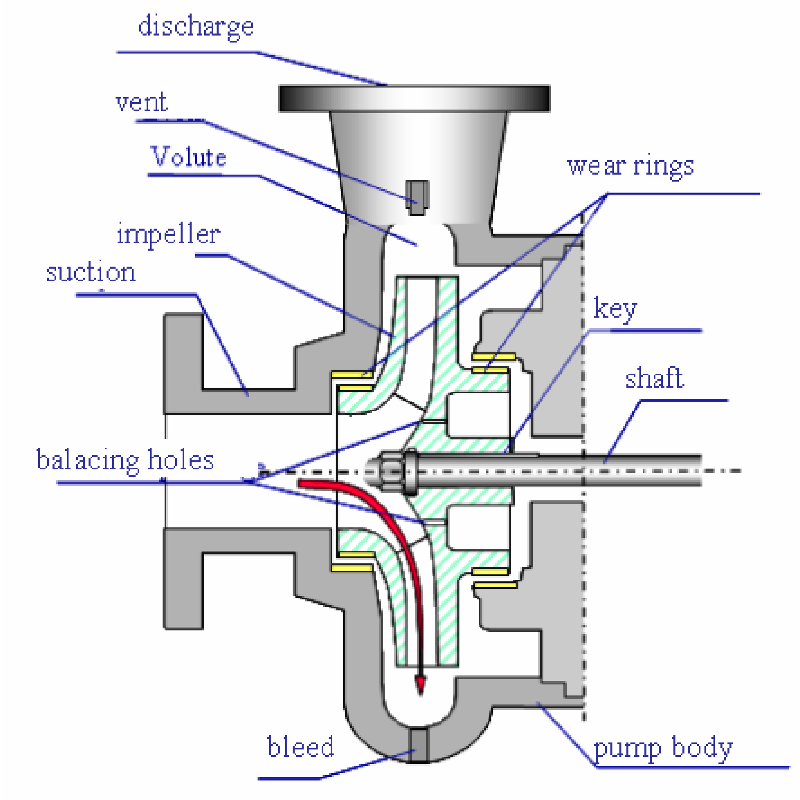
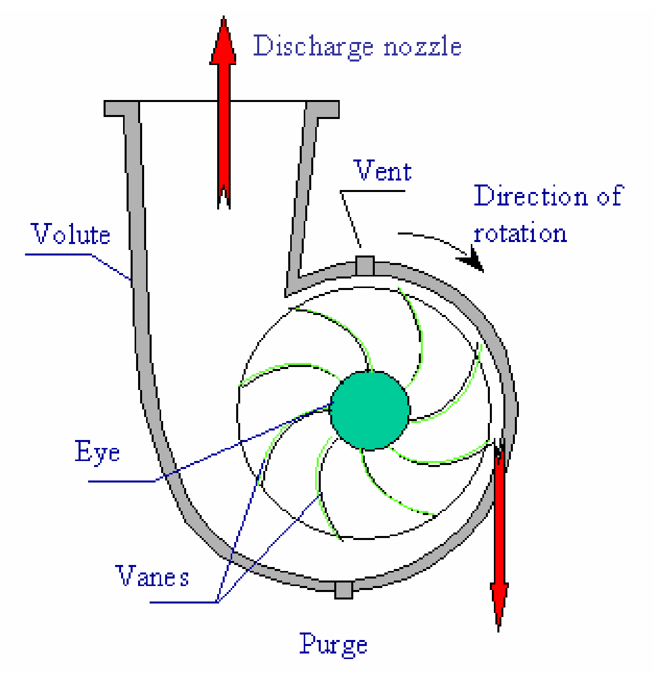


Figure 24: Hydraulic function (1) – Single-stage Pump



At the **impeller** outlet the liquid is collected in the **volute,** which directs it to the **discharge nozzle.**

The liquid passes into the **wheel** or **impeller,** which imparts velocity and pressure energy to it.

In the pump the liquid obtains a pressure increase (pump Δp), which is measured with pressure gauges at the suction and discharge.

Figure 25: Hydraulic function (2) –Single-stage Pump

Sealing rings or wear rings are installed to control the clearance between the wheel and the valve body, and to limit the inevitable leakage of fluid at the wheel outlet to the suction.

The effectiveness of the rings depends on the value of the clearance.

If this is too great it will reduce the performance levels of the pump.

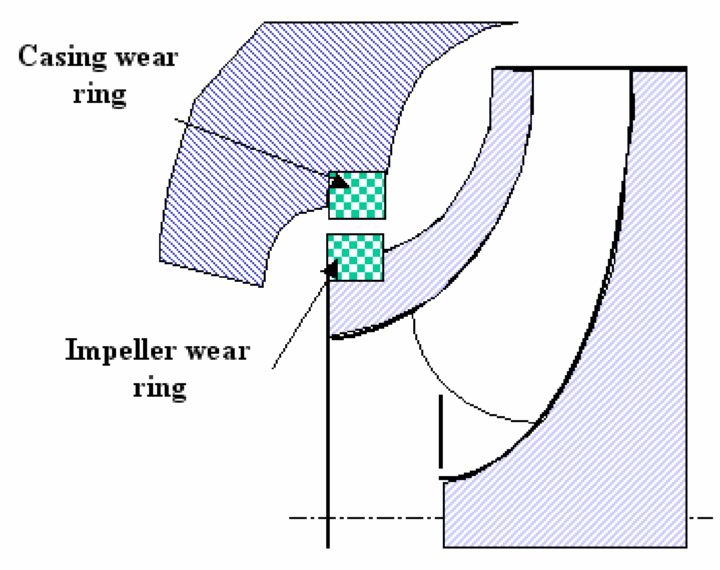
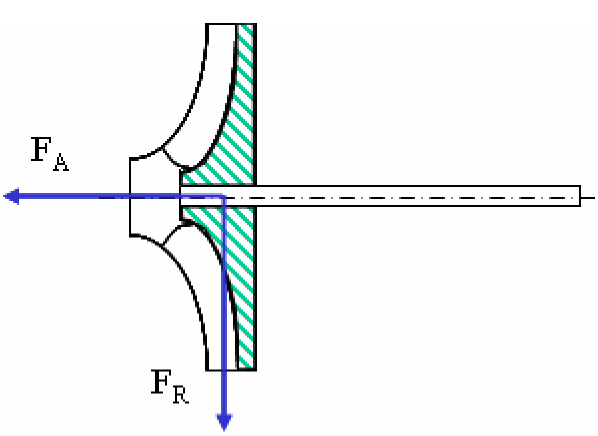


Figure 26: Sealing or wear rings

On the other hand, too low a clearance increases the risk of contact between the rings, and the danger of deterioration. To prevent this, the rings are made from materials of different hardness.

On the volute a **vent** is used for filling the pump, and a **bleed** at the bottom point is used for draining it.

2.2.2. Rotor axial and rotation guide function



The wheel is joined integrally onto the shaft by means of a key, and locked with a nut.

The assembly: Wheel – Key – Nut – Rotating parts of the bearings and coupling, forms the ROTOR.

Figure 27: Rotor

In motion the **rotor is subject to 2 forces:**

- A **Radial force FR**, due to its weight.
- An **axial force FA**, towards the front of the impeller: a resultant force of the forces generated by the liquid pressure on the surfaces of the impeller.

So the impeller needs to be **guided in rotation** and **axially** immobilised**.**

2.2.2.1. Rotation Guide Function

The rotation guide function is performed by **two bearings**

The wheel (impeller) may either be **overhanging** the bearings (low- or medium-power pump),

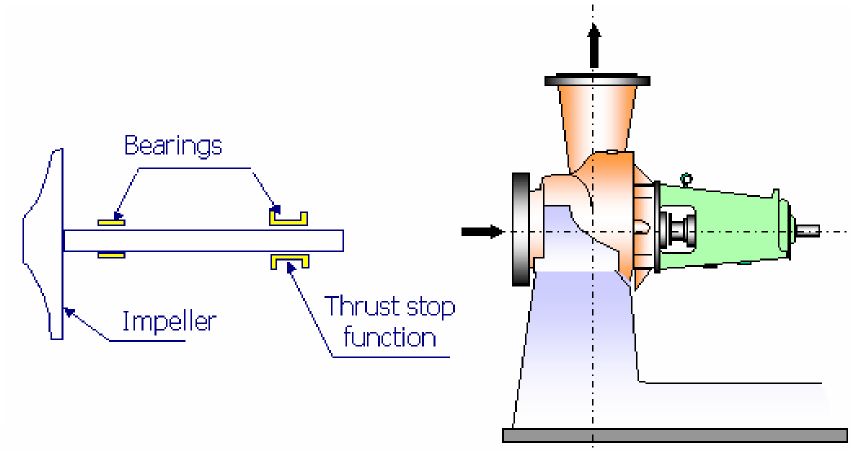
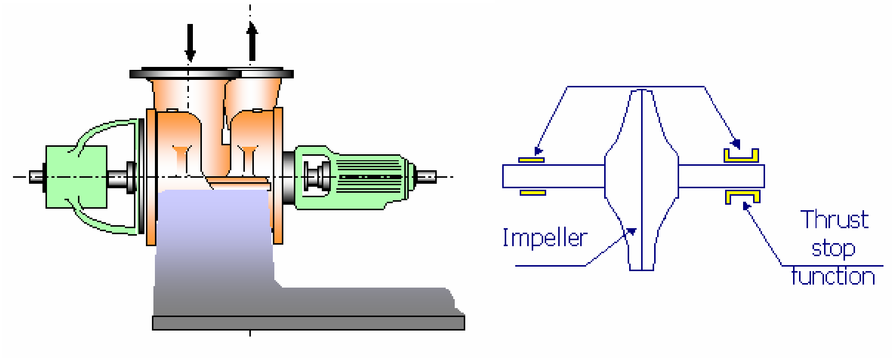


Figure 28: Overhung impeller



or be **placed between** the two bearings (pumps with 2-eye impeller and multi-stage pumps.)

Figure 29: Impeller between two bearings

Either a **ball bearing** or a **roller bearing** can perform the rotation guide function.

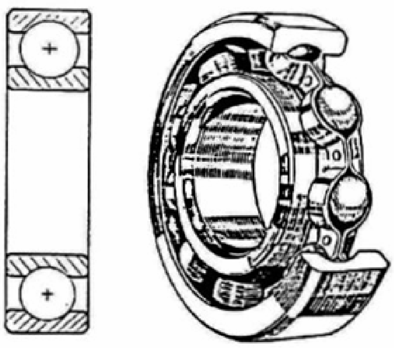


Figure 30: Ball bearings

The service life of these bearings is long, provided that they have been correctly fitted and are well lubricated

When the pump is off, the balls, but the rollers more so, may mark the rings if vibrations spread from a nearby machine

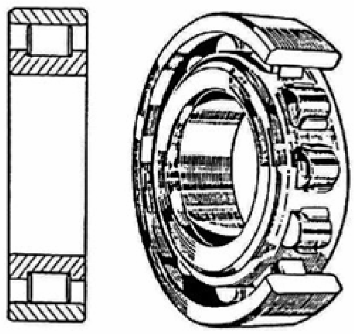
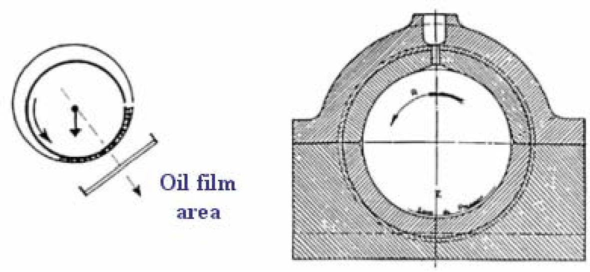


Figure 31: Cylindrical roller bearing

A shaft rotates in a bore known as the **bush**, made from antifriction metal. The presence of an oil film prevents friction between the two metals.



In very rare cases, **plain bearings** can be found with the wheels overhanging.

Figure 32: Plain bearings

2.2.2.2. Axial guide function

The axial positioning of the rotor is in the vast majority of cases ensured by a **stop**. In fact if roller bearings are used, the stop function is often provided by an axially locked ball bearing (deep groove or with 2 rows of angular contact balls opposite each other).

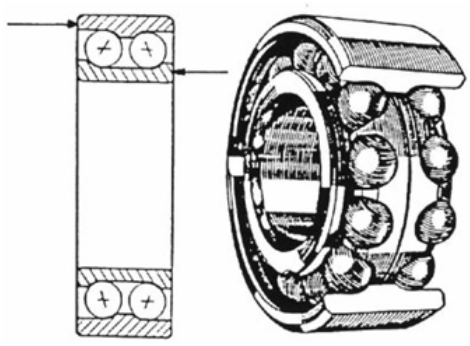


Figure 33: Bearing with 2 rows of angular contact balls

On big pumps plain stops or pad stops may be found.

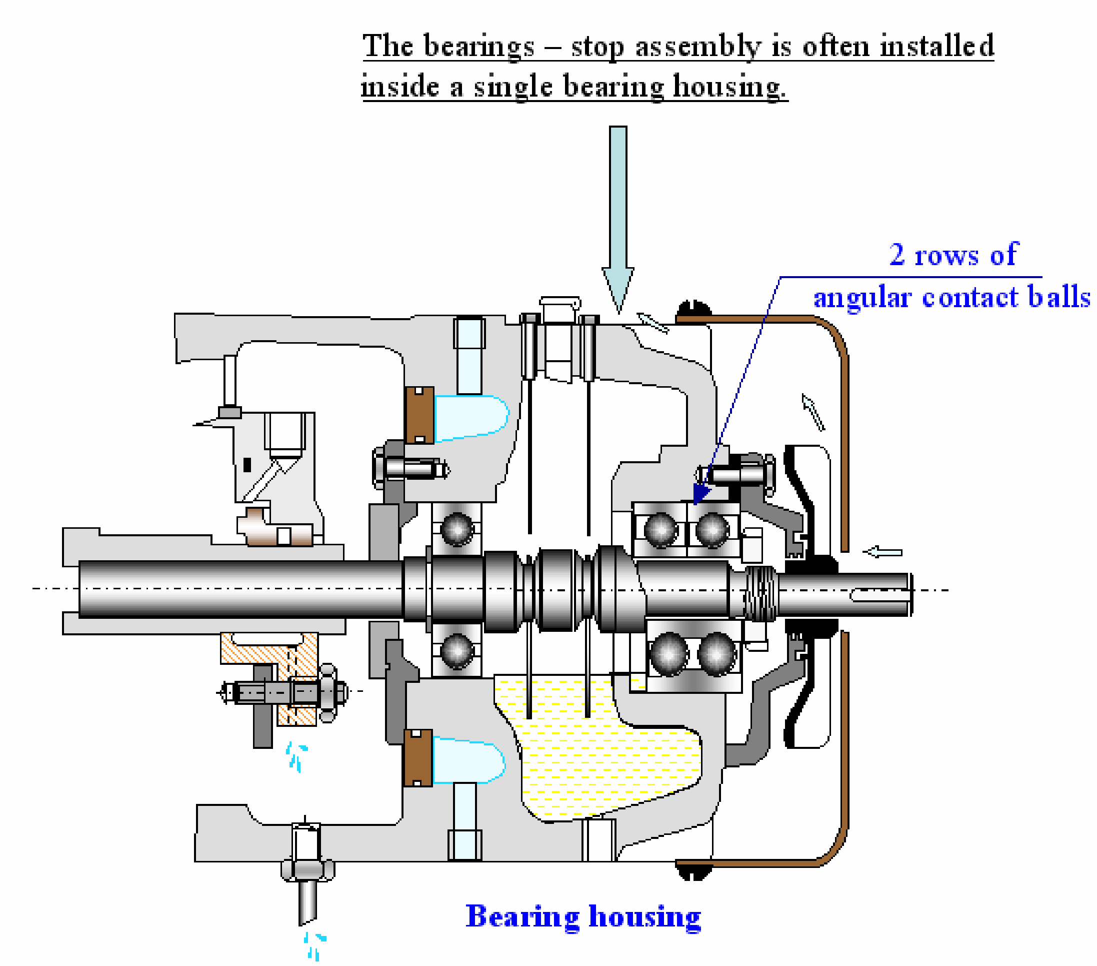


Figure 34: Bearings – stop assembly

Manufacturers design impellers in the appropriate shape or, as on multi-stage pumps, use balancing systems such as a drum, discs or even use opposing pairs (or groups) of wheels.

Aim: Limit the axial force to acceptable values for the stops.

2.2.3. Lubrication Function

Any rotating mechanical component (ball bearing, roller bearing, bearing bush...), requires appropriate lubrication in order to work properly.

Otherwise, overheating, excessive wear, seizing and even locking will occur.

There are two distinct types of lubricants: ***grease and oil.***

- **Grease lubrication** is reserved for bearings. It is used for low power pumps (< 10 kW) or pumps with a maximum rotation speed of 1500 rpm.

  Grease consumption is very low, but it needs to be topped up from time to time.

  Any excess grease (balling) leads to overheating which may cause deterioration.

- **Oil lubrication** is the most common on “process” pumps.

  Various lubrication systems are used

  - Oil bath
  - Autonomous circulation by means of thrower or ring
  - Forced circulation
  - Oil mist.

Let us look in detail at how the main lubrication systems work

2.2.3.1. Oil bath or pick-up

This system is very common for bearings immersed directly in oil. The oil level must provide sufficient lubrication, but the balls must not be excessively immersed.

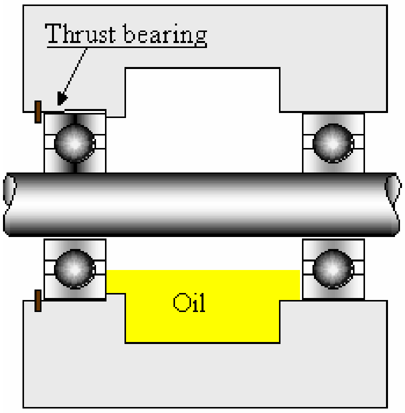
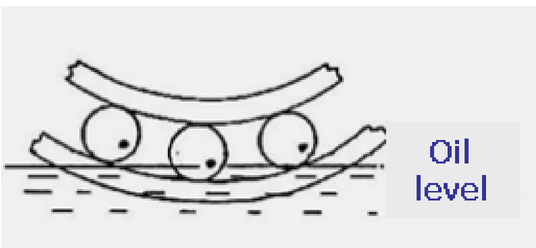


Figure 35: Oil bath (1)



It is considered that only quarter of the lower ball should be in the oil.

Figure 36: Oil bath (2)

So this oil bath bearing lubrication system is inappropriate if the bearings are different sizes.

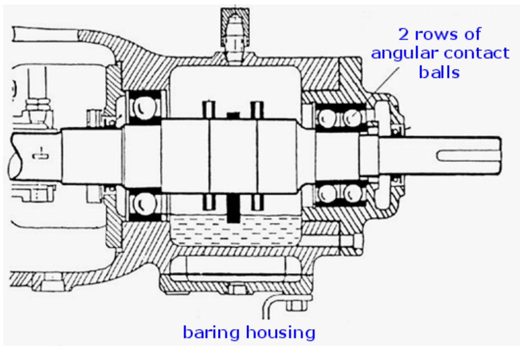


Figure 37: Inappropriate oil bath bearing lubrication system

2.2.3.2. Autonomous circulation

The oil is projected by rotation of the throwers which are immersed in the oil. This system is used mainly for bearings.

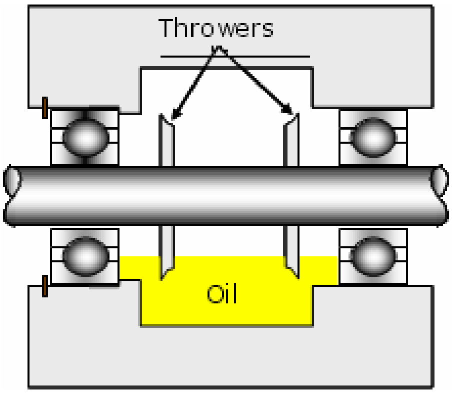


Figure 38: Autonomous circulation - Throwers

This is then channelled to the bearings by means of the suitable shaping of the housing.
We can also find oil lifting rings which supply oil to the shaft. This system is found in roller bearings, but also on plain bearings.

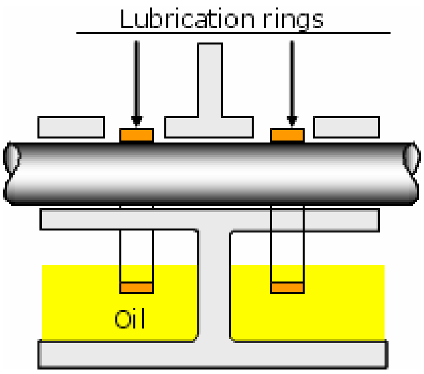


Figure 39: Bearing with bush fitted with lubrication rings

Too low an oil level will stop the oil lift function.

Too high a level may lead to leaks on the shaft and slow the ring, resulting in poor lubrication or splashing of bearing components, damaging the resistance of the bearings.

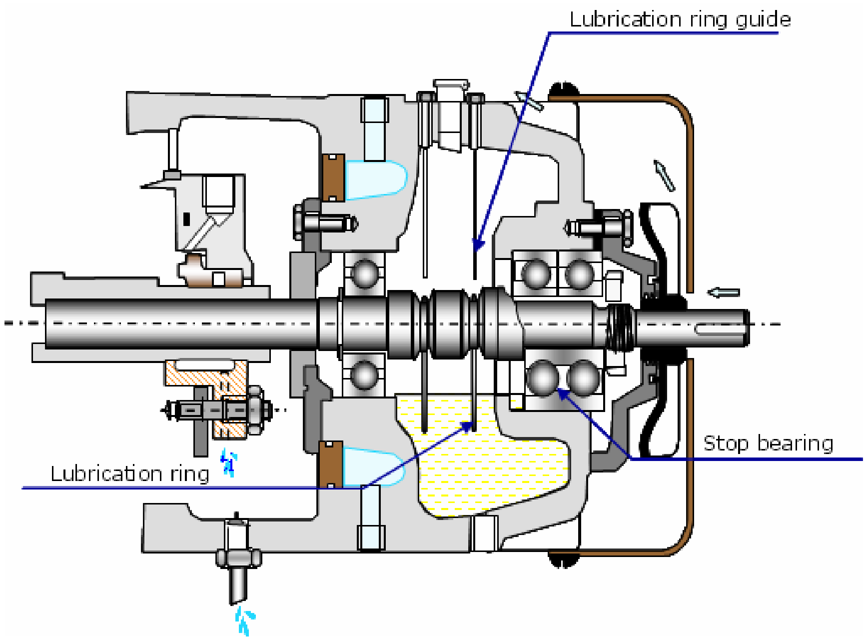


Figure 40: Roller bearing fitted with lubrication rings

2.2.3.3. Forced circulation

The lubrication pump may be **independent** or **coupled** to a machine.

In this case, an additional system can generate the oil circulation before the machine is started, until when the coupled pump takes over.

The oil is filtered, and generally **refrigerated**, either in the oil box, or by an exchanger on the discharge line.

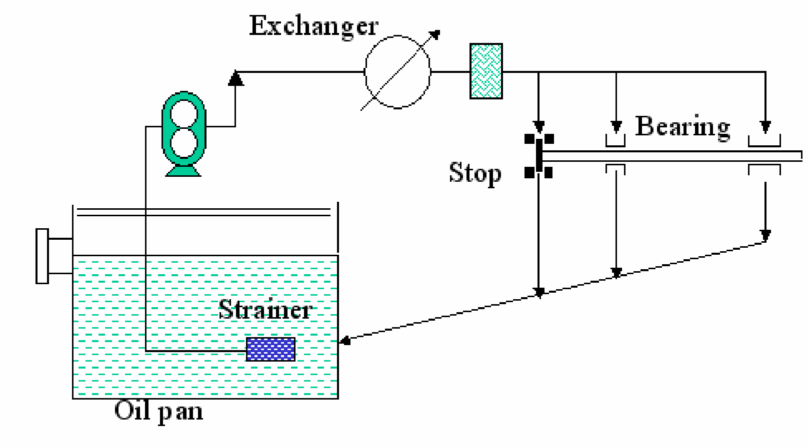


Figure 41: Forced circulation (plain bearings)

A **geared accelerator pump** draws oil from an oil reserve and distributes it to the various greasing points (stop, bearing...)

The pressurised oil circulation **system** may be fitted with **safety devices** (temperature, pressure...) which prevent the machine from starting, or shut it down, in the absence of lubrication.

The reserve may either be inside one of the machine's bearings or in an oil box.

One of the benefits of forced circulation is **effective evacuation of the heat** from the bearings generated either by bearing friction (in the case of plain bearings and plain stops) or by transfer of heat from the pumped liquid at a high temperature.

2.2.3.4. Conditions for correct lubrication

In conclusion, regardless of the system used, two conditions must be satisfied for the lubrication to be satisfactory:

- The oil must be present in sufficient quantity (not too much or too little)
- The oil must be of the appropriate quality.

Oil in sufficient quantity

In the case of pick-up lubrication or lubrication by autonomous circulation, it is essential to provide the correct oil level in the bearing housing; not too high or too low.

This level may be:

- Either established upon activation and monitored by a **visual level indicator**.

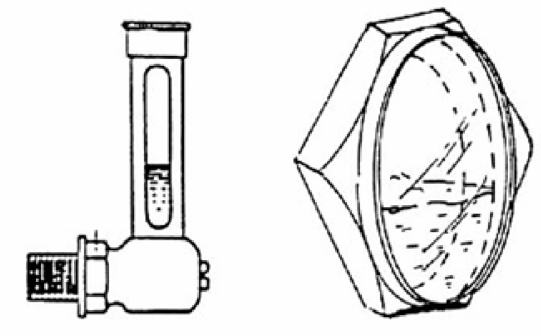
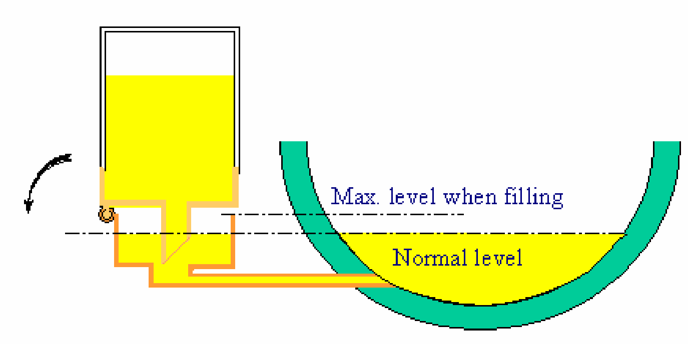


Figure 42: Visual level indicator



- Or provided by a topping-up device that retains a constant level, known as the **constant level reservoir**.

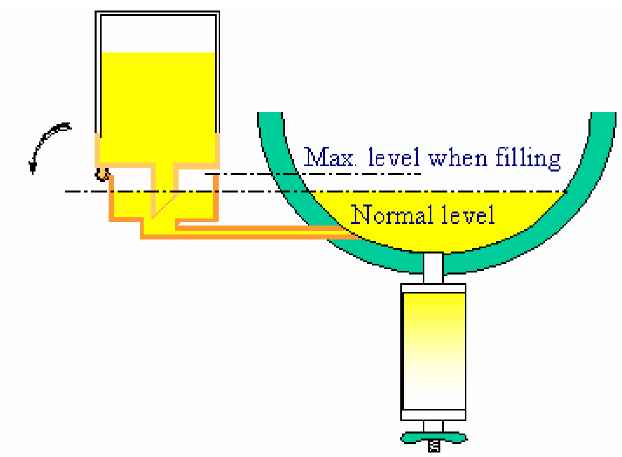
Figure 43: Constant level reservoir

Oil of appropriate quality

- The oil used must be that stipulated for this use. It must be clean, free from solid impurities and water
- The storage can and filling tube must be fitted with their covers to prevent contamination by a foreign matter.

A **drip chamber** is often installed so that the condition of the oil can be seen, and so that water, deposits or used oil can be bled off.

Figure 44: Cover and drip chamber



Finally, **the oil temperature** must not be:

- **too low**: to maintain good viscosity
- **too high**: to prevent thermal oxidation.

70°C is the normal maximum.

To avoid reaching these temperature limits, some bearings are fitted with cooling fins or equipped with refrigerants.

As for the motor, lubrication of the bearings (with grease or oil) follows the same rules as those described for the pump.

2.2.4. Sealing function

By definition, a pump is used for raising the pressure of a liquid, so the interior of a pump contains a pressurised liquid, which can escape into the atmosphere along the shaft.

This leakage therefore needs to be reduced or eliminated by means of a packing seal, which may be either braided or mechanical.

Leakage is dangerous in the case of liquefied gases, hot or toxic products.

It may also pose environmental problems.

The operation of the **packing seals*** will be studied in detail below.

The flushing liquid is generally the pumped product itself. It is taken from the pump discharge and sent to the packing, either via an external pipe, or via a channel inside the packing casing.

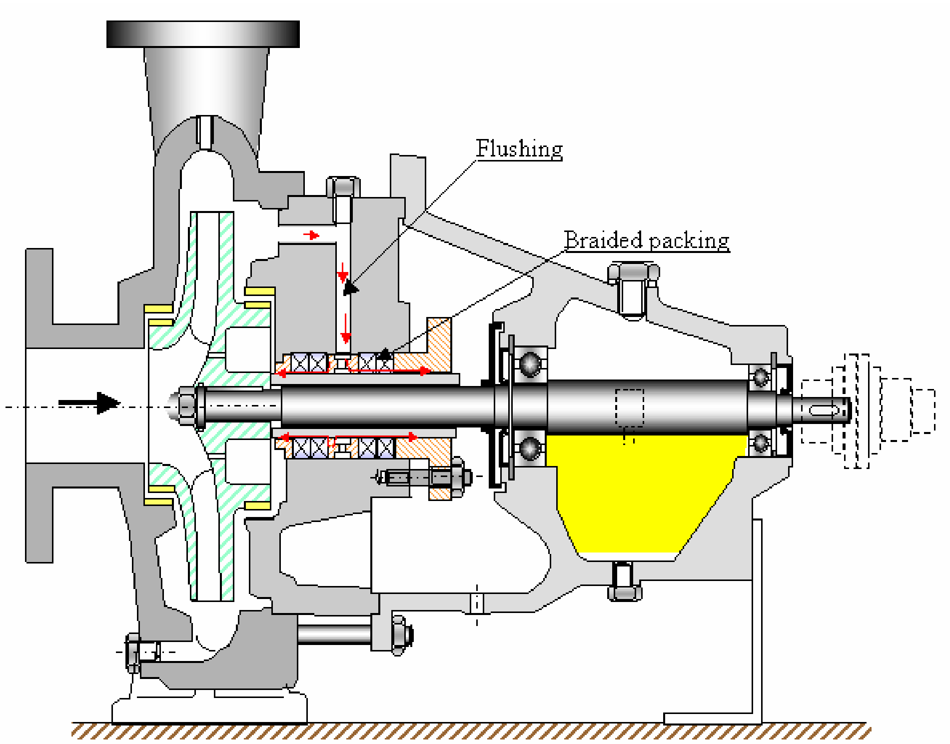


Figure 45: Flushing – Sealing function

It is sometimes useful to supply an injection behind this packing, with the aim of decreasing leaks, or "quenching". The fluid used for quenching may be water or steam.

To work correctly, a packing seal must be constantly cooled and supplied by a so-called "**flushing**", also called "circulation" liquid.

If the sealing systems pose too many problems, under certain conditions we can use packing free pumps (wet pit pump, magnetic drive pump).

Certain applications require the use of double packing, into which a sealing liquid different from the liquid conveyed by the pump is injected.

2.2.4.1. Packing box

The **packing box** contains a lantern ring, flushed either by the pump itself, (internal supply), or by an external source, thereby forming a hydraulic seal.

The role of this **lantern ring** is very important.

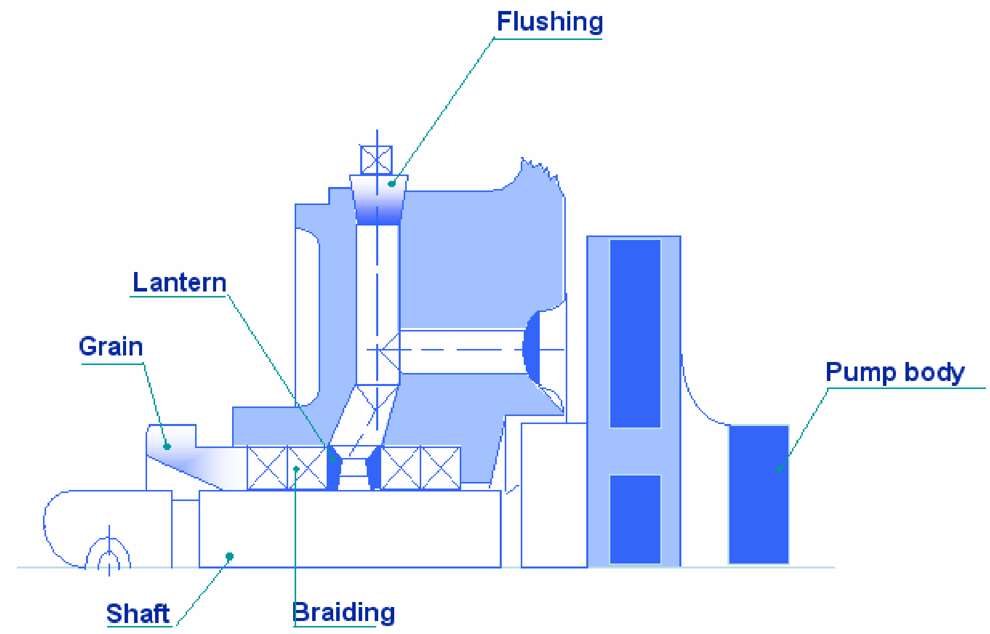


Figure 46: Packing box

It is responsible for cooling and lubricating the packing, preventing air from re-entering the pump and, in the case of an independent supply, expels the light solid particles in suspension in the pumped liquid.

This is of particular benefit in the case of pumps with open impellers, for charged liquids.

Important: Under no circumstances must a gland be locked, as this will lead to faster wear of the packing and to scoring on the sleeve.

2.2.4.2. Braids and seals

The design of dynamic seals (gland packing) intended to form seals between two moving parts - either both of them, or one in motion relative to the other – must take into account the following:

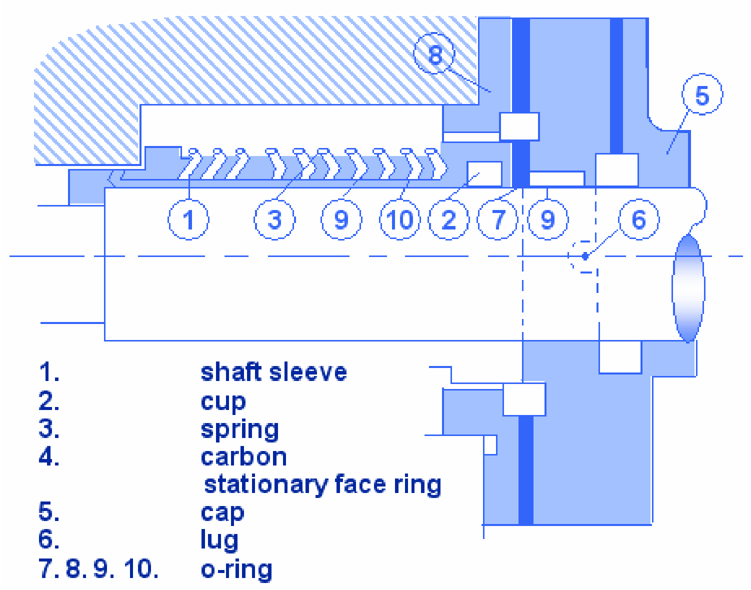
- the nature of the fluids conveyed,
- the nature of the metals in contact with the packing,
- the temperatures,
- the rotation or travelling speeds,
- the operating pressures,
- friction.

Cotton based braids are used for water.
Graphite coated diamond strand tresses are used for steam.

Specially manufactured braids are currently used according to the products conveyed, the temperature and the pressures.

2.2.4.3. Mechanical packing

The aim of mechanical packing is to form a seal on rotary devices; it is increasingly tending to replace braided packing.



Description

The mechanical packing is fitted inside a packing box.

The shaft sleeve (1) is part of the packing, and drives the cup (2), which is freely mounted on the sleeve to compensate for misalignment.

A seal (6) prevents leakage between the sleeve and cup.

Figure 47: Mechanical packing

The carbon stationary face ring (4) is housed inside the cap (5): O-ring (7) acts as a “damper” to the stationary face ring, and forms a seal between the cap and face ring.

O-ring (8) prevents leaks between the cap and the packing box.

The spring (3) is fitted tight onto the shaft sleeve and the cup: it presses the surfaces of the face ring and the cup against each other.

O-ring (9) forms a seal between the shaft and sleeve.

Operation

The shaft sleeve (1) joined onto the shaft rotates, driving a cup (2) by means of the spring (3). This cup abrades against the stationary face ring (4), which is joined with the cap (5). This face ring is secured with a lug (6), and the packing is sealed between the cup and stationary face ring contact faces.

Lubrication

Liquid circulation is provided if it is necessary to:

- cool the friction faces in contact,
- heat up these faces,
- protect these faces from sediment accumulation.

2.2.5. Cooling Function

If the pumped product is warm, it may be necessary to:

- Cool the packing casing to maintain good mechanical resistance. Depending on the circumstances, the refrigerant may be water or steam.
- Cool the bearing housing, enabling the oil viscosity to be maintained at a correct value (mechanical resistance of bearings).
- Cool the base uprights to prevent them expanding (risk of misalignment of pump with the motor).

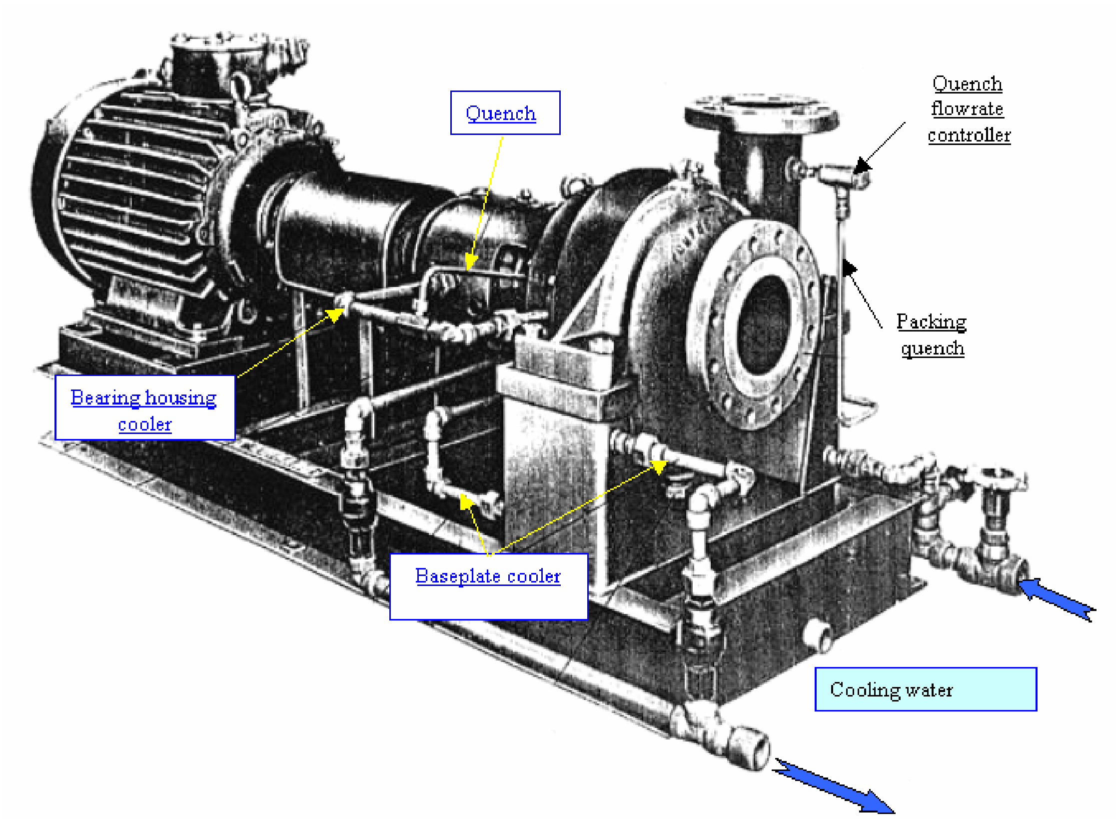


Figure 48: Cooling function

2.2.6. Assembly Function

Dismantling a pump to inspect the impeller or repair the packing or the bearings must be possible without removing the suction and discharge pipes.

For this reason, pumps are divided into two parts:

- When the **mobile part** is under repair, a blind flange is fitted onto the pump casing or on the suction and discharge flanges to protect against any leakage from the shut-off valves.

  The mobile part consists of the packing casing and the bearing and rotor housing.

  Once the intermediate part of the coupling has been removed, the mobile assembly can be slid off without touching the main pipes.

- **The pump body,** where the suction and discharge pipes are fitted. It normally remains fixed to the base when repairs are to be made to the rotating parts.

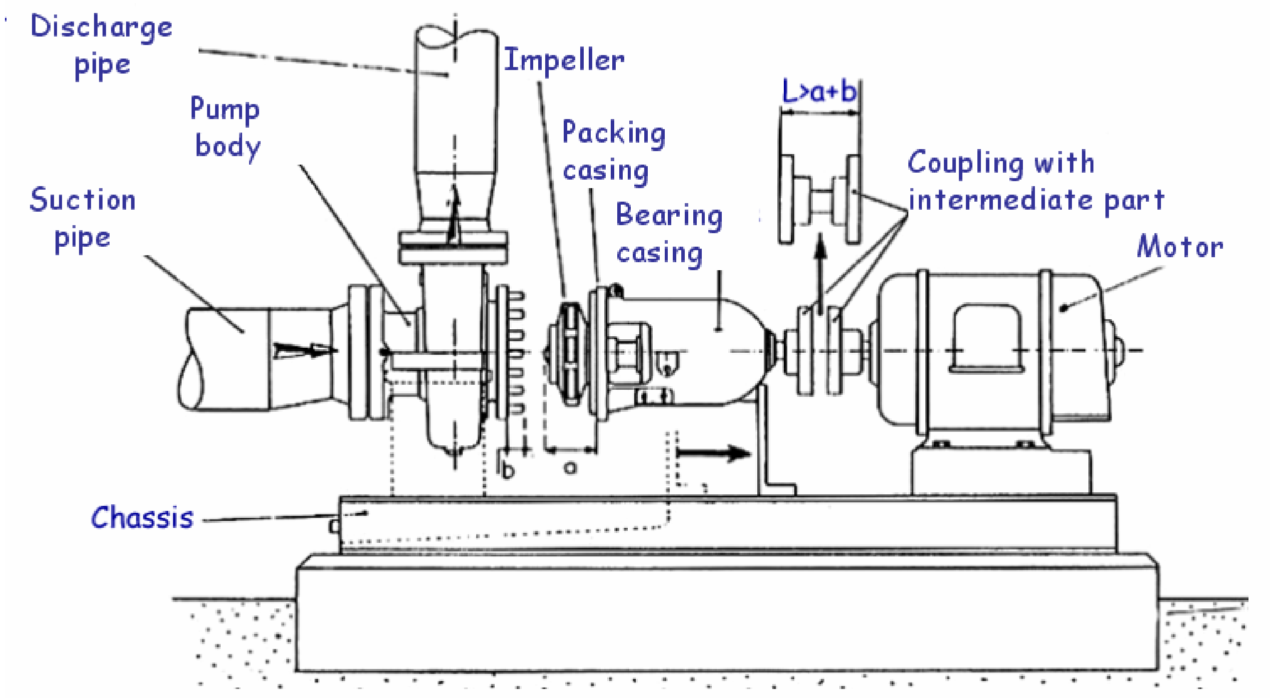


Figure 49: Assembly function

2.3. POSITIVE DISPLACEMENT PUMPS

A positive displacement pump has a well-enclosed pump barrel inside of which moves a meticulously adjusted moving element. It develops its action through the following principle:

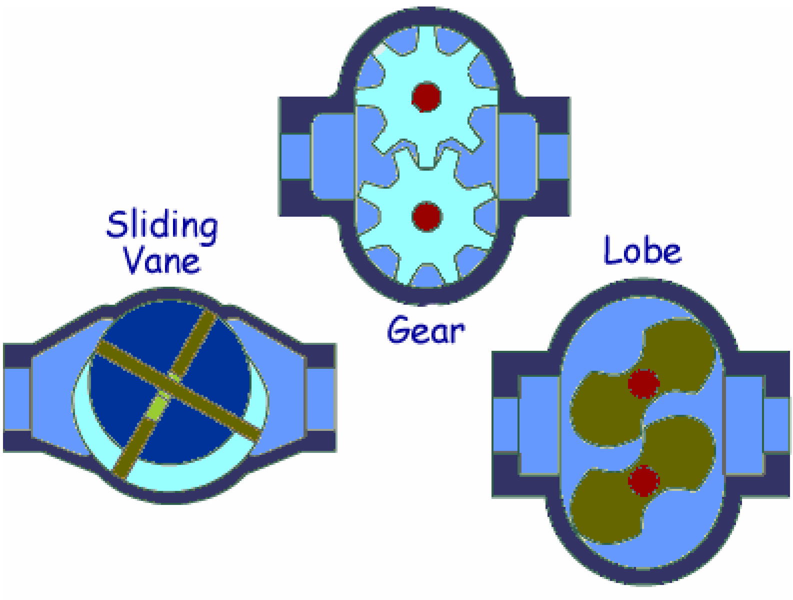
Execution of a cyclic movement, during which a given volume of liquid enters a compartment before being discharged at the end.

