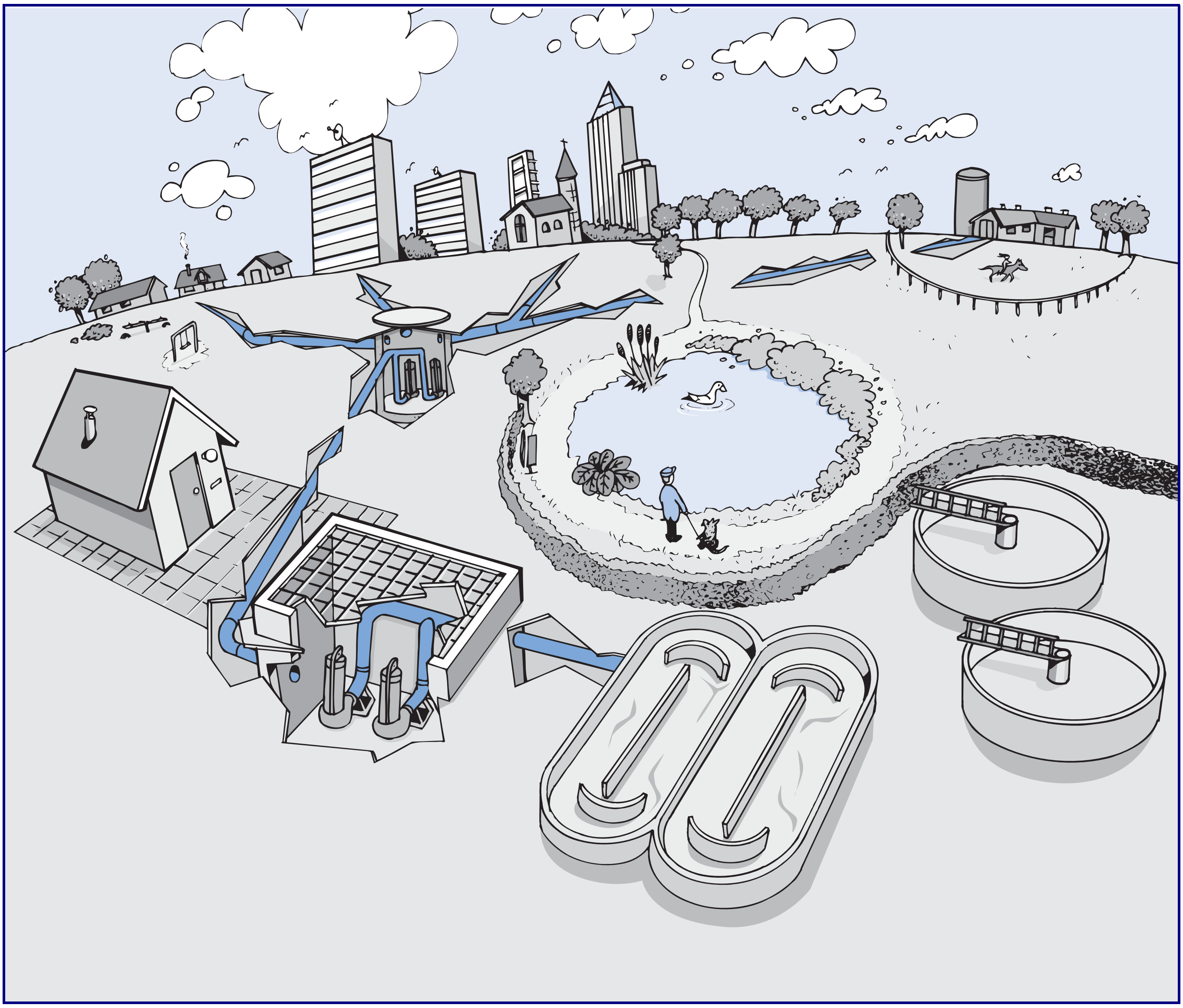
Wastewater Pumps

Engineering Manual

The smarter choice.



GRUNDFOS

Third edition. Only minor textual changes.

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Contents

1. General

1.1. Pump system layout

Layout of wastewater systems in private, public and industrial wastewater and rain water discharge systems must be made in accordance with local regulations.

This engineering manual is a supplement to such regulations.

1.2. Location of pump system

The following should be considered when selecting the best location for the pump system:

- Inlet layout to prevent cavitational problems
- Preparation for later capacity extension and water hammer problems
- Service access
- Environmental considerations, including access for flushing
- Operation and maintenance

In addition for pit located **outside building:**

- Minimum distances to foundations
- Soil and groundwater conditions
- Area reservation/site acquisition
- Route for pump system outlet
- Power supply
- Location of flood-proof power board
- Emergency overflow or flood protection
- Dry or wet pump installation
- Valve position (dry or wet pit)
- Prefabricated or on-site made pit

In addition for pit located **inside building:**

- Special room
- Hermetically sealed, prefabricated tanks with ventilation to the open (minimum 50 mm pipe)
- Emergency overflow
- Flood protection
- Pipe dimensions and penetration of wall

1.3. Types of pump system

This manual distinguishes between three basic wastewater types:

1. Drainage and sump pumping
2. Effluent and screened water pumping
3. Sewage and faeces pumping

Pump selection, pipe dimensions and the consequences of pump failure will be different for the three wastewater types.

