



Process engineering

Pumps, turbines and compressors

Centrifugal pumps (1)

In this lesson we will look at the most important points that should be considered when purchasing a centrifugal pump. In addition, we will include a summary of the most important advantages of this type of pump.

We will also take a look at various types of centrifugal pumps.

The choice of the centrifugal pump always depends on the system in which the pump is to be placed. For this reason, this lesson will also look quite extensively at the pipe resistances that are encountered in the system. We will also examine the way in which the pipe characteristics of such a system are established.

Finally we will, in this lesson, clarify what is meant by the manometric discharge pressure and the manometric head of a pump.

Contents of the lesson

- 1 Purchase specifications and advantages of centrifugal pumps
- 2 The design and construction of a centrifugal pump
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Lesson

1. Purchase specifications and advantages of centrifugal pumps

- information

If a centrifugal pump has to be purchased then the following data important:

- the quantity of liquid to be displaced;
- the properties of the liquid to be pumped, such as the density, the temperature, the vapour pressure and the viscosity;
- the required head (net static head) and the expected line resistance;
- (possible) solids content and contamination of the liquid to be pumped;
- the type of operation: continuous or start/stop operation;
- the method of drive and control.

- net static head

- type and size

After this information is known or acquired, then the type and size of the centrifugal pump can be determined.

It is also of great importance that the suction head is chosen carefully because the flow of the liquid to the suction nozzle of the pump depends on this to a great extent.

1.1 Advantages of centrifugal pumps

- advantages

The centrifugal pump is one of the most frequently used pumps in the industry. To explain why this is so, we have drawn up a list of advantages of this pump:

1. The pump has a very even delivery.
2. Air chambers at the discharge or suction side are therefore unnecessary and thus occupy no space.
3. The driving mechanism does not suffer from variations in power or momentum. This means that the pump operates practically free of vibration. For this reason, a light base plate construction can also be used.
4. The pump only occupies a small floor space.
5. The pump consists of relatively few moving parts. Wear and tear and resulting breakdowns are therefore infrequent.
6. The pump has a very large capacity in relation to its dimensions.
7. The pump can operate at high speeds of rotation. A direct coupling to an electric motor or a steam turbine is thus possible. As a result, there is no energy lost in a reducing gearbox, for example.
8. The pump can be started with a closed discharge valve, or operated (temporarily) in this situation.

**- disadvantages**

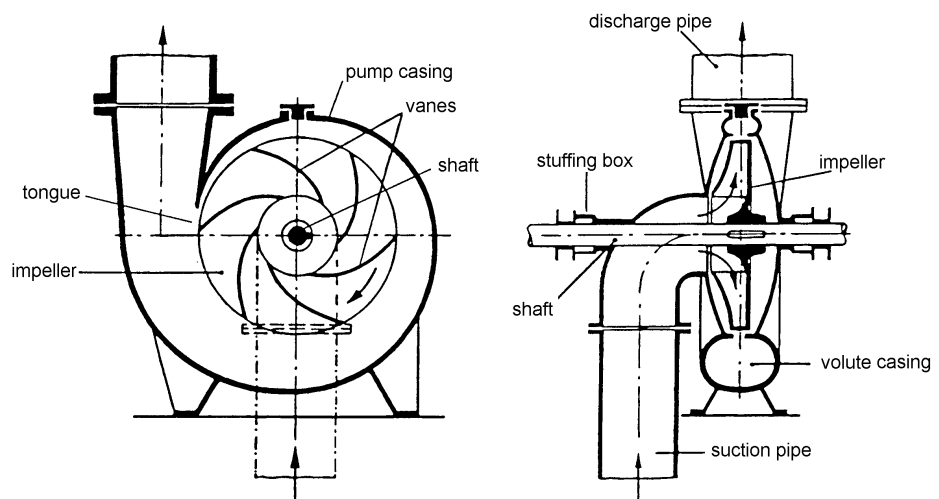
Apart from a large number of advantages the pump has a number of disadvantages or less favourable characteristics, however. The most important are:

1. A generally less favourable total efficiency ($\pm 65\%$). More advanced and therefore (much) more expensive pumps do obtain higher efficiencies.
2. There is always an open connection between the suction and the discharge sections of the pump. For this reason the pump itself cannot draw in liquid over a certain height, the centrifugal pump is not self-priming.

2. The design and construction of a centrifugal pump

- impeller

In its simplest form, a centrifugal pump, shown in figure 1, consists of a shaft with an impeller, which is enclosed in a pump casing. The impeller consists in its simplest form of a disc on which a number of vanes are mounted. The most frequently used design consists of a plate with a hub, which is connected to a ring plate by a number of curved vanes.



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Figure 1

Cross-section and longitudinal view of a (simple) centrifugal pump

- ball bearings or sleeve bearings

The shaft is supported on the outside of the pump casing by ball bearings or slide bearings. The apertures through which the shaft passes into the casing are sealed using stuffing boxes.

Question 1

What are the main components in a centrifugal pump?

When the pump is in operation, the suction pipe and the pump casing are completely filled with liquid. The impeller forces the liquid into a rotary motion, whereby the liquid moves from the central point outwards, under the influence of centrifugal force.

- centrifugal force



- **constant flow of liquid**
- **disrupted flow of liquid**
- **pump cuts out**

As a result of the pressure on the liquid in the suction vessel, the space that is thus emptied is immediately filled by another liquid particle.

In this way there is a constant flow of liquid through the suction pipe as long as the entry to the suction pipe lies below the level of the liquid. If, for some reason, the level of the liquid falls below the suction pipe, then the flow of liquid is interrupted, so that air or gas enters the pump through the suction pipe. The impeller then draws in gas or air and the space vacated by the liquid particles is then occupied by vapour or air. Replacement with liquid is now no longer possible: the pump cuts out.

- **not self-priming**

It can be seen from this that a centrifugal pump is not self-priming. This is in contrast to positive displacement pumps which are capable of removing gas or air from a pump casing.

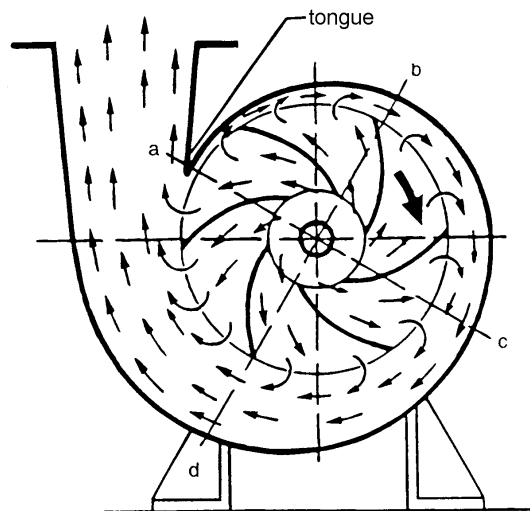
A prerequisite for the proper operation of a centrifugal pump is evidently that the liquid should not contain large vapour or air bubbles, nor should vapour or air be able to get into the casing. This vapour or air can collect in the pump casing causing the pump to cut out.

- **suction pressure**

The displacement of the liquid in the impeller reduces the pressure in the suction pipe, the suction pressure, as is also the case with displacement pumps.

2.1 The shape of the centrifugal pump

We may ask ourselves how the unusual shape of the centrifugal pump came about. To answer this let us look at figure 2.



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Figure 2

Increasing flow in and explanation of the shape of the volute casing

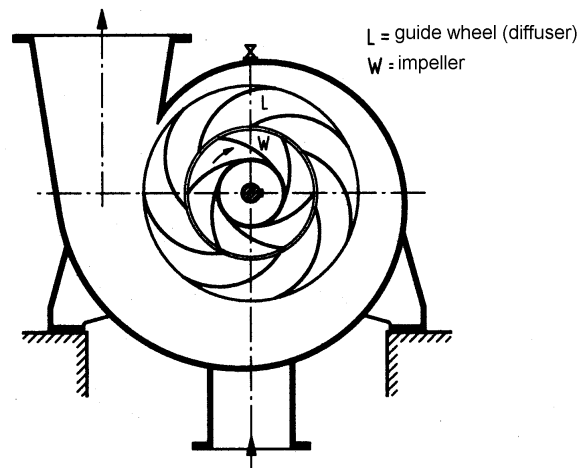


In this drawing, the impeller and the pump casing are divided into four parts by the lines a-c and b-d. In the first part, going from a to b around the circumference of the impeller, a quarter of the liquid volume which enters the impeller through the suction opening should then be able to pass through the section of the pump casing at point b.