This movement displaces the liquid between the suction aperture and the discharge aperture.

Such pumps can be classified into two categories:

- Rotary displacement pumps:
- Reciprocating displacement pumps:

2.3.1. Rotary pump operating principle



Rotary pumps consist of a moving part which rotates actuated by a rotational movement around an axis which itself rotates in the pump barrel and induces movement of the pumped liquid by displacement of the volume from the suction point to the discharge point.

Figure 50: Rotary displacement pump operation

2.3.2. Reciprocating pump operating principle

The volumes produced at suction and discharge result from the alternating displacement of a *piston or a plunger* on its axis, inside a cylinder.

There is a time when the cylinder is filled (suction) and a time when it is emptied (discharge). The liquid flow produced by the pump will therefore be discontinued.

When the piston moves to create suction conditions, the cylinder must be filled with liquid from the suction piping. The discharge opening must be closed and the suction aperture opened.

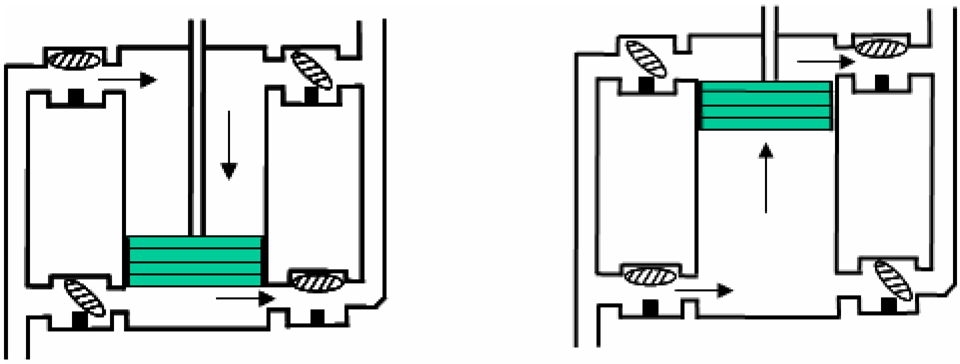


Figure 51: Example of the operation of a double-acting reciprocating pump

On the other hand, when discharging, the discharge aperture must be open and the suction aperture closed.

This is done using a set of valves.

A reciprocating displacement pump always has suction valves and discharge valves.
There are 2 main categories of reciprocating pumps:

- Simplex: 1 cylinder – single acting
- Duplex: 2 cylinders – double acting.

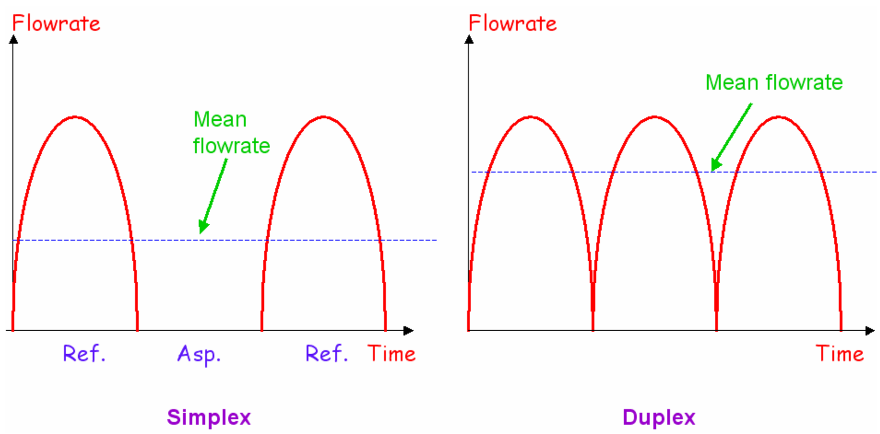
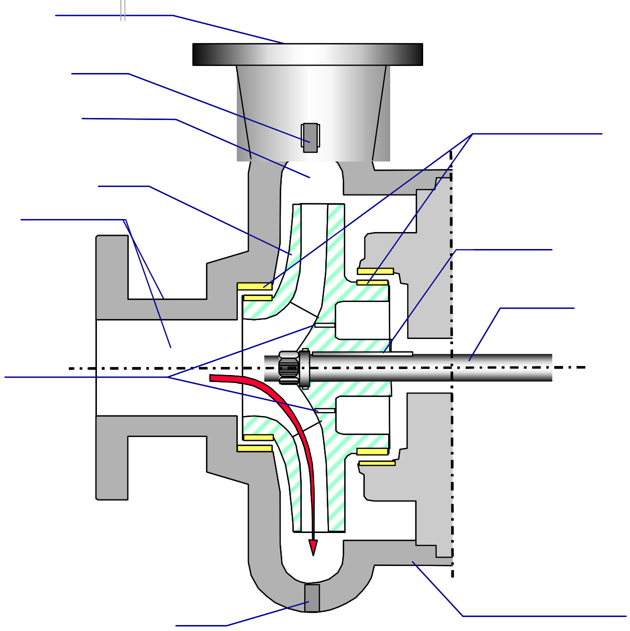


Figure 52: Pump rate

2.4. EXERCISES

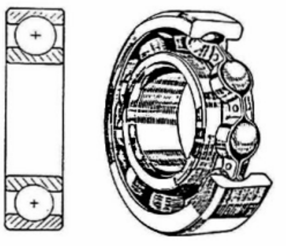
16. What are the different functions of a centrifugal pump?

17. Complete the following diagram:



18. What is the function of the bearings?

19. What type of bearing is this?



20. A stop ensures the axial positioning of the rotor

❑ True

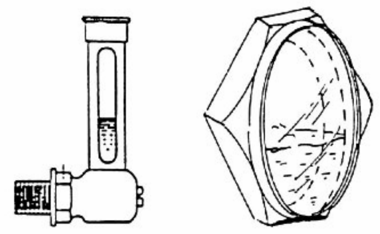
❑ False

21. Grease lubrication is the most common on "process" pumps.

❑ True

❑ False

22. What type of controller is this?



23. The oil temperature must not be too low to maintain proper viscosity.

❑ True

❑ False

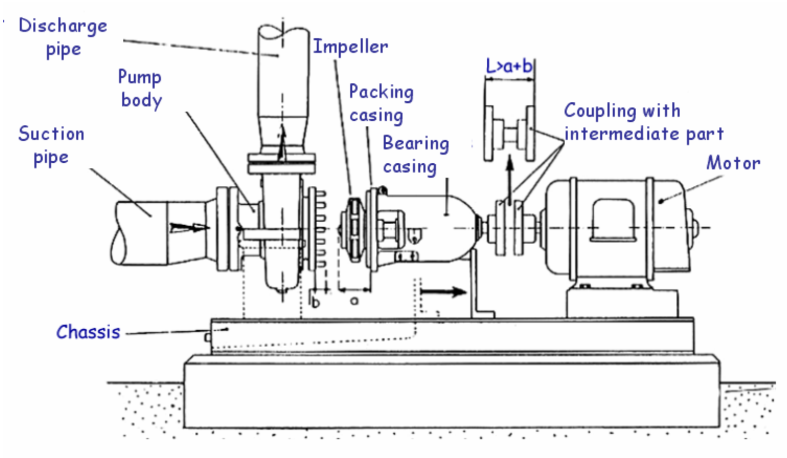
24. The oil temperature must not be too high to avoid thermal oxidation.

❑ True

❑ False

25. What 2 types of seal packing can be found along a shaft?

26. It is impossible to repair the packing or its bearings without disassembling the suction and discharge piping on this type of pump.



❑ True

❑ False

27. The execution of a cyclic movement, during which a given volume of liquid enters a compartment before being discharged at the end, is the operating principle of a positive displacement pump

❑ True

❑ False

28. Rotary pumps consist of a moving part actuated by a rotational movement around an axis, which turns in the pump barrel and induces movement of the pumped liquid by displacing the volume from the suction point to the discharge point.

❑ True

❑ False

29. The volumes created in a reciprocating pump, at suction and discharge, result from the reciprocating displacement of a piston or a plunger on its axis inside a cylinder.

❑ True

❑ False

3. VARIOUS TYPES OF PUMPS

As previously stated, the pumps can be classified under two main types: centrifugal and positive displacement. We are going to detail them in this chapter.

3.1. CENTRIFUGAL PUMPS

3.1.1. Centrifugal pump technology

This family of pumps is very widespread throughout oil industry.
Physical principle: it is the use of centrifugal force that increases the pressure of the liquids.

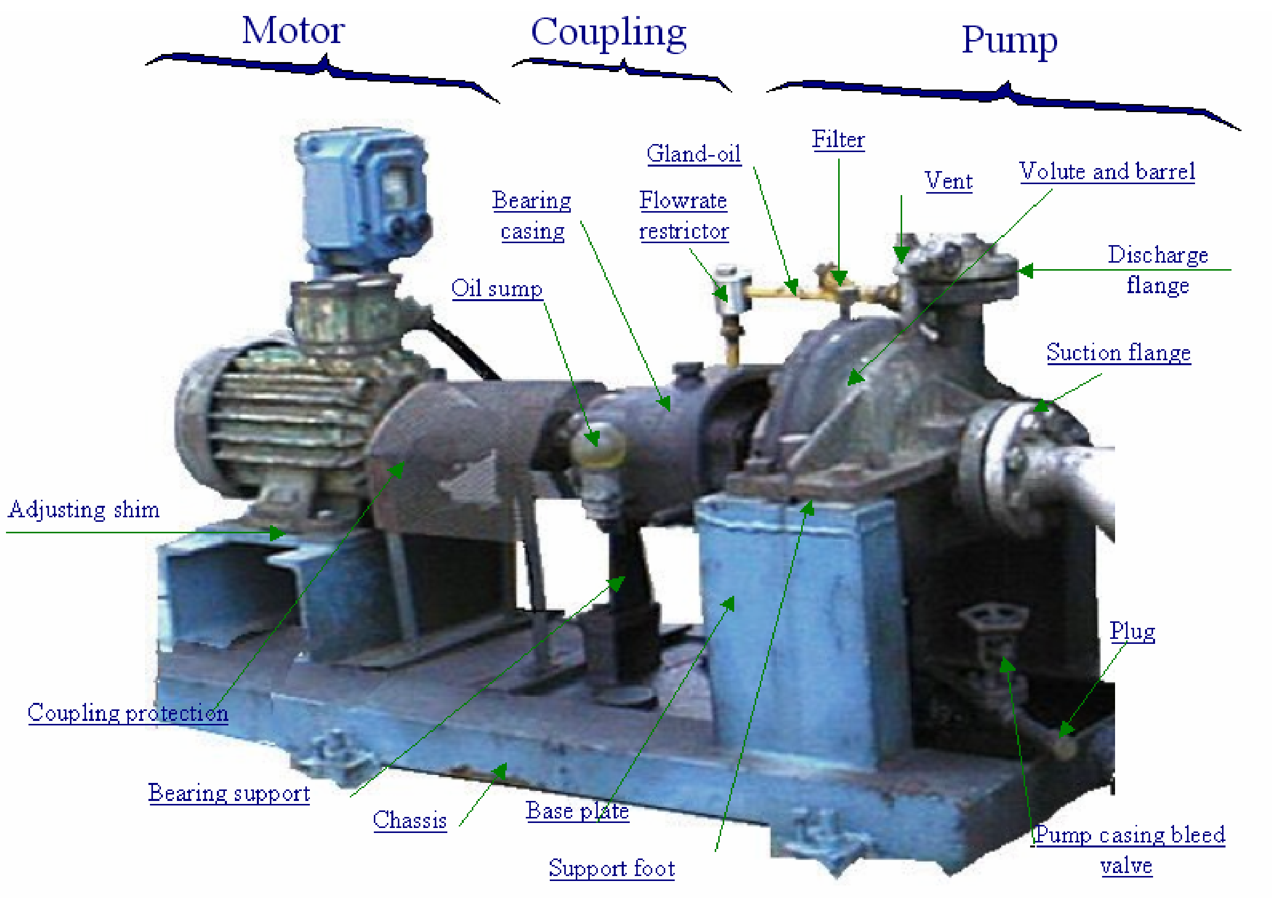


Figure 53: Example of a centrifugal pump

The impeller (or wheel) is the element that converts the energy received through the shaft into hydraulic energy.

The volute, a part of the **pump barrel,** extends the hydraulic effect of the wheel.

The shaft which supports the impeller and supplies the latter with energy must be guided into rotation by one or several **bearings** (usually roller bearings).

The main bearing must be correctly lubricated (oil supply and temperature limitation).

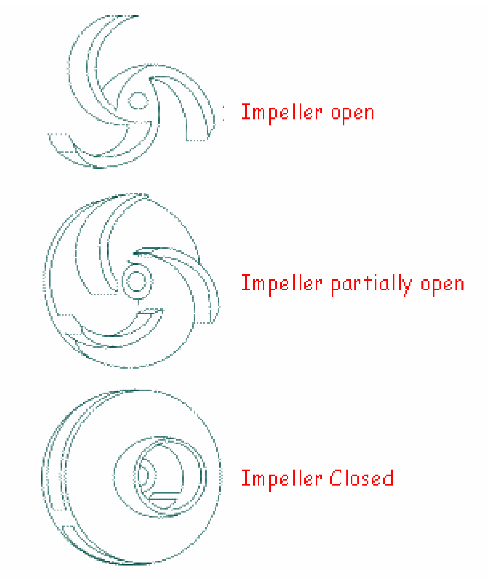


Figure 54: Various types of impellers

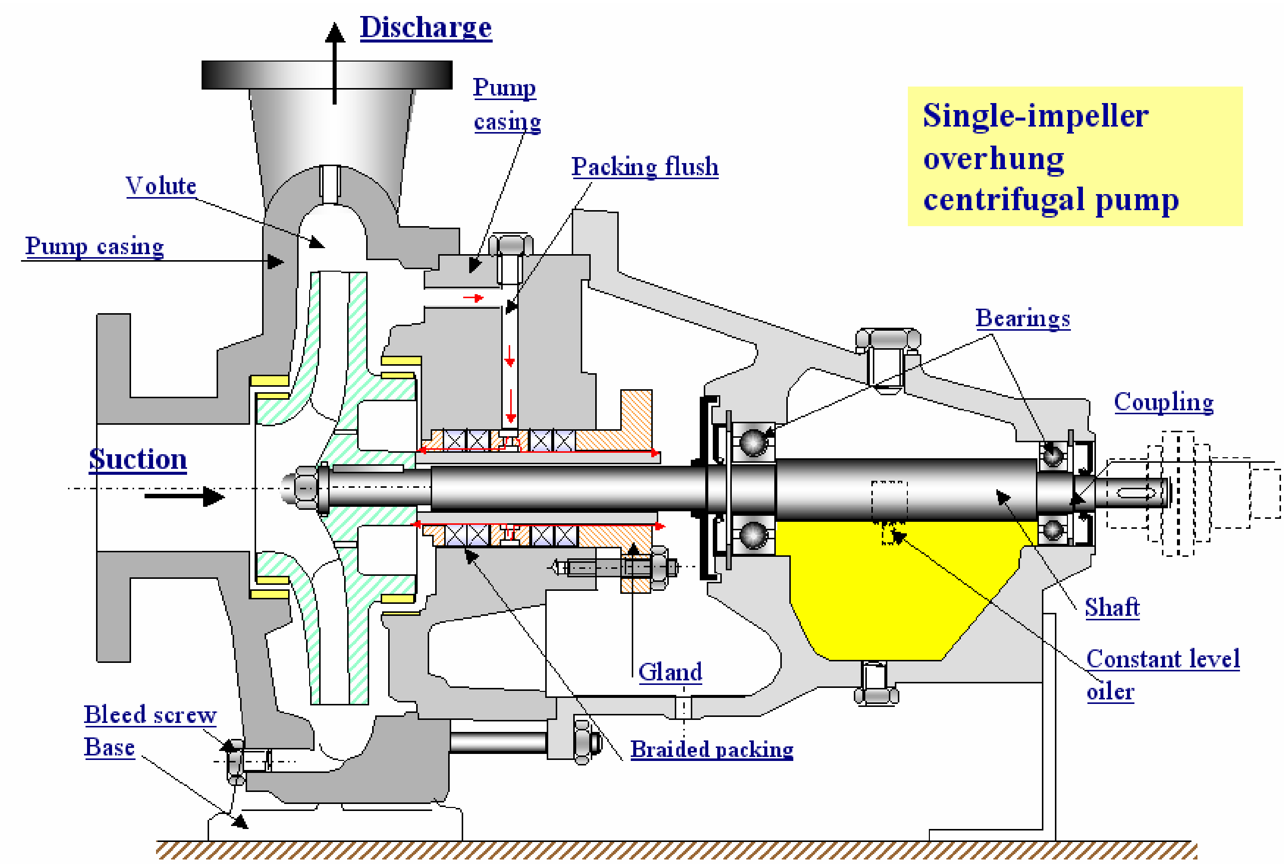


Figure 55: Cross sectional diagram of a single-impeller overhung centrifugal pump

A seal must be installed between the liquid under pressure in the pump and the atmosphere. Either **braided** or **mechanical packing** are used for that. Such packing (braided or mechanical) require very accurate working conditions which require the installation of **auxiliary lines** (lubrication, flushing, sealing, dilution, cooling of the **packing body**).

The link between the shaft and the motor (electric, turbine, etc.) is provided with a **coupling**.

The equipment service life depends on the coaxiality between the driving shafts and driven shafts. To avoid positional variations of one axis relative to the other, pumps may be foot-mounted, and even comprise a cooled pedestal very hot pumps (e.g. 300°C).

The drive is usually provided with "3000 rpm" asynchronous motors or steam turbines but also by diesel engines or gas turbines (in the case of a pipeline). In the latter cases, speed can be varied directly from the drive machine.

To ensure sufficient liquid elevation, impellers may be added to the pump (or pumps must be mounted in series).

As for series-mounted pumps, the work of one impeller is combined with that of the preceding one.

3.1.2. Details of the main centrifugal pumps

3.1.2.1. AA (Axial suction) type "Process" pumps

This is the name given to the pumps with only one overhung wheel and whose suction branch axis is combined with the machine rotation axis.

The discharge branch is vertical.

The AA-process pumps are well adapted for **moderate flows** and for **average** or **poor elevation heads.**

As their technology is simple, their price is reasonable and maintenance is generally low.

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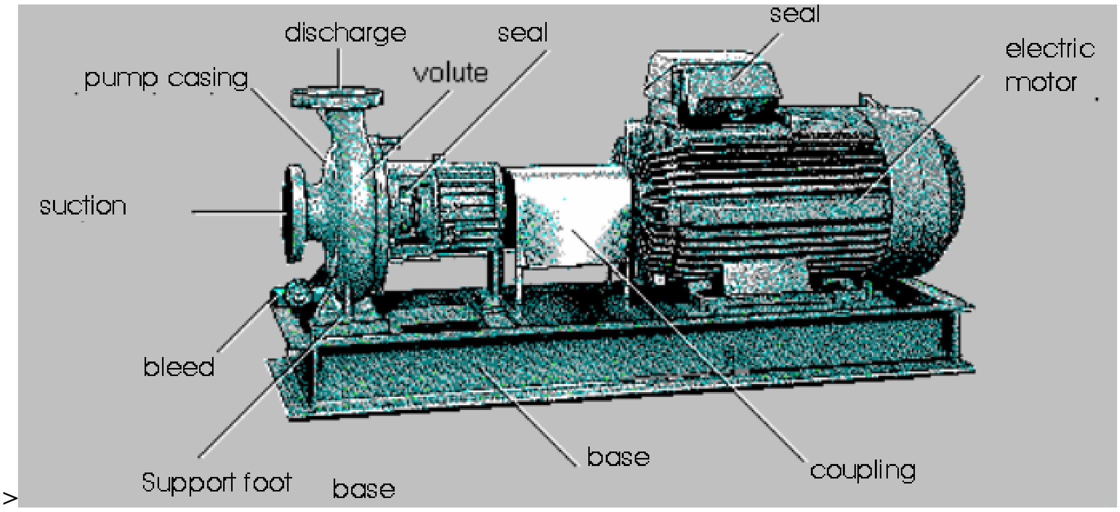


Figure 56: External view of a single-impeller pump

The discharge port is always smaller than the suction port.

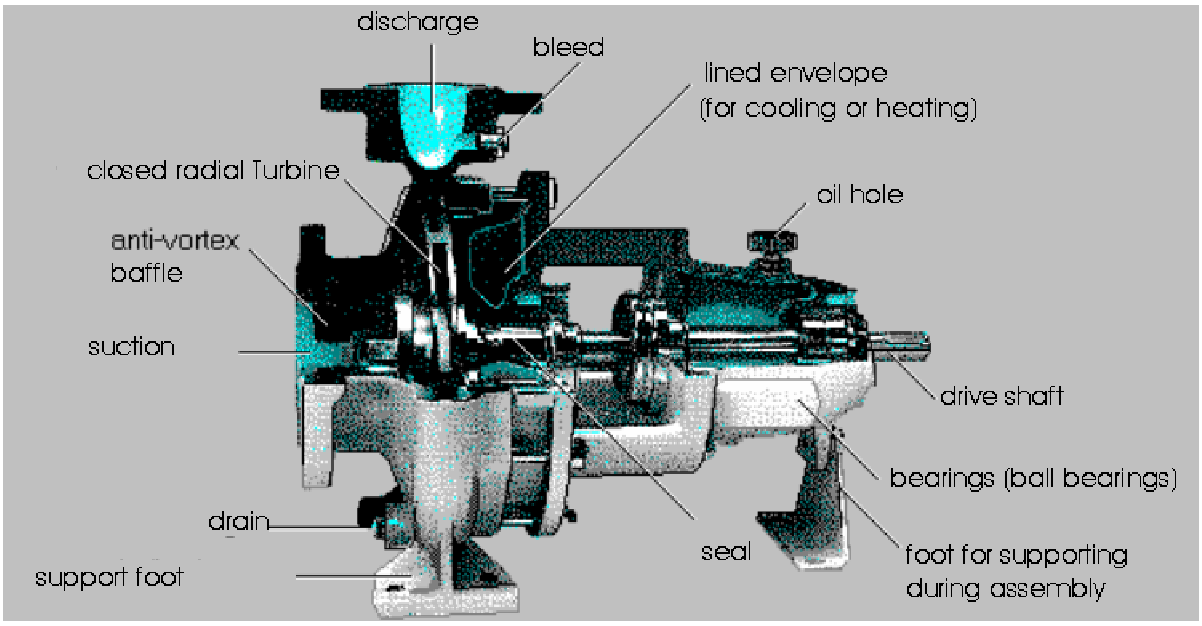


Figure 57: Cutaway view of a single-impeller pump

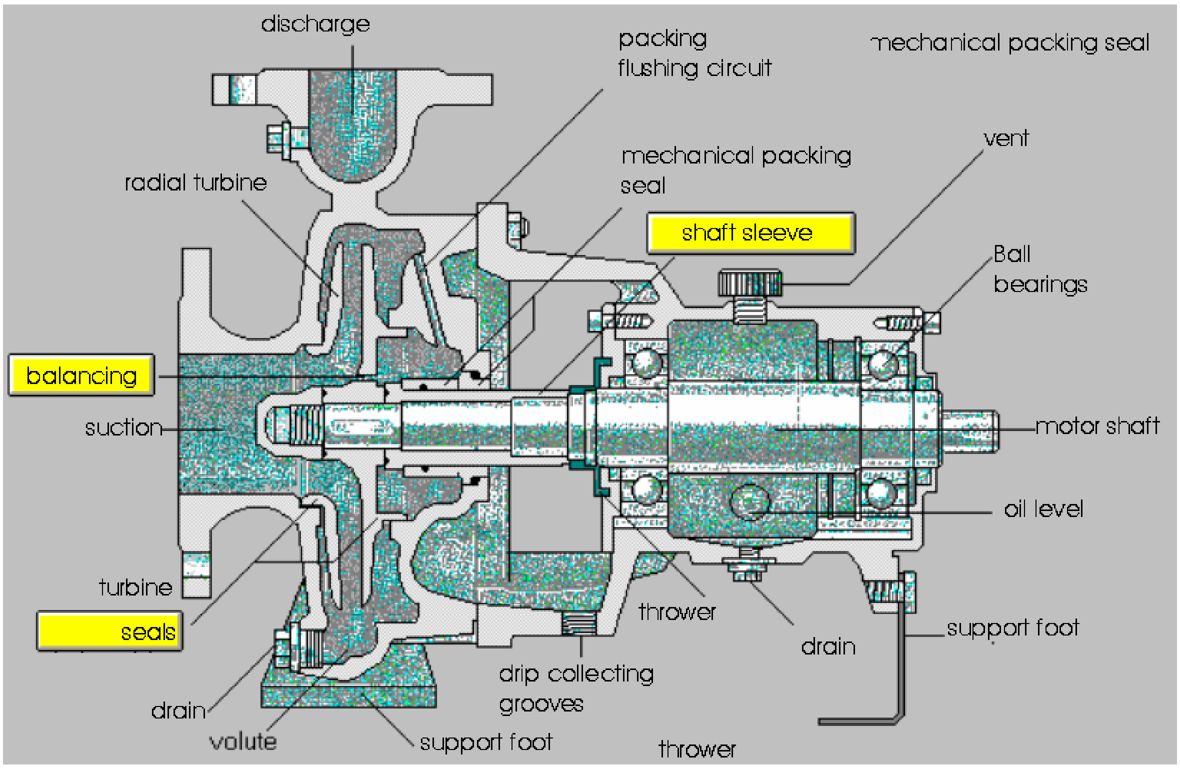


Figure 58: Cross sectional view of a single-impeller pump (1)

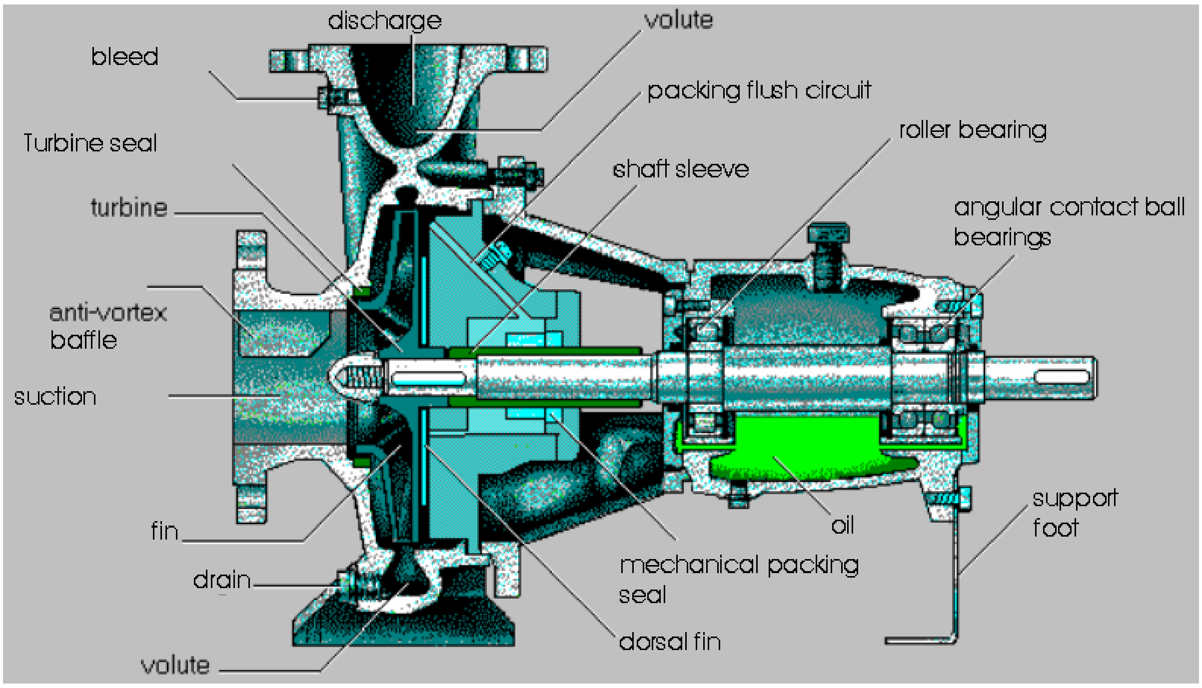


Figure 59: Cross sectional view of a single-impeller pump (2)

In this view, the distribution of the thrusts on the turbine is obtained by blades positioned at the back that also decrease the pressure of the liquid on the packing.

3.1.2.2. TT (Top-branches) type "Process" pumps

The suction and discharge branches of these pumps are vertically mounted with the flanges in the same horizontal plane

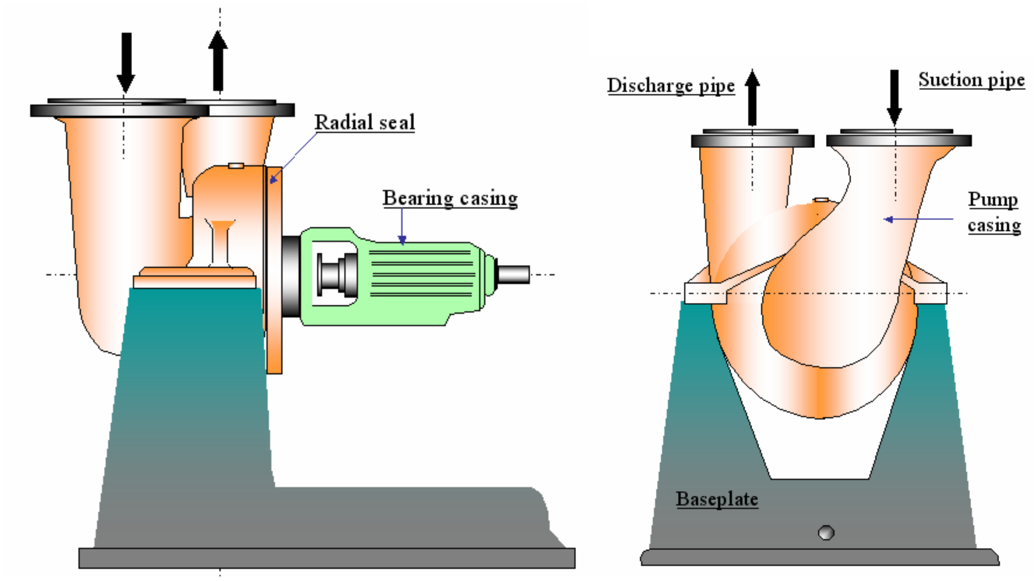


Figure 60: TT process pump, overhung wheel

These pumps may be equipped with:

- **Only one overhung wheel**.

Radial plane disassembly is performed as for AA process pumps. Dual wheel models also exist (Dual suction eye wheel)

Some TT process pumps are also equipped with **dual overhung wheels** and 2 radial sealing surfaces

Figure 61: Process pump, only one overhung wheel

- **Dual wheels** positioned between two main bearings.

The pump has 2 radial sealing surfaces. These pumps are used for **common flowrates** (100-400 m^3/hr) or **high flowrates** (2000 m^3/hr – transport pump) and for **average elevation heads**.

Their installation is convenient in a unit, where their vertical branches easily match with the downward connections of a pipe rack.

Figure 62: TT process pump, dual wheels between main bearings

3.1.2.3. Foot-mounted pumps

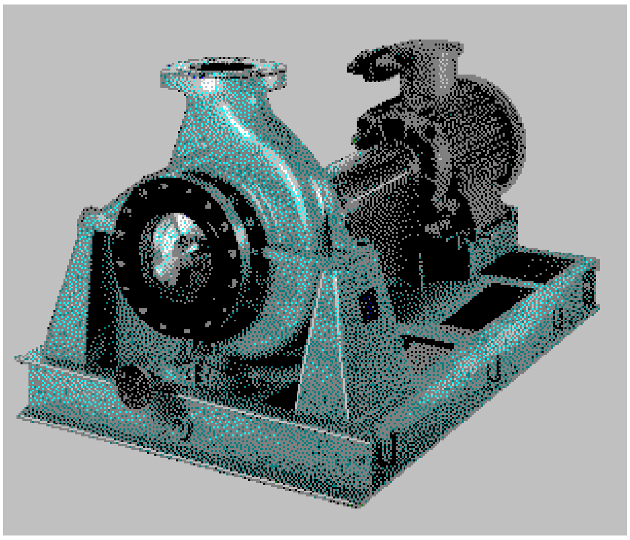


Figure 63: External view of a foot-mounted pump

These pumps are reliably and carefully designed for use in continuous rough working conditions and can work without failure at 25 bars and 450°C.

In cases of high temperatures, the pump will expand, but the rotation axis will not be displaced.

They often have a special split volute, which allows them to be less sensitive to the working conditions.

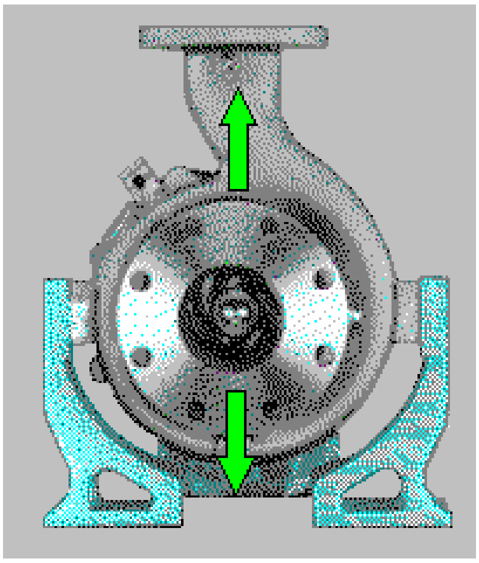


Figure 64: Expansion of the pump

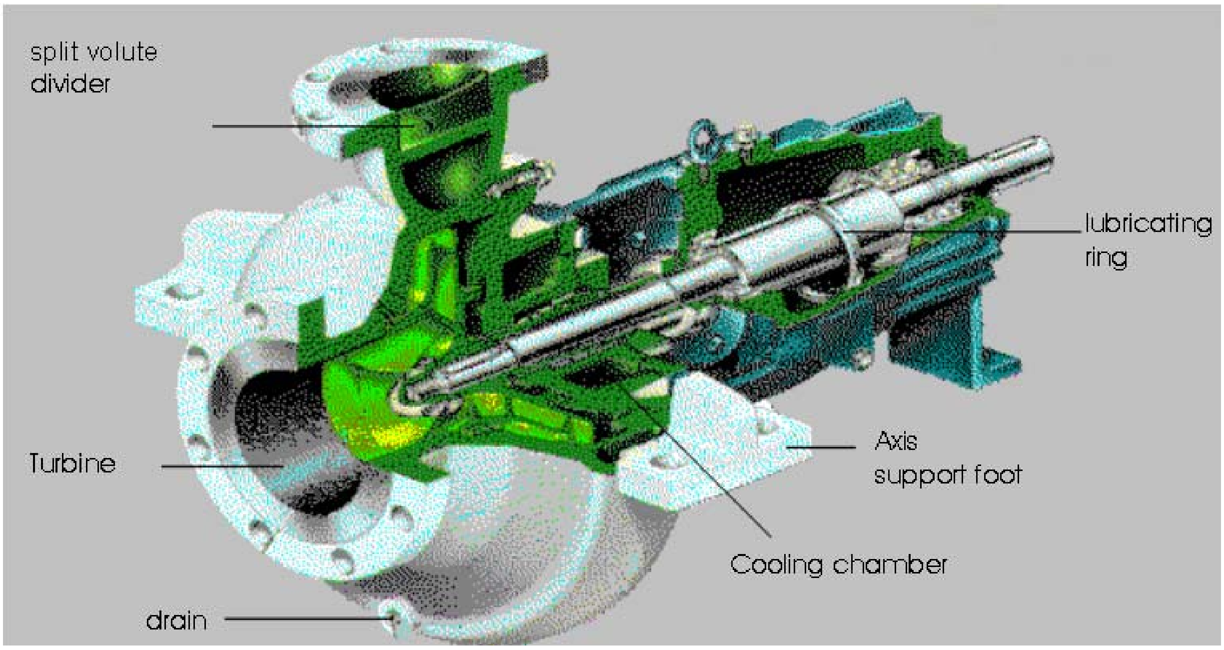


Figure 65: External view of a foot-mounted pump

3.1.2.4. Bearing pedestal pumps

Seal flushing (also termed quenching): liquid is removed from the high pressure area of the turbine to perform liquid scavenging, or "flushing" which lubricates, cools and cleans the seal.

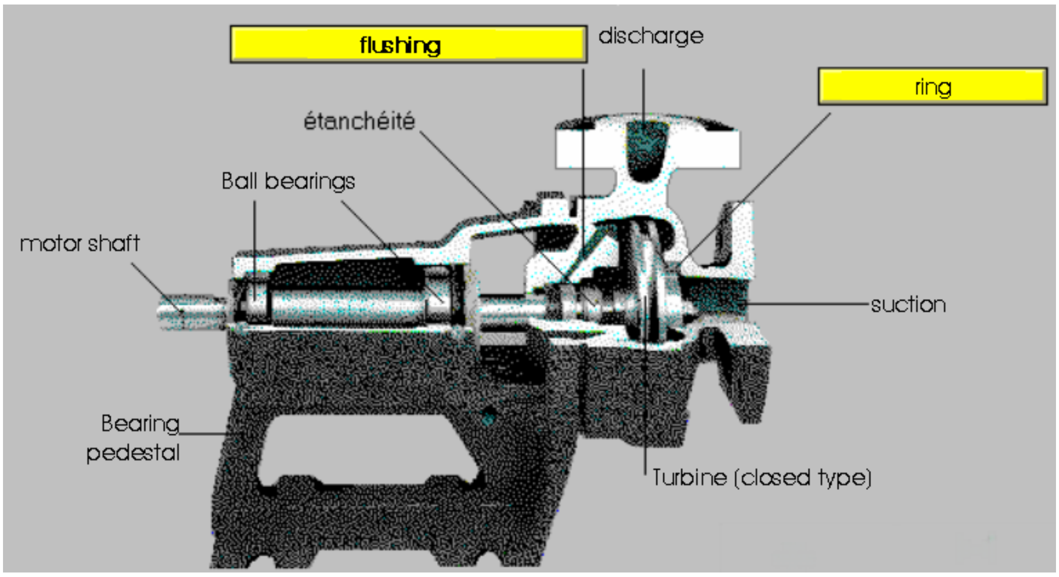
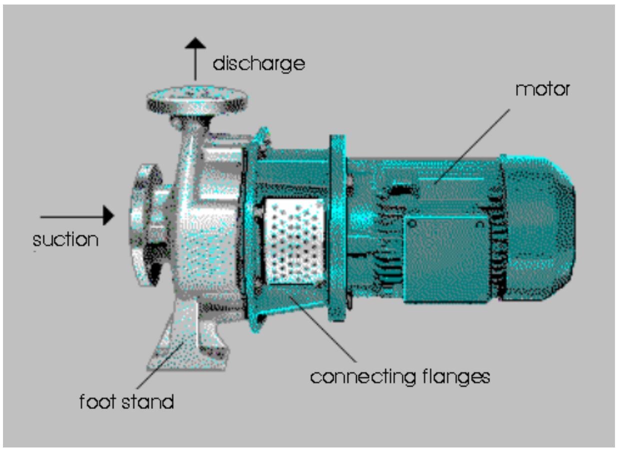


Figure 66: Cutaway view of a bearing pedestal pump

The removable wear ring is a seal that limits the internal re-circulation between the high pressure section and the suction

3.1.2.5. One-piece pumps

The "one-piece" pumps, including "in-line" pumps and "immersed (or plunger)" pumps, are pumps whose motor is directly positioned on the pump casing. The motor alignment depends only on the precision machining.



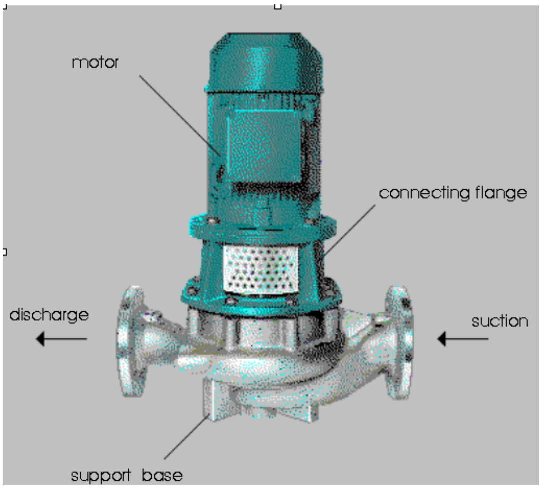
The assembly is only installed on the ground by means of the pump barrel feet. As the pedestal no longer has a guidance function, it is very simplified. For small size "in-line" mounted pumps, it may even be sometimes replaced with the piping itself which thus act as a support.

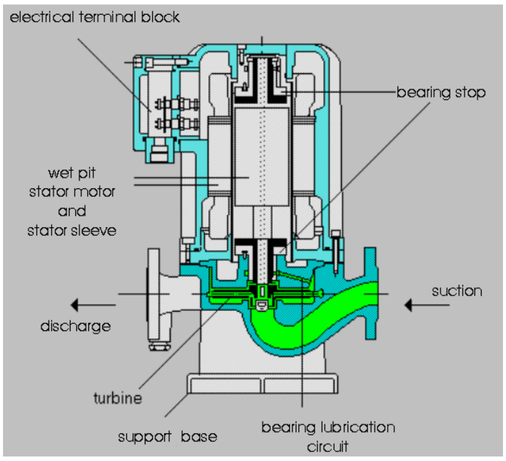
Figure 67: External view of a one-piece pump

3.1.2.6. "In-line" pumps

The name of this pump is due to the alignment of the suction flange and the discharge flange: the pump can be in-line mounted in the piping. The pump is so-called one–piece; i.e. it directly acts as a support for the motor.
For small powers installed, it is often the piping which supports the pump.

Figure 68: External view of a one-piece pump

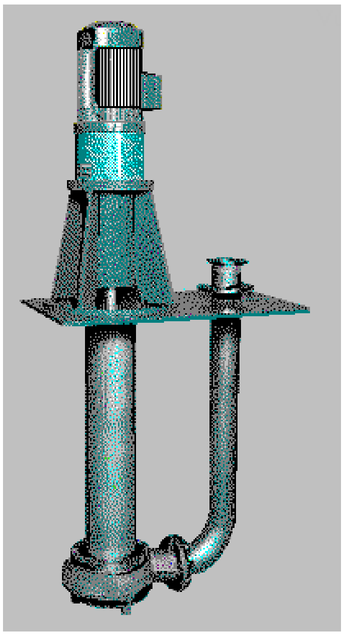




As for any traditional centrifugal pump, suction takes place at the centre of the turbine. The only particularity is that here, the suction branch includes a cast elbow in the pump barrel. The cross section shows a "wet pit" system which will be described in the seal part.

Figure 69: Cross section of an "in-line" pump

3.1.2.7. Vertical pumps

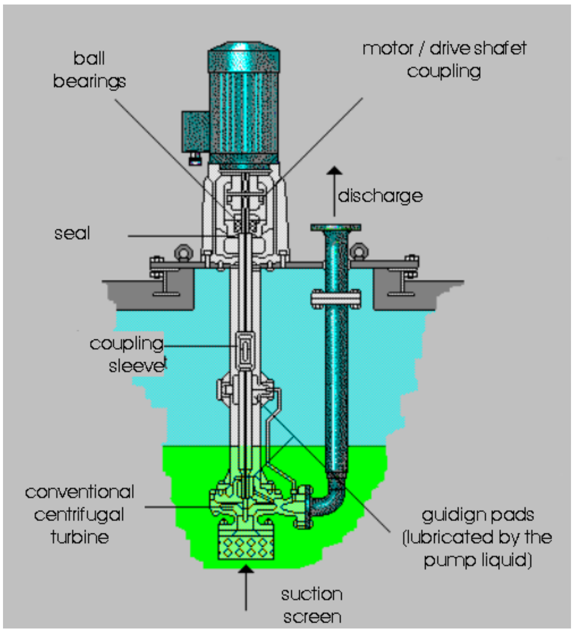


This type of pump is used for emptying pits or buried tanks, when an immersed pump cannot be used.

The significant axis length is a problem, therefore it must be guided step by step to prevent it from swinging.

The weight of the assembly in rotation is supported by ball or roller bearings located under the electric motor.
With this pump, there is no sealing system for the product.