1.3.1. Drainage and sump pumping

5–10 mm maximum particle size expected in pumped liquid with only a limited content of long fibres.

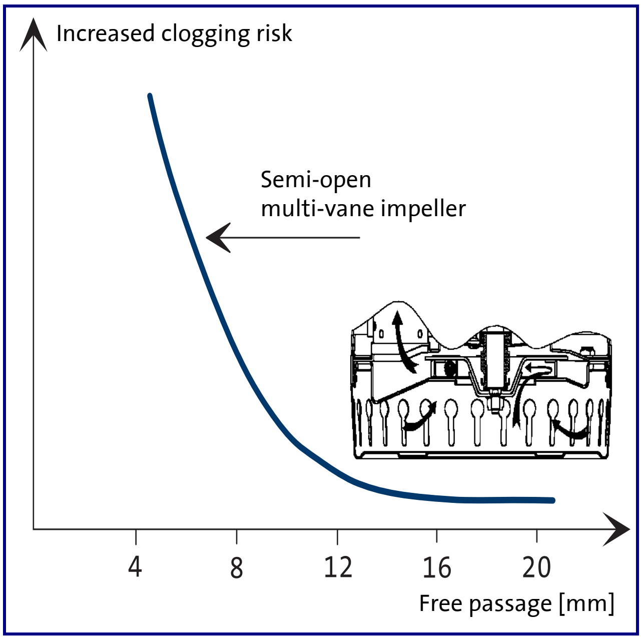


Fig. 1 Diagram showing the relation between risk of clogging and dimension of free pump passage. Good protection against clogging is achieved with 10–12 mm free passage.

Field of application
Cellar drainage, fountains, contractor pumping from excavations and any application using flexible horizontal discharge hoses.

Pump failure in drainage applications will normally only result in flooding that requires normal cleaning. If this is not acceptable, the installation should be upgraded with an effluent type of pump in order to reduce the risk of clogging as much as possible. This will increase both initial and operating costs of the pump by more than 60%.

1.3.2. Effluent and screened water pumping

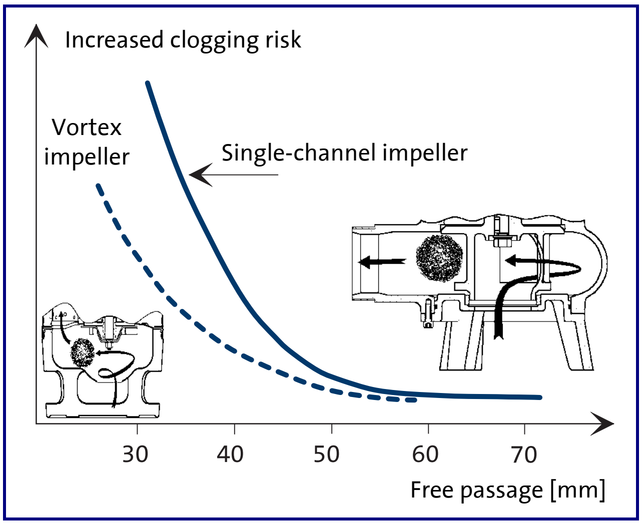


Fig. 2 Diagram showing the relation between risk of clogging and dimension of free pump passage. Good protection against clogging is achieved with 35–45 mm free passage.

25–35 mm maximum particle size expected in pumped liquid with a moderate content of long fibres, e.g. hair from human beings, pets and brushes.

Field of application
Pumping at purification plants, pumping from septic tanks, rainwater pits along roads and grey wastewater with no content of toilet matter.

Pump failure in effluent applications will normally cause great expense for considerable cleaning and disinfection before drying-out can take place.

If this is not acceptable, then to reduce the risk of clogging as much as possible, the installation should be upgraded to a sewage type of pump or by fitting grinding gear. This will increase both initial and operating costs of the pump by more than 60%.

It is usually cost-effective to use sewage pumping equipment for effluent handling duty only when Q is > 10 l/s.

1.3.3. Sewage and feaces pumping

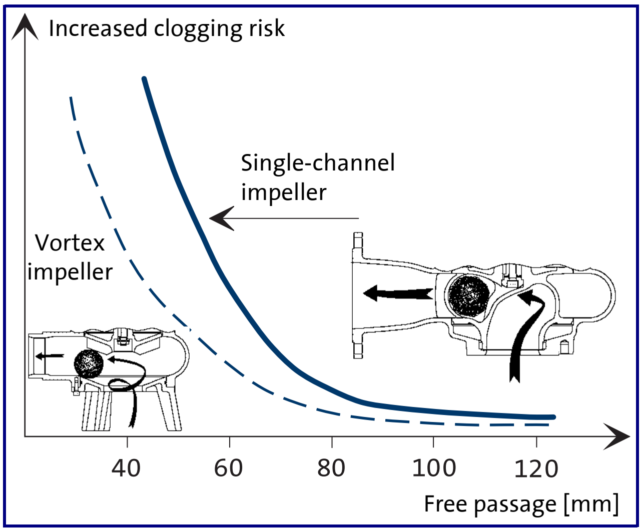


Fig. 3 Diagram showing the relation between risk of clogging and dimension of free pump passage. Good protection against clogging is achieved with 70–80 mm free passage.

70 mm maximum particle size expected in pumped liquid and a high content of solids, e.g. children's shoes, toys, tooth brushes and tampons is to be expected.