Going from b to c a further quarter is added, so that the section of the pump casing will have to be half the size of the suction opening in the impeller. This also applies to the next sections of the pump. If the sections of the suction and the discharge pipes are equal in size, then the liquid flow rates in both pipes are equal. After all the pump draws in as much as it discharges.

- velocity

We know that the liquid in the impeller acquires a high velocity. What happens to that high velocity, if the liquid flow rates in the suction and the discharge pipes are the same? This velocity is to a large extent converted into pressure!



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Figure 3
Centrifugal pump, fitted with a diffuser

- guide wheel or diffuser

Often a stationary guide wheel or diffuser is placed around the impeller. This is shown in figure 3. The liquid flowing out of the impeller is thus guided in the direction of the discharge better than in pumps where this guide wheel is not fitted.

Moreover, the liquid velocity is converted into pressure in the guide wheel. As the vanes guide the liquid in the direction of discharge, there will also be less turbulence, therefore the losses that occur are smaller. These pumps can provide higher discharge pressures than pumps without a guide wheel. If an even higher pressure is required then a number of impellers are used in sequence on one shaft. The liquid flowing out from the first impeller is led to the inlet side of the next impeller and so on, so that the pressure is increased in stages.

**- several impellers
- stepwise increase
in pressure**

Question 2

Explain why air chambers are not needed with centrifugal pumps.



3. Some constructions of centrifugal pumps

- field of application

Centrifugal pumps have very different constructions, not only as a result of the various manufacturers, but mostly as a result of the wide range of uses for such pumps.

Distinctions can be made between:

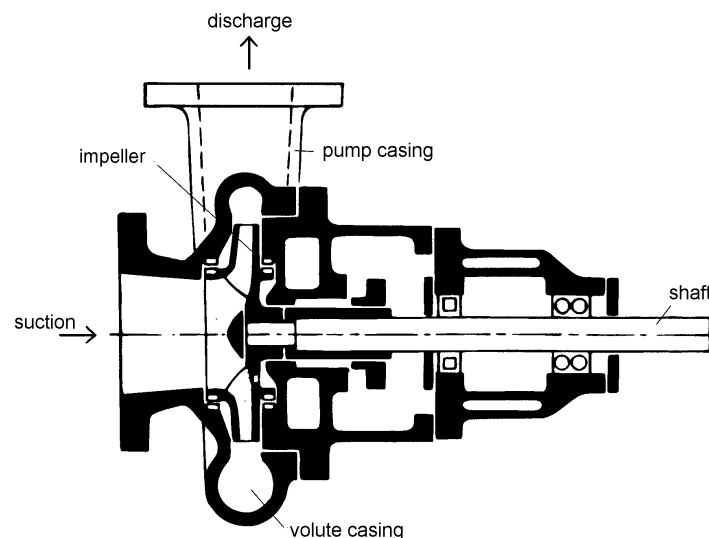
- the nature of the product to be pumped;
- capacity;
- differential pressure;
- temperature of the liquid;
- extent of any impurities.

Centrifugal pumps can be divided into:

- horizontal pumps;
- vertical pumps;
- single impeller pumps;
- multi-stage pumps.

3.1 Horizontal pumps

Figure 4 is a highly simplified drawing showing a horizontal pump.



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Figure 4

Simplified drawing of a horizontal centrifugal pump

- base plate

- stuffing box

- sliding ring seal

It is called a horizontal pump because the pump and the motor shaft lie in a horizontal plane. Both are mounted on a base plate. The pump shown here has one impeller with one suction nozzle. The shaft seal consists of a stuffing box with a soft packing. Apart from these pumps there are also designs in which the shaft seal consists of a mechanical or sliding ring seal.



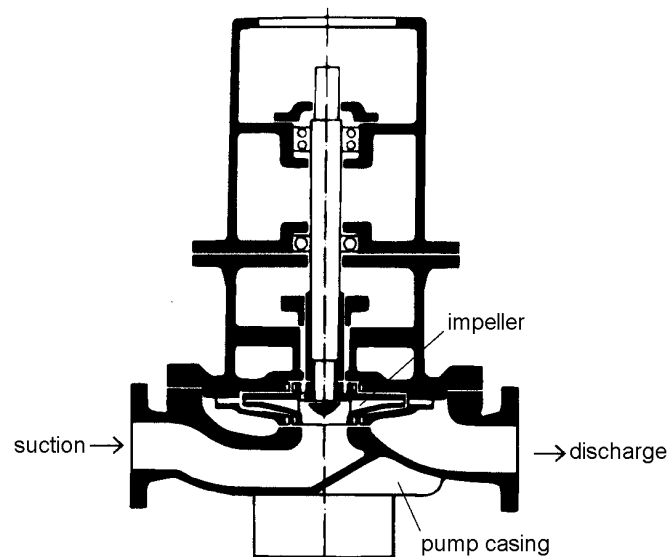
3.2 Vertical pumps

- short installation length

Figure 5 shows a simplified drawing of a vertical pump. The pump shaft is in a vertical plane and the drive is fitted above the pump. The impeller here is also a single impeller with only one suction opening. This type of pump has a shorter installation length whilst the installation height can be considerable.

Question 3

Where would vertical pumps often be used?



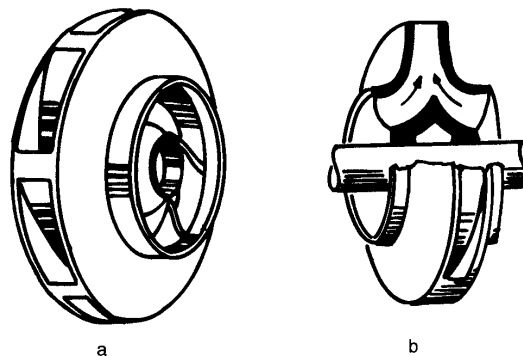
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Figure 5 Simplified drawing of a vertical centrifugal pump

3.3 Single impeller pumps

- one impeller
- suction opening

Pumps are shown in figures 4 and 5 with one impeller; these are called single impeller pumps. There are two versions of this type of pump; both are shown in figure 6. Figure 6 shows a single impeller with one suction opening and a single impeller with two suction openings.



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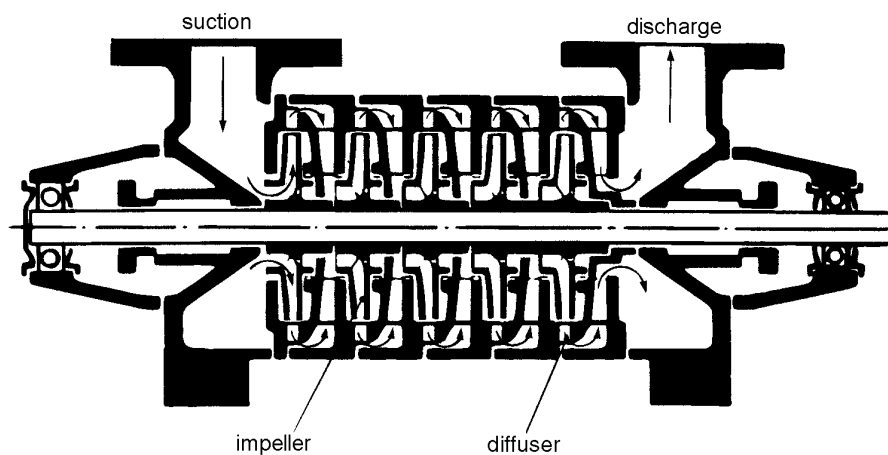
Figure 6

Example of an impeller with single (a) and double (b) suction



3.4 Multi-stage pumps

A multi-stage pump has, as the name suggests, more than one impeller. The pump which is shown schematically in figure 7 has, for example, 5 impellers on one shaft. These impellers are mounted in series, which means that the liquid from the first impeller is diverted and transported to the inlet of the second impeller, from there to the third and so on.