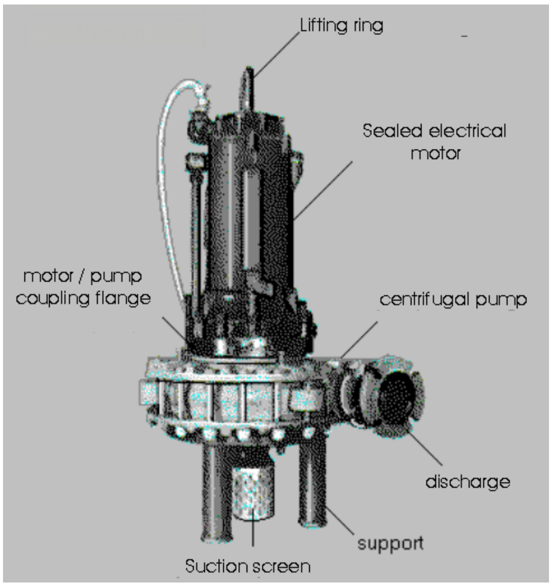
Figure 70: External view of a vertical pump



Bearings are positioned away from the liquid. Seals protect them from water, dust, fumes and the liquid.

Figure 71: Cross sectional view of a vertical pump

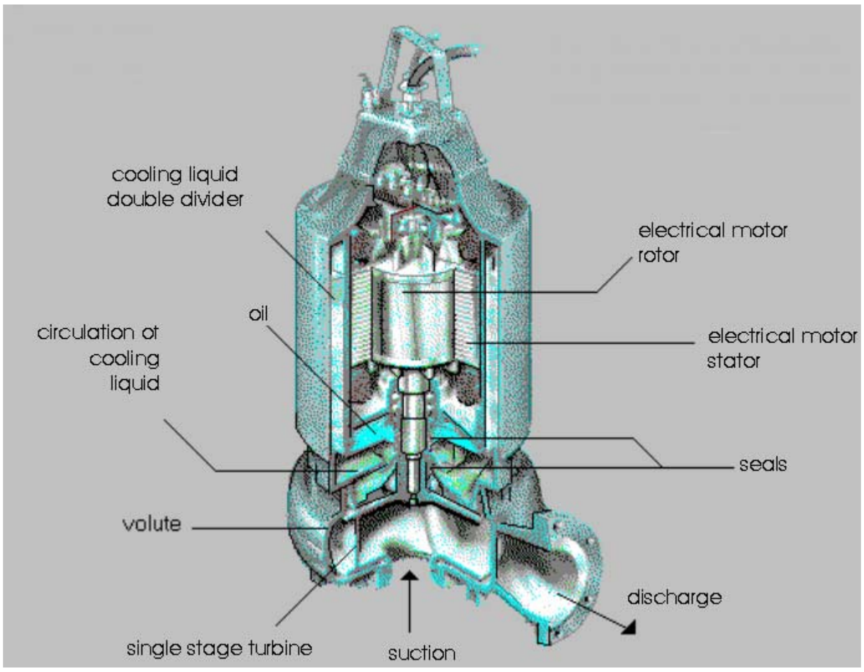
3.1.2.8. "Immersed" pumps



Immersed or submersible pumps, are traditional centrifugal pumps with a one-piece design, i.e. whose motor is directly supported by the pump barrel. It is generally vertical mounted.

The assembly is designed to operate immersed in the pumped liquid. The motor is therefore sealed. Its cooling is provided with circulation of an auxiliary liquid or pumped liquid.

Figure 72: External view of an immersed pump



Humidity sensors are installed in the motor as well as in the oil tank.

An ingenious guide rail system is used to automatically position and remove the pump from its support placed at the bottom of the pit.

Figure 73: Cutaway view of an immersed pump

The immersed pump can therefore be removed without having to go down into the pit, nor even to drain it beforehand, which particularly facilitates maintenance operations.

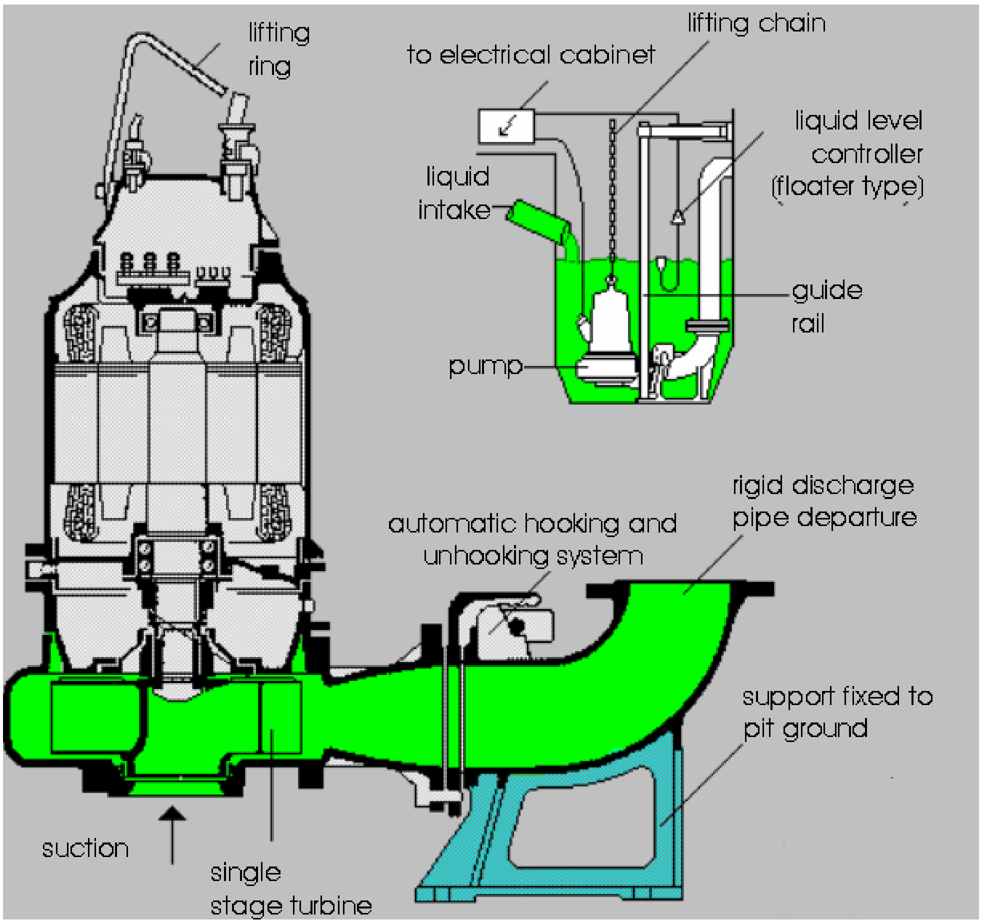


Figure 74: Immersed pump positioning system

3.1.2.9. Non-metallic pumps

- **Graphite**
  The pump barrel is made of saturated graphite to eliminate porosity.

  The turbine is made of polyvinylidene fluoride and polypropylene.
  Rigidity of the pump barrel is ensured by a metallic casing (Carbon is resistant to 170°C)

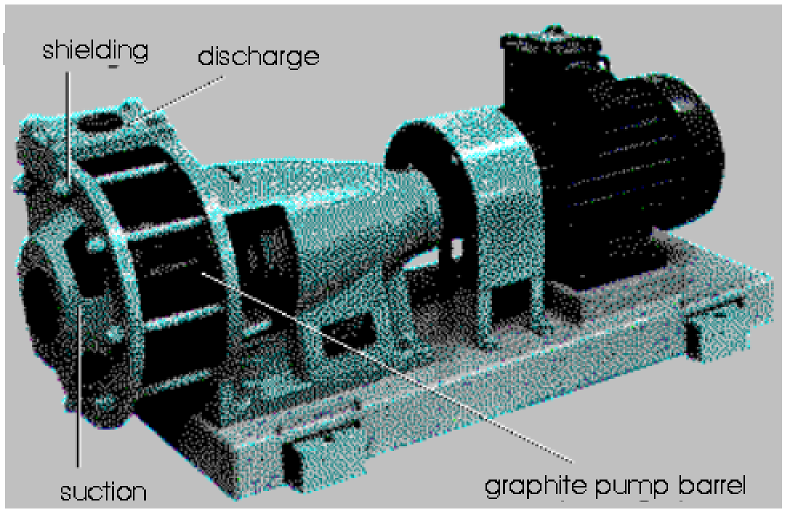
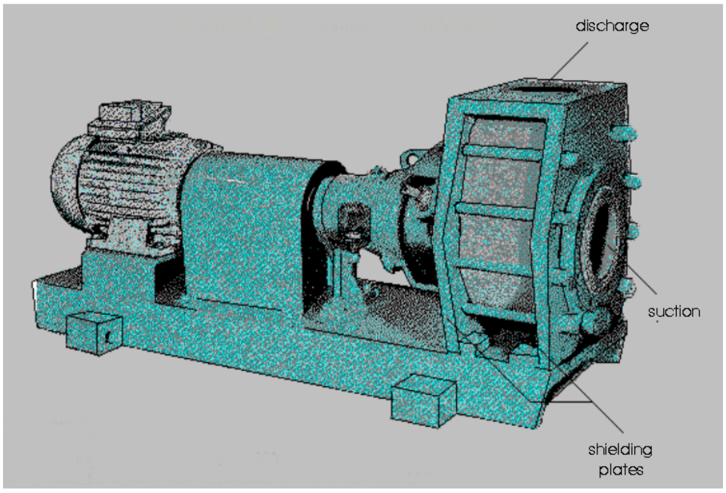


Figure 75: Graphite pump

- **Plastic**



The materials used are:

- Polyethylene: P.E. to 80°C
- Polypropylene: PPH to 90°C
- Polytetrafluoroethylene (or Teflon): to 120°C
- Polyvinylidene fluoride: PVDF up to 150°C

Figure 76: Plastic pump

Special attention must be paid to cooling the sealing device as plastics do virtually not dissipate the heat.

- **Coated**

  This is a process-type pump, but all the parts in contact with the pumped liquid are made of plastic material, either solid as for the turbine or very thick as for the cylinder or back end of the pump.

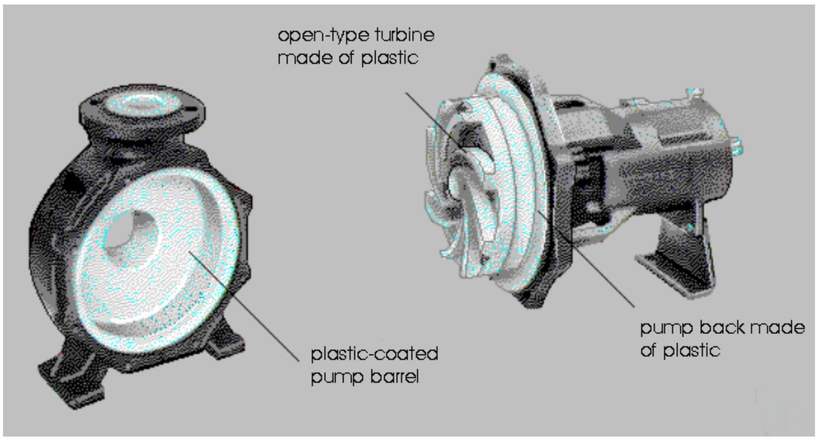


Figure 77: Coated pump

3.1.2.10. Multi-stage high pressure pumps

The high pressure pumps consist of stages arranged in series. Each stage corresponds to an elementary centrifugal pump, i.e., a turbine rotating in a volute or a diffuser.

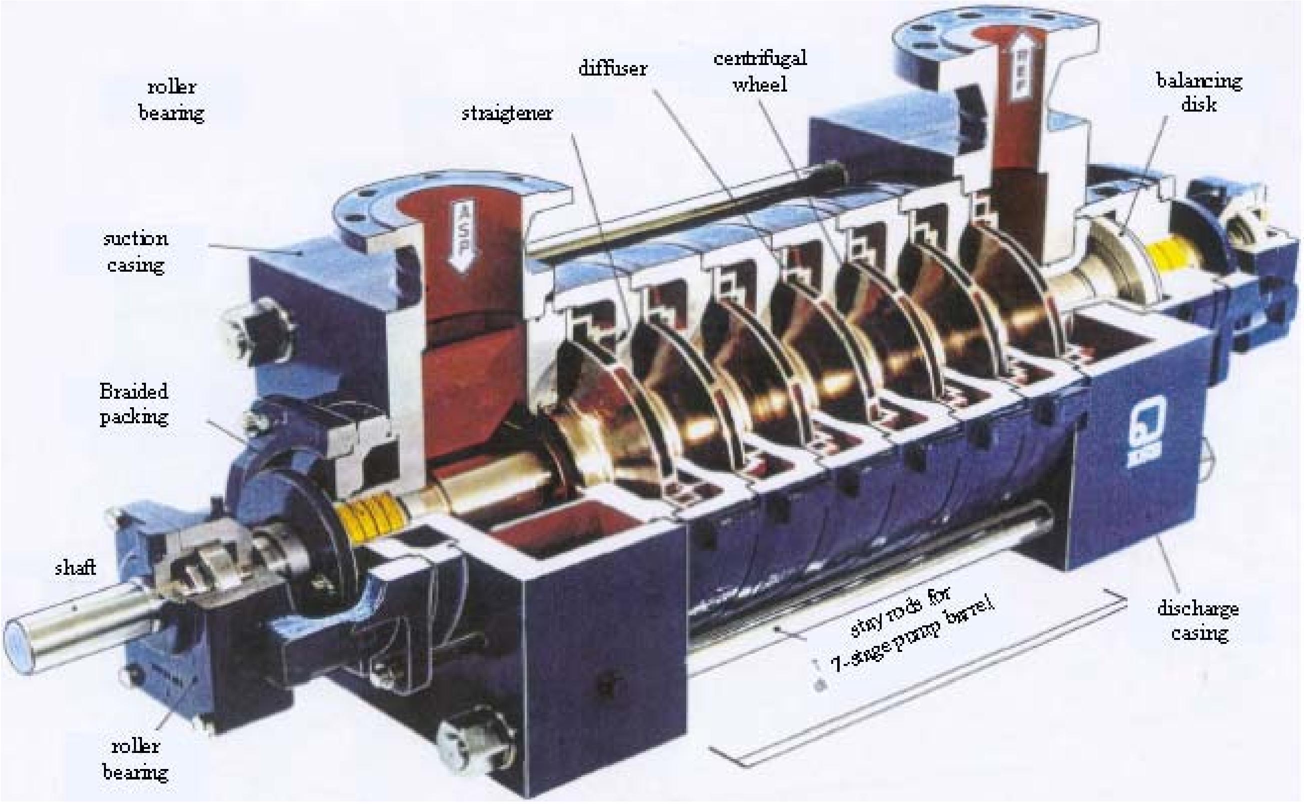


Figure 78: Cutaway view of a multi-stage pump

About twenty stages can therefore be assembled, thereby exceeding a discharge pressure of 400 bars for a rate of 1 000 m^3/hr.

A piston or a balance disk recover all the axial thrusts.
The radial thrusts are balanced by the symmetry of the diffusers.

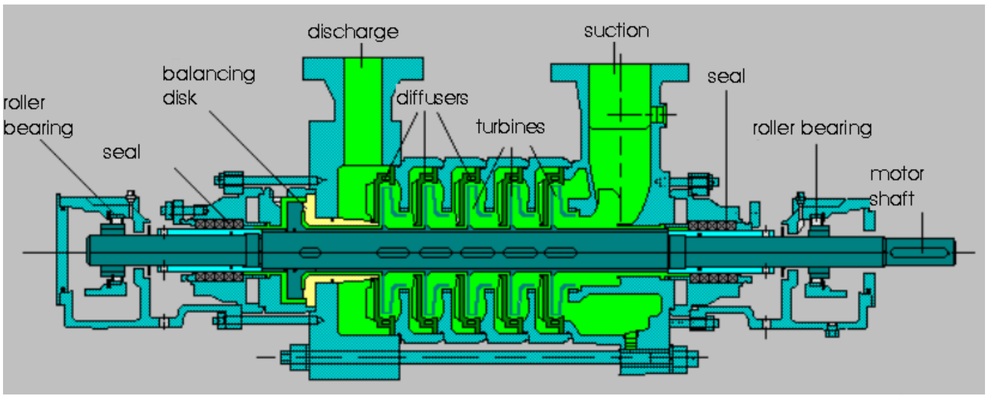


Figure 79: Cross sectional view of a multi-stage pump

3.1.2.11. Well pumps

Well pumps or boring pumps are generally used for retrieving seawater, ground water or river water. They are also used for the pumping hydrocarbons. The maximum depth is limited to 120 metres, mainly due to the length of the drive shaft.
Beyond that, "immersed electric pumps" or immersed pumps that can discharge at 120 metres are used.

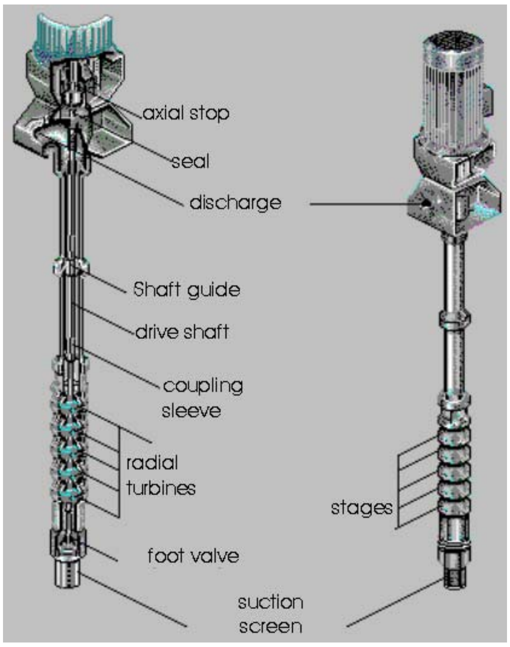
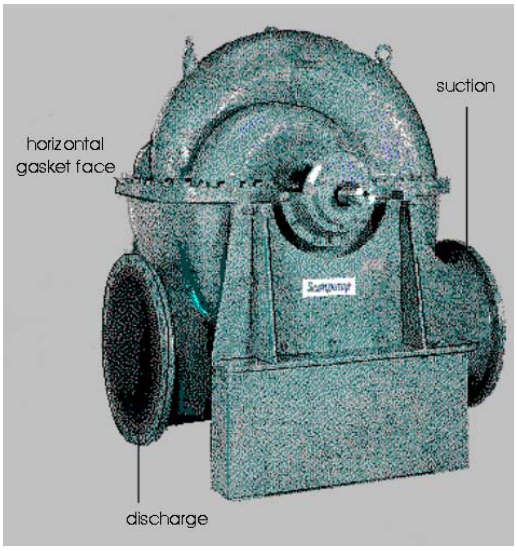


Figure 80: Cutaway and external views of a well pump

3.1.2.12. "Double flow" pumps



Double flow pumps often have a horizontal sealing surface. They are used for very high flowrates at moderate pressures.
Their required **NPSH** is very low. The turbine consists of 2 traditional radial turbines, assembled back to back. Therefore, there is suction from each side.

Figure 81: External view of a double flow pump

The two suctions are joined on a single flange: mounting is "in-line".

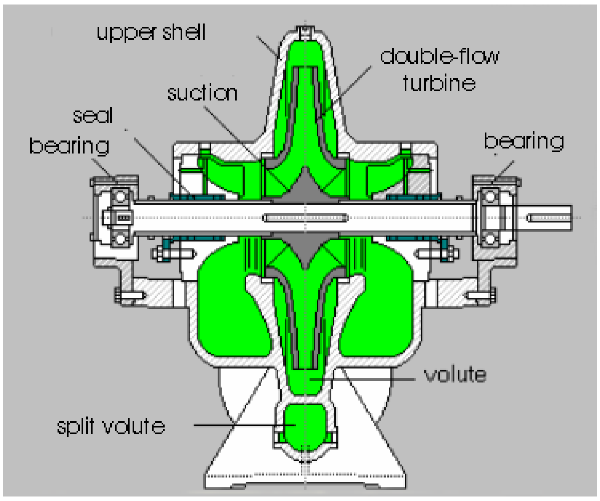
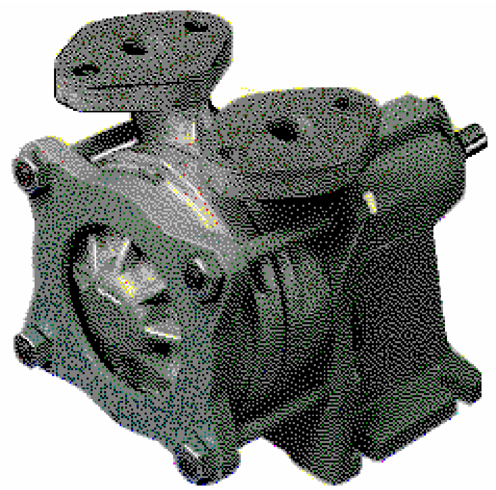


Figure 82: Cutaway and external views of a double flow pump

3.1.2.13. "Side channel" pumps

Side channel pumps are often called "self-priming". In fact, they are centrifugal pumps that do not dry up if it sucks a gas and liquid mixture.



Side channel pumps are capable of very high TMH, but the flowrates are poor. They are very sensitive to wear so the rotation speed is limited to 1 450 rpm and slurry or abrasive liquids are banned. They have a very low resistance to cavitation and have a rather high NPSH requirement.

They are nearly always positioned horizontally and must be started up with discharge and suction valves entirely open.

Figure 83: External view of a side channel pump

A check valve installed at the discharge will avoid problems of rotation in the wrong direction when stopped.

The two characteristic elements of a side channel pump are:

- An open turbine with radial blades
- A cylinder including the "side channel", a suction eye, a discharge eye, an auxiliary channel and an auxiliary discharge eye.

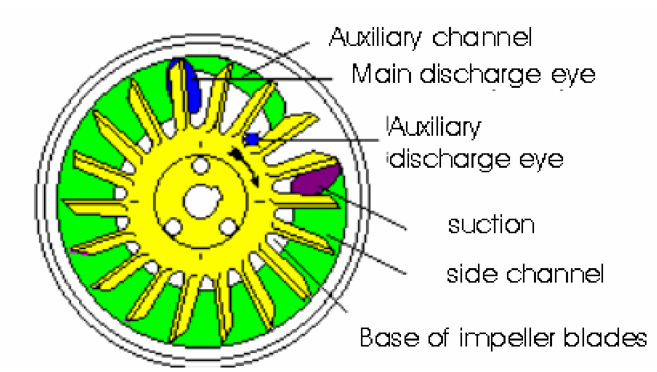


Figure 84: Characteristic elements of a side channel pump

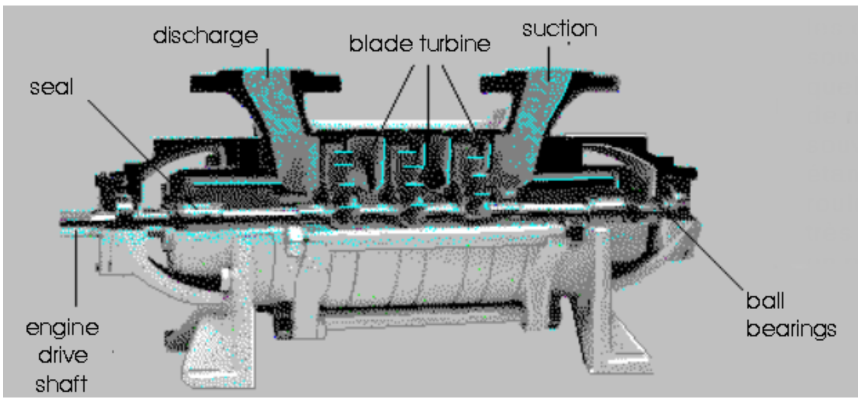


Figure 85: Cutaway view of a multi-stage side channel pump

Side channel pumps are often multi-stage pumps in order to obtain very high TMHs (hundreds of metres)

Very often, the seals and the bearings have a very easy access. They can be changed without complete disassembly of the pump.

Centrifugal pumps can have a very low NPSH requirement, but are subject to drying up if the pumped liquid contains gas bubbles. Side channel pumps have exactly the opposite properties.

"Low NPSH" side channel pumps therefore use a traditional centrifugal turbine installed ahead radial blade turbines.
Therefore it offers the combined characteristics of resistance to cavitation and to drying up.

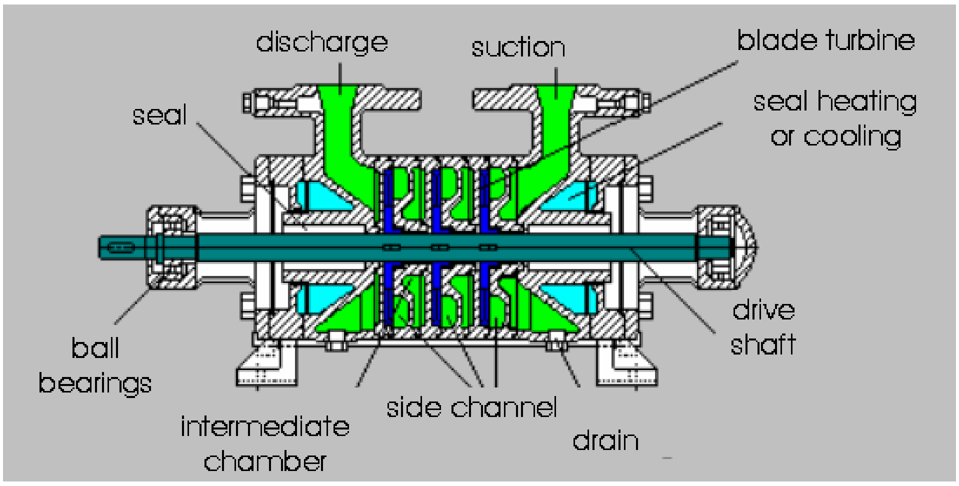
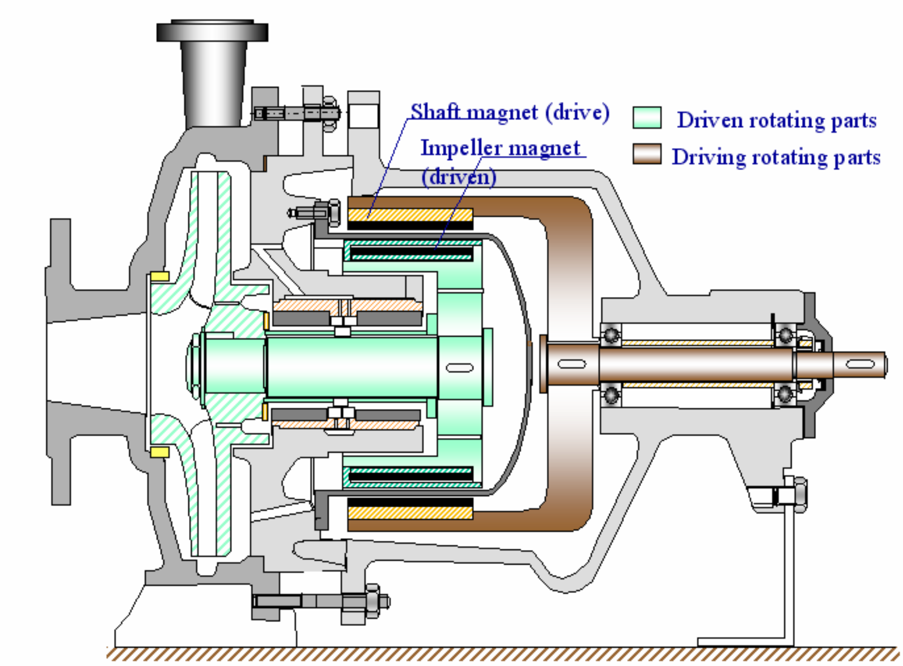


Figure 86: Cross sectional view of a multi-stage side channel pump

3.1.2.14. Magnetic drive pump

Pumping toxic products (e.g. benzene) is a delicate operation due to the *risk of emission into the atmosphere* at the drive shaft passage. This is always a possibility, whatever type of packing is installed. The solution to this problem is *magnetic drive*.

The pumped fluid lubricates the shaft that holds the wheel.



Consequently these pumps cannot *run without liquid* or run dry (as the shaft may seize up)

Their elevation head is limited to 100 metres, and their flowrate is limited to 100 m^3/hr

Figure 87: Cross section of a magnetic drive pump

3.2. POSITIVE DISPLACEMENT PUMPS

3.2.1. Displacement pump technology

Displacement pumps consist of an air-tight enclosed volume (pump barrel) with a moving element inside which alternately increases and decreases the volume of the chambers as it moves. The movement is cyclic: a given volume of liquid is sucked in at the beginning and is discharged at the end. This volume corresponds to the pump displacement.

Once started, displacement pumps cause an upstream pressure drop which causes the liquid suction: They are called “self-priming”.

Displacement pumps allow much higher TMHs than those of centrifugal pumps.

The discharge pressure is therefore higher.

On the other hand, the flowrate is generally lower, but it virtually does not depend on the network characteristics.

The efficiency of this type of pump is often very close to 90%.

If the discharge line is plugged, the displacement pump must immediately be stopped so as to avoid the risk of a significant pressure increase in the pump, which would cause serious damage.

If the valves on the discharge circuit can be closed, a safety device must be installed at pump discharge. A bypass fitted with a safety valve and linked to the suction tank is a good solution.

The flowrate is adjusted by acting on the rotor rotation speed for rotary pumps and on the piston frequency or stroke for reciprocating pumps.

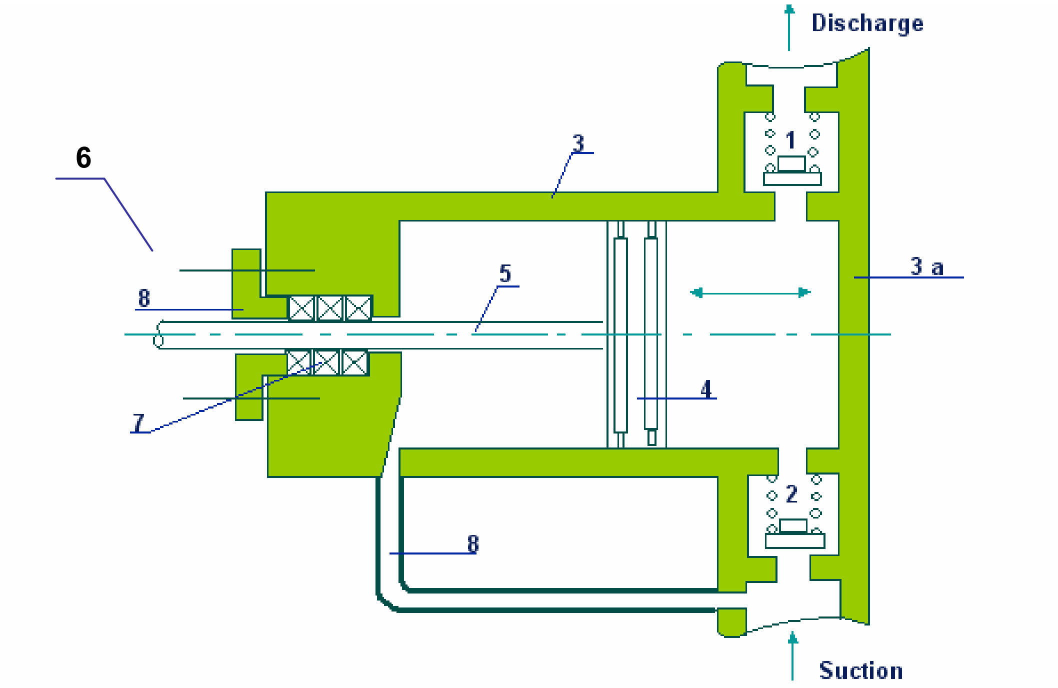
The use of a regulating valve on the discharge circuit is of course excluded.

All the different types of displacement pumps for liquids available on the market are based two operating principles:

- Reciprocating displacement pumps (e.g. for pumping chemical products such as demulsifiers or antifoam)
- Rotary displacement pumps (with a fixed displacement) (e.g. flare drum pumps for condensate recovery)

3.2.2. Details of reciprocating displacement pumps

3.2.2.1. Single-actings reciprocating pump



1. Discharge valve
2. Suction valve
3. Pump barrel - 3 a – end of pump barrel
4. Piston
5. Piston rod
6. Packing box gland
7. Braided packing
8. Recovery line.

Figure 88: Single-acting reciprocating pump

Operating principle

1. The piston is driven towards the gland (6-7) – the pressure in chamber A decreases:
   - closure of the discharge valve1,
   - opening of the suction valve 2,
   - the liquid fills the pump barrel.

2. The piston is pushed back to the bottom of the pump barrel (3a) – the pressure in chamber A increases:
   - closing of the suction valve 2,
   - opening of the discharge valve1,
   - the liquid is discharged to the outside.

For a complete displacement of the piston (a round trip) just one stroke develops the pressure, with the piston stroke at the end of the pump barrel, which is why it is called a "Single-acting reciprocating pump" .

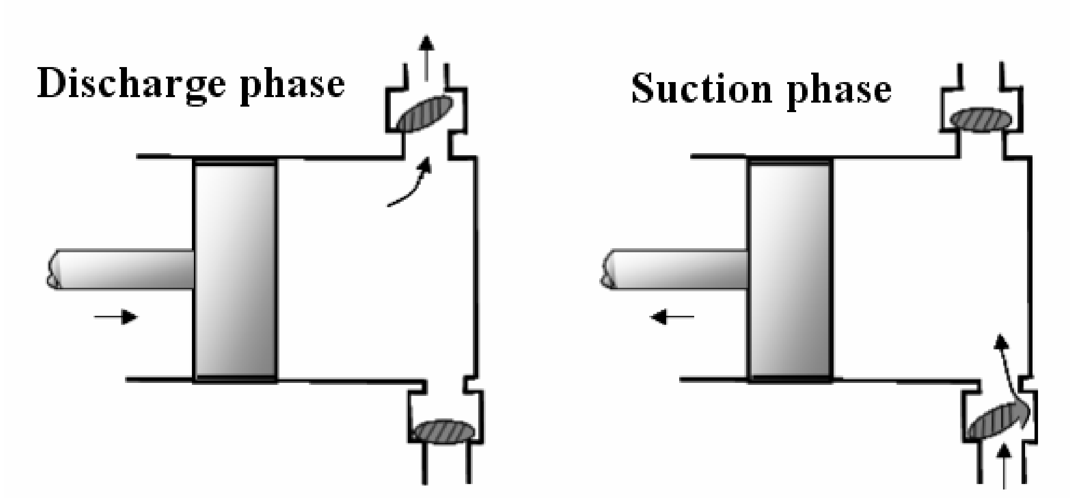


Figure 89: Piston pump principle

Taking this operation into account, the pump only discharges the liquid for half the cycle and, consequently, the flowrate is not constant in the time, but is pulsating. If the mean flowrate per hour is Q_m, then the maximum instantaneous discharge rate is 3.14 Q_m (see diagram above).

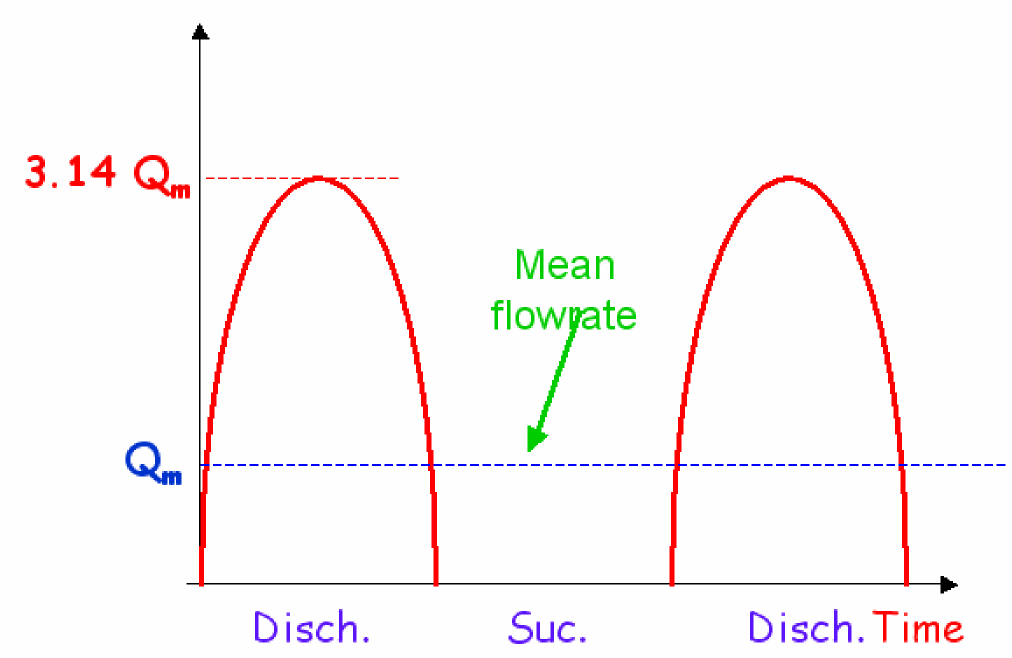


Figure 90: Flowrate vs. time for a single-acting reciprocating pump

3.2.2.2. Double-acting reciprocating pump

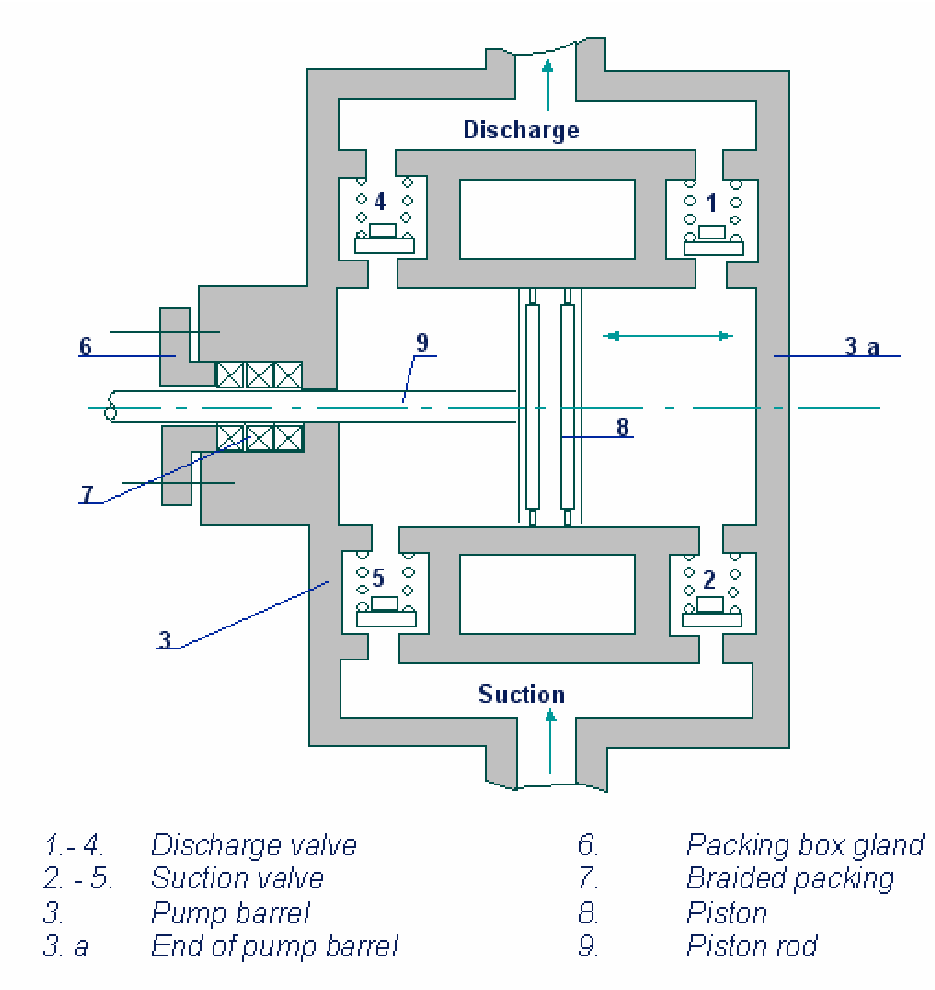


Figure 91: Double-acting reciprocating pump

Operating principle

1. The piston is driven towards the gland (6-7):
   - closure of the discharge valve1
   - closure of the suction valve 5
   - opening of the suction valve 2
   - opening of the discharge valve 4

2. The liquid fills the pump barrel at the bottom end (3a) and the liquid is discharged at the port end (valve 4).

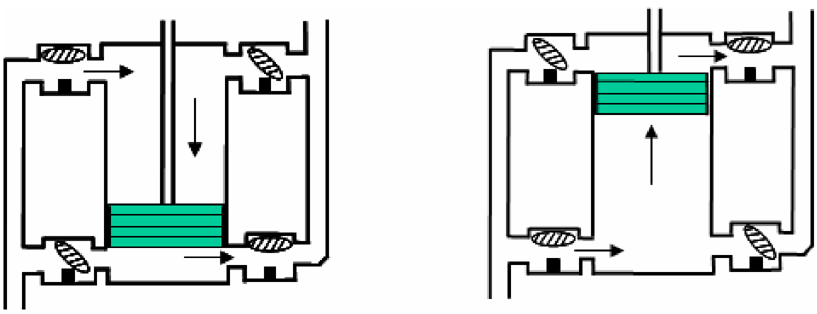
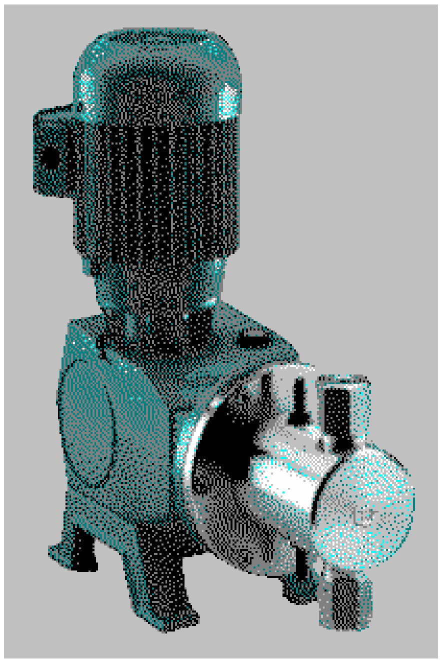


Figure 92: Double acting reciprocating pump principle

3.2.2.3. Metering reciprocating pump

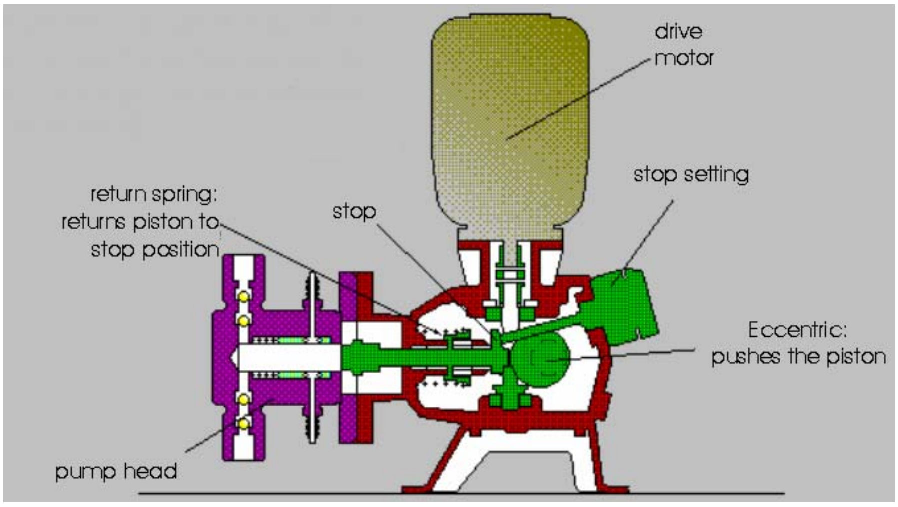


The piston is adjusted by acting on the stop lead.

This governs the volume of liquid discharged.