Where, particularly in southern Europe and the United States, water closet discharges are only 50 mm, it is possible to install 50–65 mm vortex pumps for domestic sewage.

Field of application
Pumping in mains and sectional discharge systems including toilet connections and pumping in systems with unknown connections and discharges.

Pump failure in sewage applications may additionally result in evacuation and rehousing of people and storage of furniture and equipment for up to 30 days due to contamination risk.

If the risk of clogging is to be reduced as much as possible, the installation must be upgraded to a vortex pump with minimum 100 mm free passage. This will increase both initial and operating costs of the pump by more than 100%.

It is usually cost-effective to upgrade to a 100 mm free passage vortex type of pump when Q is > 20 l/s.

1. General

Domestic sewage pumping in pipes with small diameter
When discharge pipes are smaller than DN 80 or pump sump is very small: Use grinder pumps for flows up to 5 l/s.

Aspects of wear and tear in heavy duty pumping of mixed sewage
The impeller type with least wear and tear is the SuperVortex. The most efficient is the smart trimming closed impeller, which is adjusted at each oil check.

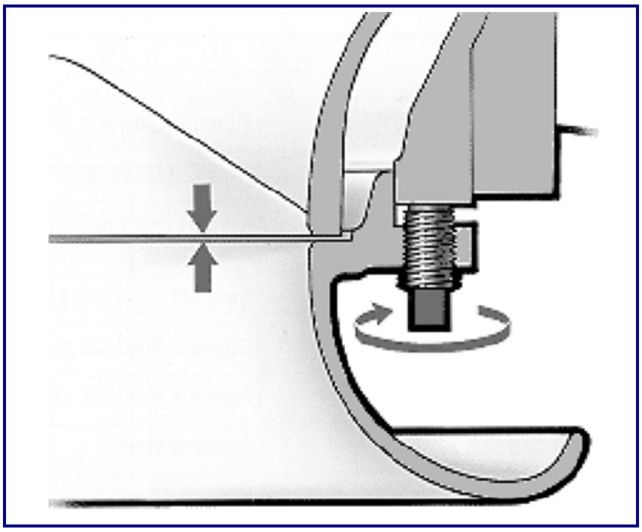


Fig. 4 Smart trimming principle

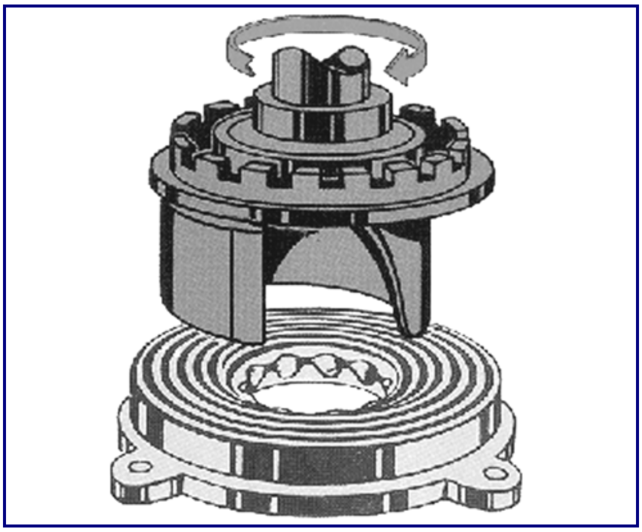


Fig. 5 Semi-open impeller and grooved wear plate

Semi-open impellers running against wear plates with cutting grooves quickly lose efficiency and capacity during the first hundred hours of operation (Fig. 5). This generally gives them the same lifetime power consumption as vortex impellers. As the time spent on unclogging the pumps is higher than for vortex pumps, the overall cost will generally be higher.

Life cycle cost comparison
Comparison of lifecycle costs between pumps with

- SuperVortex impeller
- semi-open single-channel impeller
- closed single-channel impeller with bronze neckring
- closed single-channel impeller with smart trimming.

Q = 20 l/s = 72 m³/h at 12 m head.

Price per kWh: 0.1 euro

Pumped volume at intermittent operation: 108,000 m³ a year = 1,080,000 m³ in 10 years.

Life cycle costs (see Figs. 6 & 7)

Pos. 1 **Investments**

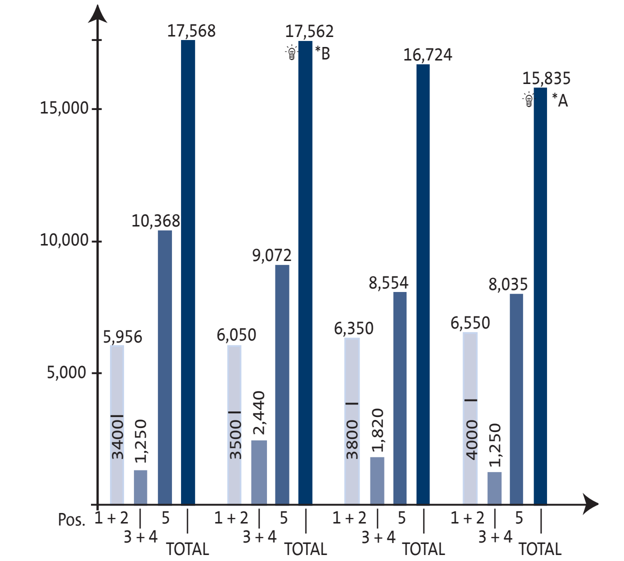
Pos. 2 **Installation and commissioning** costs

Pos. 3 **Maintenance costs** over 10 years for oil check, megging, trimming and replacement of shaft seal when broken: 1,250 euro.