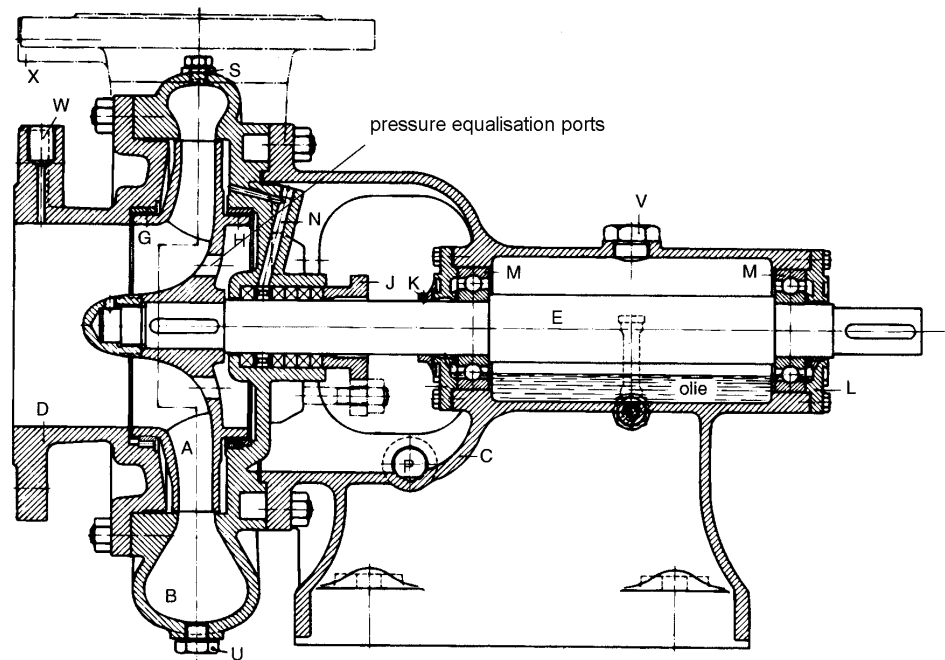


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Figure 7
Simplified drawing of a multi-stage pump

3.5 Horizontal pumps with a single impeller

Figure 8 shows a more detailed drawing of a single impeller pump with one-sided suction.



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A = impeller
B = volute casing
C = frame
D = suction nozzle
E = pump shaft
G = wear ring
H = wear ring
J = gland
K = centrifugal washer

L = retaining cap
M = radial bearing
N = liquid seal passage
P = leakage liquid drain
S = filler /vent cap
U = drainage cap
V = oil filler cap
W = connection to pressure gauge
X = connection to pressure gauge

Figure 8

Cross-section of a single impeller pump provided with single suction

- pressure
equalisation ports

- lantern ring
- gland

- penetration of air

The back plate of the impeller is provided with openings (pressure equalisation ports). These will cause the axial forces on the impeller to (largely) cancel each other out.

In this pump, only the casing is fitted with wear rings (G and H). The stuffing box is filled with soft packing. After the first ring there is then an H-shaped spacer ring, the lantern ring, followed by the other rings which are then squeezed together by the packing pressure element J, usually known as the gland. The lantern ring is located upstream of a passage N that is connected to the discharge of the pump, so that the stuffing box is subject to discharge pressure in order to prevent air penetrating the pump. If this happens then this may cause the pump to cut out, as mentioned earlier.

Question 4

What is the actual function of the H-shaped lantern ring?



- splash or centrifugal washer
- oil reservoir

The stuffing boxes with soft packing will always have a slight leakage to prevent the packing from running dry and then becoming hot. The leakage liquid is drained off through opening P. A washer is fitted on the pump shaft between the packing compressor and the bearing, the splash or centrifugal washer K, which prevents leakage liquid from passing along the shaft into the bearing. An oil reservoir is provided between the bearings to lubricate the ball bearings .

Question 5

What is the reason for the back plate of the impeller to be provided with holes?

- easily accessible

The pump casing consists of three sections, the frame C, the volute casing B and the suction nozzle D, on which the suction pipe is mounted. This design makes the pump easily accessible, so that inspections and repairs are easy to perform.

Question 6

Why do the ball bearings in the pump in figure 8 have to be able to withstand axial displacement of the shaft, despite the fact that the impeller is balanced?

3.6 Close-coupled pumps

In current vertical pumps the impeller is usually mounted directly on the extended motor shaft. This means that there is no coupling, so that the entire structure is shorter than would be the case with a coupling. These are called close-coupled pumps.

- 'in-line' pumps

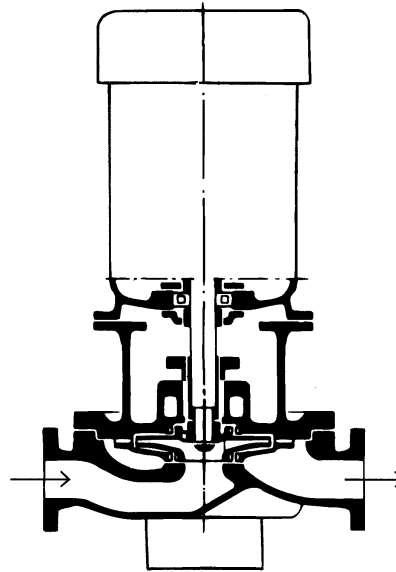
Figure 9 is a simple drawing of such a pump.

These pumps are installed as 'in-line' pumps. The smaller versions have no base plates but are supported by the suction and discharge pipes. They are in fact integrated into the pipe system.

Larger pumps are supported by a base plate. To dismantle the pump it is sufficient to disconnect the electricity supply and to remove the bolts of the pump cover.

- pipe system maintained

The motor, the pump cover and the impeller can now be taken out of the pump casing. The advantage of such a method is that the coherence of the pipe system can be maintained.

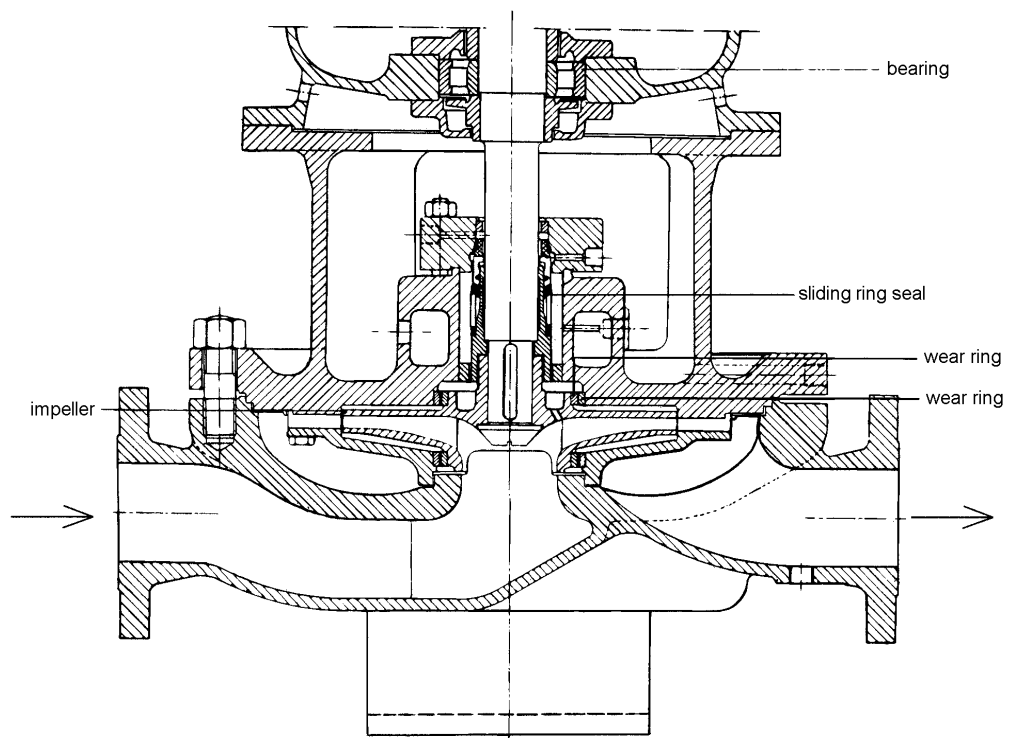


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Figure 9
Simple drawing showing a close-coupled pump

- seals

Figure 10 shows a cross-section of a pump. This pump is provided with a mechanical or sliding ring seal, whereas the impeller and the casing are fitted with wear rings.