- Flowrate: up to 6 m^3/hr
- Pressure: up to 500 bars
- Viscosity: up to 30,0000 centipoise
- Temperature: up to 150°C

Figure 93: External view of a metering pump



- All liquids, depending on materials which compose the pump
- Metering accuracy : around 1%

Figure 94: Cross section of a metering pump

- Self-priming: up to 4m (for water)
- May be immersed.
- Safety: a relief valve must be installed on the discharge

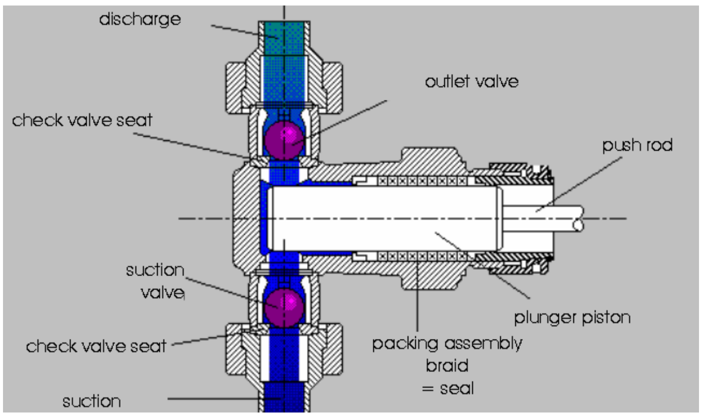


Figure 95: Detailed view of the pump head

3.2.2.4. Air-operated reciprocating pump

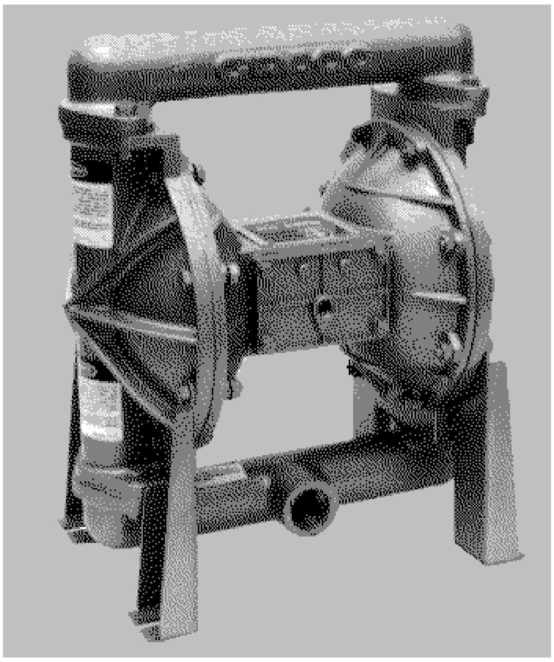


Figure 96: Air-operated reciprocating pump

Operating principle:

the **diaphragms** are alternately pushed by the compressed air from a pneumatic regulator.

When one diaphragm is pushed, it pushes on the liquid and it brings back the other diaphragm using a control rod.

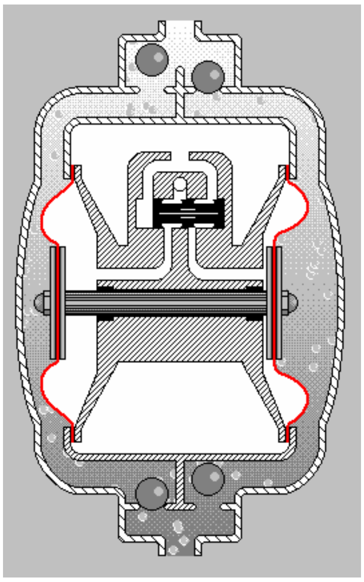


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Figure 97: Diaphragms

The **control rod** connects the two carriers of the diaphragm.

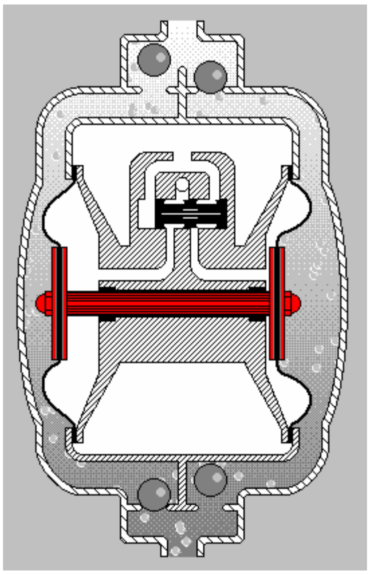
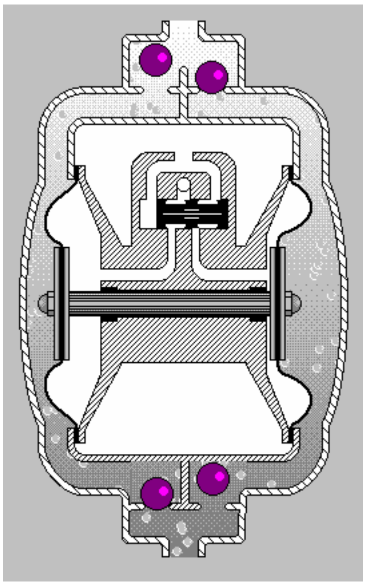


Figure 98: Control rod

It allows one diaphragm to work under suction while the other works under discharge.
This type of operation is called "double acting".



The **valves** are balls, or flaps which return by their own weight. It is therefore essential to respect the pump operating position so that the valves can close themselves by gravity.

Figure 99: Valves

The **regulator** alternately directs the compressed air to the rear of one diaphragm whilst the other is vented.

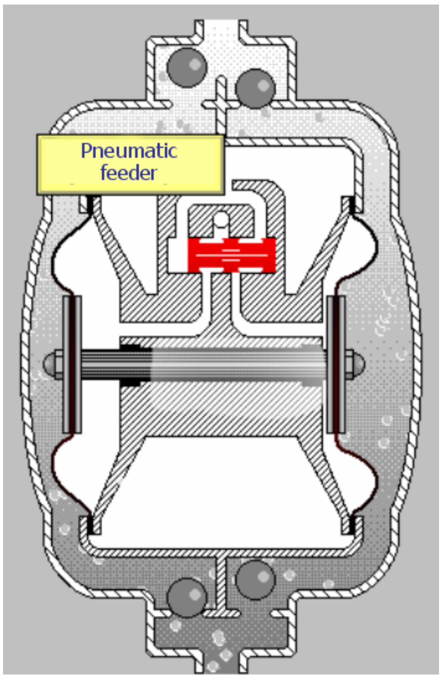
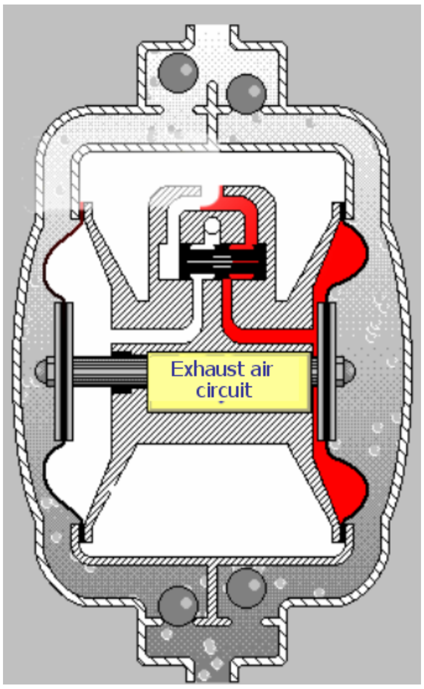


Figure 100: Regulator



The waste air is vented into the atmosphere across a **silencer** so that noise level is less than 76 dBA.

Figure 101: Waste air flow

The compressed air is carried to the rear of a diaphragm which is then pushed and thus discharges the liquid.

If the pressure in the discharged liquid reaches the same pressure as the compressed air, the pump automatically stops. The pump will only restart if the pressure of the liquid is lower than that of the compressed air.

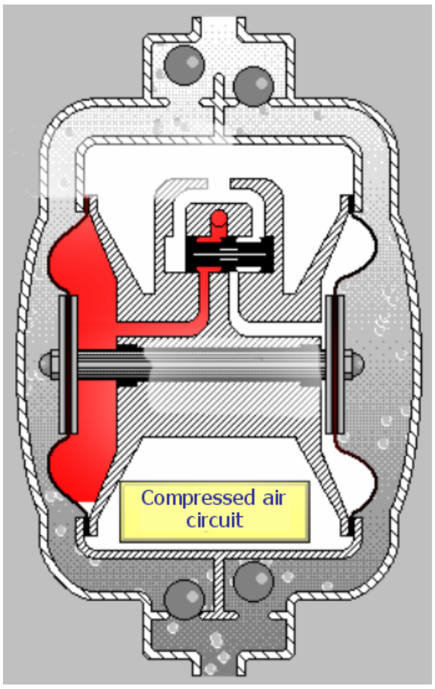


Figure 102: Compressed air circuit

Field of use:

- Flowrate: up to 60 m^3/hr
- Pressure: up to 10 bars
- Viscosity: up to 20,000 centipoise
- Temperature: up to 100°C
- Liquids: particles up to 6mm (acids, compounds, solvents, oils, water)
- Explosion-proof: control by compressed air
- Self-priming: dry up to 4m; 7m in cold water
- Can be immersed and can work dry
- Safety: the liquid pressure cannot exceed the compressed air pressure

3.2.2.5. Single-acting pitcher pump

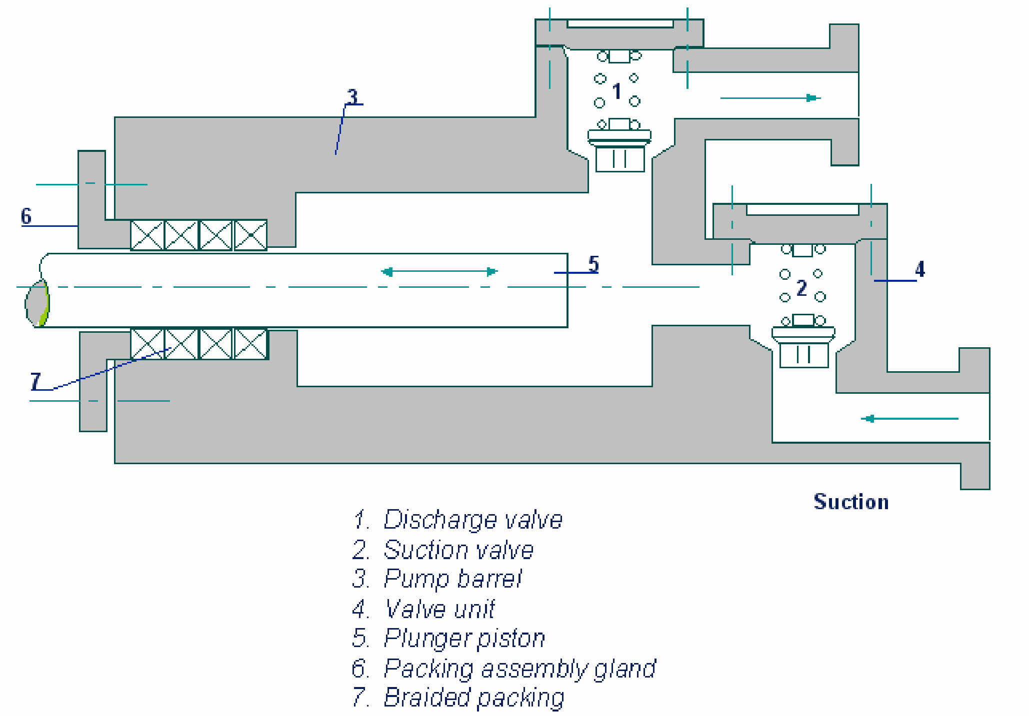


Figure 103: Single acting pitcher pump

Operating principle

Identical to the single-acting reciprocating pump

Advantages

- No piston ring
- Allows very high pressures of several hundred bars to be obtained.

3.2.2.6. Diaphragm pump

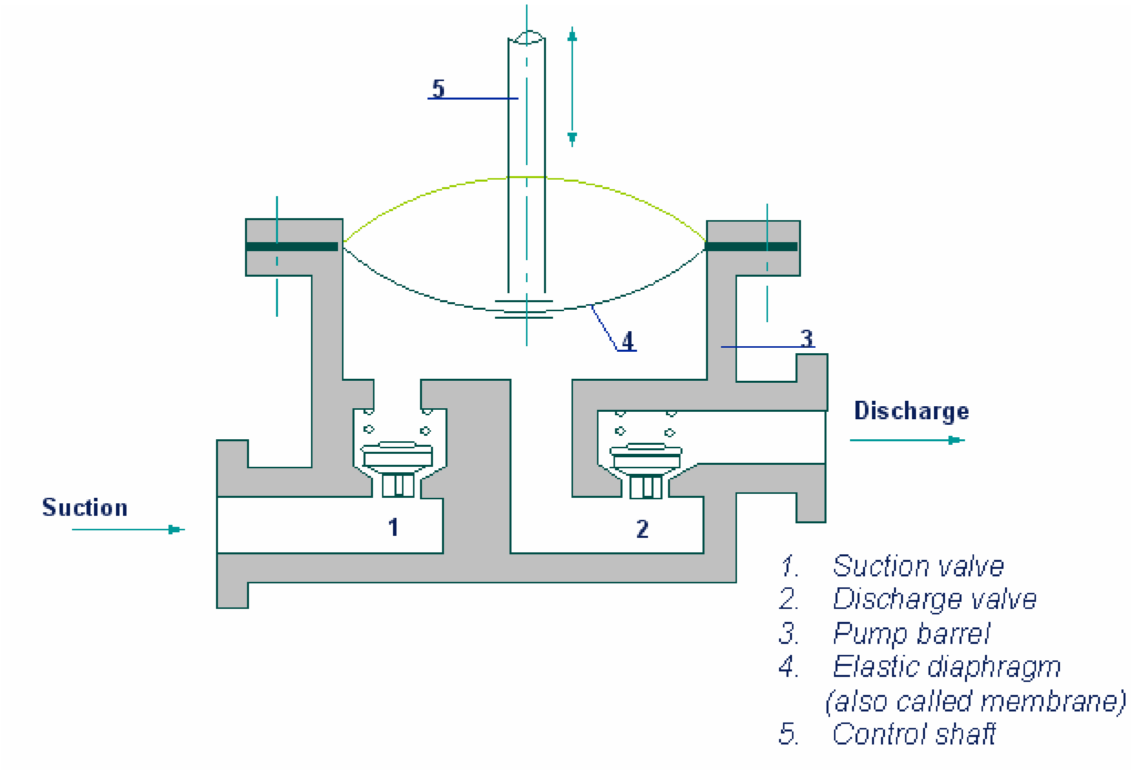


Figure 104: Diaphragm pump

Operating principle

Identical to a single-acting reciprocating pump.

For this type of pump, the piston is replaced by a soft diaphragm which may be distorted, which under the alternating action of a control rod creates a volume variation.

1. As the rod moves upwards

- closure of the discharge valve,
- opening of the suction valve,
- the pump barrel fills with liquid.

2. As the rod moves downwards

- closure of the suction valve,
- opening of the discharge valve,
- the liquid is forced towards the outside of the pump barrel.

Theoretical discharge

Equal to the volume created by the distortion of the diaphragm.

3.2.3. Details of the rotary displacement pumps

3.2.3.1. Vane pumps

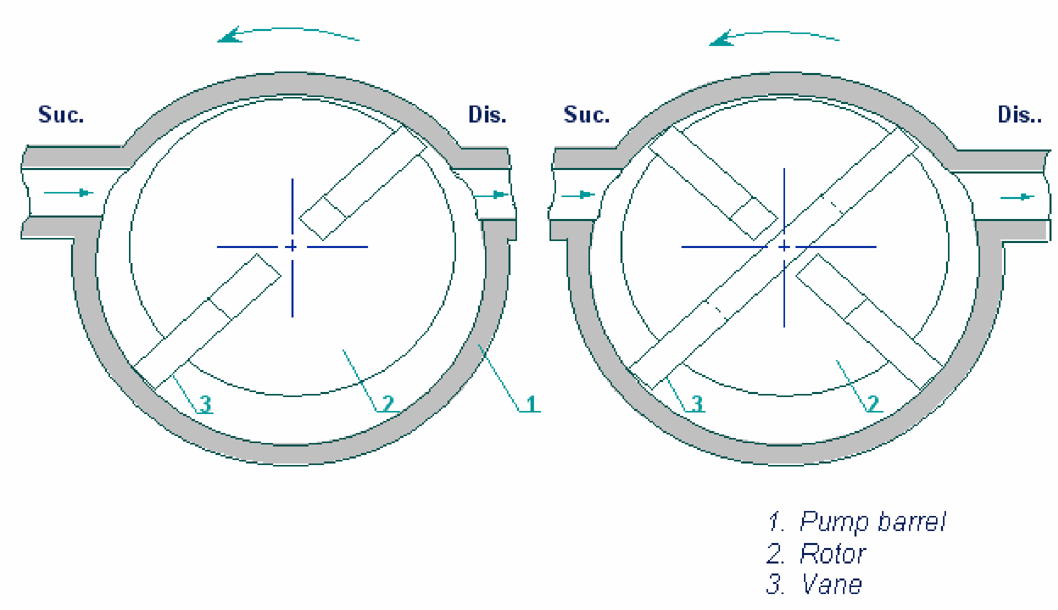


Figure 105: Vane pump

Operating principle

In a circular pump barrel with two openings (suction and discharge), a rotor turns whose diameter is tangential to the pump barrel, it is located in the middle of the two lights.

This rotor has vanes embedded in slots (the number varies according to the type of pump) which move thereby trapping the product to be pumped.

Under the combined action of:

- the centrifugal force,
- possible springs,
- pump barrel rotor offset.

The vanes rub on the pump barrel causing volume variations which generate suction and discharge.

This type of device is used either for liquid transfers or for obtaining high vacuum.

The design of the vane pump, vane compressor or vane engine is more or less the same.

3.2.3.2. Gear pumps

Operating principle
In an appropriate shaped pump barrel with suction (Suct.) and discharge (Dis.) ports, two gears turn whose teeth drive the liquid between the notches of the teeth and the pump barrel.

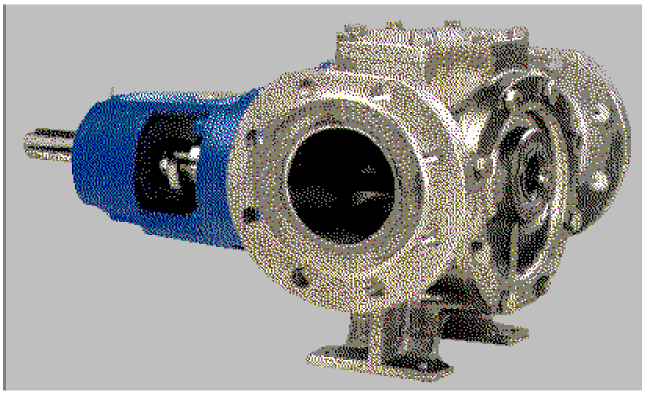


Figure 106: External view of a gear pump

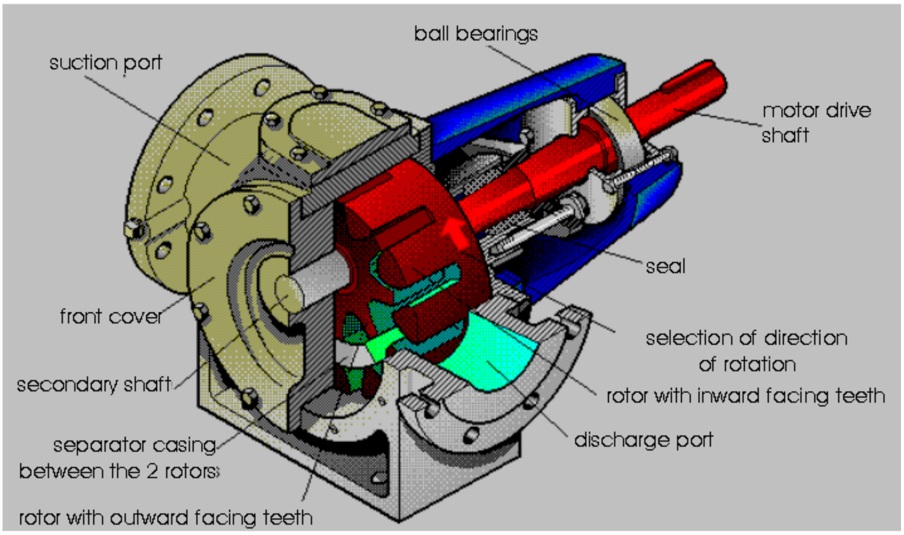


Figure 107: Cutaway view of a gear pump

Advantages

- Self-lubricating
- Self-priming (subject to a reserve of a lubricating coating)
- Flowrate and pressure depend on the speed.

Disadvantages

- Limited use for dry and abrasive liquids (rapid wear, therefore loss of performance).

Use

Accelerator for circulation, greasing of machines, tachymetric pumps, etc.

- Flowrate: up to 170 m^3/hr
- Pressure: up to 16 bars
- Viscosity: up to 80 000 centipoise
- Temperature: up to 260°C
- Rotation speed: up to 1 800 rpm
- Liquids: non-lubricating or corrosive, or with abrasive particles
- The operating direction is reversible
- Self-priming
- Can be immersed.
- Safety: a relief valve must be installed on the discharge. It must operate with the discharge open.

3.2.3.3. Lobe pumps

- Flowrate: up to 200 m^3/hr
- Pressure: up to 12 bars
- Temperature: up to 150°C

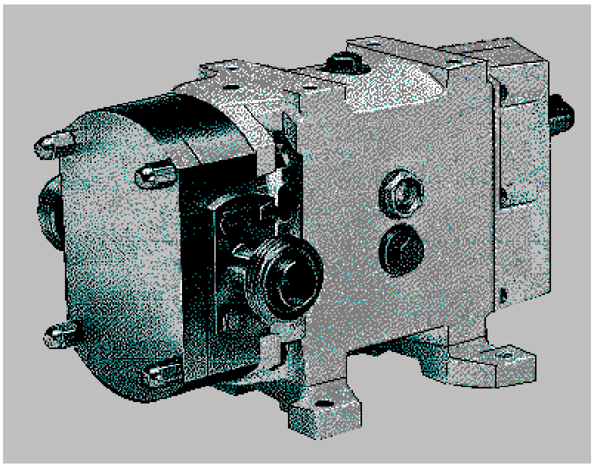
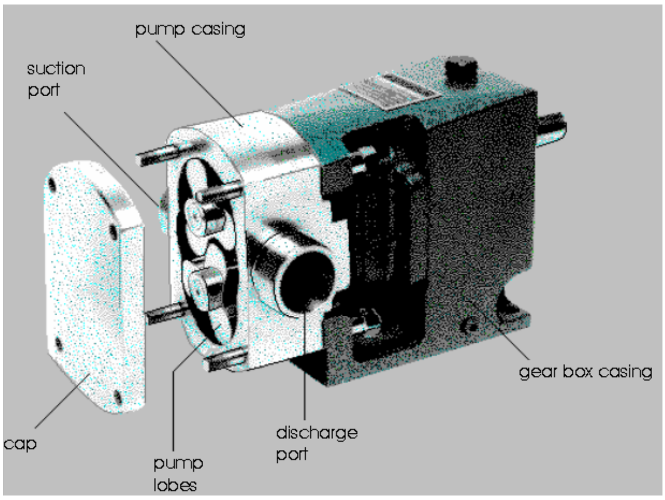


Figure 108: External view of a lobe pump



- Liquids: fragile, extremely viscous, slurry but not abrasive
- The operating direction is reversible

Figure 109: Open lobe pump

- Self-priming: up to 8m (for water)
- Safety: a relief valve must be installed on the discharge
- Can be operated dry

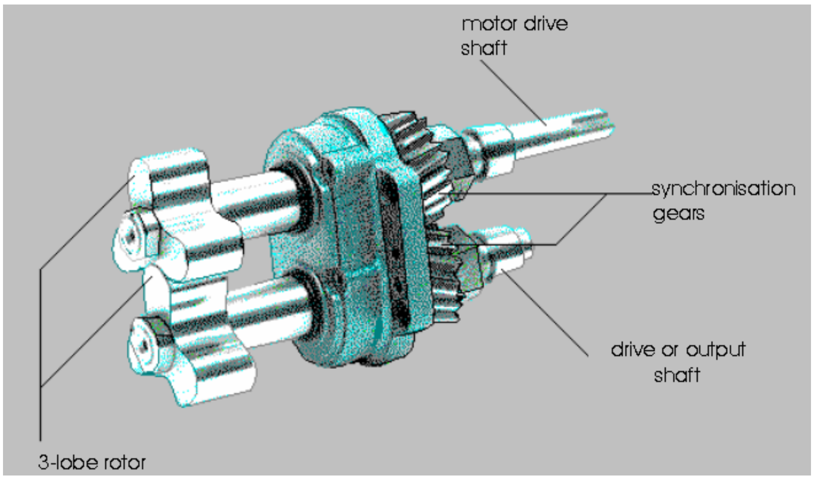


Figure 110: Internal view of a lobe pump

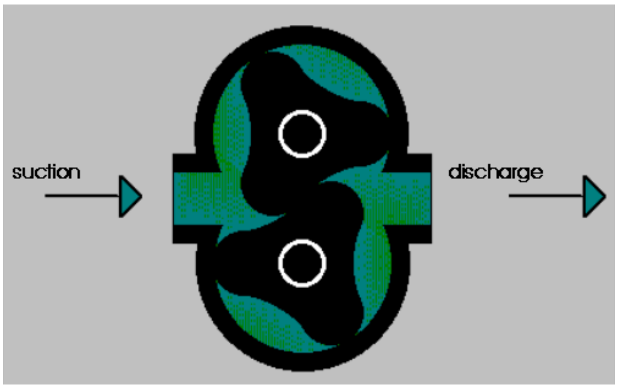
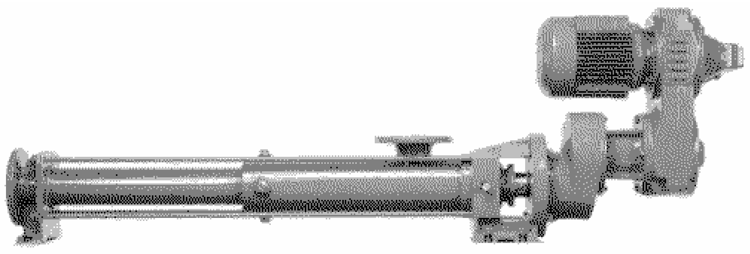


Figure 111: Lobe pump operation

3.2.3.4. Progressive cavity pumps (MOINEAU Pump)



- Flowrate: up to 240 m^3/hr
- Pressure: up to 200 bars
- Temperature: from – 40°C to 130°C
- Very slurry or heterogeneous liquids
- Reversible

Figure 112: External view of a MOINEAU pump

- Runs very silently
- Self-priming: up to 9m (for water)
- Safety: a relief valve must be installed on the discharge

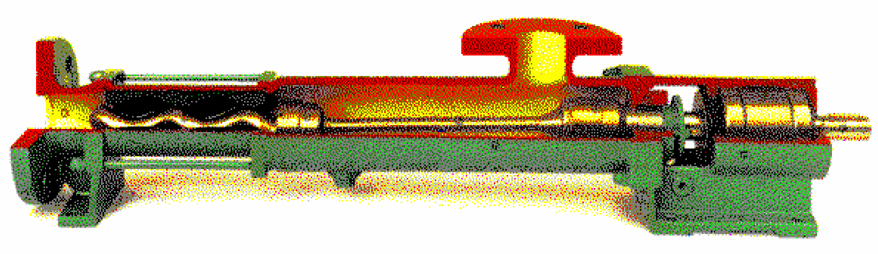
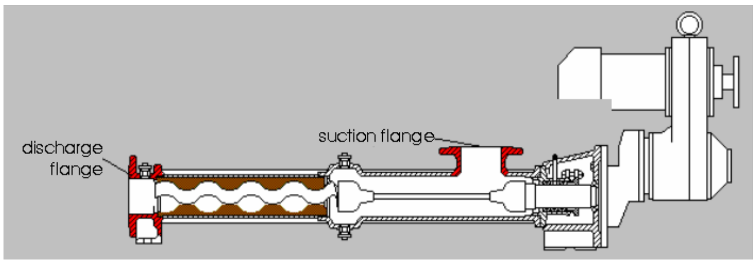


Figure 113: Cutaway view of a MOINEAU pump

- Does not support running dry or with abrasive particles
- Use with very viscous and fragile products.



Discharge flange: it often has a pressure gauge and a by-pass system through a relief valve.

Figure 114: Discharge flange MOINEAU pump

Suction flange: for very viscous products or those containing large solid particles or large quantities, an feed hopper can be installed instead of the suction flange.

The rotor is a metallic screw, often hollow so as to dampen the vibrations.
The most recent materials are heat treated steel or various types of stainless steel.

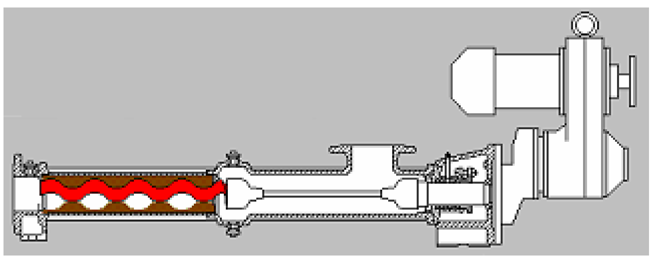
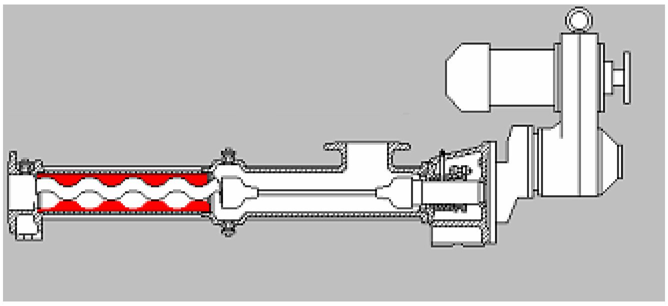


Figure 115: MOINEAU rotor pump

Chrome coatings increase abrasion resistance.
Mechanically, the rotor comprises a more-or-less sinusoid-shaped single-threaded screw whose pitch is half the pump's stator ring pitch.



The stator is made of moulded elastomer glued in a metallic sheath.
It can be very easily disassembled and put back in place, without any joint at the ends.

Figure 116: MOINEAU pump stator

Mechanically, it comprises a double-threaded screw whose pitch is double that of the stator.

The pitch difference between the rotor thread and the stator double thread generates closed cavities on all sides: the cells.
The rotor rotation moves these cells, by "screwing" them from the supply casing to the discharge.

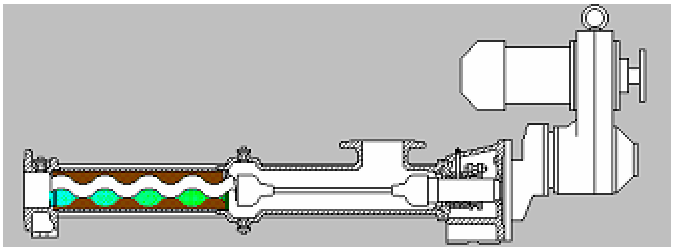
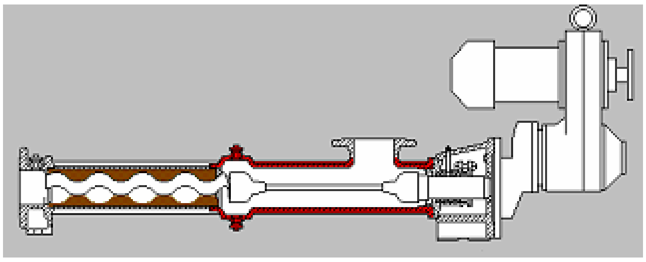


Figure 117: MOINEAU pump cavities



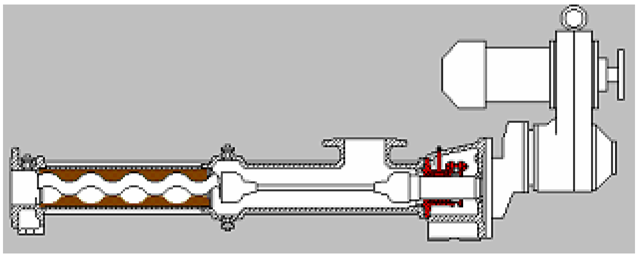
The supply casing generally has a drain screw and a screw for bleeding the gases.

Figure 118: MOINEAU pump supply casing

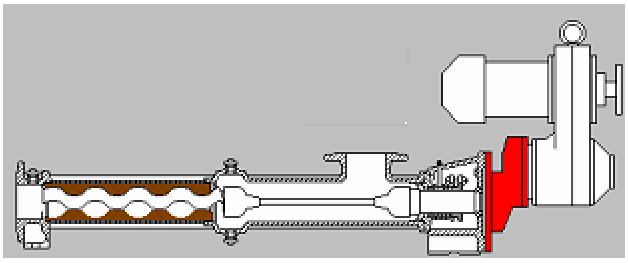
Its must be long to decrease the angularity of the connecting rod due to rotor/stator ring misalignment.
It can be fitted with an access door and a double casing for reheating or cooling.

The seal shown here is ensured by a braided gland with a rinsing or lubricating lantern ring.

Figure 119: MOINEAU pump seals



The seal can be ensured by a single gland or by single or double mechanical packing or even by a magnetic drive.



The main bearings which determine the "line shafting" are, very often, type "O" tapered roller bearings, mounted back to back.

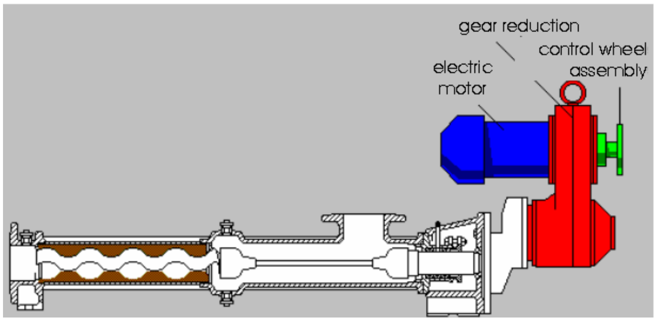
Figure 120: MOINEAU pump gear reducer

They are subjected to axial stress due to the thrust of the discharge pressure on the rotor end.

They are subjected to significant radial stress due to the reaction of the rod which works at an angle and to the loads due to the motor-reducing gear drive, the main bearing includes a gear reducer.

To be able to modulate the rate, it is necessary to vary the rotor rotation speed.

Figure 121: Speed variation system of on a MOINEAU pump



This speed variation may be:

- Mechanical, via a system of mobile-groove pulleys (as shown opposite).
- Electrical, generated by frequency variation or by direct-current shunt motor.
- Hydraulic: generated by a hydraulic motor

It can only have one reducer, without the possibility of variation.

3.2.3.5. Rotary liquid ring pump

This pump does not convey liquid but gas.
It is generally used as a vacuum pump and sometimes as a compressor.
Low heating of the gas.

Provide a cooling device for the liquid ring.

- either an exchanger on a closed circuit
- or continuous renewal of the liquid

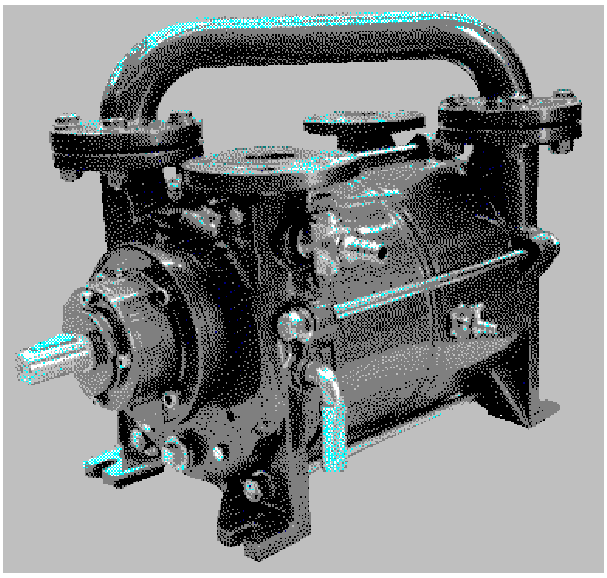
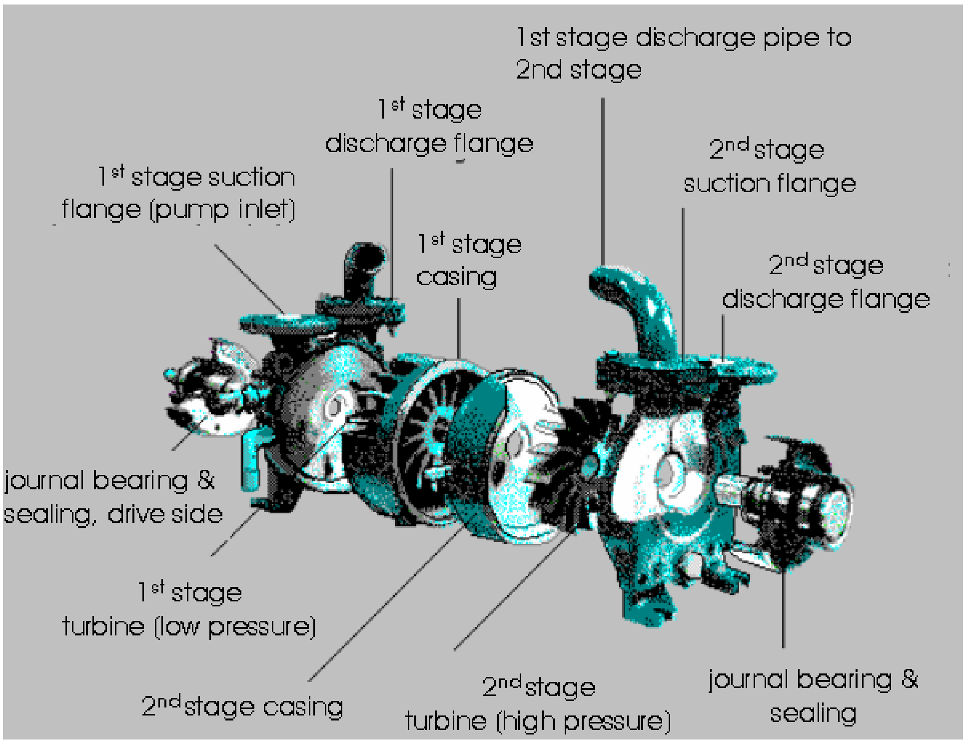


Figure 122: External view of a rotary liquid ring pump



Maximum flowrate: 30,000 m^3/hr

Maximum vacuum: 25 torrs, i.e. about 30 mbars.

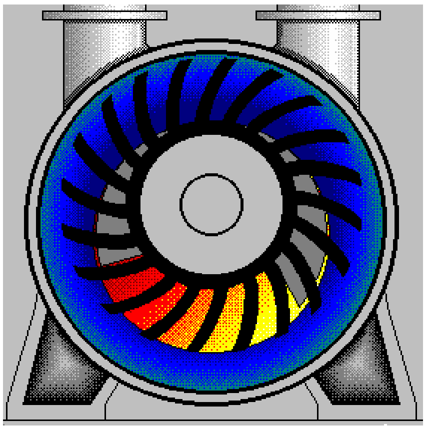
Where used as a compressor: maximum pressure 11 bars.

Figure 123: Cutaway view of a rotary liquid ring pump

Intake gas temperature is limited by the liquid ring boiling entry at the operating temperature.

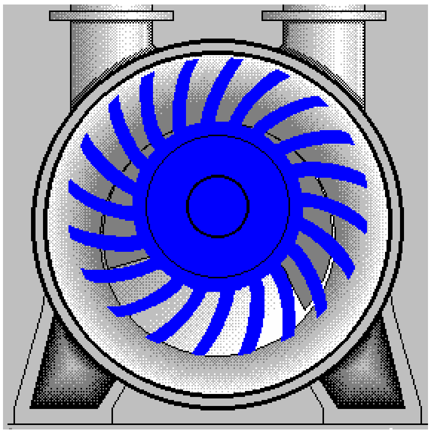
It can suck in a gas loaded with solid or liquid particles, which will be therefore washed.

Safety: check valve, good liquid level, temperature monitoring.



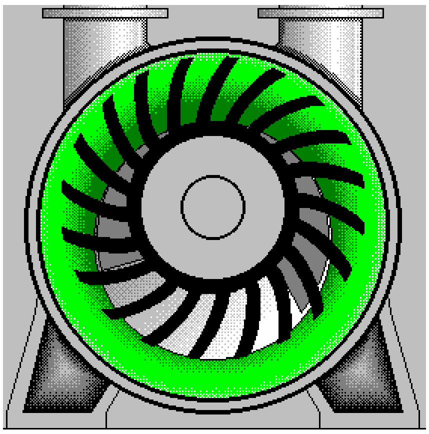
A radial bucket-wheel turbine rotates the liquid contained in the pump barrel. By means of the centrifugal force, the liquid is flattened against the pump barrel wall and forms the "liquid ring". The most commonly used liquid is cold water.
The turbine is offset in relation to the pump barrel. The cell volume made by the bucket-wheels and the liquid ring continually varies.

Figure 124: Rotary pump – diagram 1



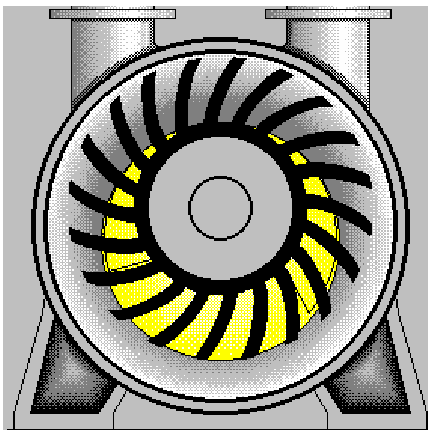
Where the bucket-wheels push out the liquid, the cell volume increases and suction is present.
Inversely, if the bucket-wheels re-submerge in the liquid ring, discharge is present. The pump can therefore suck up and discharge a gas on a continuous basis.
The turbine (or wheel, or rotor) is the only moving mechanical part.

Figure 125 : Rotary pump – diagram 2



The bucket-wheels (or vanes, or blades) are curved forward so as to retain the liquid ring which would, without that, be pushed back by the pressure difference that exists between two successive cells.
Rotation of the turbine flattens the liquid at the edge, against the pump barrel, whilst forming a ring that is, more or less, of constant thickness.
The liquid is often called sealant liquid, or also, sealing liquid.

Figure 126: Rotary pump – diagram 3

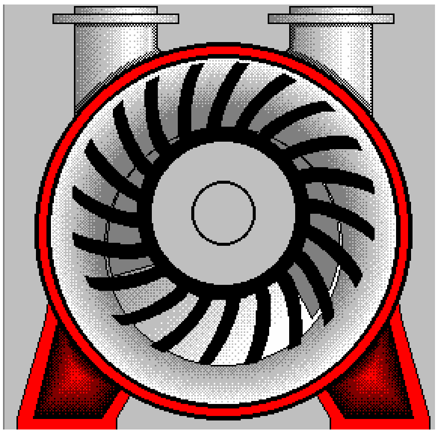


The turbine offset to the liquid ring axis creates cells (or cavities) whose volume varies.

The cell volume
- begins by increasing: this is the gas suction phase (low pressure)
- remains more or less constant: this is the gas transportation phase (low pressure)
- finishes by decreasing: this is the gas discharge phase (high pressure)

Figure 127: Rotary pump – diagram 4

The pump barrel hasn't the same axis as the turbine.



It contains the liquid which, driven by the turbine rotation, will be flattened at the edge and will form a liquid ring, concentric to the pump barrel.

Figure 128 : Rotary pump – diagram 5

The discharge eye is an port linked to the discharge flange.
The discharged gas is at high pressure.
The discharge eye is often made up by a series of slots or holes blanked by ball or leaf valves.
This device permits the pump to have a broader operating range by matching variations in pressure conditions or vacuum.