Pos. 4 **Repair costs** over 10 years
Vortex impeller: no foreseeable cost
Semi-open impeller: 9 times dismantling of pump for impeller adjustment, one replacement of impeller and wear plate.
Closed impeller: one replacement of neckring.
Closed smart trimming impeller: no foreseeable cost as impeller trimming is performed from the outside in connection with oil check (see diagram).

Pos. 5 **Average power consumption:**
Average watt hour/m³/m head x capacity x head x 10 years x price per kWh.

1. General



***A**
The saving by using a 100 mm smart trimming impeller instead of a 100 mm SuperVortex impeller amounts to 11%.

***B**
The saving by using a 100 mm single-channel semi-open impeller running against a wear plate with cutting grooves compared with a 100 mm SuperVortex impeller amounts to less than 1%. This saving will seldom compensate for the increased clogging risk of the semi-open impeller.

Fig. 6 Diagram of lifetime costs

Lifetime cost in euro of pumps with different impeller types (see also Figs. 6 & 7)

	Super-Vortex	Single-channel, semi-open	Closed, neckring sealed	Closed, smart trimmed
Pos. 1	3,400	3,500	3,800	4,000
Pos. 2	2,550	2,550	2,550	2,550
Pos. 3	1,250	1,250	1,250	1,250
Pos. 4	0	1,190	570	0
Pos. 5	10,368	9,072	8,554	8,035
Total	**17,568**	**17,562**	**16,724**	**15,835**

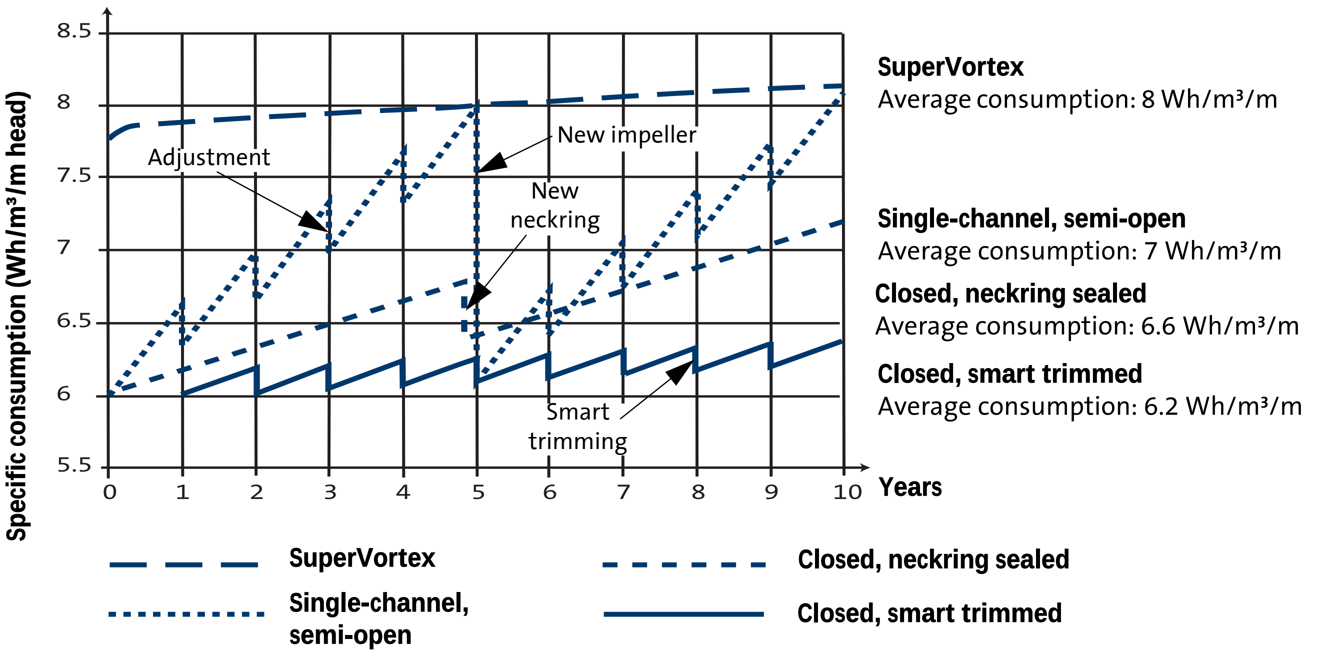


Fig. 7 Power consumption per cubic metre raised one metre (kWh/m³/m head)

1.4. Inflow

1.4.1. General

Calculation of inflow in relatively large systems must be made by companies/persons, who are insured against faulty estimates and calculations.

Calculation of the capacity of the pump system depends very much on inflow and variations of this, which should be carefully estimated. If there is great uncertainty concerning the amount of inflow, measurements should be made, if possible.

The amount of inflow from single-family and semi-detached houses is usually so small that it is the self-cleansing ability of the vertical pump riser main which determines the required capacity of the pump system.

Inflow typically consists of one or more of the following types of water:

- Drainage and infiltration water
- Rainwater
- Wastewater

Calculating the inflow

Please note that local authorities often have different regulations as to layout and dimensioning of pump systems.