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Figure 10
Example of a vertically mounted centrifugal pump. The wear rings on the impeller in the casing are clearly visible



4. The line resistance

Before discussing the term line resistance, we have to examine the topic of the flow of liquids in pipes in more depth.

- laminar or turbulent parallel
- eddies

- usually turbulent

This flow can be laminar or turbulent. Laminar flow is free from turbulence; the streamlines are almost parallel to the walls of the pipe (see figure 11). In a turbulent flow, strong eddies occur in the liquid; the streamlines run in different directions (see figure 12). A laminar flow only occurs at very low flow rates and/or with very thick, viscous (syrupy) liquids. In practice, a turbulent flow occurs nearly all the time in pumps.

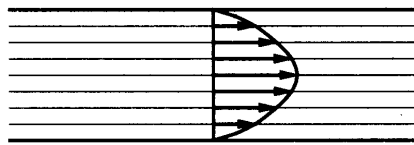
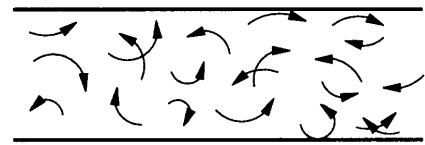


Figure 11
Laminar flow



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Figure 12
Turbulent flow

- dependent

The line resistance is dependent on:

- the velocity of the flow and the type of flow in the pipe;
- the length of the pipe;
- the viscosity of the pumped flow;
- the shape of the pipe (cross-section);
- the roughness of the pipe wall;
- the resistance of obstacles in the line (such as elbows, filters, valves and the like);
- the number of obstacles in the line.

4.1 Determination of the line resistance

- complicated

- tables or graphs

- $p_{\text{pipe resistance}} (p_{\text{pr}})$

The total resistance in a pipe for both laminar and turbulent flows or a combination thereof can be calculated. The often-changing circumstances which occur in practice make the calculations more extensive and complicated. A quicker determination of the resistance that is sufficiently accurate in practice can be made using tables or graphs. In these, the total pressure loss including the velocity pressure is included.

In table 1 the total pipe resistance p_{pr} is given for straight pipes with a length of 100 m. This is done for various pipe diameters and for different liquid velocities and therefore also for various volume flows q_v .

It is assumed that a liquid has the same viscosity as that of water. When determining the p_{pr} value of shorter or longer pipes, the p_{pr} values obtained from

the table should be multiplied by the factor $\frac{l}{100}$

in which l = the actual length in m.



- low resistance

To keep the resistance in a pipe system as low as possible, all the changes relating to the flow through the pipes should be made as gradually as possible, in other words by using wide elbows, trumpet-shaped inlet pieces and conical reducers when changing to a different pipe diameter.

Question 7

How many times larger is the resistance in a pipe with a length of 150 m and a length of 250 m than that for a pipe system which is 100 m in length?

- fittings and accessories

If fittings and accessories are included in a pipe, its resistance will be much more than that of a pipe with a similar length and diameter without fittings and accessories. Table 2 can be used to determine quickly the resistance for these fittings and accessories.

- equivalent resistance length

In table 2, the resistance of a number of fittings and accessories is expressed in terms of an equivalent length of pipe in m. In other words, the true length of a pipe, in which fittings and accessories have been fitted, should be increased by the equivalent resistance length of the fittings and accessories concerned.



Table 1

Total pipe resistance p_{pr} for straight pipes with a length of 100 m at various pipe diameters and various liquid velocities

pipe diameter	Pressure loss p_{pr} in straight pipes per 100 m of length for liquids with the viscosity of water (p_{pr}) Volume flow q_v (l/min)							
	liquid velocity (m/s)							
	0,5	0,75	1,0	1,5	2	3	4	5
15 mm ½"	q_v p_{lw}		10 0,91	15 2,15	20 3,7			
20 mm ¾"	q_v p_{lw}	13 0,43	18 0,68	26 1,55	36 2,7	54 6,4		
25 mm 1"	$q_v = 14$ $p_{lw} = 0,14$	21 0,34	28 0,54	42 1,2	56 2,1	84 5,0	112 8,0	140
32 mm 1¼"	$q_v = 23$ $p_{lw} = 0,105$	34 0,26	47 0,41	70 0,94	95 1,62	142 3,8	190 6,2	235 8,8
40 mm 1½"	$q_v = 36$ $p_{lw} = 0,08$	54 0,2	72 0,32	108 0,74	145 1,3	216 3,0	288 4,8	360 6,8
50 mm 2"	$q_v = 58$ $p_{lw} = 0,064$	84 0,16	115 0,25	173 0,58	230 1,0	345 2,4	460 3,8	575 5,4
70 mm 2¾"	$q_v = 115$ $p_{lw} = 0,045$	170 0,11	225 0,18	340 0,4	450 0,7	675 1,65	900 2,6	1125 3,7
80 mm 3½"	$q_v = 150$ $p_{lw} = 0,038$	225 0,095	300 0,15	450 0,35	600 0,62	900 1,45	1200 2,3	1500 3,2
100 mm 4"	$q_v = 240$ $p_{lw} = 0,03$	360 0,075	480 0,12	720 0,28	960 0,48	1440 1,15	1920 1,8	2400 2,5
125 mm 5"	$q_v = 380$ $p_{lw} = 0,024$	570 0,058	760 0,095	1140 0,22	1520 0,39	2280 0,88	3040 1,4	3800 2,0
150 mm 6"	$q_v = 540$ $p_{lw} = 0,02$	810 0,048	1080 0,078	1620 0,18	2160 0,31	3240 0,72	4320 1,15	5400 1,65
200 mm 8"	$q_v = 1000$ $p_{lw} = 0,014$	1500 0,035	2000 0,056	3000 0,13	4000 0,23	6000 0,54	8000 0,84	10 000 1,2
250 mm 10"	$q_v = 1600$ $p_{lw} = 0,011$	2250 0,027	3000 0,045	4400 0,1	6000 0,18	9000 0,41	12 000 0,66	15 000 0,9
300 mm 12"	$q_v = 2150$ $p_{lw} = 0,009$	3225 0,022	4300 0,037	6450 0,075	8600 0,15	12 900 0,35	17 200 0,54	21 000 0,76
400 mm 16"	$q_v = 4000$ $p_{lw} = 0,005$	6000 0,016	8000 0,027	12 000 0,06	16 000 0,11	24 000 0,25	32 000 0,4	40 000 0,56
500 mm 20"	$q_v = 6400$ $p_{lw} = 0,002$	9600 0,013	12 800 0,021	19 200 0,05	25 600 0,086	38 400 0,2	51 200 0,31	64 000 0,43



Table 2
Resistance of fittings and accessories in equivalent pipe length

Dimensions in mm →	15	20	25	32	40	50	70	80
Fittings	equivalent length in m							
Elbow 90° R = 3d	0,5	0,75	1	1,25	1,5	2	2,5	3
Standard elbow 90°	1	1,5	2,25	2,75	3,5	5	5,75	6,4
Square elbow	2	3,1	4,75	6,1	7,5	10	11,4	12,7
Standard tee	1,25	1,7	2,35	3	3,75	5,5	7	8,5
Tee enlargement	0,75	1,2	1,35	1,5	2	3	4,25	5,7
Check valve	2	3	4,5	5,5	6,75	8	9,5	11
foot valve	2,1	3,25	4,75	6,2	7,5	10	9,5	11
globe valve	5	7,3	9	12	15	19,5	22	25
slide valve	1	1,5	2	2,5	3,1	4	4,75	5,4

Dimensions in mm →	100	125	150	200	250	300	400	500
Fittings	equivalent length in m							
Elbow 90° R = 3d	3,75	4,75	6	7,5	—	—	—	—
Standard elbow 90°	7,5	8,7	10	14	18	23	33	42
Square elbow	15	16,5	20	28	—	—	—	—
Standard tee	11	14,5	16,5	21,5	—	—	—	—
Tee enlargement	6,5	8	9,6	11,5	—	—	—	—
Check valve	14,5	16,5	20	26	35	44	65	80
foot valve	14,5	16,5	20	26	35	44	65	80
globe valve	30	35	40	50	70	81	105	140
slide valve	6	7	8	10	16	22	33	46

5. Line characteristics

- graph

Another way to determine the pipe resistance quickly is by means of a graph.