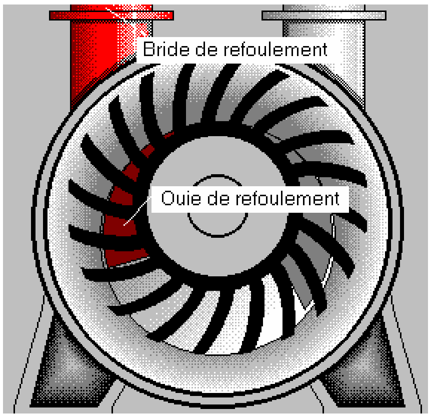
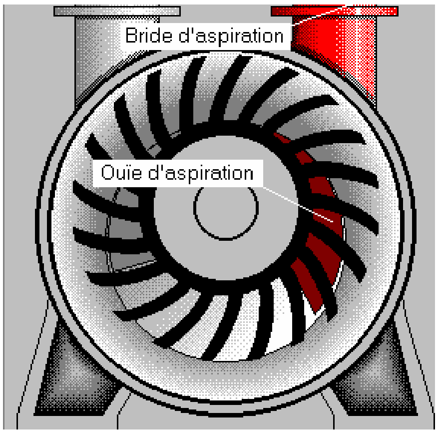


Figure 129: Rotary pump – diagram 6



The suction eye is a port linked to the suction flange.
The suctioned gas is at a low pressure

Figure 130: Rotary pump – diagram 7

3.3. SUMMARY OF THE TYPES OF PUMPS

As a summary of this section, here is a table and graph which lists the main types of pumps and their scopes of use:

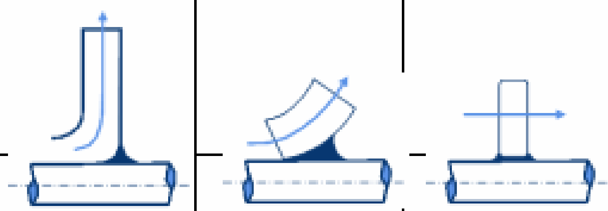
	Positive Displacement Pumps		Centrifugal pumps		
Pressure increase principle	By transfer of a volume from suction point to discharge point		Use of centrifugal force, with acceleration followed by deceleration		
Main types of pumps	Alternating	Rotating	Centrifugal	Centrifugal	Axial impellers
	Piston Plunger Diaphragm pump	Vane pumps with threaded rod gears			
Advantages et disadvantages	Strong ΔP possible	ΔP possible moderate	High	ΔP possible	Low
	Pulsated flowrate	Regular Flowrate	Low	Flowrate	High
	Flowrate independent of ΔP	Flowrate varies little with ΔP	Flowrate regular Flowrate highly variable with ΔP Not adapted to very low flowrates Not adapted to viscous products		
	Adapted to low and very low flowrates				
	Viscous liquids may be pumped	Adapted to viscous products			

Table 3: Summary table of the main pump types

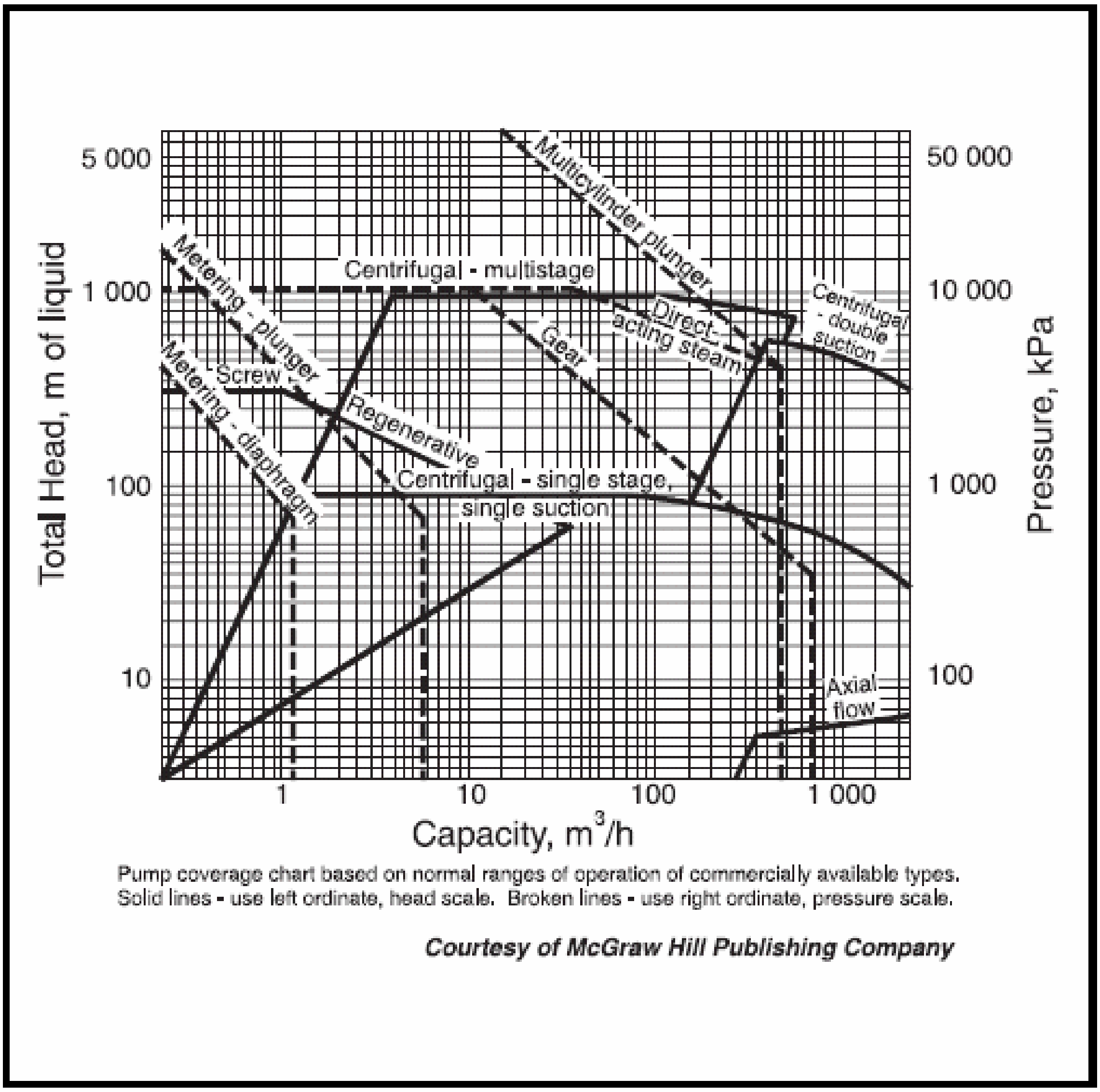


Figure 131: Pump selection graph

3.4. ADVANTAGES AND DISADVANTAGES OF DIFFERENT PUMP TYPES

In this chapter we are going to deal with the different advantages and disadvantages that are related to the two main types of pumps:

- **Displacement pumps**
  - Reciprocating displacement pumps:
    - piston pump
    - diaphragm pump
  - Rotary displacement pumps:
    - gear pump
    - screw pump
    - impeller pump
    - progressive cavity pump
- **Centrifugal pumps**

3.4.1. Reciprocating displacement pumps

Reciprocating pump qualities:

- Heavy-duty design allowing continuous operations.
- Low-speed reducing wear and facilitating suction of fluids and of viscous products.
- Operation flexibility (variable rate)
- Easy maintenance and replacement of wear parts.
- High displacement efficiency, with sluggish viscosity.
- High mechanical efficiency (90%)

Reciprocating pump disadvantages:

- Weight – Price – large overall dimensions
- Jerky flowrate.

	Advantages	Disadvantages	Use
Piston	Accurate flowrate Adjustable flowrate High efficiency	Jerky flowrate High price Sensitive to particles Limited chemical resistance	Pure, slightly corrosive non–hazardous liquids P → 100 bars V → 20 m^3/hr
Diaphragm	Accurate flowrate Adjustable flowrate High efficiency Less sensitive to particles Very good chemical resistance	Jerky flowrate High price Limited operating temperature	Slurry, corrosive, hazardous liquids P → 20 bars V → 30 m^3/hr

Table 4: Summary table of advantages and disadvantages of reciprocating displacement pumps

3.4.1.1. Piston pumps

Advantages:

- Can run dry without damage.
- High efficiency (90%).
- Very significant discharge pressure.

Disadvantages:

- Limited rate.
- Rather low viscosity.
- Impossible to pump solid particles.
- Functional only if perfectly sealed between the cylinder and the piston.
- Significant discharge pulsations.

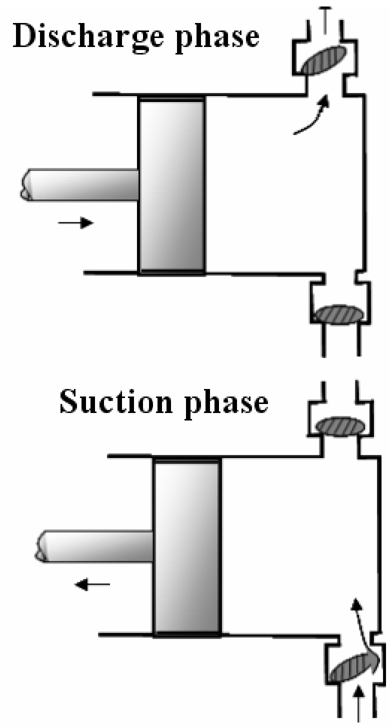


Figure 132: Principle - Piston pump

3.4.1.2. Diaphragm pumps

Advantages:

- Dry operation without damage
- Absolutely clean pumped liquid
- High efficiency (90%)

Disadvantages:

- Limited rate.
- Rather low viscosity
- Impossible to pump solid particles
- Functional only if perfectly sealed between the cylinder and the piston.
- Significant discharge pulsations. (indispensable cushioning system)

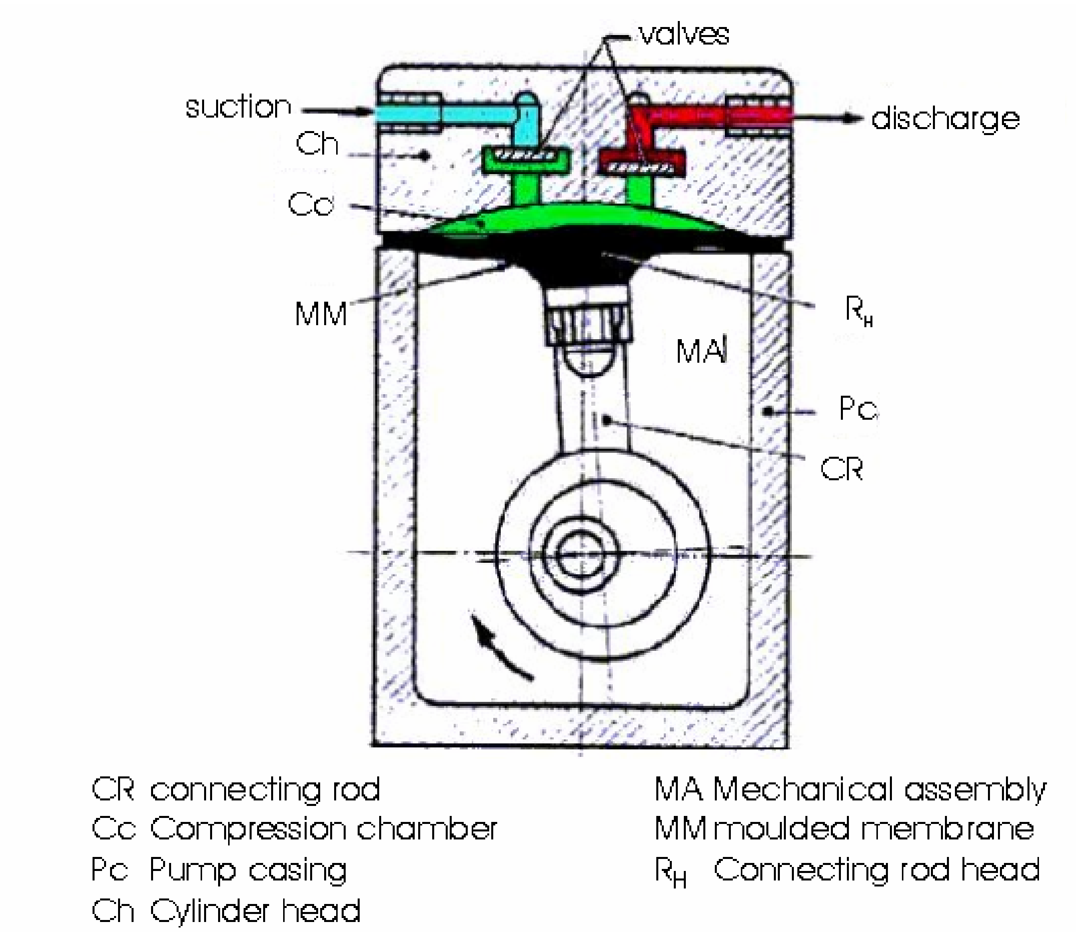


Figure 133: Diaphragm pump - Principle

3.4.2. Rotary displacement pumps

Rotary pump qualities:

- Low purchase cost
- Self-priming qualities
- No internal valves
- Low range of rate pulsations
- Excellent efficiency.

Rotary pump disadvantages:

- Limitation on discharge pressure by a quality safety valve mounted as a by-pass.
- 6 000 hour working life

	Advantages	Disadvantages	Use
Gear Screw Lobe	Uniform flowrate Adjustable flowrate Flowrate accuracy High efficiency Reduced overall size	Sensitive to particles Sensitive to corrosive liquid Complicated mechanics	Pure and viscous liquids P → 100 bars V → 200 m^3/hr
Peristaltic type Oscillating piston	Accurate flowrate Adjustable flowrate Resistant to corrosive liquids Self-priming Slightly sensitive to solids and suspensions	Jerky flowrate Limited operating temperature Pipe or diaphragm wear	Corrosive and slurry liquids P → 4 bars V → 20 m^3/hr
Offset screw	Adjustable flowrate Slightly sensitive to solids and suspensions Stator ring easy to move	Significant overall size Limited operating temperature Stator ring wear Sensitive to corrosive liquids	Slurry and viscous liquids P → 10 bars V → 150 m^3/hr

Table 5: Summary table of advantages and disadvantages of rotary displacement pumps

3.4.2.1. External gear pumps

Advantages:

- Regular rate.
- The pump is reversible.
- The herringbone gear pump supplies a more uniform movement.
- Valves not required

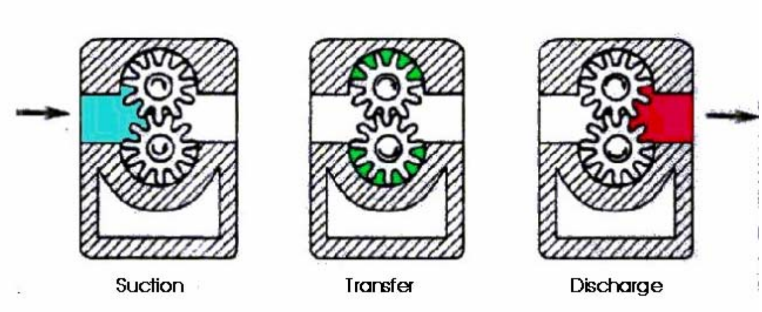


Figure 134: Principle - External gear pumps

Disadvantages:

- Wearing parts are numerous (bearings, 2 or 4 sealing housings)
- They do not allow solid particles to pass through without risk of total damage to the mechanism
- They poorly support abrasive products that accelerate mechanical wear of the split gears and reduce the tightness between the pump barrel and the teeth.

3.4.2.2. Internal gear pumps

Advantages:

- Regular rate.
- The pump is reversible.
- Only one sealing housing is necessary
- Low NPSH requirement

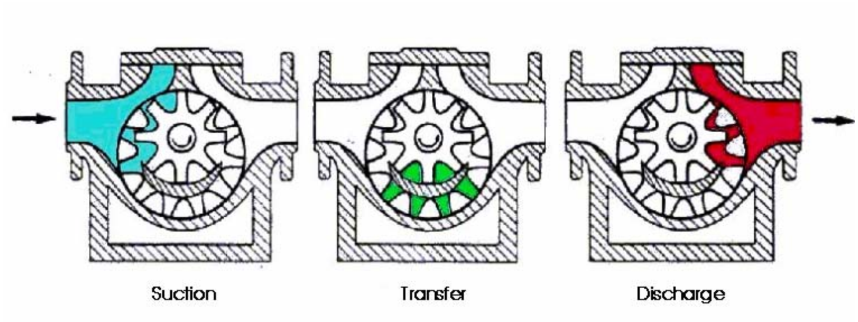


Figure 135: Principle - Internal gear pumps

Disadvantages:

- Low suction power
- They do not allow solid particles to pass through without risk of total damage to the mechanism
- The overhang can induce a shaft overloaded.

3.4.2.3. Screw pumps

Advantages:

- Regular rate.
- The pump is reversible.
- The pump is silent.

Disadvantages:

- They do not allow solid particles to pass through without risk of total damage to the mechanism.

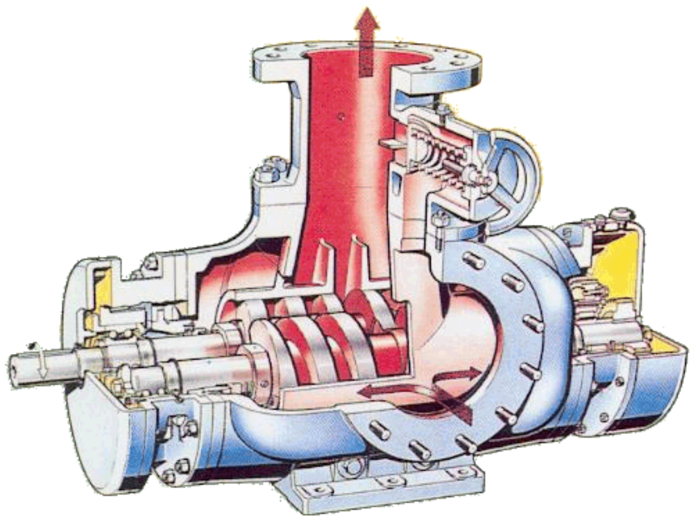


Figure 136: Principle - Screw pump

3.4.2.4. Impeller pumps

Advantages:

- There is no stirring, nor throttling nor emulsification of the pumped liquid
- Regular rate.
- The pump is reversible.

Disadvantages:

- The blades wear the cylinder due to rubbing
- Pumping of viscous fluids is difficult.

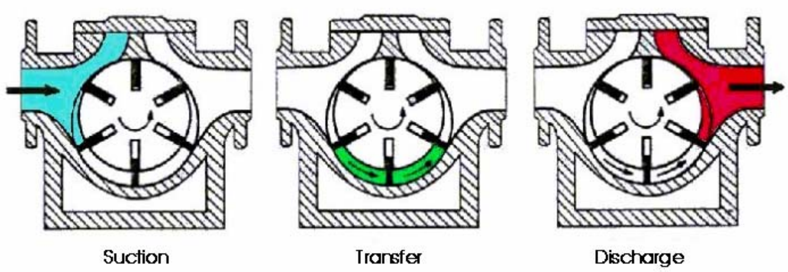


Figure 137: Principle - Impeller pump

3.4.2.5. Progressive cavity pumps

Advantages:

- Regular rate.
- They are silent.
- They are reversible.

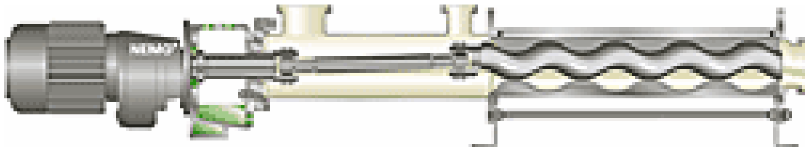


Figure 138: Principle - Progressive cavity pump

Disadvantages:

- They must not operate as a vacuum pump
- They cannot be used in very high temperatures (max. 70 to 80°) because of the stator ring
- Maintenance is rather difficult and costly
- Significant overall size.

3.4.3. Centrifugal pumps

Advantages:

- simple design machines, without valve, easy to use and not too costly
- with similar characteristics, they are more compact than displacement pumps
- their efficiency is often better than the displacements pumps
- they match with a very large range of liquids
- their rate is regular and operating is silent
- where there is clogging or obstruction of the discharge line, the centrifugal pump does not get damaged and the installation does not risk cracking open. Thus the pump behaves like an agitator…

Disadvantages:

- impossible to pump liquids that are too viscous
- production of a slightly risen differential pressure (from 0.5 to 10 bars)
- they are not self-priming
- when stopped, these pumps do not prevent the flow of liquid by gravity (therefore, it is required to provide valves…)

<table>
<tr><th></th><th>Advantages</th><th>Disadvantages</th><th>Use</th></tr>
<tr><td>General</td><td>Stable flowrate
Low price
Small overall size
Reliable</td><td>Not self-priming
Interdependent flowrate and carrying pressure
Low efficiency</td><td>Significant rates
Pure liquids and suspensions</td></tr>
<tr><td>Magnetic drive</td><td rowspan="2">No sealing system
No pollution of the liquid</td><td>Sensitive to particles
Limited temperature
Limited power</td><td rowspan="2">Pure, toxic and corrosive liquids</td></tr>
<tr><td>Wet pit</td><td>Sensitive to particles</td></tr>
</table>

Table 6: Summary table of advantages and disadvantages of centrifugal pumps

3.5. EXERCISES

30. A double-flow pump has one suction port and two discharge ports.

❑ True

❑ False

31. Find the definitions which match the following elements:

Shaft ●	● Element which converts energy received through the shaft into hydraulic energy.
Main bearings ●	● Part of the pump barrel which extends the hydraulic effect of the wheel.
Impeller ●	● Supports the impeller and conveys the energy to it.
Braided or mechanical packing ●	● Guides the shaft during rotation.
Volute ●	● Seal installed between the fluid under pressure and the air.
Auxiliary lines ●	● Used for packing

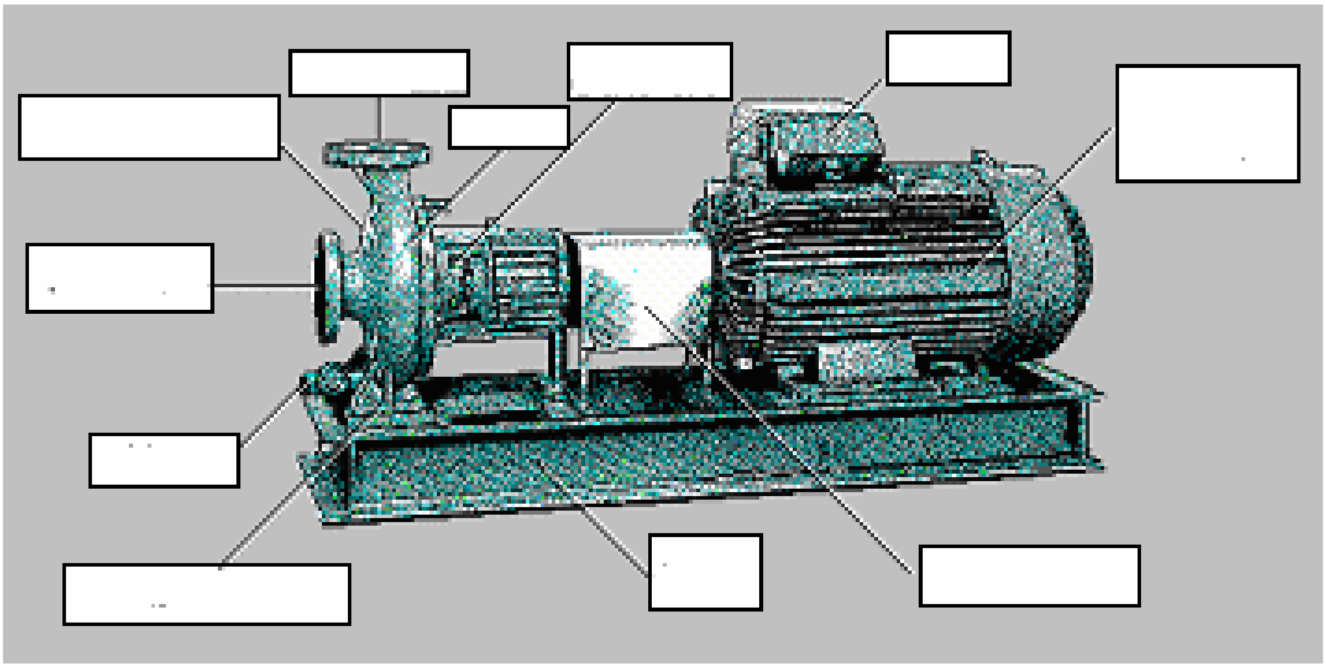
32. Which is which?

Open impeller ●

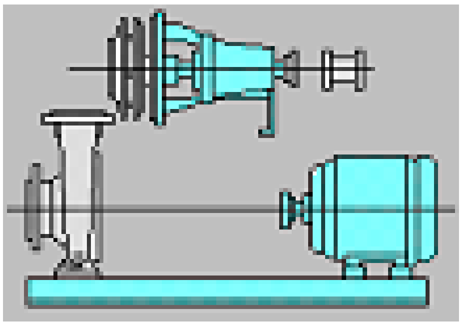
Closed impeller●

Partially open impeller●

33. Complete the following diagram:



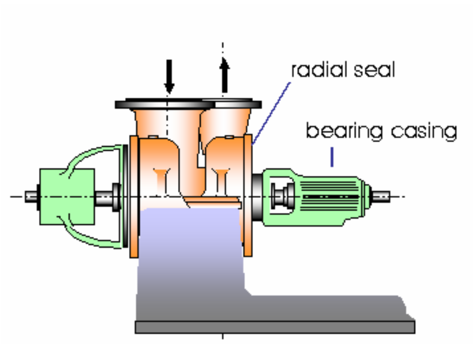
34. The "Back-Pull-Out" system allows the mobile assembly to be removed whilst leaving the pump barrel and motor in place



❑ Yes

❑ No

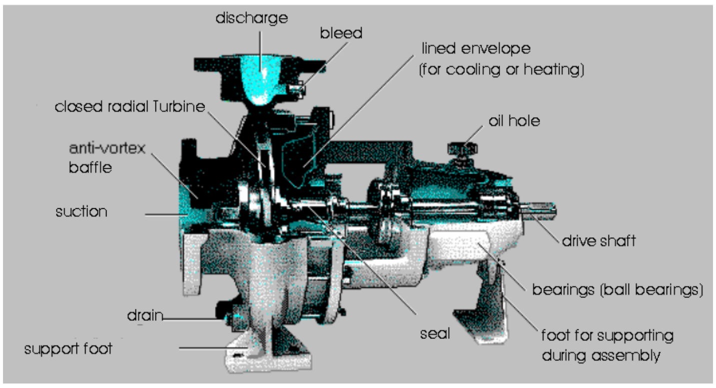
35. What is the category of this pump?



❑ A-A

❑ T-T

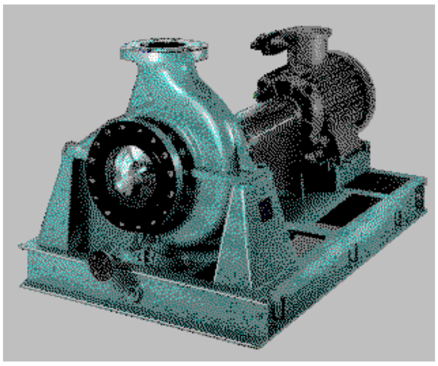
36. What is the category of this pump?



❑ A-A

❑ T-T

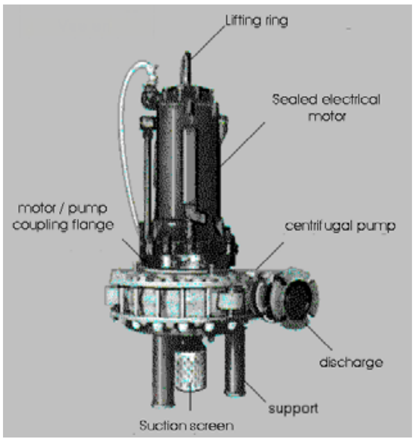
37. A foot-mounted pump is used for continuous, rough operating conditions



❑ A-A

❑ T-T

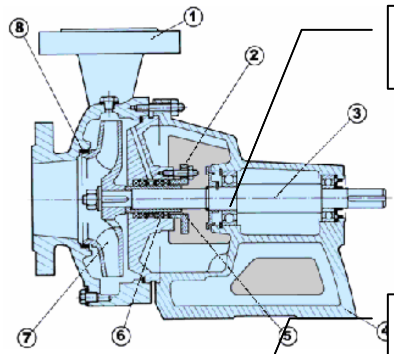
38. An immersed pump is not a one-piece design



❑ True

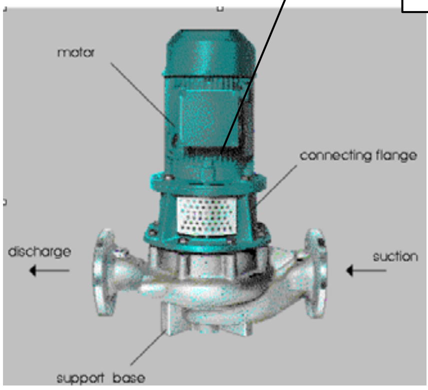
❑ False

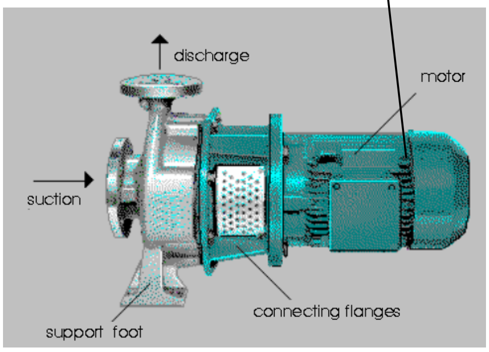
39. In which categories would you classify these pumps?



A

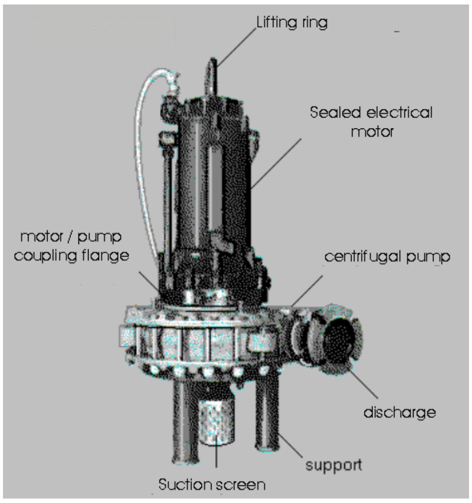
B





A ●	● In-line
B ●	● One-piece
C ●	● Pedestal bearing

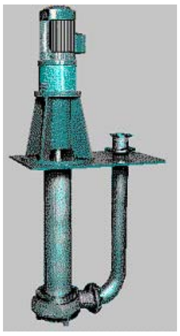
40. Can an immersed pump be removed without having to go down into the ditch?



❑ Yes

❑ No

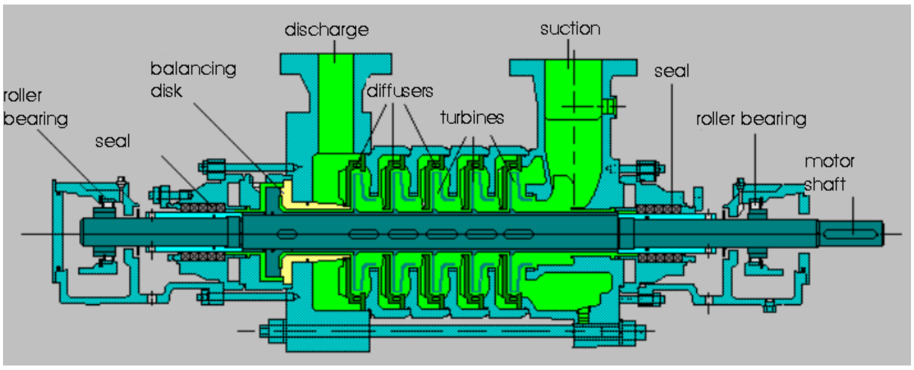
41. A vertical pump is used for emptying pits or buried tanks, when an immersed pump is not suitable.



❑ True

❑ False

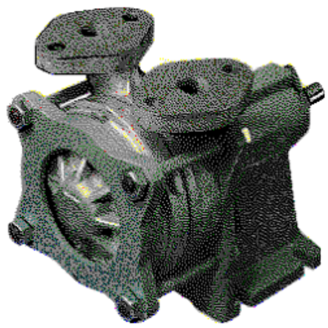
42. Multi-stage pumps are used for discharging liquids at very low pressures



❑ True

❑ False

43. Side channel pumps do not dry up if they suck in a gas and liquid mixture.



❑ True

❑ False

44. Side-channel pumps must start up with the discharge closed

❑ True

❑ False

45. Magnetic drive pumps are used for toxic and corrosive products

❑ True

❑ False

46. Displacement pumps are so-called "self-priming" since, from start-up, they cause an upstream pressure drop which allows the liquid to be sucked in.

❑ True

❑ False

47. Centrifugal pumps allow TMHs that are much higher than those of displacement pumps.

❑ True

❑ False

48. The efficiency of displacement pumps is often very close to 90%.

❑ True

❑ False

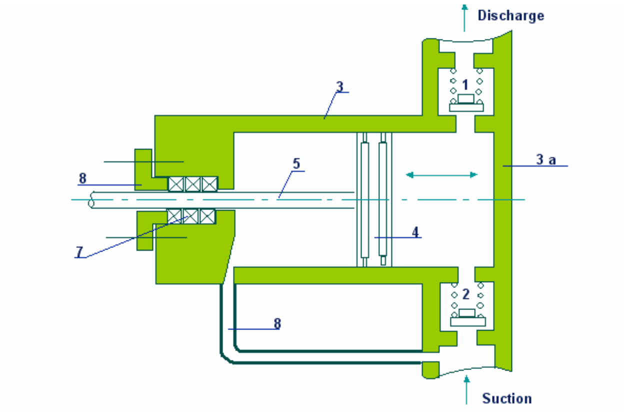
49. The flowrate is adjusted by acting on the rotation speed of the rotor for rotary pumps and on the frequency or stroke of the piston for reciprocating pumps.

❑ True

❑ False

50. What are the two operating principles for displacement pumps?

51. Is this a reciprocating pump?

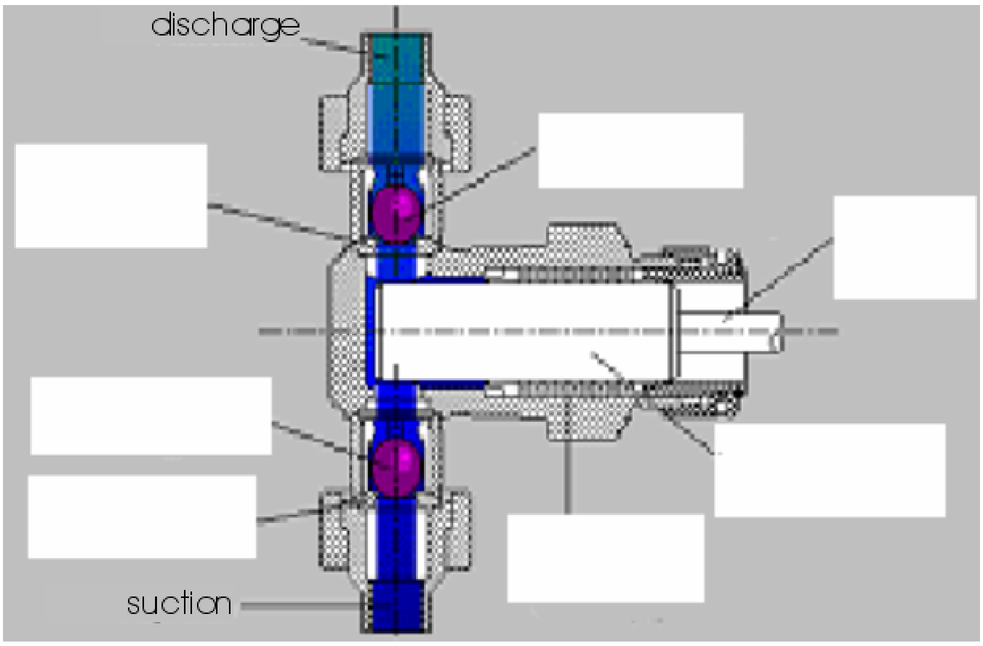


1. Discharge valve
2. Suction valve
3. Pump barrel - 3 a – end of pump barrel
4. Piston
5. Piston rod
6. Packing box gland
7. Braided packing
8. Recovery line.

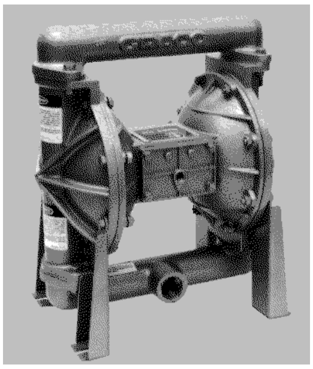
❑ Single acting

❑ Double acting

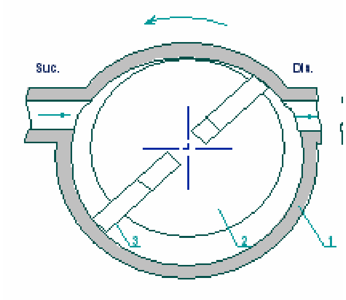
52. Complete the diagram of a metering pump head:

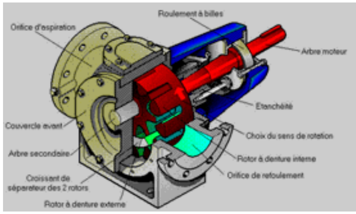


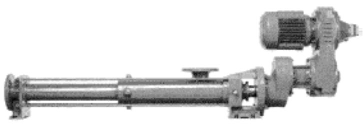
53. What is this type of pump?

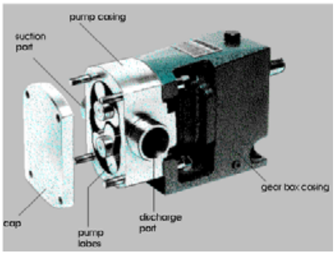


54. What are these types of rotary displacement pumps?





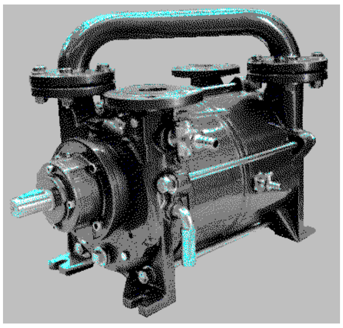




55. MOINEAU pumps are used for pumping slightly viscous liquids

❑ True

❑ False



56. What type of pump is used for carrying gas and not liquid?

57. Give 3 advantages of reciprocating pumps

58. Give 2 disadvantages of reciprocating pumps

59. Give 3 advantages of rotary pumps

60. Give 1 disadvantage of rotary pumps

61. Give 3 advantages of centrifugal pumps

62. Give 2 disadvantages of centrifugal pumps

4. PUMP DATA AND REPRESENTATION

This chapter describes how a pump is represented in the main documents provided to the operator.

4.1. REPRESENTATION ON PFD (PROCESS FLOW DIAGRAM)

Fluid flow plan (FFP/PFD): this document published during the project phase presents the main process capacities and lines together with their main operating parameters in a simplified format.

The PFD (Process Flow Diagram) examples below show a pumping system on a separation unit.

The GX 301 A/B/C oil pumps suck in the oil separated in the DS 303 and dispatch the oil upstream into an export pipe after passing through two desalters DS305 and DS306.

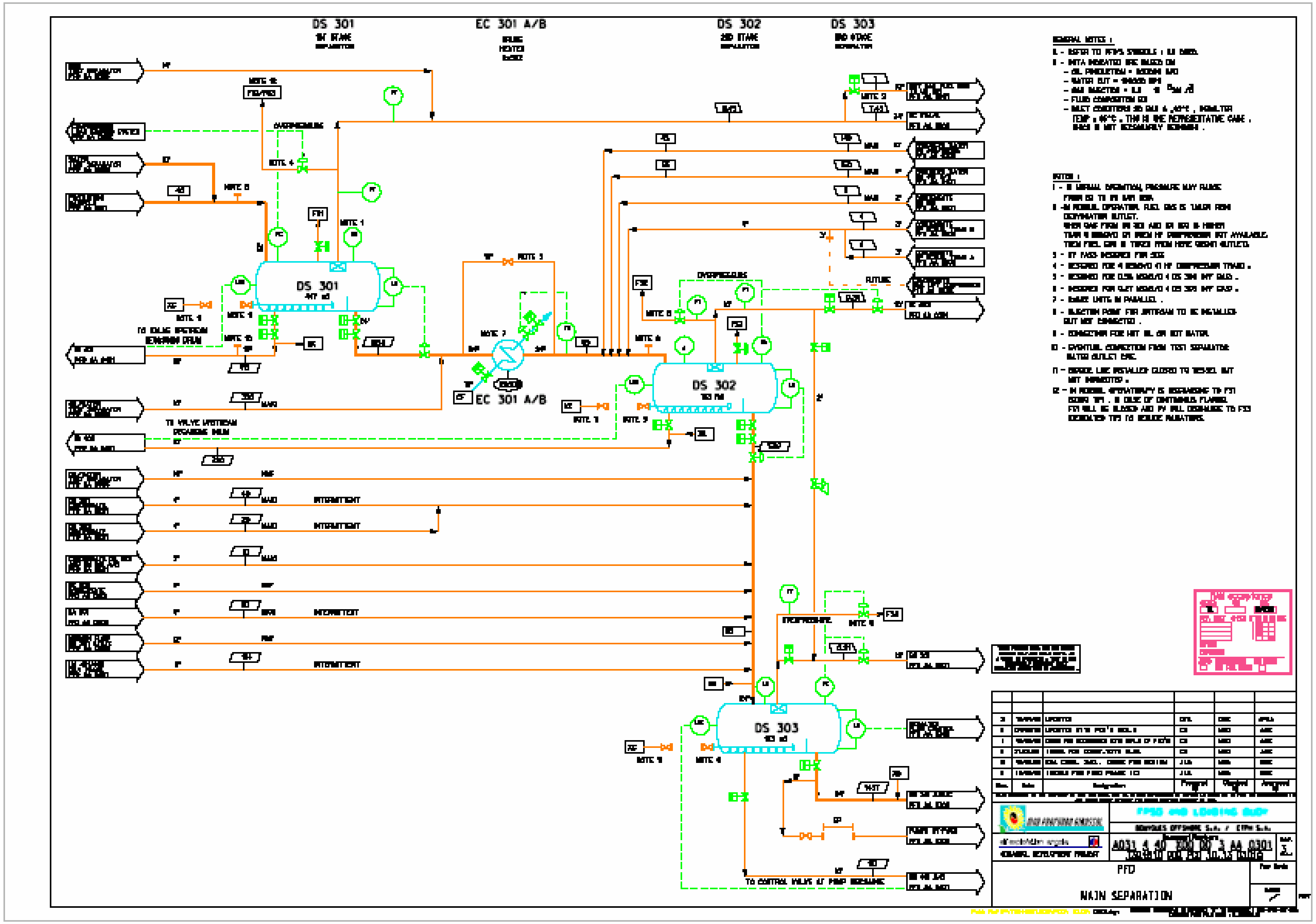


Figure 139: Example of PFD – upstream pump circuit

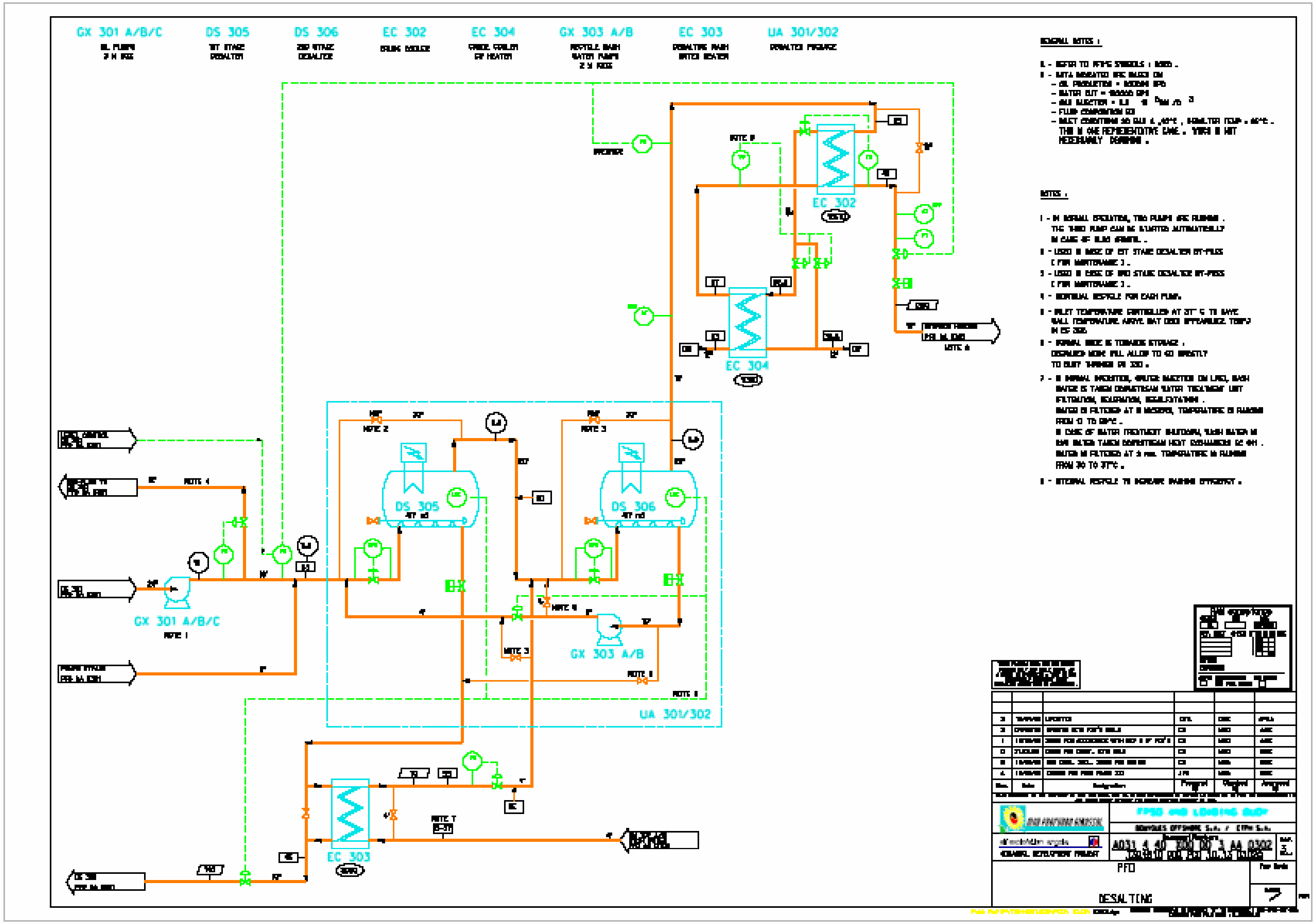


Figure 140: Example of PFD – downstream pump circuit

4.2. REPRESENTATION ON P&ID (PIPING & INSTRUMENTATION DIAGRAM)

This document published during the project phase presents all the process capacities and lines together with all their operating parameters in a much more complex format than the PFD.