The rated amount of discharge water consists of

Qd,r = the rated amount of drainage water (l/s)

Qr,r = the rated amount of rainwater (l/s)

Qs,r = the rated amount of wastewater (l/s)

Approximate graphical determination of Qd,r is shown in Fig. 10, Qr,r in Fig. 13 and Qs,r in Fig. 16.

Rated inflow in common systems

The rated discharge (Qr) in common systems is calculated like this:

Qr = Qs,r + Qr,r + Qd,r (l/s).

Rated inflow in separate systems

The rated discharge flow in separate systems is calculated like this:

Qr = Qs,r in wastewater pipes (l/s)

Qr = Qr,r + Qd,r in rainwater pipes (l/s).

When dimensioning pipes transporting both pumped and unpumped water, the probability of simultaneously occurring peak water flows must be taken into consideration. Because of this it may be necessary to minimize the rated discharge flow by increasing the accumulation capacity in the pump sump. If a gravitational pipe transports pumped water, the self-cleansing gradient can be reduced, based on the rated discharge flow.

1.4.2. Drainage and infiltration water

The rated amount of drainage water is usually small and is often estimated. In case of porous soil in the surroundings and drainage under the groundwater level, the rated amount of drainage water should be based on a hydrogeologic test.

1.4.3. Rainwater

The rated rainwater flow is calculated like this:

Qr,r = i x φ x A, where

i = the rated rain intensity ($l/s/m^2$)
A = catchment area in m^2 (horizontal projection)
φ = discharge coefficient

The calculation of rain intensity is based on consideration of the consequences of flooding.

The discharge coefficient is a measure of the rainwater runoff from the catchment area. The coefficient varies with the type of surface.

The catchment area is the area from which water flows to the discharge system.

1.4.4. Wastewater

The rated wastewater flow is based on the assumed wastewater flows qs,a from the individual installations, taking the probability of simultaneous discharge into consideration.

1. General

c.1 Assumed wastewater flow (qs,a)
The assumed wastewater flow is the inflow to the discharge system from an installation, floor outlet or the like during normal use.

c.2 Rated wastewater flow (Qs,r)
The rated wastewater flow is based on the size of the discharge installation, defined as

- coupling pipes which only transport discharge from one installation or one rainwater inlet
- connecting pipes where the assumed total wastewater flow is less than 12 l/s. Connecting pipes are pipes which transport discharge from more than one installation and more than one rainwater inlet
- connecting pipes where the assumed wastewater flow is $\geq$ 12 l/s.