- pipe characteristic

Here the pipe resistance is expressed as a function of the quantity of liquid flowing through the pipe. The curve obtained in this way is called the pipe characteristic. This means the line which expresses the nature of the pipe of a certain length and diameter in relation to the quantity of liquid flowing through it and the resistance which occurs as a result.

- nominal diameter

As an example, a pipe characteristic is shown in figure 13 for a smooth NW 80 pipe with a length of 100 m. NW 80 means a pipe with a nominal diameter of 80 mm. The volume flow q_v in l/m is plotted on the horizontal axis of the graph and the total pipe resistance in bar is plotted on the vertical axis. The graph applies to a liquid with a viscosity equal to that of water. Finally, figure 14 shows a graph for water for smooth, seamless steel pipes with a length of 100 m and various pipe diameters. Here the volume flow q_v in m^3/h is plotted on the vertical axis and the total pipe resistance p_{pr} in bar is plotted on the horizontal axis.

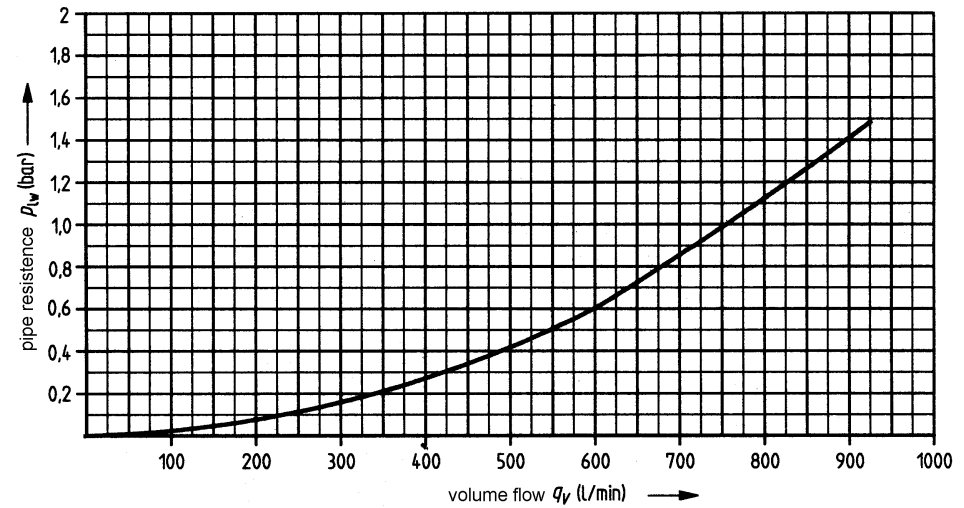
- liquid flow rate

If, for instance, the liquid flow is $300 m^3/h$, then the resistance in a 100 m pipe with a diameter of 300 mm is 0.05 bar. For a pipe with a diameter of 150 mm, the resistance is 2 bar. In both cases, the liquid velocity can also be deduced.

For a pipe with a diameter of 300 mm, the velocity lies between 1 and 1.5 m/s and for a 150 mm diameter pipe, the velocity is approximately 5m/s.

**Question 8**

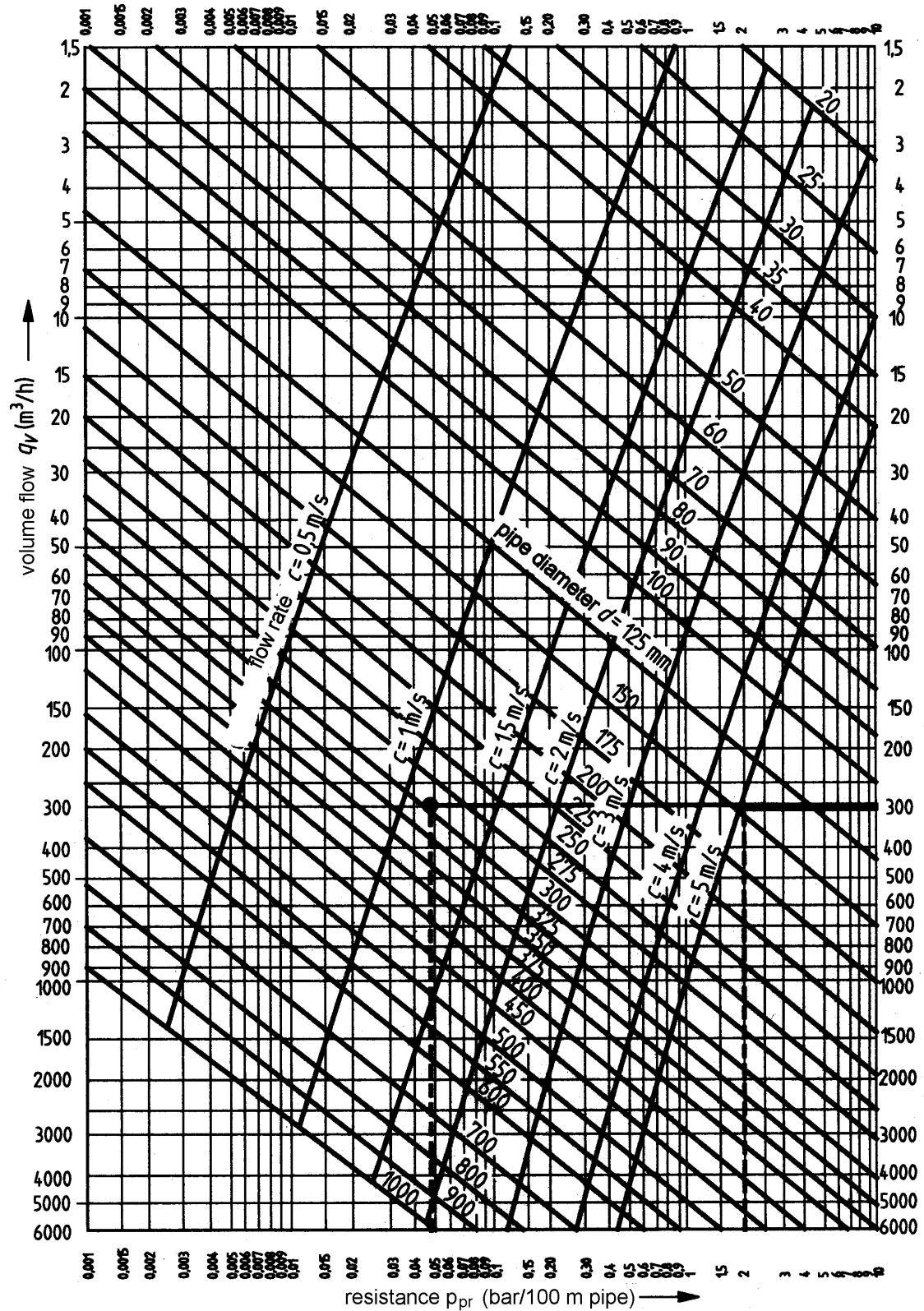
What advantage do pipes have when they are smooth on the inside?