The example below reiterates the previous example but in a much more detailed format: The P&ID.

This pumping system comprises three pumps.

Two pumps are in service. The other is an automatic backup and may be activated during peak flows (occurrence of a bottleneck).

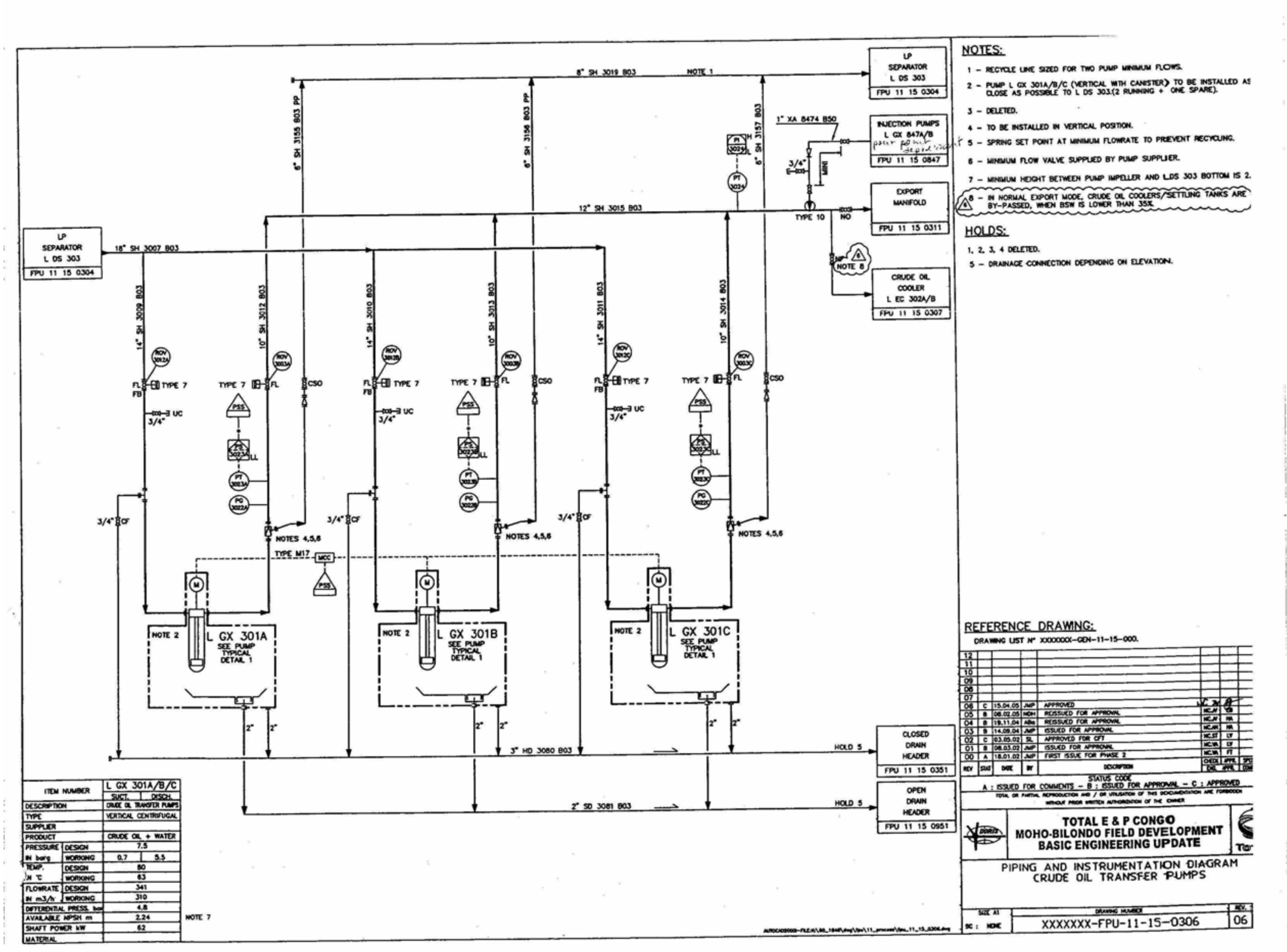


Figure 141: Example of PID – separation pumping system

4.3. PUMP DATASHEETS

	FIG. 42 PROCESS DATA SHEET PUMP	
	Job	Unit :
	Service : DEMETHANISER REB. PUMP	Item : Spare : YES

No.	Item	Unit	Value
1	**FLUID HANDLED**		
2	Fluid circulated		
3	Pumping temperature	°C	Nor. 27 Max. 85
4	Viscosity at P.T.	cPo	0.13
5	Vapor pressure at .T.	bar abs	18.20
6	Specific gravity 15/4		0.504
7	Specific gravity at P.T.		0.500
8	**OPERATING CONDITIONS, EACH PUMP**		
9	Capacity	m3/h	Nor. 162 Rated 200
10	Discharge pressure	bar gage	23.05
11	Suction pressure	bar gage	Nor. Rated 18.70
12	Differential pressure	bar	4.35
13	Differential head	m	88.7
14	NPSH available	m	10.2
15	Hydraulic horse power	kW	24.2
16	**PUMP**		
17	Proposed type		
18	Efficiency	%	(Estimated) 68
19	Estimated power rated	kW	35.6
20	Speed	RPM	2980
21	Corrosion or erosion due to		-
22	Recommend materials		CS
23	**DRIVER**		
24	Type		ELECTRIC MOTOR
25	Rating	kW	45
26	Speed	RPM	2980
27	VOLTS/Phase/Cycle		380/3/50
28	Efficiency	%	(Estimated) 88
29	Estimated operating Load	kWh/h	40.5

Table 7: pump process datasheet

FLOWSERVE Pump Division

Pompe	: 6X11DMXD-B
Courbe n°	: 6X11DMXD-2-6
Nombre d'étages	: 7

Client	:	Débit	: 420.0 m3/h
Numéro de Poste	: P1	Hauteur	: 1350.0 m
Service	: Injection	Densité	: 1.030
Référence IDP	: 9999-W0000	Vitesse	: 4372 rpm
Date	: décembre 13, 2005		

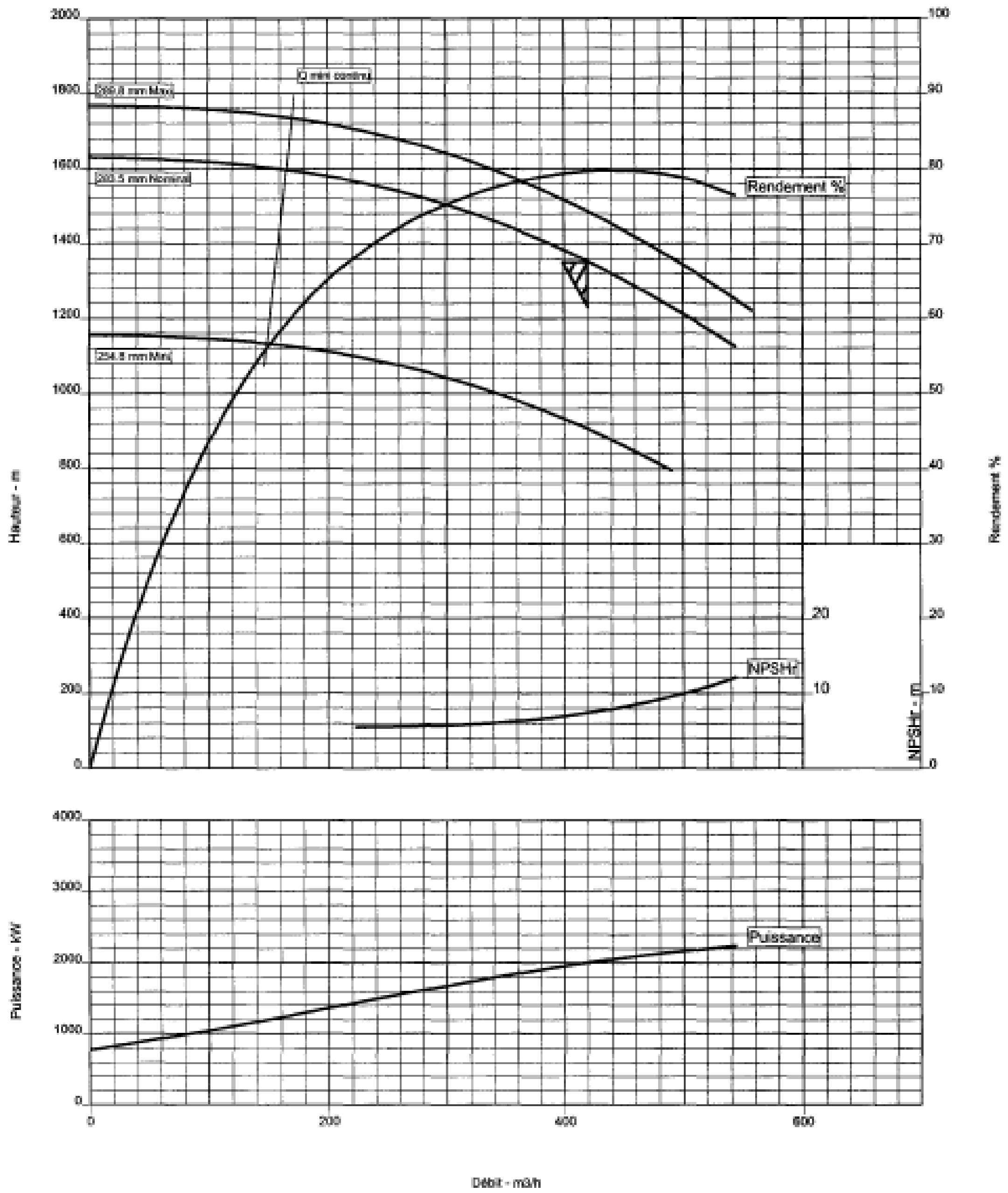


Figure 142: pump operating curve

4.4. PUMP SIZING

4.4.1. Sizing

A number of terms need to be identified to allow for the sizing of the pumps.

- The pressure difference between the outlet and suction flanges of a centrifuge pump is called the elevation head of the pump. This is expressed in metres of liquid columns.
- This head expressed in metres does not depend on the density of the liquid, whereas the ΔP of the pump expressed in bars does depend on the density.
- The (required) NPSH of a pump represents the pressure drop between the suction flange and the impeller input. This is expressed in metres and its value is generally between 3 and 5 metres.
- For certain special pumps, the NPSH may be less than 1 metre. This value is important when there is a risk of liquid vaporisation (cavitation).
- The actual elevation head established is linked to the resistance of the circuit.
- This resistance is established by adding :
    - the ΔP between the suction and outlet capacities,
    - the height difference between the levels of these capacities,
    - head losses in the circuit (piping, valves, etc.).
- The operating point on a graph { height, flow } is the point at which the pump curve and the circuit curve intersect
- The flow adjustment is generally made by altering the head losses by means of a valve. This may also be achieved by speed variations.

4.4.2. Elements to be taken into account

4.4.2.1. Minimum flow

- Low flowrates (in the event of a limited discharge) tend to create internal recirculation which can result in premature damage. This is why the manufacturer generally specifies a minimum flowrate for correct operations.

- Non-existent flowrates (closed discharge): the energy supplied by the pump is converted into heat, the liquid is heated and may vaporise. A closed discharge may cause major damage to the pump very quickly (within a few minutes).

In order to prevent these problems, a recirculation line is generally used which sends some of the liquid back to the suction point (from the upstream pump or drum). This recycled flow is assured either by a flow regulation valve or by a specific minimum flow control valve “Schroeder” valve

4.4.2.2. Flow control

When a pump is selected the theoretical operating point (obtained from the curves) never corresponds to the actual operating points (the parameters change over time in any case). It is therefore necessary to associate the pump with a system which allows the required flow to be obtained at any time. Since the operating point is the intersection between the H curve (network) and the TMH curve (pump) it is necessary to act on either one or the other.

- Alterations in the H curve (network curve): by positioning a valve at the pump discharge point: 100% open valve, no change in the curve, the more the valve is closed, the more the head losses increase and the curve rises with the point of intersection with TMH moving to the left and the flow Q decreasing.
  An identical result is obtained by using a recirculation valve. This valve will also alter the network curve but it is the recirculation flow value above all which will regulate the flow actually sent to the destination point (the recirculation returning to the starting point).

- Alterations in the TMH curve (pump curve): it is possible to alter the operating point without modifying the network by varying the pump rotation speed: the more the speed is reduced, the more the curve “decreases” moving the operating point to the left and thereby reducing the flow. This principle is complex and generally only used for large capacity pumps.

4.4.2.3. Importance of operating conditions

When a pump is selected it is important not only to take into account the nominal operating point but also to ensure that the pump operates correctly according to the possible process variations:

- The flow may vary and the pump must therefore be selected so that its minimum / maximum flows are compatible with these variations.
- The levels (suction / discharge) may therefore vary the pressures (particularly NPSH) and the pump must be adapted to these possible variations.
- The product may vary (temperature, viscosity, etc.). Viscosity is a major element and it is important to ensure that the pump (for which the pump curve is generally established for water) will operate correctly for a much more viscous product.

In order to deal with these potential problems, a margin of 10 to 20% is observed with regard to the nominal operating flow when the pump is selected.

4.4.2.4. Taking the pump efficiency into account

The centrifugal pumps have an efficiency curve (according to Q_v) which passes through a maximum level corresponding to a flow for which this pump consumes the minimum amount of energy. It is therefore important to ensure that the operating point is in the zone in which this pump provides a maximum efficiency.

4.4.2.5. Operation of pumps in parallel and in series

- In series: this is the case when the $NPSH_r$ is not attained. In this case a pump is installed upstream to “cram” the main pump and thereby prevent cavitation problems. This is also the case when requirements are liable to vary over time.

FLUID PUMPED Liquid : ....
Pumping temperature: .... °C
Vapor pressure at T. : .... Bar a
Density at P.T. Kg/m3
Specific gravity at P.T. ....

Viscosity at P.T. .... CP o
Specific gravity 15/4 ....
Normal flow at P.T. m3/h
Safety factor .... %
Design flow at P.T. m3/h

SUCTION PRESSURE (at suction flange) (3)

Min. pressure in suction drum .... Bar a
Min. elevation h........... m
0.981 x 10^{-4} x .... m x ..... Kg/m3 = ... Bar

Total (1) .... Bar a
Δp. suction line Total (2) – .... Bar

Suction pressure (3) = (1) — (2) .... Bar a

AVAILABLE NPSHA (15)

Suction pressure (3) .... Bar a
Vapor pressure at T. (14) .... Bar a

Total (15) (3) – (14) .... Bar

$10.197 \times \frac{(15)}{\text{SP.GR at P.T.}} = 10.197 \frac{......}{......} = ... m$

DISCHARGE PRESSURE (at discharge flange) (13)

Max. destination pressure ...... Bar a
Max. elevation H...... m
0.981 x 10^{-4} x ...... m x ...... Kg/m3 = ... Bar

Total (4) .... Bar a

Δ p discharge line (5) .... Bar
Δ p exchanger (6) .... Bar
Δ p heater (7) .... Bar
Δ p orifice (8) .... Bar

Total Δ p friction loss . (9) .... → .... Bar

Δ p control valve
= (9) ...... bar x 0.2 = (10) .... Bar
Estim. pressure variation = (11) .... Bar
Total Δp control valve
(10)+(11)=(12) .... Bar → .... Bar

Discharge pressure (13)=(4)+(9)+(12) .... Bar a

DIFFERENTIAL PRESSURE (16)

Discharge pressure — suction pressure=(16)=(13) – (3)= .... — .... = ... Bar

$\text{DIFFERENTIAL HEAD (17)} = 10.197 \times \frac{(16)}{\text{SP.GR at P.T.}} = 10.197 \times \frac{.......... \text{Bar}}{..........} = ... m$

$\text{HYDRAULIC HORSE-POWER} = \frac{(\text{flow } m^3/h) \times (16)}{36} = \frac{(........ m3/h) \times (........ bar)}{36} = ... kW$

BRAKE HORSE-POWER P

Pump efficiency ηg = ... (estimated)

$P = \frac{\text{Hydraulic Horse Power}}{\eta g} = \frac{...................... kWh/h}{......................} = ... kW$

PHp = 1.341 x P = 1.341 x .... kW = ... HP
Pcv = 1.3591 x P = 1.3591 x .... kW = ... CV

$P = 4.35 \times 10^{-4} \times \frac{(..... GPM) \times (..... PSI)}{...........} = ... kW$
English unit

DESIGN OPERATING LOAD
Motor estimated size : .... kW
Motor estimated efficiency ηm = ...

$\text{Design Operating Load} = \frac{BHP}{\eta m} = ... kWh/h$

FLUID PUMPED Liquid : ....
Pumping temperature: .... °C
Vapor pressure at T. : .... Bar a
Density at P.T. Kg/m3
Specific gravity at P.T. ....

Viscosity at P.T. .... CP o
Specific gravity 15/4 ....
Normal flow at P.T. m3/h
Safety factor .... %
Design flow at P.T. m3/h

SUCTION PRESSURE (at suction flange) (3)

Min. pressure in suction drum .... Bar a
Min. elevation h........... m
0.981×10^{-4} x .... m x ..... Kg/m3 = ... Bar

Total (1) .... Bar a
Δp. suction line Total (2) – .... Bar

Suction pressure (3) = (1) — (2) .... Bar a

AVAILABLE NPSHA (15)

Suction pressure (3) .... Bar a
Vapor pressure at T. (14) .... Bar a

Total (15) (3) – (14) .... Bar

$10.197 \times \frac{(15)}{\text{SP.GR at P.T.}} = 10.197 \frac{\ldots\ldots}{\ldots\ldots} = \ldots\ldots\ldots$ m

DISCHARGE PRESSURE (at discharge flange) (13)

Max. destination pressure ...... Bar a
Max. elevation H...... m
0.981×10^{-4} x ...... m x ...... Kg/m3 = ... Bar

Total (4) .... Bar a

Δ p discharge line (5)................ Bar
Δ p exchanger (6)................ Bar
Δ p heater (7)................ Bar
Δ p orifice (8)................ Bar

Total Δ p friction loss . (9)................
→ .... Bar

Δ p control valve
= (9) ...... bar x 0.2 = (10).................. Bar
Estim. pressure variation = (11) .... Bar
Total Δp control valve
(10)+(11)=(12) .... Bar
→ ...... Bar

Discharge pressure (13)=(4)+(9)+(12) .... Bar a

DIFFERENTIAL PRESSURE (16)

Discharge pressure — suction pressure=(16)=(13) — (3)= .... — .... = ... Bar

DIFFERENTIAL HEAD (17) $= 10.197 \times \frac{(16)}{\text{SP.GR at P.T.}} = 10.197 \times \frac{\ldots\ldots\text{Bar}}{\ldots\ldots\ldots} = \ldots\ldots\ldots$ m

HYDRAULIC HORSE-POWER $= \frac{(\text{flow m}^3/\text{h}) \times (16)}{36} = \frac{(\ldots\ldots\text{ m3/h}) \times (\ldots\ldots\text{bar})}{36} = \ldots\ldots\ldots$ kW

BRAKE HORSE-POWER P
Pump efficiency ηg = ... (estimated) $P = \frac{\text{Hydraulic Horse Power}}{\eta g} = \frac{\ldots\ldots\text{ kW h/h}}{\ldots\ldots} = \ldots\ldots$ kW

PHp = 1.341 x P = 1.341 x .... kW = ... HP
Pcv = 1.3591 x P = 1.3591x .... kW = ... CV

$P = 4.35 \times 10^{-4} \times \frac{(\ldots\ldots\text{GPM}) \times (\ldots\ldots\text{PSI})}{\ldots\ldots\ldots} = \ldots\ldots$ kW
English unit

DESIGN OPERATING LOAD
Motor estimated size : .... kW
Motor estimated efficiency ηm = ...

Design Operating Load $= \frac{\text{BHP}}{\eta m} = \ldots\ldots$ kWh/h

Table 8: Pump calculation sheet

4.5. EXERCISES

63. What do the initials PCF and PFD signify in English?

64. What do the initials PID signify in English?

5. PUMPS AND PROCESS

5.1. LOCATION AND CRITICALITY

As we have seen above, a pump is used to transfer a liquid from one point to another:

- Transfer from the separation unit to the desalination unit
- Injection of demulsifier in the separation
- Evacuation of condensates in a pipe drum
- Injection of methanol in the gas dehydration by-pass

If this function is interrupted, it is easy to understand that this will cause serious problems with regard to the correct operation of the facilities.

Let us consider the example of pumps used for the processing of oil which transport oil from a separator to a desalter. The criticality will be high because the interruption of these pumps will result in a production stoppage.

The evacuation of liquids from the separator situated upstream of the pumps will become impossible as this will irrevocably result in a high level in this drum.

This is why, among other things, a backup pump is nearly always installed in the event of problems or pump maintenance.

Therefore the flow in the PFD example presented below is 3*50% which makes up for the possible stoppage of a pump.

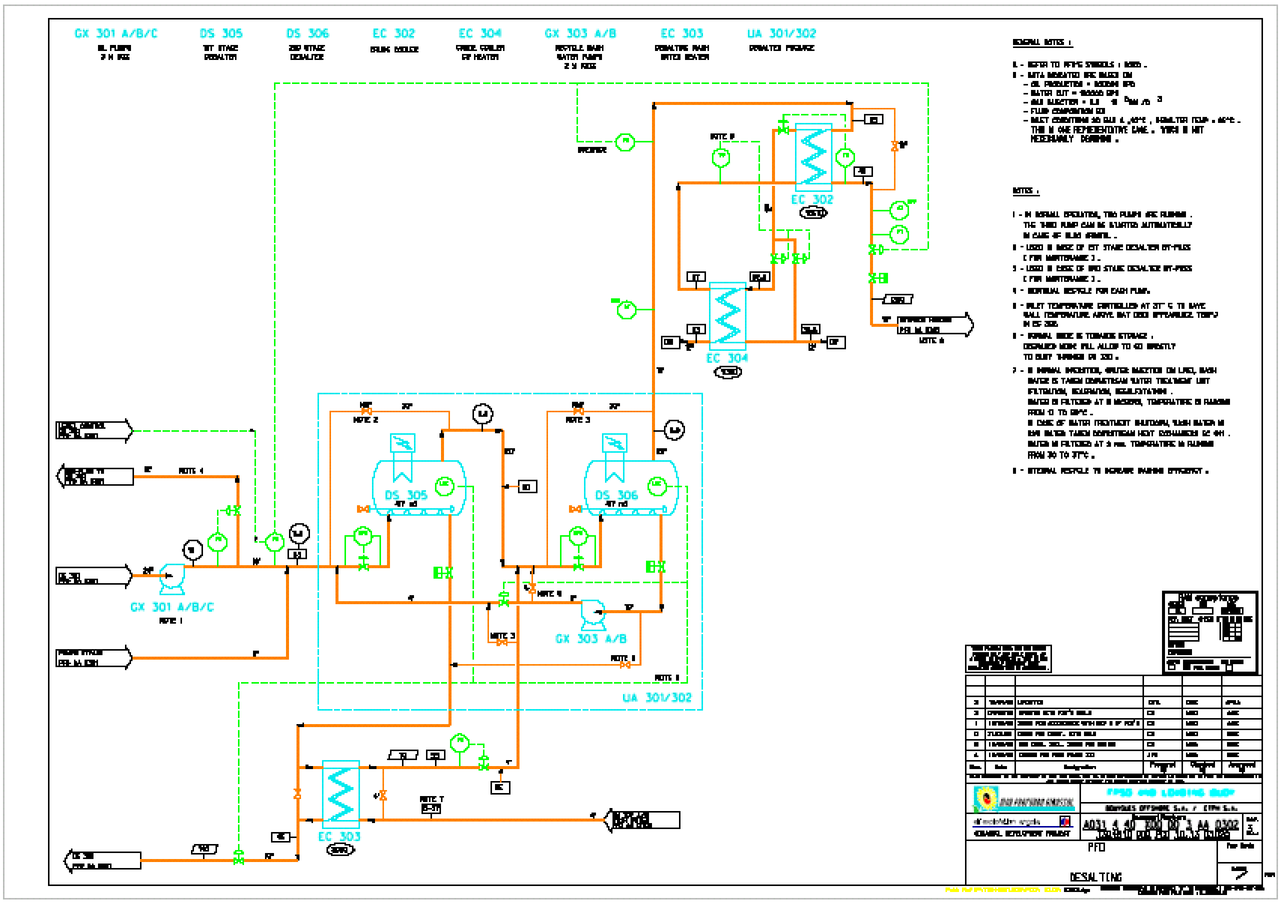


Figure 143: PFD - GX301 A/B/C pumps in Girassol

5.2. EXERCISES

65. As far as the treatment of oil is concerned, what is the level of criticality if the pumps transporting oil from a separator to a desalter become inactive?

❑ Low

❑ Average

❑ High

6. AUXILIARIES

Various elements are required to guarantee the correct operation of a pump.

In general it can be said that:

- **The equipment surrounding** a centrifuge pump: lines, their supporting equipment, pump base and supports must be **perfectly rigid, well positioned and clean** so that the **alignment** with the driving motor does not deteriorate, which could result in **severe vibrations**.

- **The auxiliary circuits**: water, steam produced must be perfectly **identified by the operator and the monitoring points known.**

- **A bearing** must be **purged regularly**, particularly when there is **steam in the environment**.

- **The appearance of the oil** must be verified every day

- **The greasing system** (greaser at a constant level, visible level, possible circuit) must be **clearly identified and monitored by the operator**. **All anomalies**, such as excessive or non-existent consumption, must be **detected rapidly**.

- **A manometer with a correct discharge function** is absolutely essential for the operation of a centrifuge pump. It is recommended that the range of **current operating** values be **identified**.

The following chapter contains details of the accessories and process lines surrounding a centrifuge pump in a unit.

6.1. ACCESSORIES AND PROCESS LINES

The suction and outlet lines are equipped with a certain number of accessories which allow for the operation of the pump.

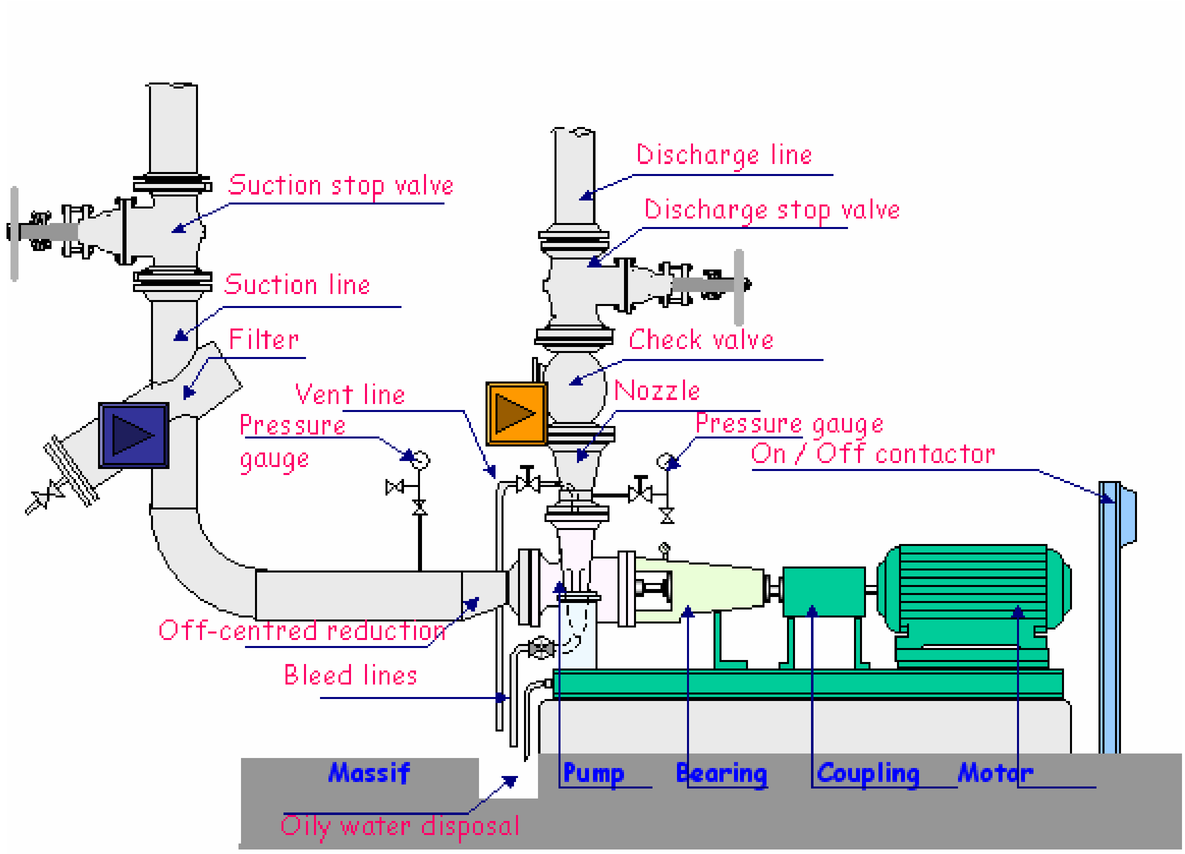


Figure 144: Accessories and process lines of a centrifuge pump in a unit

The system generally contains:

- **2 sectioning valves**: suction and discharge allowing for insulation.
- **A bend** (case of an axial suction pump) assembled sufficiently far from the pump

  Aim: to prevent the dissymmetrical distribution of the liquid in the impeller (generating vibrations.)

- **A temporary or permanent filter**, positioned at the suction point: protection of the pump against the arrival of foreign bodies which could damage it.

The system notably contains:

<u>Filters assembled directly in the piping between flanges</u>

Chinese cap filter and trapezoidal filter.
These filters may be vertical or horizontal.

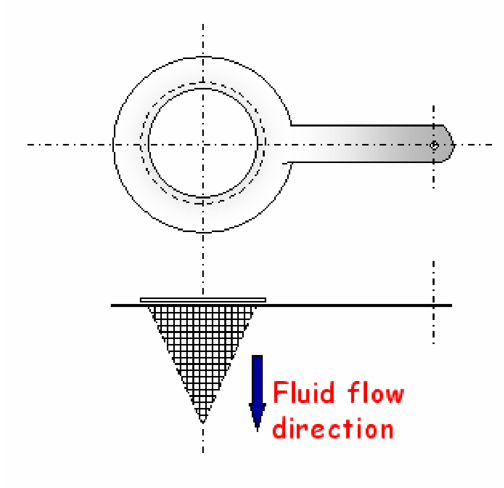


Figure 145: Chinese cap filter

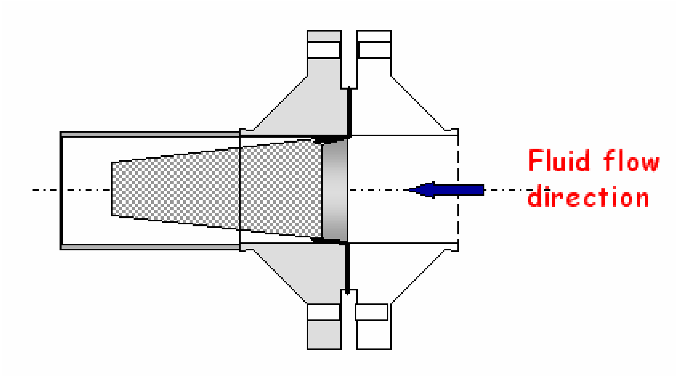


Figure 146: trapezoidal filter

<u>Filters assembled in a 90° T or a 45° bypass.</u>

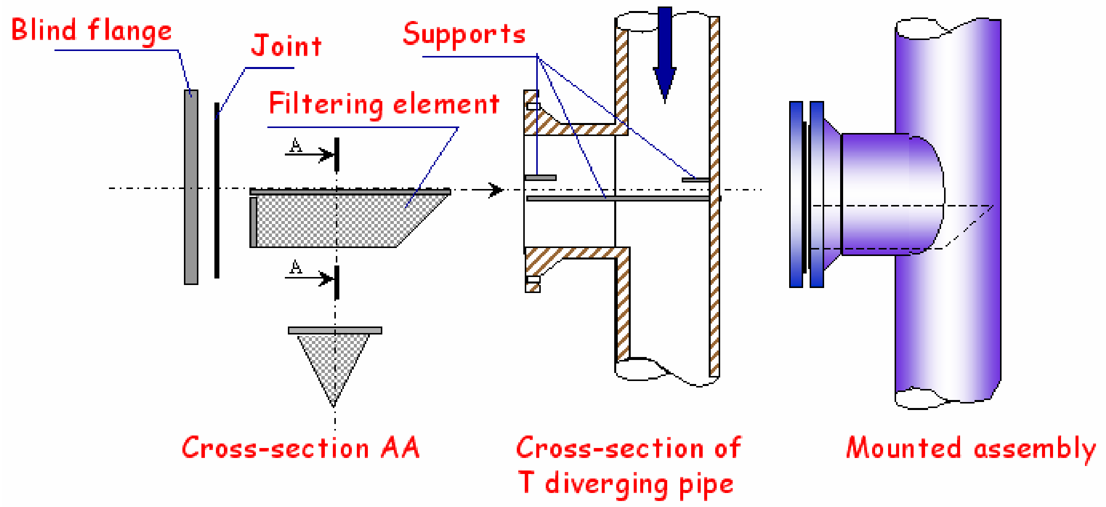
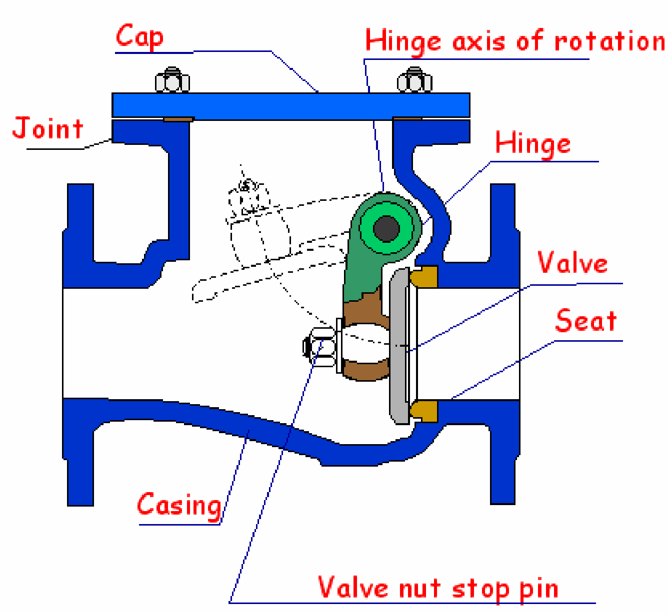


Figure 147: T filter

- **An outlet check valve**



Role: to prevent the liquid from returning via the pump (which may happen when the pump is inactive). This could cause the machine to rotate in reverse, resulting in mechanical damage.

Figure 148: Swing check valve

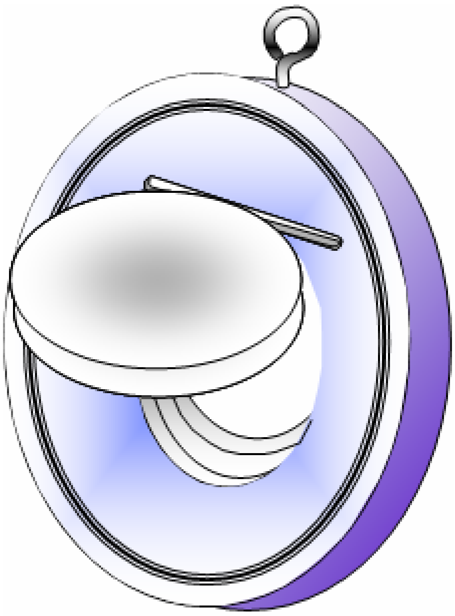


Figure 149: Flap valve

- **2 manometers**, one for suction, the other for discharge, to control the pump performance and the detection of certain operating problems.

The discharge manometer is **essential**.

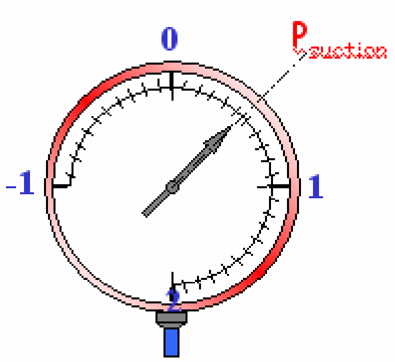


Figure 150: suction manometer

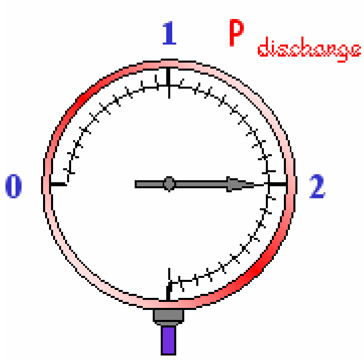


Figure 151: discharge manometer

- **The suction and discharge pipes**: generally have a diameter exceeding the corresponding flanges assembled on the pump.

- **A reduction before the pump suction flange. This must be off-centred** with the straight generator positioned in the upper section.

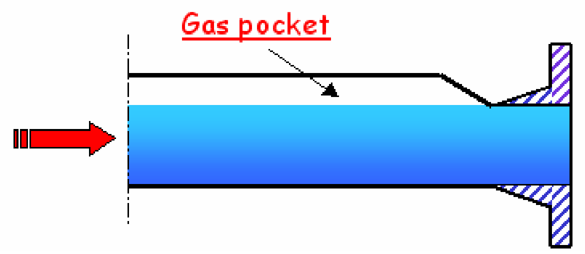


Figure 152: Reduction

Otherwise, the high point created by the largest diameter facilitates the accumulation of gas which, when it is freed, may create surges on all the mobile parts of the pump and may even trigger the latter (installation not recommended)

- **A divergent tube** positioned after the outlet flange. This should be as long as possible to prevent vortices and vibrations and therefore to channel the liquid correctly.

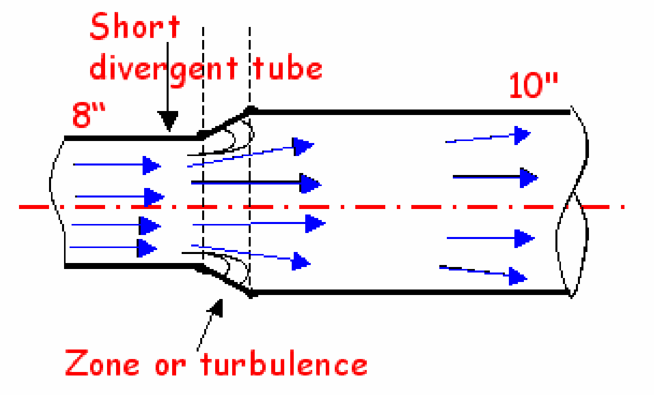


Figure 153: Formation of vortices with a short divergent tube

6.2. THE ASSOCIATED CIRCUITS

6.2.1. Cooling

When the pumped product is hot, it may be necessary to:

- Cool the packing body in order to maintain the mechanical resistance of the packing. The cooling fluid may be water or steam depending on the case. [1]
- Cool the bearing housing, which maintains the viscosity of the oil at a correct value (mechanical maintaining of bearings). [2]
- Cool the base stands to prevent them from dilating (risk of misalignment of the pump compared with the motor). [3]
- Cool the sealing liquid. [4]

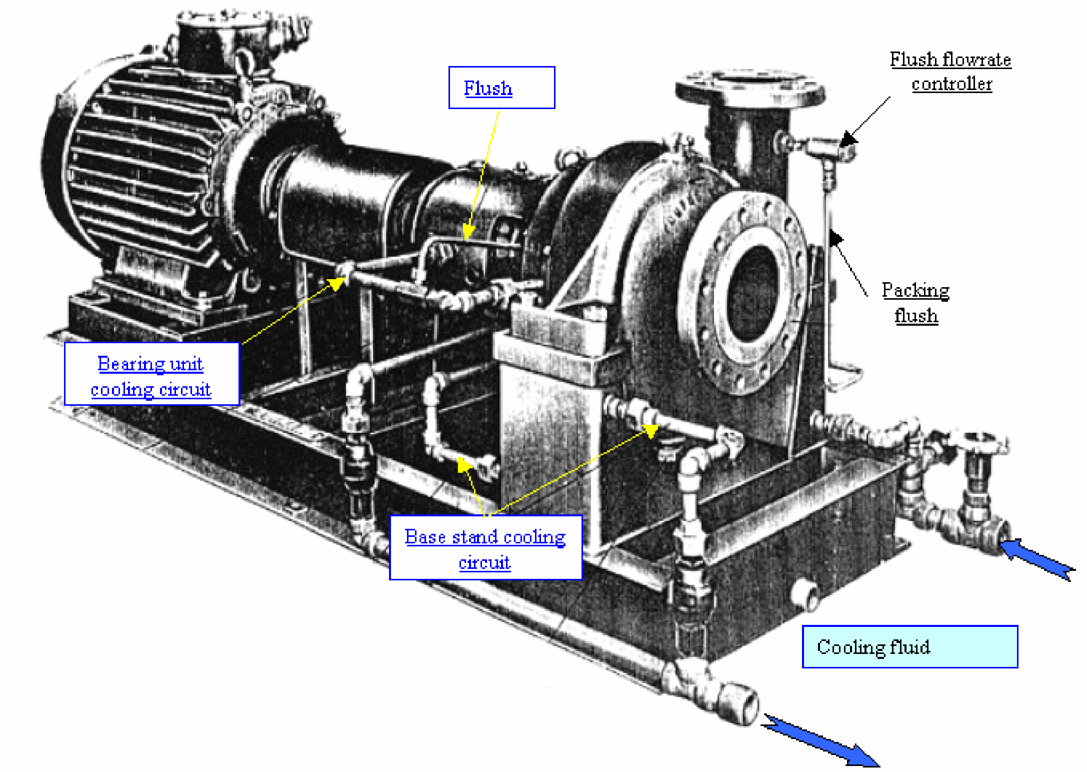


Figure 154: Cooling a centrifugal pump

6.2.2. Lubrication

All rotating mechanical units (ball bearings, roller bearings, bearing brush, etc.) require appropriate lubrication to ensure that they operate correctly.

Otherwise heating, excessive wear and tear, seizing and even blocking may occur. Lubrication with oil is the most common solution for “process” pumps.

The lubricating pump may be **independent** or **coupled** with the machine.

In this case, an additional system establishes circulation of he the oil before the machine is activated, until the coupled pump takes over. [1]

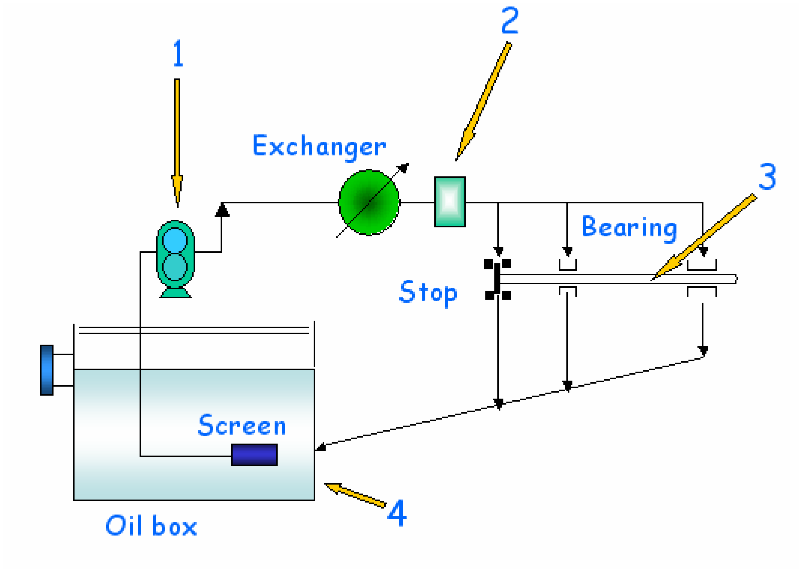


Figure 155: Lubrication system

The oil is filtered, generally **cooled**, either in the oil case or via an exchanger on the outlet line [2]

Forced circulation (rolling bearings and smooth bearings). A **gear accelerator pump** draws the oil from an oil reserve and distributes it to the different lubricating points (stop, bearing, etc.) [3]

The pressurised oil circulation system may be **fitted with safety systems** (temperature, pressure, etc.) which prevent activation or provoke the stoppage of the machine in the absence of lubrication.

The reserve may be contained either in one of the machine’s bearings or in an oil case. [4]

One of the advantages of forced circulation is that **the proper evacuation of heat** in the bearings, stemming either from friction due to the bearing action (case of smooth bearings and smooth stops) or to the transfer of heat from the liquid pumped at a high temperature.