1. General

Fig. 8 KP: typical pump for the application below

Fig. 9 AP 12: typical pump for the application below

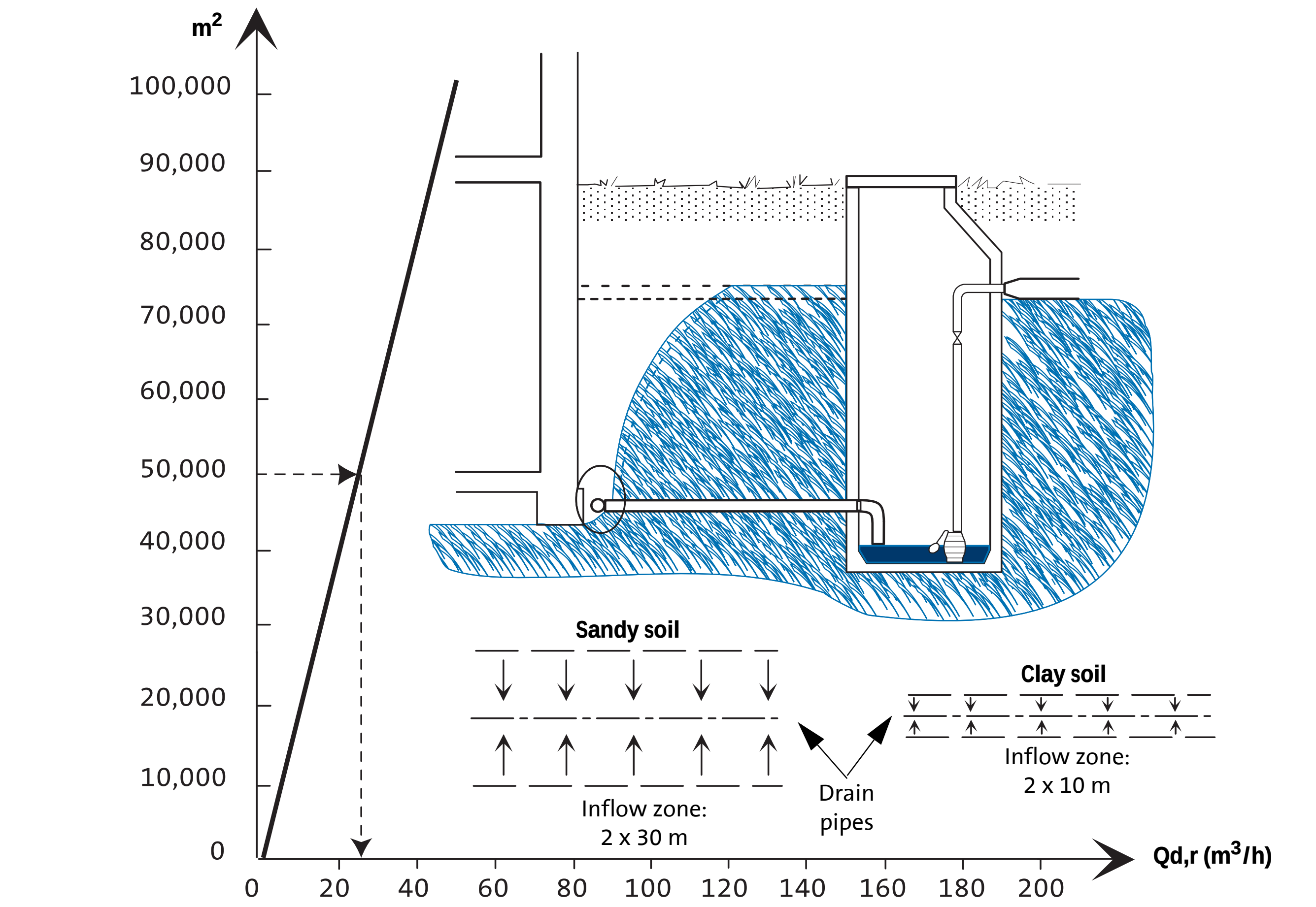


Fig. 10 Lowering of ground water table (drained area only)