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Figure 13

Pipe characteristic NW 80, 100 m long



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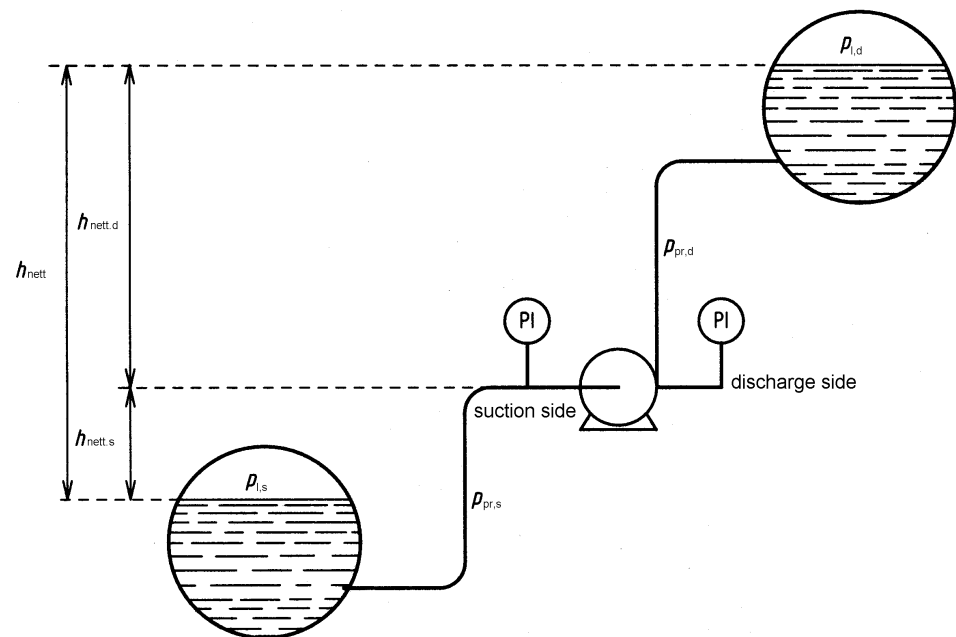
Figure 14
Resistance of water in new, smooth seamless steel pipes in bar per 100 m of pipe (p_{pr})



6. The manometric differential pressure

Manometric differential pressure of a pump is understood to mean the differential pressure between the discharge and the suction sides of a pump in operation.

The pressures on the discharge and suction sides of a pump are indicated by means of pressure gauges. In figure 15 the positions of these gauges are shown in a drawing. We will look first at the pressure which is indicated by the pressure gauge on the suction side of the pump: the manometric suction pressure.



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Figure 15

Pump installation with the suction vessel positioned lower and the discharge vessel positioned higher

6.1 The manometric suction pressure

- nett static suction side

Assuming that liquid is drawn in from a suction vessel with a pressure above the liquid level of $p_{l,s}$. The liquid level in this tank lies at a distance $h_{nett,s}$ ($h_{net\ static, \text{ suction side}}$) below the centre of the pump. If the liquid in the pipe were stationary, then the pressure gauge on the suction side of the pump would indicate the static suction pressure $p_{stat,s}$. For this pressure the following applies:

$$p_{stat,s} = p_{l,s} - p_{nett,s} \quad (1)$$

In which:

$p_{l,s}$ - pressure in the suction vessel (bar)

$p_{nett,s}$ - pressure which is caused by the liquid column ($h_{nett,s}$) (bar)

$p_{stat,s}$ - static suction pressure (bar)

**- liquid column**

However, when the liquid column is above the pump, then this column is also works in the same direction and this pressure has to be added to the pressure in the suction vessel.

The pressure as a result of the liquid column in this example counteracts the pressure in the suction vessel $p_{l.s}$. The $p_{l.s}$ should therefore be reduced by the $p_{nett.s}$. The pressure thus obtained is the static pressure precisely for that pump. (see also figure 14).

$p_{nett.s}$ can be calculated with the aid of the following formula from $h_{nett.s}$:

$$p_{nett.s} = h_{nett.s} * g * 10^{-5} \left[m * \frac{kg}{m^3} * \frac{N}{kg} * 10^{-5} \right] \quad (2)$$

In which:

$h_{nett.s}$ head of the liquid column (m)

$p_{nett.s}$ pressure which is caused by the liquid column (bar)
the density of the liquid (kg/m^3)

g the gravitational acceleration (m/s^2 or N/kg)

10^{-5} a factor to convert the pressure from Pascal ($1 Pa = 1 N/m^2$) into bar
($1 bar = 10^5 Pa$)

Remark

Since the pressure unit 'bar' is often used with pumps, you will also find bar is used in this lesson in addition to N/m^2 or Pa. Note that these units are simple to convert into one another.

- liquid does flow**- velocity pressure**

Whenever liquid does flow, the pressure gauge before the pump will show a different and lower pressure. We are then dealing with the pipe losses that occur and, moreover, with the dynamic or velocity pressure. As a result of the resistance in the pipe between the medium and the wall a loss of pressure will occur in the pipe. On the suction side this is indicated by $p_{pr.s}$ (in bar).

In addition, some of the static pressure will be converted into a velocity pressure. For this velocity pressure the following holds on the inlet side:

$$p_{v.s} = \frac{1}{2} * \rho * c_s^2 * 10^{-5} \quad (3)$$

In which:

$p_{v.s}$ velocity pressure on the suction side (bar)

density (kg/m^3)

c_s velocity of liquid in the suction pipe (m/s)



The pressure that the pressure gauge indicates for the pump is then:

$$p_{\text{man.s}} = p_{\text{l.s}} - p_{\text{nett.s}} - p_{\text{pr.s}} - p_{\text{v.s}} \quad (4)$$

In which:

$p_{\text{man.s}}$	manometric suction pressure (bar)
$p_{\text{l.s}}$	pressure in the liquid vessel on the suction side (bar)
$p_{\text{nett.s}}$	pressure which is caused by the liquid column (bar)
$p_{\text{pr.s}}$	the pipe resistance on the suction side (bar)
$p_{\text{v.s}}$	velocity pressure on the suction side (bar)

6.2 The manometric discharge pressure

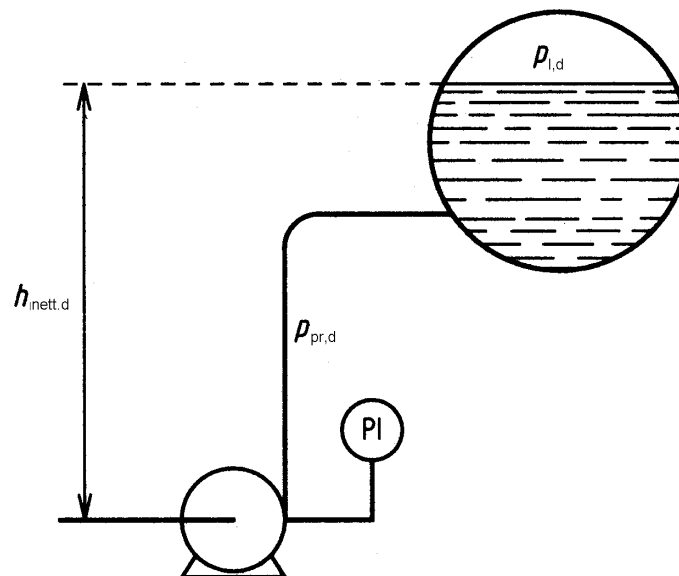
- pumped into a
discharge vessel

Now we will look at the pressure as is indicated by the pressure gauge on the discharge side of the pump.

Assume that we pump the liquid into a discharge vessel, in which the pressure on the liquid surface is $p_{\text{l.d}}$.

The liquid level in the vessel lies at a distance of $h_{\text{nett.d}}$ above the centre of the pump. If the liquid in the pipe were at a standstill, then the pressure gauge would indicate a static pressure ($p_{\text{stat.d}}$). This is the same as:

$$p_{\text{stat.d}} = p_{\text{l.d}} + p_{\text{nett.d}} \quad (5)$$



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Figure 16
Random positioning of a discharge vessel

In which:

$p_{\text{stat.d}}$	static discharge pressure (bar)
$p_{\text{l.d}}$	pressure in the liquid vessel on the discharge side (bar)
$p_{\text{nett.d}}$	pressure which is caused by the liquid column (bar)



The pressure $p_{\text{nett.d}}$ which is caused by the liquid column is derived from the following equation:

$$p_{\text{nett.d}} = h_{\text{nett.d}} * r * g * 10^{-5} \quad (6)$$

In which :

$h_{\text{nett.d}}$ height of the liquid column (m)
 r density (kg/m³)
 g gravitational acceleration (m/s²)

$p_{\text{nett.d}}$ here is added to $p_{\text{l.d}}$, because the pressure as a result of the liquid column is complemented by $p_{\text{l.d}}$.