6.2.3. Other associated circuits

Other auxiliary circuits may also exist in the vicinity of a pump. Purging circuits used to empty the pump body and upstream / downstream pumps. Diesel fuel lines to rinse the pump or steam lines depending on the type of pump and the product carried.

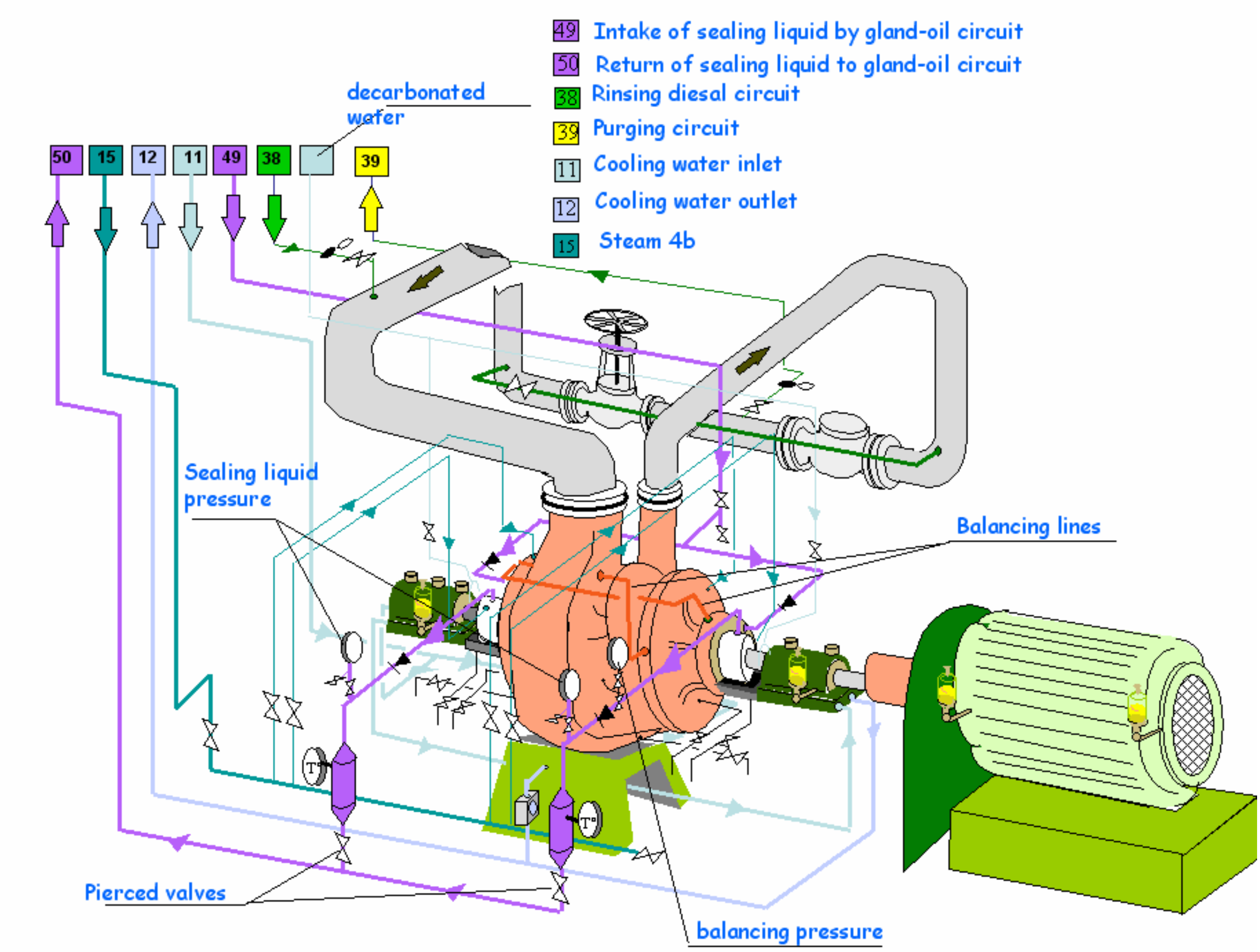


Figure 156: diagram of associated circuits equipping a hot pump

6.3. EXERCISES

66. The filter protects the pump against the arrival of foreign bodies which could damage it. It is situated at the outlet of the pump.

❑ True

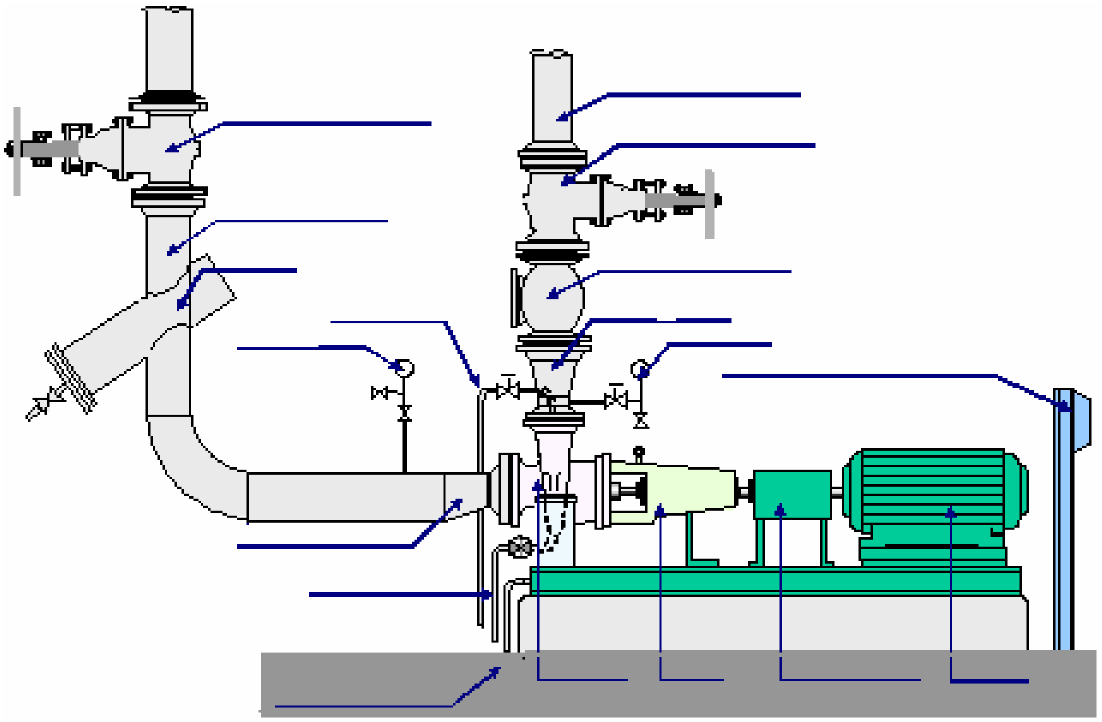
❑ False

67. The valve positioned at the outlet prevents the liquid from returning through the pump.

❑ True

❑ False

68. Complete the following diagram



69. The suction and outlet pipes generally have the same diameters as the corresponding flanges assembled on the pump.

❑ True

❑ False

7. OPERATING PARAMETERS

7.1. NORMAL OPERATIONS

Pump operation consists in ensuring that it provides the desired flow for the longest possible time.

The running of the machine may also influence its lifespan. The operator must therefore monitor the following elements whilst the machine is in operation:

- **For centrifugal pumps**
    - The outlet pressure
    - The suction pressure
    - The pressure difference in the suction filter.
    - The bearing temperature
    - Abnormal noises (water hammer, cavitation : phenomena explained below)
    - Mechanical imperviousness leaks
    - The average cooling temperature
    - The oil lubrication system (pressure, temperature and level)
    - The power consumption in amperes (intensity)
    - Les vibrations

- **For volumetric pumps**
    - The outlet pressure
    - The suction pressure
    - Leaks in the pump.
    - The oil lubrication system (pressure, temperature and level)
    - The cooling system
    - Check safeguarding system.

In addition, a certain number of hydraulic problems may disturb, or even prevent, the correct operation of the pump.

This is notably the case **at the time of initiation** in the event of **water hammer** or **cavitation.**

Details of these three phenomena are provided in the following pages

7.1.1. Priming

For a pump to be operational, it must provide sufficient pressure, which is not possible when it is full of liquid. By “purging” the air (or the gas) from the pump, the priming (or initiation) of the pump will be guaranteed.

A vent is often positioned on the body of the pump or on the pump outlet tube for this purpose.

When a non-primed pump is activated, the rotation generates an overpressure which depends on the density of the fluid (liquid + gas) in the wheel channels. The presence of gas in the wheel does not allow for the attainment of the highest pressure and, furthermore, the speed of the liquid in front of the vent orifice reduces this pressure due to the effect of kinetic energy. This explains the difficulties faced when priming a rotating pump.

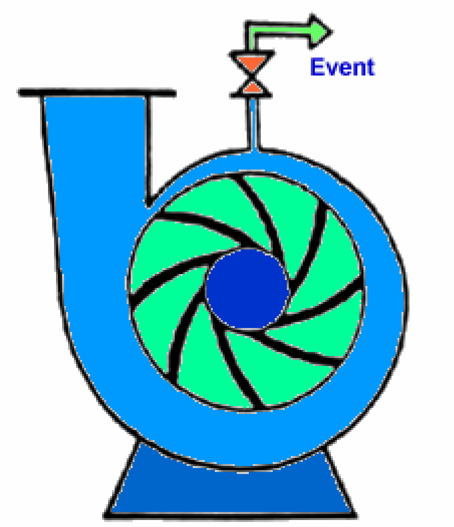


Figure 157: vent

Unpriming of a pump in operation generally requires the pump to be stopped and reinitiated.

In addition, when a rotating pump is to be primed, there is always a risk of the seal rings or the mechanical packing seizing because there is little or no liquid in the pump during this operating phase.

It is therefore **always preferable to prime a pump when it is not in operation** by introducing a liquid at a pressure which allows for the evacuation of air.

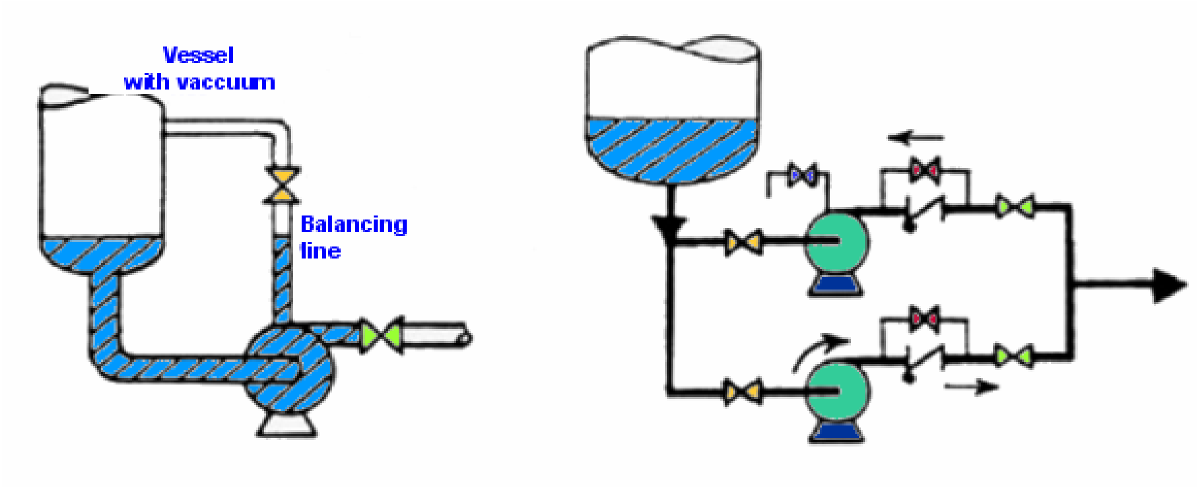


Figure 158: filing a pump in which the pressure is lower than the atmospheric pressure

If the **suction pressure is lower than the atmospheric pressure**, the pump may be filled:

- **By suction** thanks to an equilibrium line connected to the equipment (vacuum). {A}
- **By discharge**: filling by the other pump with the same process function {B}
- **By an external liquid** which is compatible with the pumped liquid introduced in the pump by an appropriate filling line

In the case of a **well suction pump**, priming may only occur if the suction piping is filled with liquid.

A leak in the foot valve makes this operation delicate or even impossible.

This operation is carried out using a foot valve which holds back the liquid which has been previously pumped or introduced in the piping or in the pump by a branch connection positioned at the outlet.

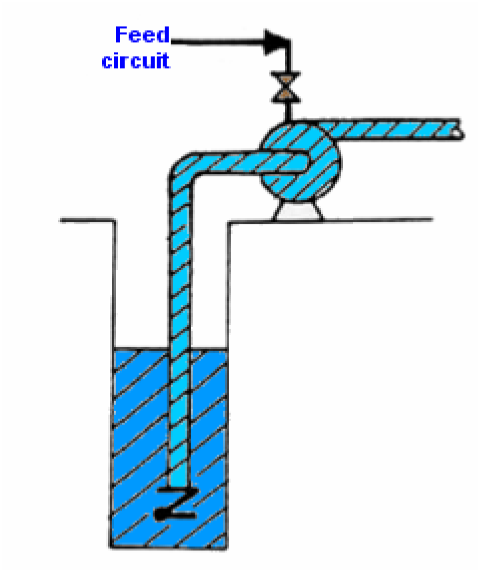


Figure 159: well suction pump

7.1.2. Self-priming

Certain pumps are said to be self-priming. This type of equipment can be classified in two families:

- Machines with an adequate reserve of liquid to allow for the gradual evacuation of the gas contained in the pump and in the suction pipe by the internal recycling of the liquid.

  In this case, the outlet piping is generally empty at the outset

- Machines which possess a primary wheel which allows for the slight compression of the gas.

A small amount of liquid is generally required to guarantee the imperviousness of the “compression wheel”.

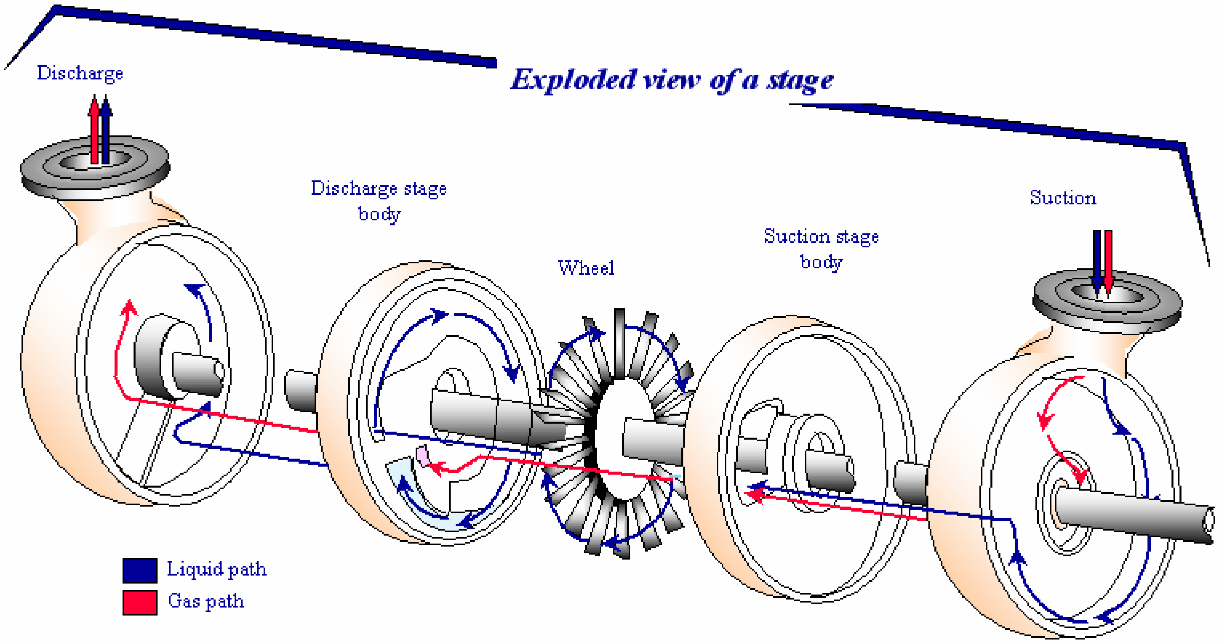


Figure 160: principle of a self-priming side channel pump

7.1.3. Water hammer

7.1.3.1. Description of the phenomenon:

A water hammer is a sudden pressure variation caused by a sudden variation in the flow.

In piping through which a liquid circulates, the **sudden closure of the valve** does not immediately block the entire volume of liquid located in the piping.

This liquid which is still in circulation is **"crushed"** against the upper surface of the valve gate producing a pressure increase whilst at the same time the pressure below the valve drops sharply.

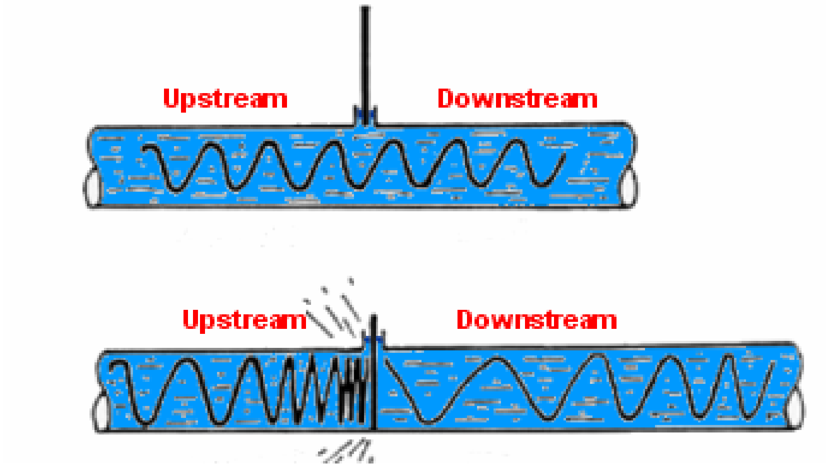


Figure 161: water hammer principle

This overpressure (or depression) located over a short distance **is shifted** in the form of a wave along the pipe (at the **speed of sound in the liquid - 7 km/s**) until it meets an obstacle which makes it move in the opposite direction.

A backwards and forwards movement of overpressure and depression is thus created which deceases over time due to the friction which triggers the movement.

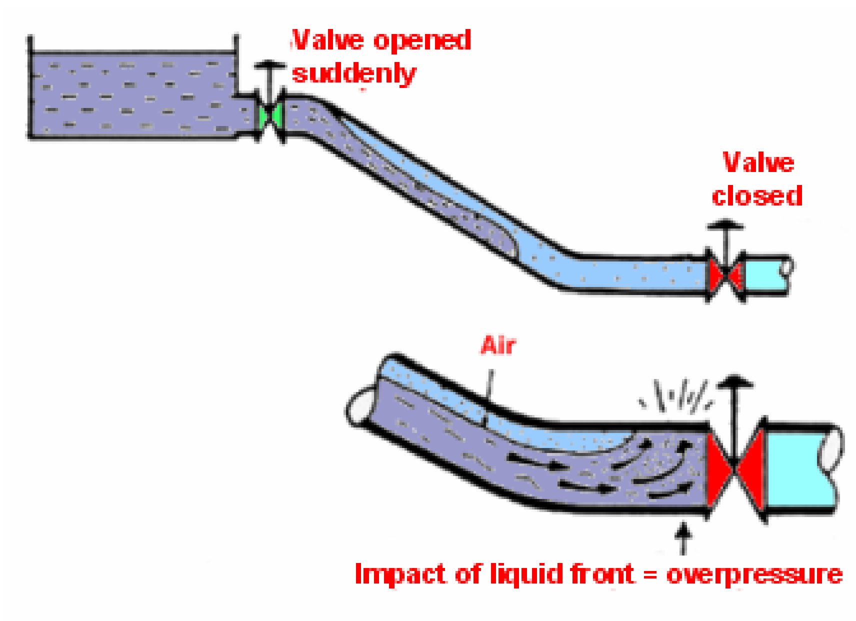


Figure 162: example of water hammer

N.B.: water hammer is often caused by the presence or air or gas in a liquid line.

Taking the example of the launch of a fire network, water hammer often occurs if the network has been incorrectly purged when it is reactivated.

When it reaches non-purged air pockets, the water obtained from the motor-driven pumps in the fire network compresses the latter and gives rise to overpressure in the network.

This phenomenon is identical to the water hammer described above, but this time it is not caused by the closure of a valve but by non-purged air pockets.

7.1.3.2. Water hammer effects and prevention

Due to the overpressure and depression created, water hammer may give rise to shocks and **failures in piping elements or mechanical parts**: joints, pump body, cap bolting, valves, etc.

Two solutions may be used to prevent these incidents:

- The **"non creation"** of water hammer
- The **overpressure of the variation** in pressure using appropriate equipment.

Preventing water hammer

The extent to the overpressure depends mainly on the **flow variation speed.**

It is therefore necessary to ensure that **only small flow variations are produced**.

It can therefore be concluded that it is preferable to:

- **Start a pump** with the discharge valve closed
- **Stop a pump** after closing the discharge valve
- **Open or close** the valves gradually (paying special attention to ¼ turn valves)
- **Using** valves and fittings free from plate
- **Filling** empty pipes slowly

Protecting against water hammer

However, it is very difficult to prevent water hammer in all cases.

The sudden stoppage of the pump is not often preceded by the closure of the discharge valve.

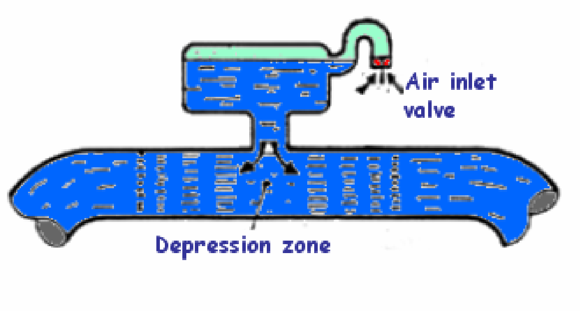
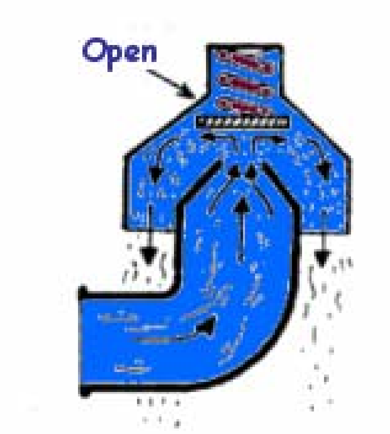


Figure 163 : equipment to protect against depression



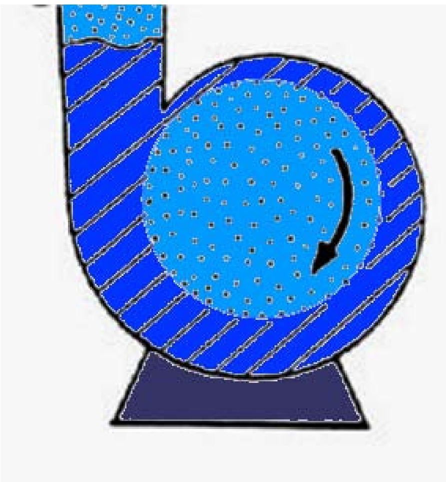
Protective equipment may be provided either to absorb water hammer, for example with an Olaer type anti-pulsating capacitor, or to protect against occasional significant overpressure by means of a delivery valve or a bursting disc for example.

Figure 164: equipment to protect against overpressure

7.1.4. CAVITATION

If the **input pressure of the wheel is less than the vapour pressure**, **partial liquid vaporisation** occurs which is reflected in the creation of gas bubbles (cavities).

These bubbles, which are carried by the liquid, move in the wheel and are therefore subject to increasing pressures.



The conditions are therefore such that the bubbles condense and are said to implode.

The formation of these bubbles increases the volume of fluid present in the low-pressure area, which has the effect of increasing the pressure in certain locations where the gas bubbles violently recondense by imploding.

The shock created by the bubbles bursting destroys the walls of the elements in contact with the fluid. A cavitation pump soon becomes worn.

Figure 165: cavitation principle

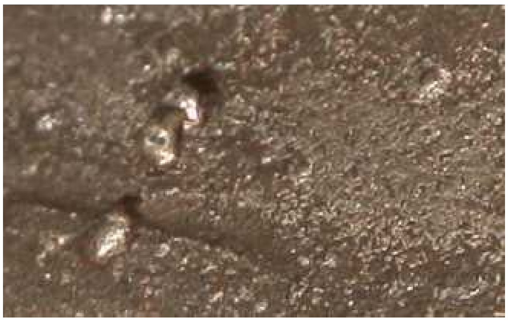


Figure 166: cavitation phenomenon relating to centrifuge pump blades

Solutions

Cavitation alters the pump’s characteristic curve which falls sharply in the flow area where the pump cavitates.
Sufficient closure of the outlet valve stops cavitation without significantly reducing the flow in relation to the cavitation situation.
This is the first solution to be applied.

The equipment is generally well designed and the **emergence of cavitation may stem from changes relating to operations or materials.**

This is also the case when the **level of the suction bottle is too low**.

Furthermore, **increases in production capacity** may well **be the cause of cavitation if** the alteration studies have not been conducted correctly.

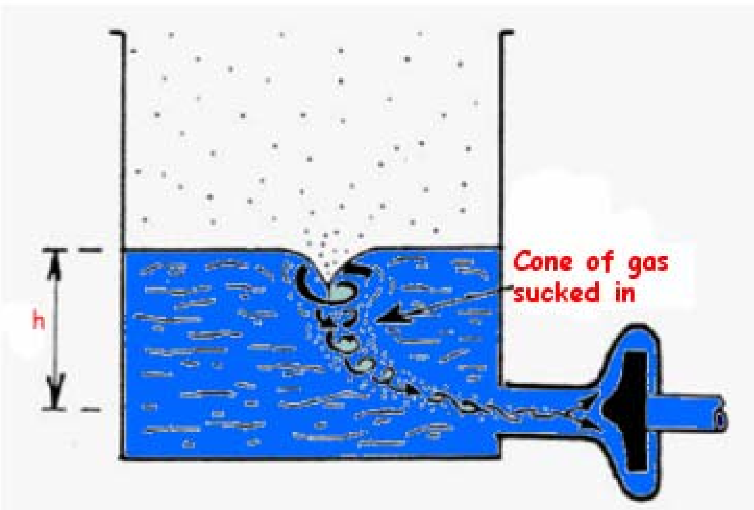
This is the case when **suction head losses have become excessive** (**dirty filter, partially closed valve**) or when the **pump repair is not correct** (**increase in internal clearances** for example).

7.1.5. VORTEX

The vortex is a mechanical drive phenomenon affecting part of the gaseous phase due to the rotation of the liquid at the pump input point.

This phenomenon occurs notably when:

- The level of liquid **h is low;** the flow of the pump is less than the nominal value.
- The pump or the pipe input are not equipped with an anti-vortex, a system consisting of crosses or expanded metal; the shape of the pipe input has not been adapted.



The gas input is generally irregular.

Each time gas enters the system, the pressure and power are reduced.

The gas "tube" may convey the noise in the pump to the surface.

Figure 167: Vortex effect

Moreover it is possible to damage the pump if its intended flow is not used.

The operator may adjust the flow to prevent the above.

There are three possible solutions:

- variation in the pump rotation speed using an electronic mechanism
- adjustment valve situated in the pump's outlet pipe to prevent the risk of cavitation: depending on the degree of openness, the head loss in the network will increase or decrease leading to a variation in the operating point.
- diverting part of the flow to the suction point to increase the flow rate

The flow adjustment is important for requirements linked to the process but also to attain a position in operating ranges with a higher output.

Operating limits

- Higher flow than intended: risk of overburdening the driving motor and risk of cavitation.
- Reduced flow: approximately 25 % of nominal flow. Risk of heating in pump.

7.2. SAFETY EQUIPMENT

The following safety equipment is generally used with pumps, and more specifically with centrifugal pumps:

- A low-pressure suction transmitter (protection against cavitation),
- A high-pressure outlet transmitter,
- If the pump is driven by an electric motor, an insufficient power safety device. This device may replace the two transmitters referred to above,
- A temperature sensor on the pump body if necessary,
- A temperature sensor on the bearings,
- Leak protection on the packing,
- Pump vibration monitoring and carrier, particularly in equipment with medium or high power.

7.3. MAX / MIN CAPACITIES

Pump	Flow	Pressure	Viscosity	Miscellaneous
Piston pump	A few l/h at 200 m3/h	Up to approx. 1 500 bars	Approx. 1 000 cPo	
Membrane pump	A few l/h at 50 m3/h (100 m3/h in certain models)	Up to 1 200 bars	Up to 50 000 cPo	Plastic membrane: pressure up to 350 bar Metallic membrane: pressure up to 1 200 bars
Gear pump	0 to 300 m3/h	Up to 20 to 30 bars	Between 1 and 20 000 cPo	Avoid dry operation Use of smooth bearings
Screw pump	< 1 000 m3/h	< 100 bars standard uses : 16 to0 bars	Max 100 000 cPo	
Progressing cavity pump	Up to 500 m3/h	Max pressure 60 bars standard uses: 4 to 16 bars		Stainless steel or cast iron rotor Polymer stator
Peristaltic pump	A few litres at 50 m3/h maxi	Up to 15 bars	Up to 60 000 cPo	Authorised particles : Less than 1/3 of the pipe diameter
Vane pumps	< 100 m3/h	< 10 bars	10 000 cPo	Bronze or plastic vanes Requires the use of self-lubricating pumped fluids
Centrifuge pump	A few l/h at over 1 000 m3/h	TMH up to 200 mCL with monocellular	< 400 cPo	
Side channel pump	Up to 30 m3/h	TMH up to 350 mCL		Self-initiating Suction of gas or steam possible

Table 9: Scopes of use of different types of pumps

7.4. EXERCISES

70. List 4 elements to be monitored during the operation of a centrifuge pump.

71. List 3 elements to be monitored during the operation of a volumetric pump.

72. It is preferable to initiate a pump by introducing liquid at a pressure which allows for the evacuation of air when:

- ❑ The pump is in operation
- ❑ The pump is inactive

73. A water hammer is a sudden pressure variation caused by a sudden flow variation

- ❑ True
- ❑ False

74. State 3 types of action to be taken to prevent water hammer

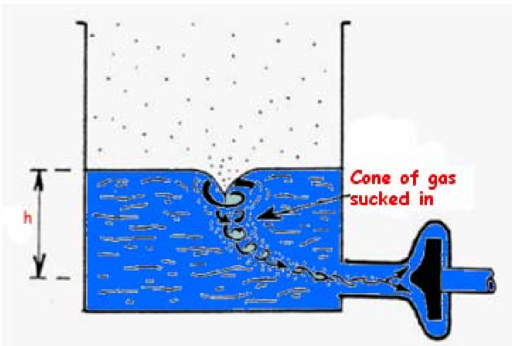
75. If the wheel input pressure is less than the vapour pressure, partial vaporisation occurs in the liquid

- ❑ True
- ❑ False

76. What is the first solution to be applied to stop cavitation without significantly reducing the flow in relation to the cavitation situation

- ❑ Sufficient closure of the suction valve
- ❑ Sufficient closure of the outlet valve

77. What is this phenomenon called? (Mechanical drawing of part of the gaseous phase due to the rotation of the liquid at the pump input)



78. What kind of safety equipment is generally found in a centrifugal pump?

8. PUMP OPERATION

8.1. PUTTING A PUMP IN OPERATION

This chapter deals with the commissioning of pumps and the precautions to be taken before and after the are put on production.

8.1.1. Centrifugal pumps

8.1.1.1. Initial start-up

Precautions to be taken before the initial start-up of a centrifuge pump:

- **In relation to the suction and discharge pipes**
    - Ensure that the pipes are clean (flushing).
    - Ensure that a temporary filter is installed (hat button).
    - Check the correct alignment of the suction and discharge flanges compared with the corresponding flanges on the pump to prevent the pump body being placed under pressure.
- **In relation to the pump**
    - Ensure that the pump is rotating freely.
    - Verify the correct pump / motor alignment.
    - Check the rotation direction.
    - Check the filling of the pump, purge the pump body and the packing quenching pipes.
    - Check the greasing of the bearings.

8.1.1.2. Start-up and commissioning

Important: A centrifuge pump must never run dry (operation without liquid), otherwise seizing and damage to the internal elements could occur.

One of the main characteristics of centrifugal pumps is their possibility of operating without any flow, at least during the launch period.

The pump can be started up with:

- the suction valve **open**,
- the suction valve **closed**,

NB: for a centrifuge pump operating with an electric motor, it is preferable to start-up the centrifuge pump with the discharge valve closed. The consumed power is at its lowest level with zero flow, which is an advantage for an electric motor because the electrical intensity passing through it is at its weakest.

The mechanical constraints are also at their lowest levels in this case. It is clear that as soon as the pump reaches its normal operating speed, the discharge valve will have to be opened fairly quickly to prevent the pump from being heated. A pump should not be operated with a closed discharge valve; otherwise the internal elements could be liable to seize.

If the discharge of a centrifuge pump remains closed for too long, the following phenomenon occurs: the liquid is heated (all the power of the motor is transformed into heat) and boils, the temporary imperviousness of the shaft is broken giving rise to a significant leak. The risk varies depending on the type of liquid involved: fire, corrosion, toxicity, expensive loss or simple cleaning.

NB: In the case of a long vertical pump without a foot valve (in other words when the pump is empty) even if the discharge valve is closed, the pump is started up as though the valve were open. It is therefore not necessary to start it with the valve closed.

8.1.1.3. After start up

- Check the packing leaks. A pump gland should drain.
- Check the suction and discharge pressures.
- In the event of manometer pulsations and suction noise, pinch the discharge until the pressure stabilises.

If it is necessary to keep the discharge pinched, this means that the network is not suitable, the discharge with the valve wide open is too great and the available NPSH is lower than the NPSH required with this discharge.

It will therefore be necessary to alter the characteristics of the network by installing either a throttling valve or a calibrated orifice at the discharge.

8.1.2. Volumetric pumps

The volumetric pumps generally encountered in oil facilities are brought into service in a very similar way; however it is important to remember that this type of pump must **always** be started with the suction and discharge valves **open**.

8.2. PROVISION OF A PUMP

The following steps must be followed to isolate a pump:

- Stop the pump
- Isolate the electrical power (see the electrical insulation procedure)
- Close the suction and outlet valve
- Depressurise the suction and outlet lines
- Respect the safety procedures recommended in the work permit.

8.3. 1ST LEVEL MAINTENANCE

The aim of this presentation is not to overwhelm you with theories but to try to teach you specific concepts to allow you to determine whether a machine is operating normally, to foresee potential problems and, if possible, to avoid or solve them.

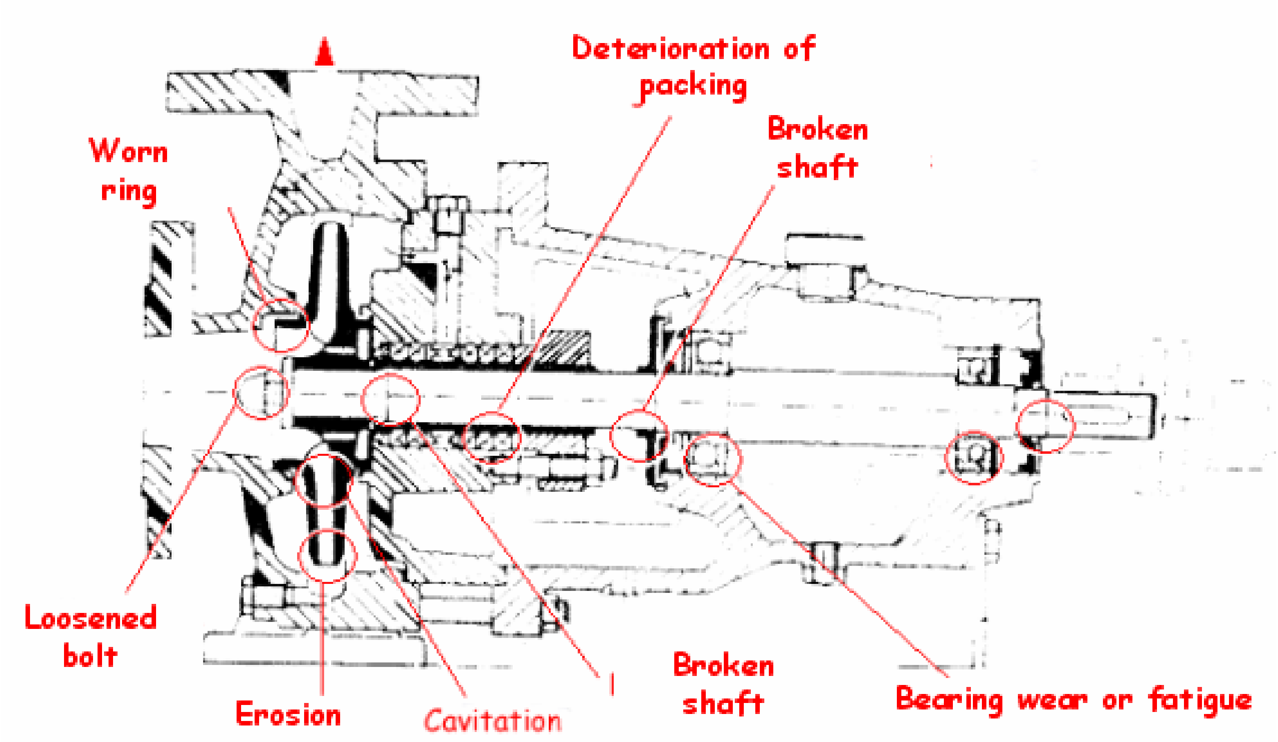


Figure 168: typical damage to centrifugal pumps

8.3.1. Analysis of symptoms

8.3.1.1. Normal noises

The average intensity of the aerial noise of a pump is between 70 and 80 dBa.
Noises differ depending on the size of the machine, its speed, the density and viscosity of the vehicle transmitted.

They can be of various origins:

- Noises due to fluid flowing through the piping
- Noises originating in the pump wheel
    - Hydraulic shocks at the blade input
    - Passage of blades in front of the volute tongue or in front of the diffuser blade inputs
- Bearing noises
- Whistling noises caused by throttling (diaphragms - valves – compressor valves)
- Motor noises
    - ventilator
    - bearings
    - magnetic noises

It should also be pointed out that motors are generally noisier than pumps (up to 110 dBa).

8.3.1.2. Anomalous noises

It is not possible to give a precise definition.

In general, concerns are raised on the subject of noise when the latter changes compared with usual operations:

- Noises of mechanical origin
    - bearings (rolling or smooth bearings)
    - vibrations (pneumatic drill noise)
    - coupling noises (worn stops, poor lineage, caulked or worn serration)

- Noises of electrical origin
    - Modulated overload noise which is very difficult to distinguish and analyse
- Noises of hydraulic origin
    - Noise when passing through excessively narrow areas or obstacles
    - Blocked filter noise (hissing).
    - Cavitation noise (an identical noise is caused when gravel passes through the pump. Also similar to crusher noise)

8.3.1.3. Cavitation

The cavitation phenomenon occurs in a pump when vapour cavities of varying sizes appear in the liquid transmitted.

When do vapour cavities occur?

When the pressure at a randomly chosen point (generally the wheel hole) falls below the liquid vapour pressure.

For a given temperature, this is the absolute pressure below which the liquid vaporises (transformation of liquid to steam).

Why can the pressure fall so low?

- Increase in head loss at the suction point
- Increase in suction height
- Suction in a vacuum tank
- Insufficient head
- Increase in the temperature of the liquid transmitted

What are the possible sources of cavitation?

- Installation
    - tank level too low at suction point
    - accidental obstruction in the suction circuit
    - unplanned increase in water temperature
    - unnoticed opening of an outlet valve
    - accidental increase in flowrate

- Pump
    - wear and tear of the wheel
    - damage to seal rings

NB : a pump may cavitate with low flowrates

Solutions

Check the above-mentioned points and amend the one or ones whose development appears to be harmful.

A pump may operate for a very short period with cavitation.

This situation should not be prolonged.

The damage is generally very rapid (depending on the material). Stop the machine.

8.3.1.4. Vibrations

In the past, inspectors used to “check” the vibrations of a machine :

- Directly by hand,
- By listening to the machine (screwdriver, pencils, etc.),
- By conducting the coin test.

Nowadays, proper measuring tools are used which allow for:

- The determination of the wear and tear of a machine,
- The determination of the deficient part of the machine, which is sufficiently precise to allow for the monitoring of the development of each machine.

Type of vibrations

A vibration is the oscillating movement of a part or part of material in relation to a point of reference.

A part which is cracked or corroded due to cracks randomly transmits the vibration or breaks due to the effect of the vibration.

Viscous or liquid media transmit vibrations by absorbing them slightly.

However, in the case of vapour or steam, the vibration is transmitted in the form of sound, infrasound or ultrasound and the absorption is fairly high.

Advantages of maintenance by vibrations

By analysing the vibrations of a set of machines, it is possible to avoid major expenditure in terms of machine maintenance. It can be said that:

- The periods between general visits are definitely extended,
- The development of each machine is monitored and disastrous faults can be avoided,
- The identification of deficient mechanical parts is improved by a more precise "diagnosis" provided by the analysis of vibrations.

To summarise, by monitoring the vibrations of a machine:

- the machine is stopped neither too early nor too late,
- the length of each intervention can be reduced.

8.3.1.5. Water hammer

Origin

All sudden changes to the flow speed of a fluid through a pipe results in the creation of a pressure wave.

This wave possesses its own propagation speed (approx. 1,000 m/s). It moves backwards and forwards inside the pipe where it originated between the two extremities of the latter.

The greater the variation in the flow speed and the shorter the time during which this variation occurs, the greater the amplitude of the propagated wave.

This phenomenon may occur in all pipes both at the suction and the outlet point of a pump and when the unit is either launched or stopped.

In general, the most dangerous cases are:

- Sudden stoppage due to the unsuspected disjunction of one or more units
- Electric pumps supplying an outlet pipe flowing into a tank
- Instant or excessively rapid closure of a sectional valve or
- A sealing tap positioned at the end of an inlet conduit

Consequences

Examples:

- Sudden increase in pressure
- Bursting of pipes
- Bursting of the pump body
- Leaks in the joint between two elements

Solutions

- repair: gradually closure of the discharge valve on the pump before stoppage
- long-term action: appointing specialists to conduct an anti-hammer study

NB: it is important not to confuse water hammer with valve knock (sudden closure of a flap valve at the discharge point)

8.3.1.6. Leaks

External leaks

- Braided pump gland – the water should always drain – the pump gland should be lubricated with a normal leak
- Mechanical packing - the film between the two friction surfaces is constantly renewed but no leak is apparent
- Joints – poorly tightened or broken joint

Internal leaks

- Liquid film in the pumps balanced by a disc and counter-disc
- Worn seal rings = internal recirculation

NB: oil leaks on bearings

In addition to the usual causes of oil leaks due to damaged joints or felt, the following may occur:

A pump operates with poor lineage. As we have seen, this may cause damage to the roller bearings (or bearings) which are heated.

The heated oil emulsifies, overflows and the bearing leaks.

The pump is stopped. The lineage is reset and the unit is reactivated.

However, the amount of oil in the pedestal bearing is no longer the same, since a certain quantity has been lost.

This may correspond to a large quantity at a certain point with insufficient oil remaining to reach the bearings or roller bearings.

8.3.1.7. Altered parameters

A further point to mention is the case where the pump no longer performs to its previous level.

This may be due to:

- Incorrect information provided by the manometer
- An upstream or downstream restriction. Example: blocked suction filter
- A change in the fluid composition (new viscosity, methanol entering the pumped liquid)

9. TROUBLESHOOTING

9.1. WHAT TO DO IF…

This chapter determines the action to be taken in response to the identification of faults in a pump.

However, before any action is taken, it is necessary to conduct a diagnosis.

The diagnosis is the identification of the cause of an operating fault. It allows for the ascertainment of the seriousness of the fault so that a decision can be reached concerning the stoppage of the machine as well as a precise indication of the work to be carried out by maintenance department.

It is essential (as far as possible) to compare the operating parameters and data of the faulty pump with its parameters just before the fault and to ensure that the operating conditions (process) have not altered in the meantime.

What are the possible causes of poor operation?

9.1.1. Zero flow

- Pump not primed,
- Insufficient speed (check the motor),
- Manometric height of the equipment greater than intended,
- Insufficient NPSH ,
- Wrong rotation direction,
- Air pockets in the suction pipes.

9.1.2. Insufficient flowrate

- Air input at the suction point,
- Insufficient speed ,
- Manometric height of the equipment greater than intended,
- Partially blocked impeller,

- Insufficient suction pressure (cavitation),
- Worn seal rings or damaged impeller,
- Foot valve too small or waterlogged,
- Foot valve not sufficiently immersed.