Fig. 11 *AP 51: typical pump for the application below*

Fig. 12 *AP 35: typical pump for the application below*

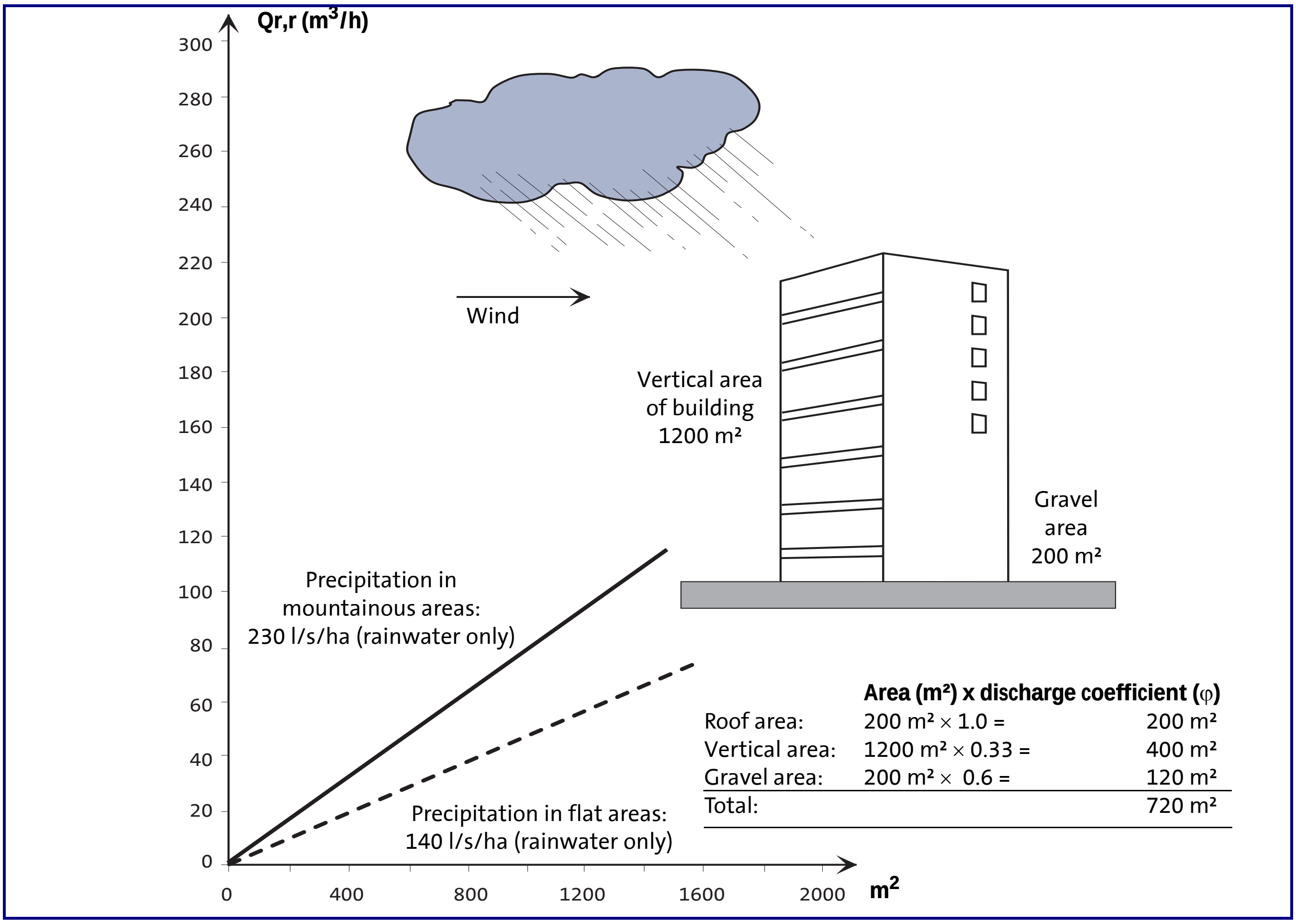


Fig. 13 *Rainwater from yards, parking grounds, roads, roofs etc.*

1. General

Fig. 14 S1 (single channel): pump for the application below

Fig. 15 SV (SuperVortex): pump for the application below

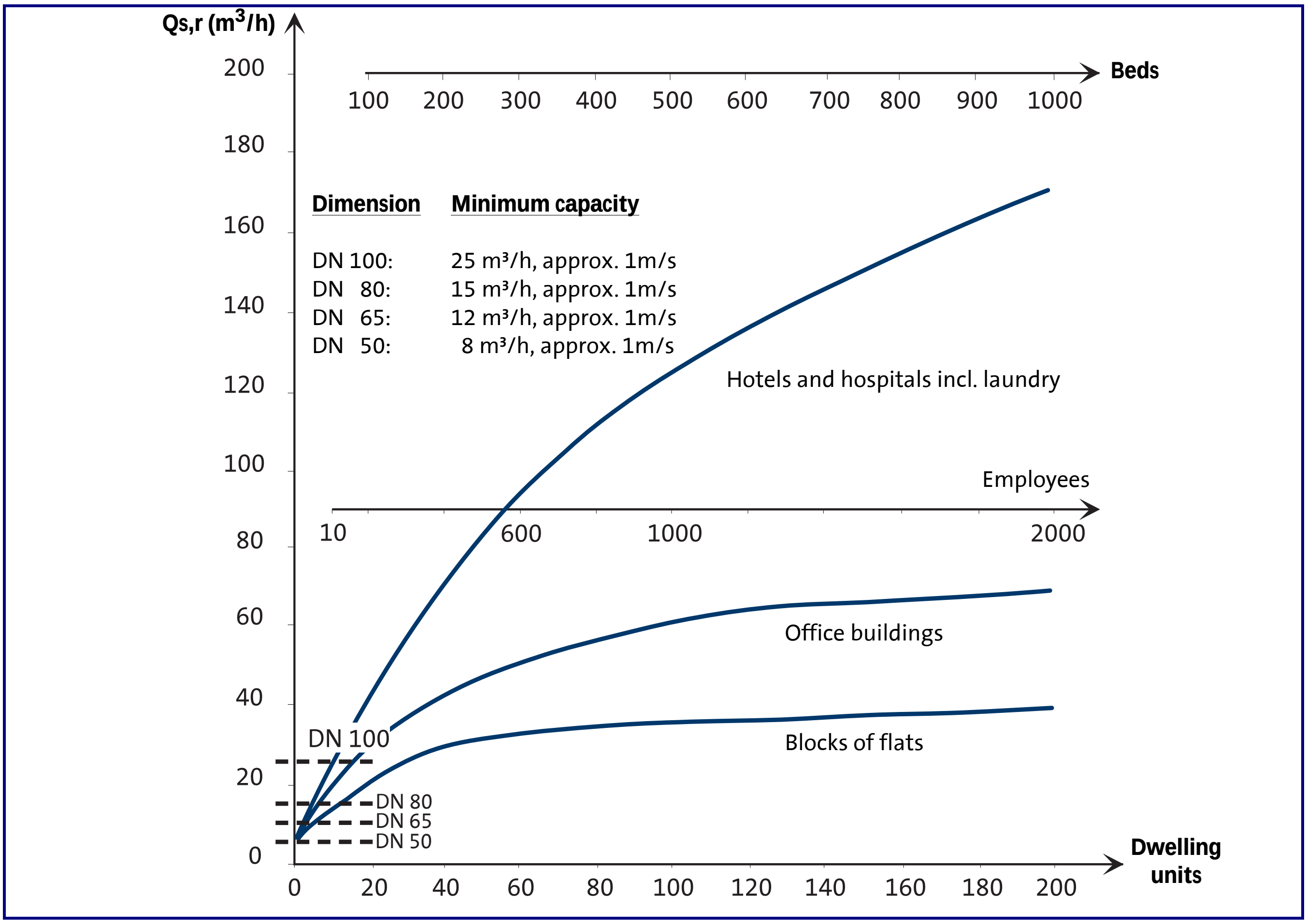


Fig. 16 Wastewater and sewage

2. Sizing of pumps

When the location and basic layout of the pump system has been chosen (including the maximum inflow), the capacity of the pump system and the pump and pipe layout can be determined.

2.1. Calculation of capacity & number of pumps and duty mode

The capacity of the pump system is calculated in such a way that it exceeds the maximum inflow. The additional capacity depends on the accuracy of the calculation of inflow. Furthermore, compensation for wear and capacity tolerances must be taken into consideration. For mass produced pumps, the international standard ISO 9906, Annex A, accepts tolerances on Q, H and P.

In the case of **small** systems, e.g. for single-family houses, semi-detached houses etc., **where faecal wastewater is pumped**, the self-cleansing ability of the riser main will often determine the minimum pump capacity:

	l/s	m³/h
DN 50	**2.2**	**8**
DN 65	**3.3**	**12**
DN 80	**4.2**	**15**
DN 100	**7**	**25**

The above figures are **independent of inflow**.

In the case of **small** pump systems (2–8 m^3/h) for wastewater including drainage and rainwater, maximum pump capacity is set to be equal to maximum inflow as pipes and sump can accumulate water. In such pump systems, it is common to use single-pump operation.

Depending on the size and variation of the inflow and the degree of inconvenience in case of pump failure, it may be a good idea to split up the capacity between two or more pumps.