When liquid then flows, the pump will also have to overcome the pipe resistance $p_{\text{pr.d}}$. Some of the static pressure will again be converted into a velocity pressure of $p_{\text{v.d}}$:

$$p_{\text{v.d}} = \frac{1}{2} r * c_d^2 * 10^{-5} \quad (7)$$

In which:

$p_{\text{v.d}}$ velocity pressure on the discharge side (bar)
 c_d velocity of the liquid in the discharge pipe (m/s)
 r density (kg/m³)

The pressure gauge on the discharge side then indicates:

$$p_{\text{man.d}} = p_{\text{l.d}} + p_{\text{nett.d}} + p_{\text{pr.d}} - p_{\text{v.d}} \quad (8)$$

In which:

$p_{\text{man.d}}$ manometric discharge pressure (bar)
 $p_{\text{l.d}}$ pressure in the liquid vessel on the discharge side (bar)
 $p_{\text{nett.d}}$ pressure which is exerted by the liquid column (bar)
 $p_{\text{pr.d}}$ the pipe resistance on the discharge side (bar)
 $p_{\text{v.d}}$ the velocity pressure on the discharge side (bar)

The manometric differential pressure (p_{man}) is now equal to:

$p_{\text{man}} = \text{pressure downstream from the pump} - \text{pressure upstream from the pump}$

$$p_{\text{man}} = (p_{\text{l.d}} + p_{\text{nett.d}} + p_{\text{pr.d}} - p_{\text{v.d}}) - (p_{\text{l.s}} - p_{\text{nett.s}} - p_{\text{pr.s}} - p_{\text{v.s}}) \quad (9)$$

$$p_{\text{man}} = p_{\text{l.d}} - p_{\text{l.s}} + p_{\text{nett.d}} + p_{\text{nett.s}} + p_{\text{pr.d}} + p_{\text{pr.s}} + p_{\text{v.s}} - p_{\text{v.d}}$$

When the pipe upstream from the pump has the same diameter as the pipe downstream from the pump, then the velocity of the liquid through the pipe in the pump will be the same as the velocity of the liquid through the pipe downstream from the pump and thus:

$$p_{\text{v.s}} - p_{\text{v.d}} = \frac{1}{2} r * c_s^2 * 10^{-5} - \frac{1}{2} r * c_d^2 * 10^{-5}$$

In that case p_{man} becomes:

$$p_{\text{man}} = p_{\text{l.d}} - p_{\text{l.s}} + p_{\text{nett.d}} + p_{\text{nett.s}} + p_{\text{pr.d}} + p_{\text{pr.s}} \quad (10)$$



Sometimes $p_{\text{nett.d}} + p_{\text{nett.s}}$ are considered as being equal to p_{nett} and $p_{\text{pr.d}} + p_{\text{pr.s}}$ as being equal to p_{pr} .

Then:

$$p_{\text{man}} = p_{\text{l.d}} - p_{\text{l.s}} + p_{\text{nett}} + p_{\text{pr}} \quad (11)$$

Finally $p_{\text{stat}} = p_{\text{stat.d}} - p_{\text{stat.s}}$ can also be taken.

$$p_{\text{stat}} = p_{\text{l.d}} + p_{\text{nett.d}} - (p_{\text{l.s}} - p_{\text{nett.s}}) = p_{\text{l.d}} + p_{\text{nett.d}} - p_{\text{l.s}} + p_{\text{nett.s}}$$

$$p_{\text{stat}} = p_{\text{l.d}} - p_{\text{l.s}} + p_{\text{nett}}$$

In that case then:

$$p_{\text{man}} = p_{\text{stat}} + p_{\text{pr}} \quad (12)$$

7. The manometric head

Instead of the manometric differential pressure p_{man} the term manometric head is often used h_{man} .

h_{man} is the head of a column of the pumped liquid, which at the bottom of this column has the same pressure as p_{man} .

This head can be calculated as follows:

$$h_{\text{man}} = \frac{p_{\text{man}} * 10^5}{r * g} \quad (13)$$

In which:

h_{man} manometric head (m)

p_{man} manometric differential pressure (bar)

r density (kg/m³)

g gravitational acceleration (m/s²)

10^5 conversion factor to convert the pressure into bar

- the same h_{man}

h_{man} is used quite frequently because the same maximum h_{man} can be obtained in centrifugal pumps at a certain q_v , regardless of the nature of the liquid being pumped.

This will be clarified in the next example.

Example

A pump, which lifts 100 m³ of water per hour a height of 20 m will with the same number of rotations be able to lift 100 m³ of petrol ($r = 700$ kg/m³) or mercury ($r = 13,600$ kg/m³) a height of 20 m, assuming that the friction losses are the same.

Question 9

Why is the power consumed dependent on the density of the liquid?



In all these cases h_{man} therefore = 20 m. Expressed in bar this is:

$$p_{\text{man}} = r * g * h_{\text{man}} * 10^{-5}$$

- ($g = 10 \text{ N/kg}$)
- water $p_{\text{man}} = 1000 * 10 * 20 * 10^{-5} = 2 \text{ bar}$
- petrol $p_{\text{man}} = 700 * 10 * 20 * 10^{-5} = 1.4 \text{ bar}$
- mercury $p_{\text{man}} = 13,600 * 10 * 20 * 10^{-5} = 27.2 \text{ bar}$

When determining $h_{\text{nett.d}}$ and $h_{\text{nett.s}}$ we have chosen to have the level of the liquid in the discharge vessel above the centre of the pump (see figure 17a) and the liquid level in the suction vessel below the centre of the pump (see figure 18a). The formulae deduced are also true when this is not the case. However the '+' and '-' signs in the formula should be given special attention.

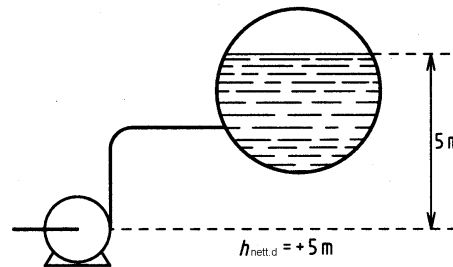
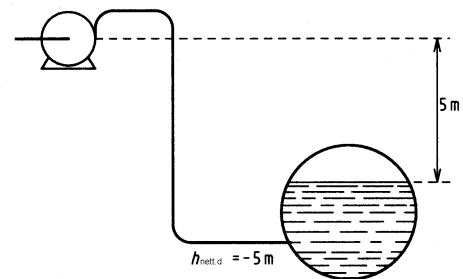


Figure 17a
Discharge vessel above the pump



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Figure 17b
Discharge vessel below the pump

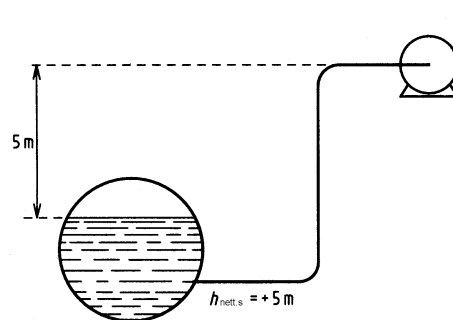
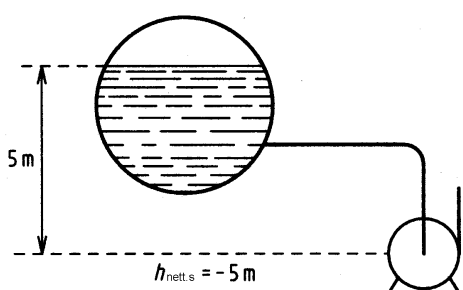


Figure 18a
Suction vessel below the pump



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Figure 18b
Suction vessel above the pump

- agreements

To make sure that the formula is also true in other cases we have to maintain the following agreements:

If the liquid level in the discharge vessel lies below the centre of the pump (see figure 17b), then a negative number is filled in for $h_{\text{nett.d}}$, and if the liquid level in the suction vessel lies above the centre of the pump (see figure 18b) then a negative number is filled in for $h_{\text{nett.s}}$.