9.1.3. Insufficient pressure

- Air input in the suction pipes,
- Emission of air or vapour in the pipes,
- Same mechanical faults as above: seal rings - impeller

9.1.4. Unpriming in operation

- Air input in the suction pipes,
- Excessive suction height,
- Emission of air or vapour in the liquid,
- Air input in the stuffing box.

9.1.5. Exaggerated absorbed power

- Excessive speed,
- Total manometric height less than intended,
- Pumped liquid with different density or viscosity from intended values,
- Mechanical faults.

9.1.6. Pump vibration

- Poor alignment,
- Insufficient foundations,
- Foreign bodies in the impeller leading to imbalance,
- Mechanic faults – non-aligned shaft,
- Friction of internal elements,
- Wear and tear of roller bearings,
- Pump without water,
- Cavitation.

9.1.7. How can cavitation be rectified?

When a pump cavitates, it is generally due to a pressure drop at the suction point; it is therefore necessary to re-establish correct pressure.

To do so, it is necessary to verify the following points:

- The total opening of the valves between the aspirator bottle and the pump
- The level of the aspirator bottle
- The loss of head in the filter
- Moderate flowrate
- The temperature and quality of the product
- An excessive internal clearance in the seal rings caused by wear and tear or an imperfect repair.

By reducing the flow in the pump by partially closing the outlet valve, it is possible to reduce and event eliminate cavitation, but this is only a temporary measure and it is always important to identify the cause of cavitation..

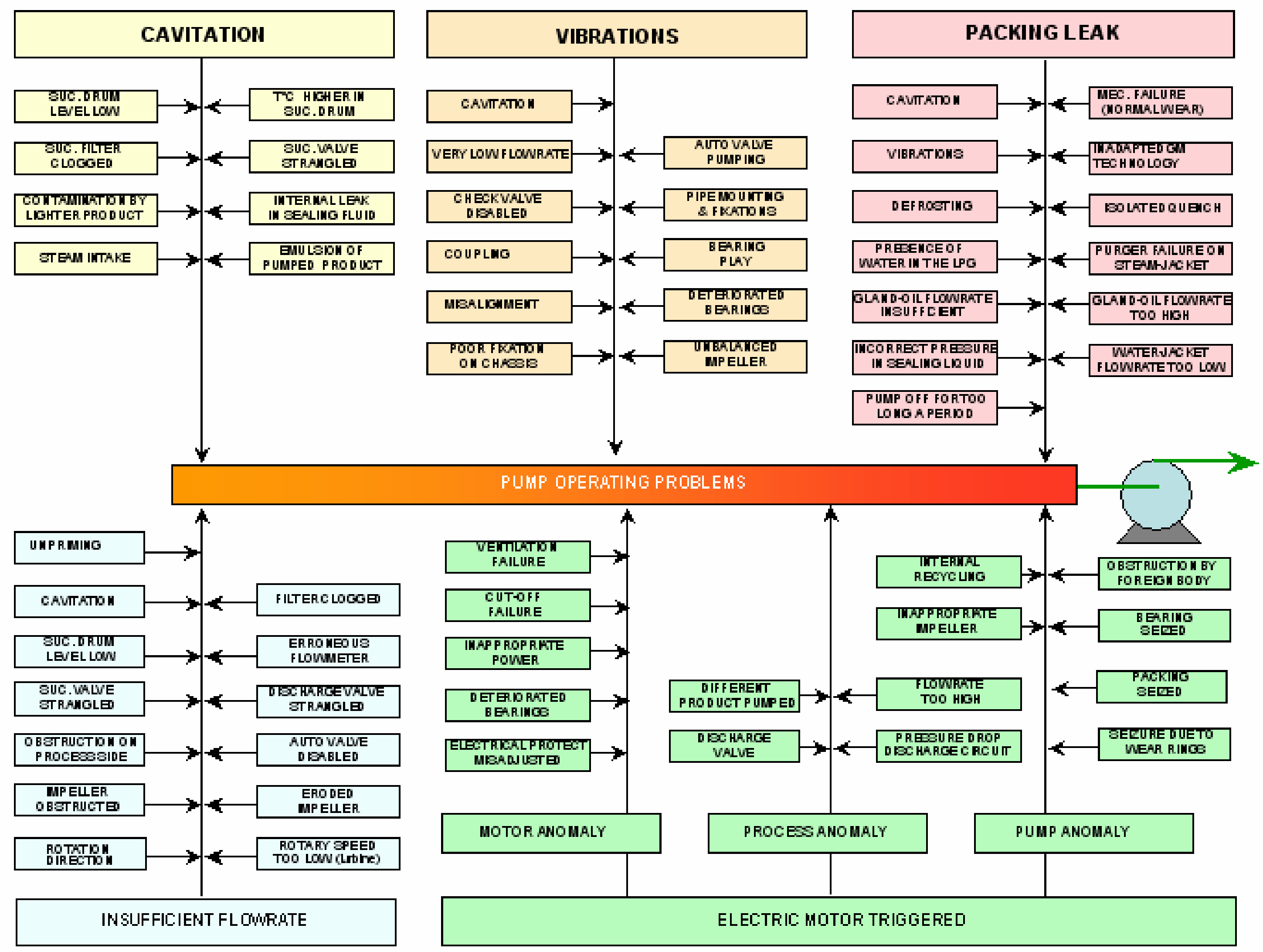


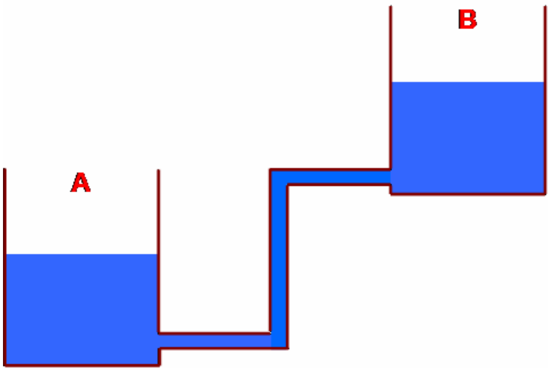
Table 10: Main causes of pump malfunctioning in operation

10. FIGURES

11. TABLES

12. CORRECTIONS FOR EXERCICES

79. What way will the fluid flow?

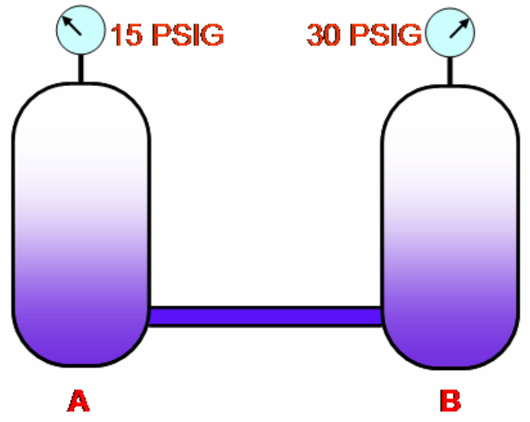


☑ B to A

80. Why?

Fluid will flow from B to A because the fluid at B is at a higher elevation, and has more potential energy than the liquid at A.

81. What way will the fluid flow?



☑ B to A

82. Why?

Fluid will flow from the higher pressure at B to the lower pressure at A.

83. What are pumps used for?

☑ Conveying a fluid from point A to point B

84. What are the 2 main categories of pumps?

- Centrifugal pumps
- Positive displacement pumps

85. What kind of pump is this?

☑ Centrifugal pump

86. What kind of pump is this?

☑ Displacement

87. What is the operating principle of a displacement pump?

The flow develops from the variation in the volume occupied by the liquid.

88. What is the operating principle of a centrifugal pump?

The liquid moves as a result of an energy increase derived from the centrifugal force.

89. What is the most common means of conveying fluids?

☑ Centrifugal

The simplest and most common means of conveying liquids (Crude, Oil, Water) is the centrifugal pump, and it is also the most economical means.

90. What are the 3 types of application for which centrifugal pumps lose their effectiveness?

☑ Pumping viscous products

As from a certain degree of viscosity, using a centrifugal pump would require using an oversized pump which would deliver a flowrate outside of its optimum specifications, and so make for very poor efficiency, and consequently a very high power consumption.

☑ Pumping liquids deemed "sensitive"

Liquids deemed "sensitive", react poorly to the internal eddies present in a entrifugal pump (milk, wine, beer, volatile liquids, etc.).

☑ Accurate and instantaneous dosing

Using a centrifugal pump would require the facility designer to use a flowmeter to control the speed of the centrifugal pump, with the risk of the pump operating outside of its optimum specifications.

91. Pumps, whether they are centrifugal or displacement, mainly convey:

☑ Liquid

Pumps, whether they are centrifugal or positive displacement, are used for conveying liquids of all types: water, hydrocarbons, more or less viscous liquids, chemicals or toxic substances such as benzene.

92. In what situation can a pump convey a gas?

Vacuum pumps such as liquid-ring rotary pumps can convey gas

93. Does the composition of the effluent affect the choice of pump to use?

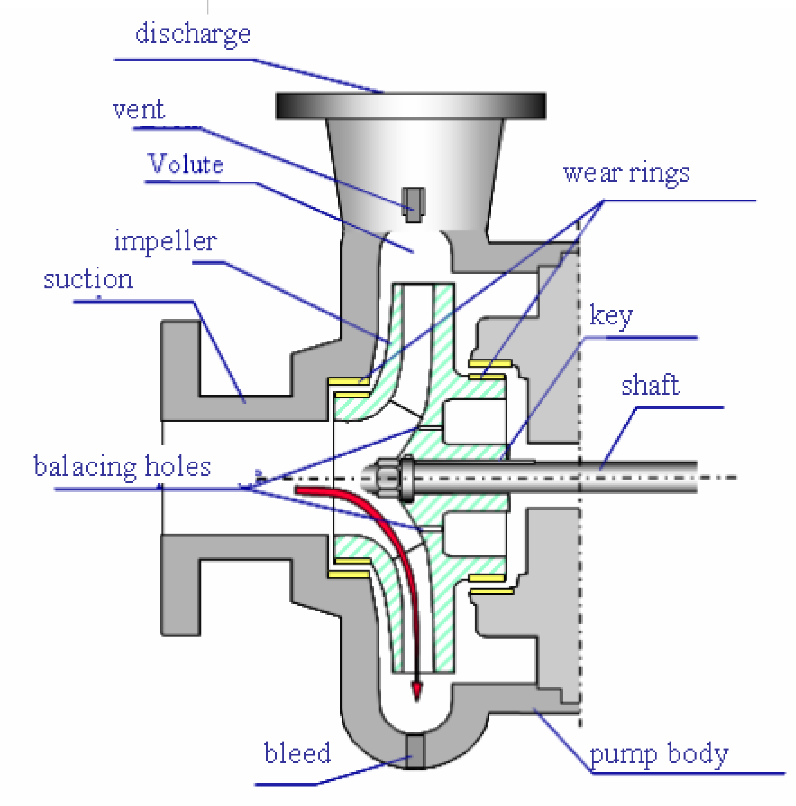
☑ Yes

Yes, it is often the composition of the effluent that will determine the type of pump to use.

94. What are the different functions of a centrifugal pump?

- Hydraulic function
- Rotation guide function
- Axial guide function
- Lubrification function
- Sealing function
- Cooling function
- Assembly function

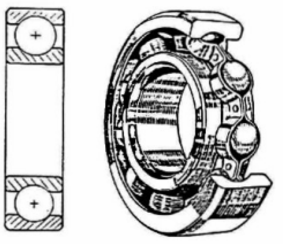
95. Complete the following diagram:



96. What is the function of the bearings?

Rotation guide function

97. What type of bearing is this?



Ball bearing

98. A stop ensures the axial positioning of the rotor

☑ True

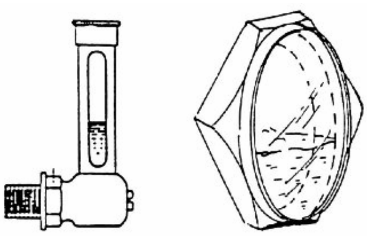
The axial positioning of the rotor is in the vast majority of cases ensured by a **stop**. In fact if roller bearings are used, the stop function is often provided by an axially locked ball bearing (deep groove or with 2 rows of angular contact balls opposite each other). On big pumps plain stops or pad stops may be found.

99. Grease lubrication is the most common on "process" pumps.

☑False

Lubrication is the most common on "process" pumps.

100. What type of controller is this?



Visual level indicator

101. The oil temperature must not be too low to maintain proper viscosity.

☑ True

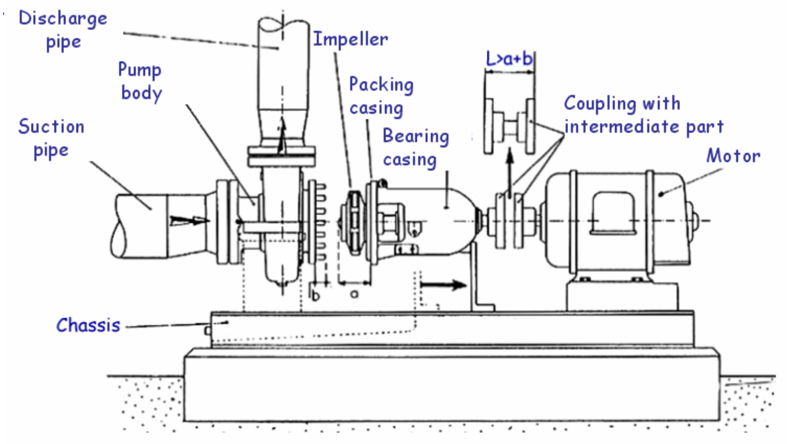
102. The oil temperature must not be too high to avoid thermal oxidation.

☑ True

103. What 2 types of seal packing can be found along a shaft?

Mechanical packing
Packing box

104. It is impossible to repair the packing or its bearings without disassembling the suction and discharge piping on this type of pump.



☑ False

Dismantling a pump to repair the packing or the bearings is possible without removing the suction and discharge pipes. For this reason, pumps are divided into two parts, a **mobile part** which consists of the packing casing and the bearing and rotor housing and the **pump body,** where the suction and discharge pipes are fitted. The pump body normally remains fixed to the base when repairs are to be made to the rotating parts.

105. The execution of a cyclic movement, during which a given volume of liquid enters a compartment before being discharged at the end, is the operating principle of a positive displacement pump

☑ True

106. Rotary pumps consist of a moving part actuated by a rotational movement around an axis, which turns in the pump barrel and induces movement of the pumped liquid by displacing the volume from the suction point to the discharge point.

☑ True

107. The volumes created in a reciprocating pump, at suction and discharge, result from the reciprocating displacement of a piston or a plunger on its axis inside a cylinder.

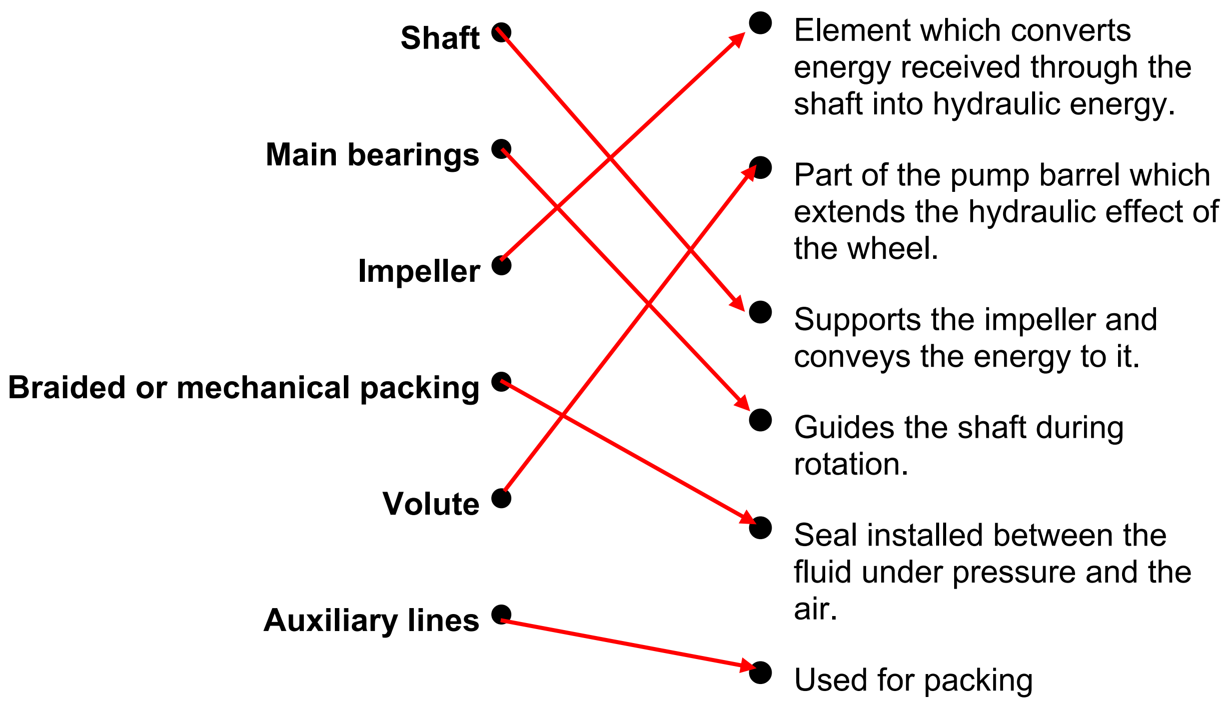
☑ True

108. A double-flow pump has one suction port and two discharge ports.

☑ False

They have two suctions, joined on a single flange

109. Find the definitions which match the following elements:



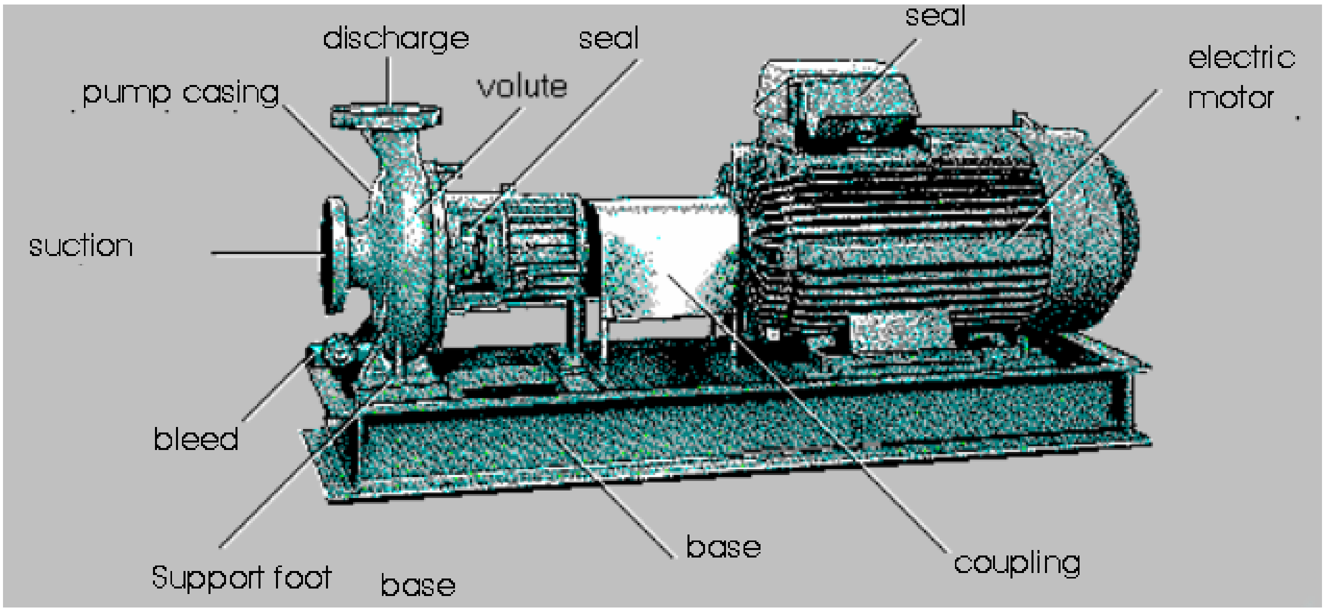
110. Which is which?

Open impeller

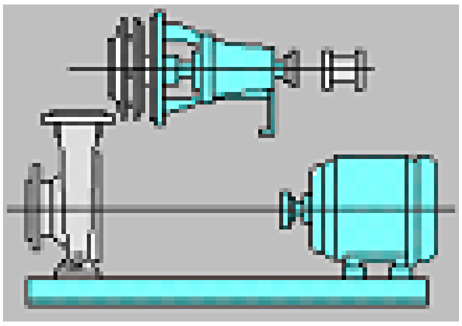
Closed impeller

Partially open impeller

111. Complete the following diagram:

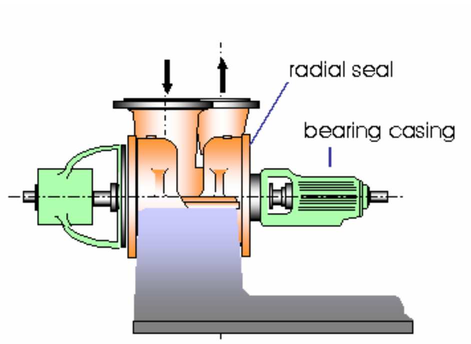


112. The "Back-Pull-Out" system allows the mobile assembly to be removed whilst leaving the pump barrel and motor in place



☑ Yes

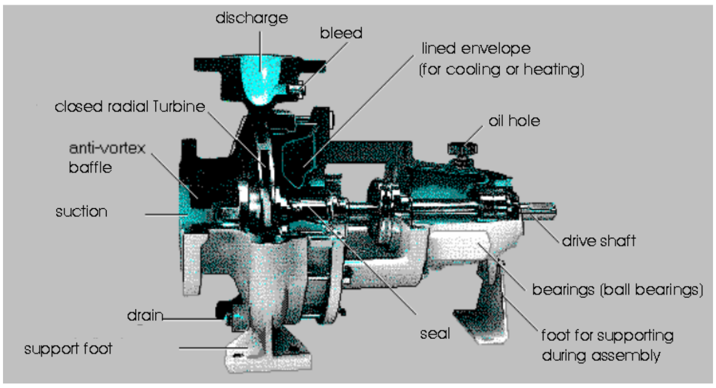
113. What is the category of this pump?



☑ T-T

The suction and discharge branches of these pumps are vertically mounted with the flanges in the same horizontal plane

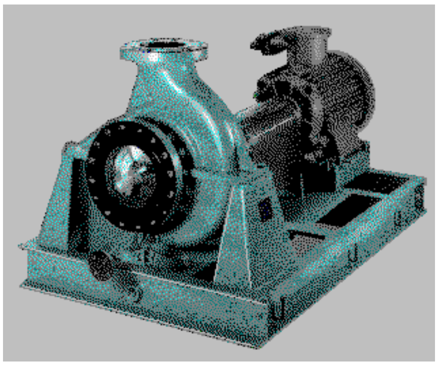
114. What is the category of this pump?



☑ A-A

This is a axial suction pump. with only one overhung wheel and whose suction branch axis is combined with the machine rotation axis. The discharge branch is vertical.

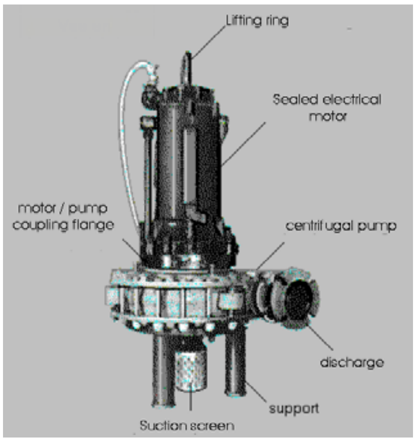
115. A foot-mounted pump is used for continuous, rough operating conditions



☑ True

These pumps are reliably and carefully designed for use in continuous rough working conditions and can work without failure at 25 bars and 450°C.

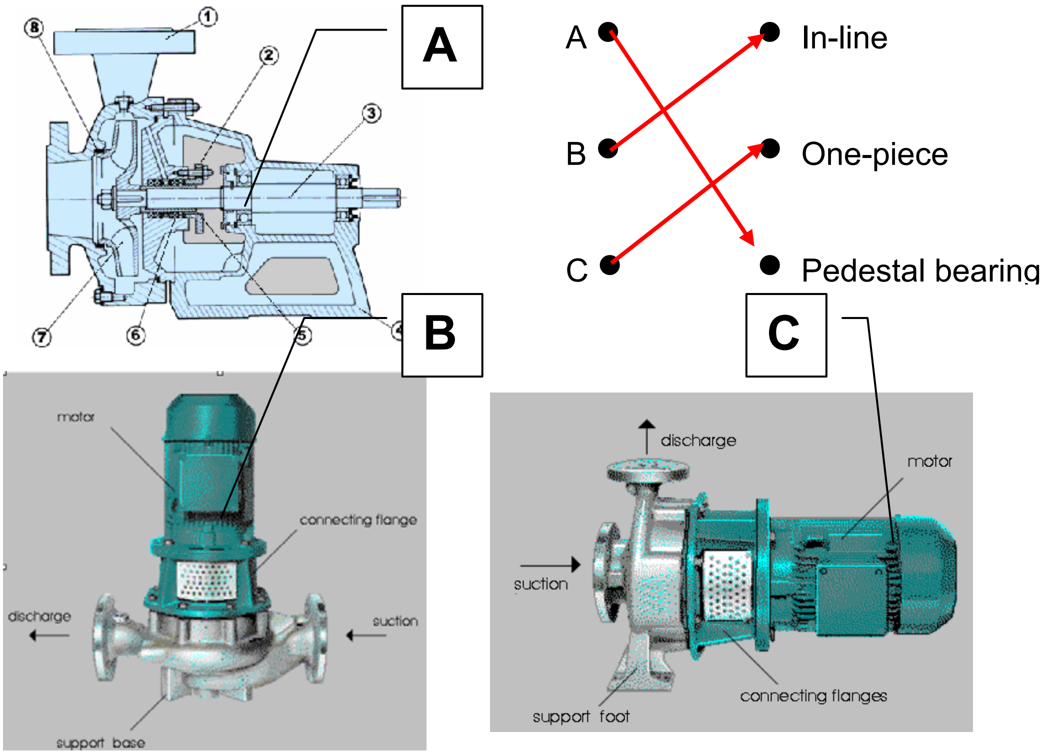
116. An immersed pump is not a one-piece design



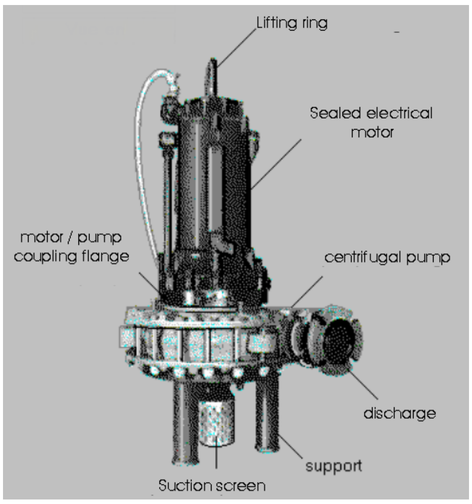
☑ False

Immersed or submersible pumps, are traditional centrifugal pumps with a one-piece design, i.e. whose motor is directly supported by the pump barrel

117. In which categories would you classify these pumps?



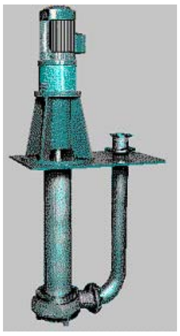
118. Can an immersed pump be removed without having to go down into the ditch?



☑Yes

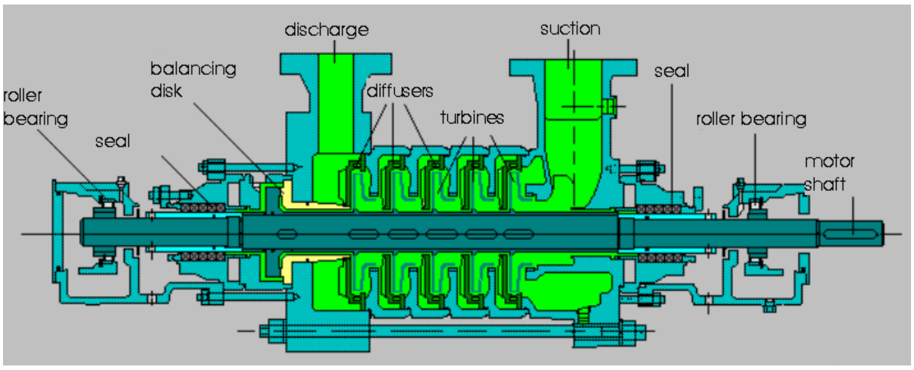
An ingenious guide rail system is used to automatically position and remove the pump from its support placed at the bottom of the pit.

119. A vertical pump is used for emptying pits or buried tanks, when an immersed pump is not suitable.



☑ True

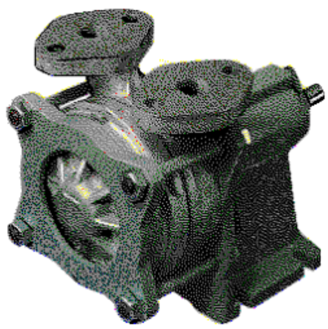
120. Multi-stage pumps are used for discharging liquids at very low pressures



☑False

About twenty stages can be assembled, thereby exceeding a discharge pressure of 400 bars for a rate of 1 000 m^3/hr.

121. Side channel pumps do not dry up if they suck in a gas and liquid mixture.



☑ True

Side channel pumps are often called "self-priming". In fact, they are centrifugal pumps that do not dry up if it sucks a gas and liquid mixture.

122. Side-channel pumps must start up with the discharge closed

☑ False

They must be started up with discharge and suction valves entirely open.

123. Magnetic drive pumps are used for toxic and corrosive products

☑ True

Pumping toxic products (e.g. benzene) is a delicate operation due to the *risk of emission into the atmosphere* at the drive shaft passage. This is always a possibility, whatever type of packing is installed. The solution to this problem is *magnetic drive*.

124. Displacement pumps are so-called "self-priming" since, from start-up, they cause an upstream pressure drop which allows the liquid to be sucked in.

☑ True

125. Centrifugal pumps allow TMHs that are much higher than those of displacement pumps.

☑ True

126. The efficiency of displacement pumps is often very close to 90%.

☑ True

127. The flowrate is adjusted by acting on the rotation speed of the rotor for rotary pumps and on the frequency or stroke of the piston for reciprocating pumps.

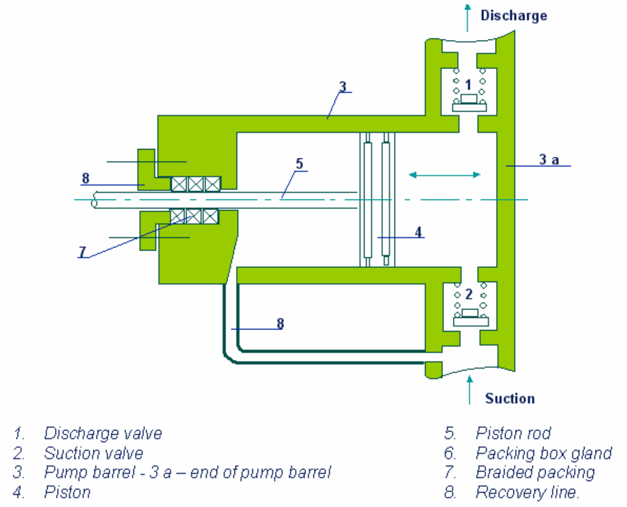
☑ True

128. What are the two operating principles for displacement pumps?

a. Reciprocating displacement pumps (e.g. for pumping chemical products such as demulsifiers or antifoam)

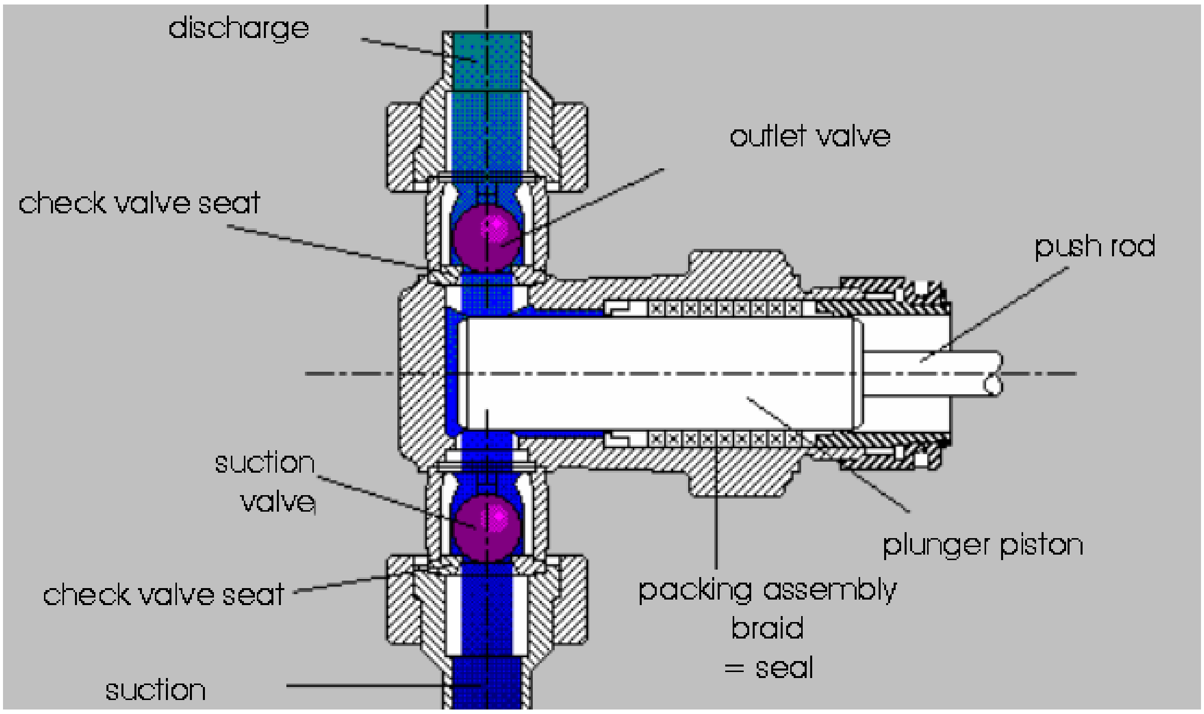
b. Rotary displacement pumps (with a fixed displacement) (e.g. flare drum pumps for condensate recovery)

129. Is this a reciprocating pump?

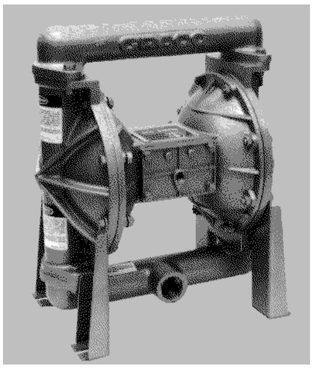


☑ Single acting

130. Complete the diagram of a metering pump head:

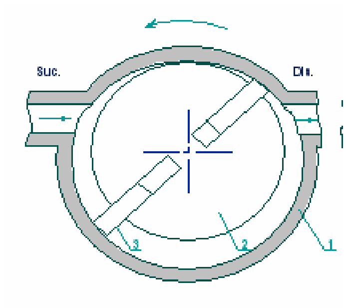


131. What is this type of pump?

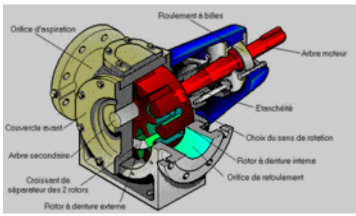


Air-operated reciprocating pump

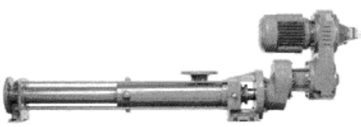
132. What are these types of rotary displacement pumps?



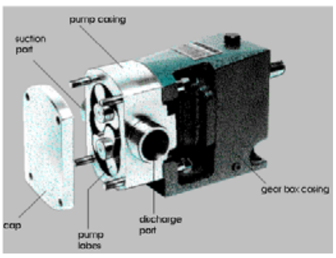
Vane pump



Gear pump



Progressive cavity pump (Moineau pump)

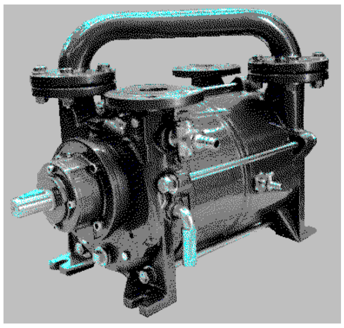


Lobe pump

133. MOINEAU pumps are used for pumping slightly viscous liquids

☑ False

They are used for very slurry or heterogeneous liquids



134. What type of pump is used for carrying gas and not liquid?

Rotary liquid ring pump

135. Give 3 advantages of reciprocating pumps

Self priming
Allow much higher TMH's than centrifugal pumps
Flowrate does virtually not depend on the network characteristics
Efficiency very close to 90%

136. Give 2 disadvantages of reciprocating pumps

Flowrate is lower than centrifugal pumps
Flowrate is not constant in time

137. Give 3 advantages of rotary pumps

Regular flowrate
Flowrate varies little with ΔP
Adapted to low and very low flowrates
Adapted to viscous products

138. Give 1 disadvantage of rotary pumps

Limited use for dry and abrasive liquids

139. Give 3 advantages of centrifugal pumps

Flowrate regular
High flowrate

140. Give 2 disadvantages of centrifugal pumps

Not adapted to very low flowrates
Not adapted to viscous products

141. What do the initials PCF and PFD signify in English?

Process Flow Diagram – Plan de Circulation des Fluides

142. What do the initials PID signify in English?

Piping and Instrumentation Diagram

143. As far as the treatment of oil is concerned, what is the level of criticality if the pumps transporting oil from a separator to a desalter become inactive?

☑ High

The criticality is high because the interruption of these pumps will result in a production stoppage.
The evacuation of liquids from the separator situated upstream of the pumps will become impossible as this will irrevocably result in a high level in this drum.

144. The filter protects the pump against the arrival of foreign bodies which could damage it. It is situated at the outlet of the pump.

☑ False

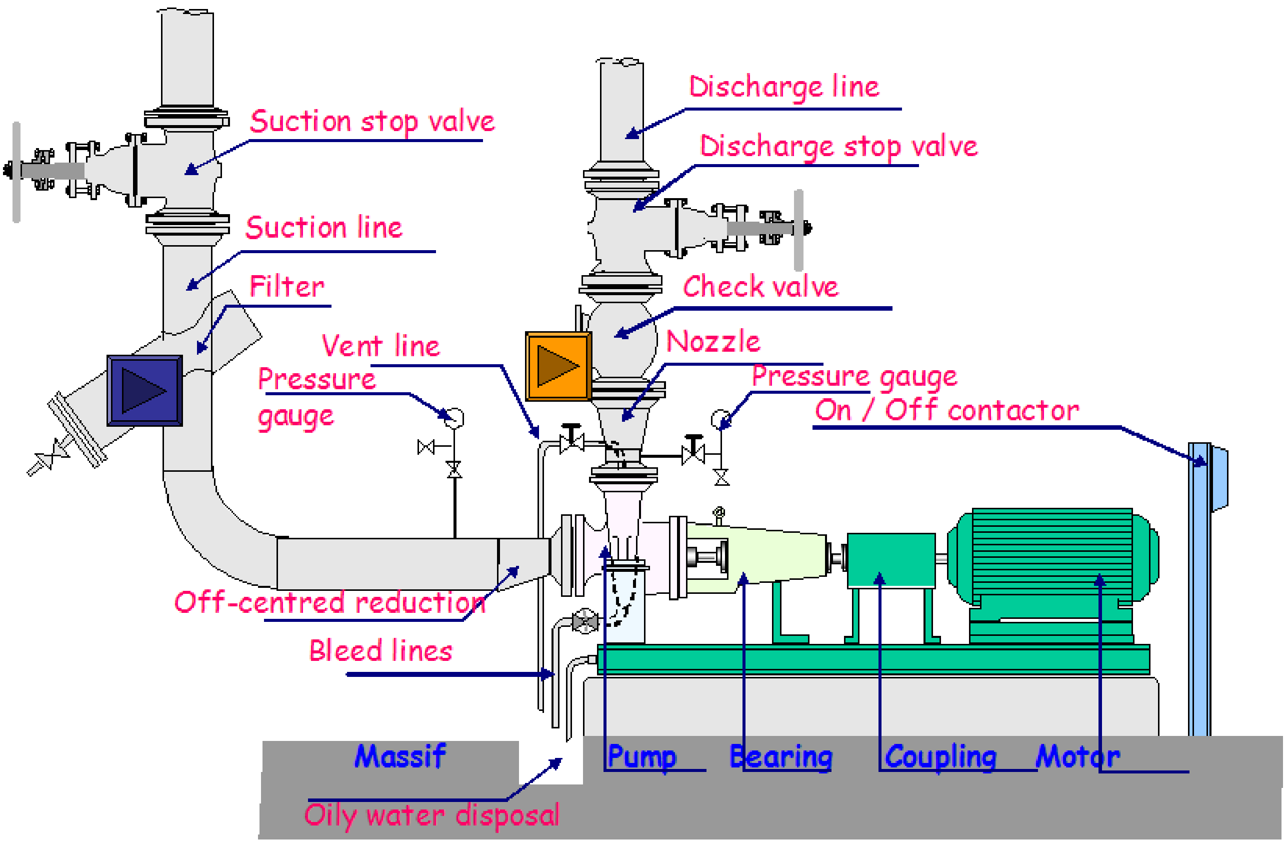
A temporary or permanent filter protects the pump against the arrival of foreign bodies which could damage it, but it is not positioned at the outlet, but at the suction point:.

145. The valve positioned at the outlet prevents the liquid from returning through the pump.

☑ True

An outlet check valve prevent the liquid from returning via the pump (which may happen when the pump is inactive). This could cause the machine to rotate in reverse, resulting in mechanical damage.

146. Complete the following diagram



147. The suction and outlet pipes generally have the same diameters as the corresponding flanges assembled on the pump.

☑ False

The suction and discharge pipes generally have a diameter exceeding the corresponding flanges assembled on the pump.

148. List 4 elements to be monitored during the operation of a centrifuge pump.

- The outlet pressure
- The suction pressure
- The pressure difference in the suction filter.
- The bearing temperature
- Abnormal noises (water hammer, cavitation : phenomena explained below)
- Mechanical imperviousness leaks
- The average cooling temperature
- The oil lubrication system (pressure, temperature and level)
- The power consumption in amperes (intensity)
- Vibrations

149. List 3 elements to be monitored during the operation of a volumetric pump.

- The outlet pressure
- The suction pressure
- Leaks in the pump.
- The oil lubrication system (pressure, temperature and level)
- The cooling system
- Check safeguarding system.

150. It is preferable to initiate a pump by introducing liquid at a pressure which allows for the evacuation of air when:

☑ The pump is inactive

It is always preferable to prime a pump when it is not in operation by introducing a liquid at a pressure which allows for the evacuation of air.

151. A water hammer is a sudden pressure variation caused by a sudden flow variation

☑ True

152. State 3 types of action to be taken to prevent water hammer

a. Start a pump with the discharge valve closed
b. Stop a pump after closing the discharge valve
c. Open or close the valves gradually (paying special attention to ¼ turn valves)
d. Using valves and fittings free from plate
e. Filling empty pipes slowly

153. If the wheel input pressure is less than the vapour pressure, partial vaporisation occurs in the liquid

☑ True

If the input pressure of the wheel is less than the vapour pressure, partial liquid vaporisation occurs which is reflected in the creation of gas bubbles (cavities).

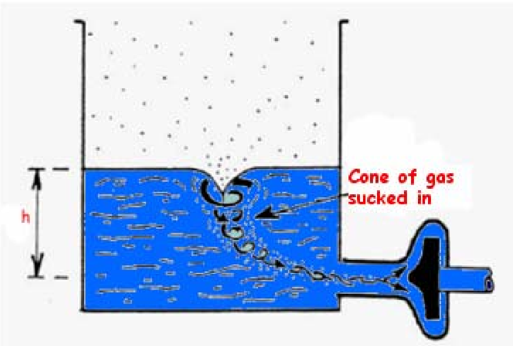
154. What is the first solution to be applied to stop cavitation without significantly reducing the flow in relation to the cavitation situation

☑ Sufficient closure of the outlet valve

Cavitation alters the pump's characteristic curve which falls sharply in the flow area where the pump cavitates. Sufficient closure of the outlet valve stops cavitation without significantly reducing the flow in relation to the cavitation situation. This is the first solution to be applied.

155. What is this phenomenon called? (Mechanical drawing of part of the gaseous phase due to the rotation of the liquid at the pump input)

Vortex



156. What kind of safety equipment is generally found in a centrifugal pump?

- A low-pressure suction transmitter (protection against cavitation),
- A high-pressure outlet transmitter,
- If the pump is driven by an electric motor, an insufficient power safety device. This device may replace the two transmitters referred to above,
- A temperature sensor on the pump body if necessary,
- A temperature sensor on the bearings,
- Leak protection on the packing,
- Pump vibration monitoring and carrier, particularly in equipment with medium or high power.