When liquid is not being drawn in from a closed suction vessel, but from an open suction vessel, then the value of 1 bar is filled in for the pressure in the suction vessel ($p_{l.s}$).



Summary

In this lesson we looked at the most important data which plays a role in the purchase of a (centrifugal) pump. The most important parameters in this case are the desired capacity, the head and the nature of the liquid to be pumped. A number of types of pumps which are used regularly were discussed.

To be able to make a good choice the resistances in the piping system in which the pump will operate have to be known. For this reason the subject of line resistance and the topic of the pipe characteristic were discussed. Finally, we looked extensively at the topic of manometric differential pressure and head.



Test

Exercises

Do not send in your answers for correction

1. A pump which is positioned in a piping system, in which the pump is placed 3 m above the suction level and the discharge level is 12 m higher than the pump, has a net static head of :
 - a. 15 meters;
 - b. 19 meters;
 - c. 25 meters;
 - d. 29 meters.
2. What factors determine the discharge pressure of a pump?
3. For a given pump the following is known:
 - a. suction head = 3.5 meters;
 - b. suction resistance = 0.5 m;
 - c. atmospheric pressure = 1 bar;
 - d. the density of the liquid being pumped = 1000 kg/m³.

Question

- a. The reading pressure gauge in the suction just before the liquid starts flowing.
 - b. The reading on the pressure gauge in the suction when the liquid is flowing.
 - c. The reading on this pressure gauge when the capacity of the pump is twice as large as is intended under b.
4. How can centrifugal pumps be distinguished?
5. How can centrifugal pumps be categorised?
6. Why does the stuffing box on a centrifugal pump leak?
7. How can any leakage liquid be prevented from flowing to the bearings?

Answers to the questions in the lesson

1. The main components of a centrifugal pump are :
 - a shaft with an impeller attached to it;
 - a pump casing.
2. No air chambers are used with centrifugal pumps. Centrifugal pumps operate without reciprocal action. There is therefore no pulsating motion. Such a pump produces a very even liquid flow and air chambers are therefore unnecessary. In fact, this is one of the greatest advantages of this type of pump.



3. Vertical pumps are used where only a small floor space is available and when the fact that they are somewhat more difficult to dismantle is not important. Such pumps have, relative to their dimensions, high capacities.
4. The H-shaped lantern ring makes it possible for the supplied liquid to be distributed evenly around the circumference of the seal. This arrangement prevents the pump from drawing in outside air.
5. The back plate of the impeller is sometimes provided with holes to balance the impeller.
6. When the pump is being started up axial forces will occur.
7. In a pipe of 150 m in length: 1.5 times as large.
In a pipe of 250 m in length: 2.5 times as large.
8. The resistance to flow is lower in pipes which are smooth on the inside.
9. The power required by the pump is determined by its capacity and by its manometric differential pressure. The manometric pressure depends on the density.

$$P = q_v * p \left[\frac{\text{m}^3}{\text{s}} * \frac{\text{N}}{\text{m}^2} = \frac{\text{Nm}}{\text{s}} = W \right]$$

With the same head, the differential pressure is therefore dependent on the density of the liquid to be pumped.

Answers to the exercises

1. a, namely $3 + 12 = 15$ metres.
2. The manometric discharge pressure of a pump, i.e. the pressure that can be read from the pressure gauge in the discharge, is determined by:
 - the pressure in the discharge vessel;
 - the height of the discharge vessel above the pump;
 - the (pipe) resistance present in the discharge section of the system; and
 - the degree to which the capacity is controlled by means of the discharge valve, which is part of the (discharge) pipe system.



3. a. When the flow is just starting (i.e. the liquid is still stationary) the reading on the pressure gauge will show:

$$p_{\text{stat.s}} = p_{\text{atm}} - \frac{h_{\text{nett.s}} * r * g}{10^5} = 1 - \frac{3.5 * 1000 * 10}{10^5} = 1 - 0.35 = 0.65 \text{ bar} \left[\frac{\text{m} * \frac{\text{kg}}{\text{m}^3} * \frac{\text{N}}{\text{kg}}}{10^5} \right] \text{ bar}$$

- b. Whenever the liquid is flowing in the manner as intended in this question and therefore taking into consideration a resistance head of 0.5 m, then the reading on the pressure gauge will be:

$$p_{\text{man.s}} = p_{\text{atm}} - \frac{h_{\text{nett.s}} * r * g}{10^5} - \frac{h_{\text{pr.s}} * r * g}{10^5} = 1 - \frac{3.5 * 1000 * 10}{10^5} - \frac{0.5 * 1000 * 10}{10^5} = 0.6 \text{ bar}$$

- c. If the pump capacity is increased by a factor '2', and therefore the flow rate too, then the resistance will increase fourfold, thus by a factor '4'. The reading on the suction pressure gauge will then be:

$$p_{\text{man.s}} = p_{\text{atm}} - \frac{h_{\text{nett.s}} * r * g}{10^5} - \frac{(4h_{\text{pr.s}}) * r * g}{10^5} = 1 - \frac{3.5 * 1000 * 10}{10^5} - \frac{(4 * 0.5) * 1000 * 10}{10^5} \\ = 1 - 0.35 - 0.2 = 0.45 \text{ bar}$$

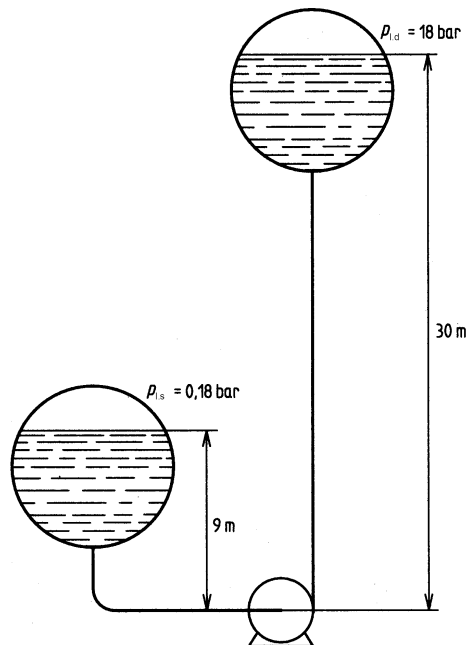
4. The way to distinguish centrifugal pumps is according to the nature of:
- the product to be pumped;
 - the volumetric capacity;
 - the pressure differential of the pump;
 - the temperature of the liquid to be pumped;
 - the degree to which impurities may be present in the liquid to be pumped.
5. Centrifugal pumps can be categorised as follows:
- horizontal pumps;
 - vertical pumps;
 - single impeller pumps;
 - multi-stage pumps.
6. The stuffing box in a centrifugal pump is set up so that it leaks. This is done so that the packing used and fitted will be cooled and therefore cannot burn.
7. Any leakage liquid, which is in any case needed to cool the stuffing box, is removed from the shaft by a centrifugal washer.



Problems and assignments

Answer and send in for correction

1. Which factors can we use to determine the manometric pressure differential?
2. A pump draws liquid in from a closed vessel in which there is an absolute pressure of 0.28 bar. The liquid level is 6 m above the centre of the pump. The pump is pumping up into a vessel that lies 20 meter higher, where the pressure 2.4 bar gauge. Calculate the net static and the static suction and discharge pressures for liquids with a density of 800 kg/m³ and 1200 kg/m³ ($g = 10 \text{ kg/m}^2$).
3. See the figure below.



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$$\begin{aligned}p_{pr.d} &= 2.2 \text{ bar} \\p_{pr.s} &= 0.18 \text{ bar} \\r &= 1000 \text{ kg/m}^3 \\g &= 10 \text{ N/kg}\end{aligned}$$

Determine

The manometric differential pressure, p_{man}

4. Why are there so many different types of centrifugal pumps?
5. What are the advantages of the close-coupled pump?
6. In a multi-stage pump with 10 impellers the last impeller has been left out. What is the differential pressure now relative to the design differential pressure?