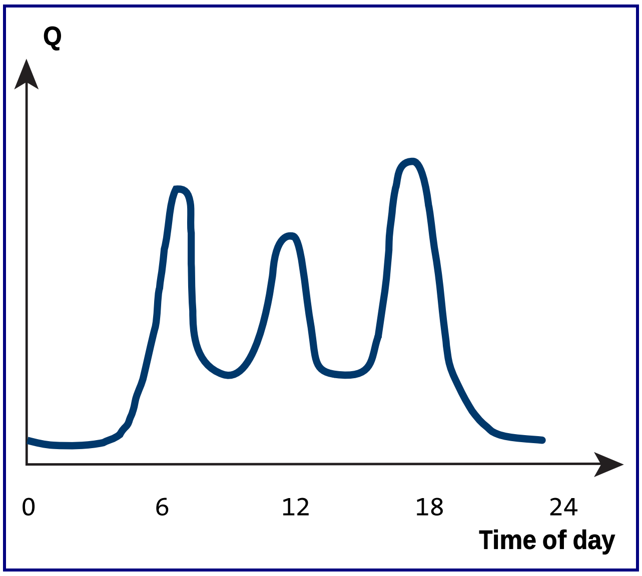


Fig. 17 Typical discharge pattern (sewage)

For **middle-sized** pump systems, it is common to use a single pump for the full discharge, but to have two similar pumps in alternating operation, i.e. 100% reserve capacity.

The decision of the need for reserve capacity must be based on the consequences of one pump being out of operation and the possibility of replacing the pump.

For pump systems with both wastewater and rainwater inflow, it is possible to have a group of pumps consisting of a number of similar pumps which can handle maximum flow of wastewater and another group of similar pumps for rainwater.

Alternating duty mode can ensure uniform wear of the pumps and constant check of operational availability. By choosing proper control equipment and correct start and stop levels, it is possible to ensure proper cut-in of the pumps so that they run simultaneously, depending on inflow.

2.2. Selection of pump and pipe layout

When the number of pumps and any split of duty between them has been decided, pump and pipe layout can be determined. The following things should be considered:

Number, type and position of fittings on internal and sometimes external discharge pipes:

- isolating and non-return valves
- flow meters or volumetric flow test equipment
- air vents
- cleaning and inspection sockets
- bends, manifolds, branchings, reductions and expansions
- flanges and unions
- adapters and compensators
- draining and pressure gauge sockets
- pipe bends

The pipe layout should be made as simple as possible and in such a way that it does not make access difficult for inspection, maintenance and replacement.

Each pump is fitted with a vertical discharge pipe, which can either be connected directly to separate external discharge pipes or to a manifold, which itself is connected to a common external discharge pipe outside the pump pit.

Necessary fittings or pipe bends are fitted to the discharge pipes and the manifold, if any, is fitted with necessary valves etc. Each discharge pipe should have its own non-return valve and isolating valve. For very small pump systems, where backflow does not occur, valves can be left out and be replaced by a vented pipe, placed above the discharge level so that the pipe below the vent is self-evacuating. This will clean the impeller of any rags or other solids.

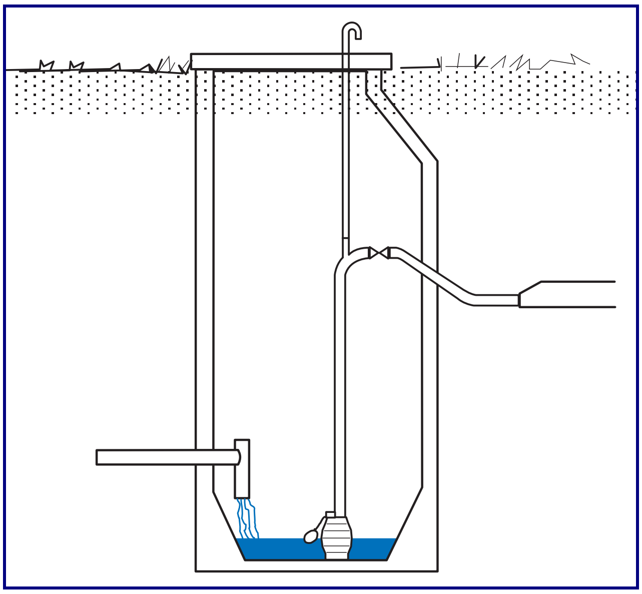


Fig. 18   Layout of simple pump sump

The internal discharge pipes should be made of a material which enables them to resist the impacts to which they are subjected:

- pressure and pressure variations
- velocity of water
- atmosphere (humid, corrosive air)
- temperature-dependent expansion
- mechanical impact
- electrolytic action

For systems pumping normal household wastewater and rainwater, hot-galvanized steel pipes or stainless steel pipes are usually used. PEM, PEH and PVC plastic pipes are sometimes used for small pump systems with low pressures.

The pipes must allow all particles passing through the pump to be transported in both internal and external discharge pipes. The question of self-cleansing must also be taken into consideration.

The water velocity should not be much less than 1.0 m/s in vertical pipes, otherwise harmful deposits may occur. Note that this is also the case during parallel operation where the amount of water per pump drops when pumping into a common external discharge pipe. Usually the dimensions of the vertical discharge pipes are chosen so that the velocity during parallel operation is between 1 and 3 m/s.

In horizontal pipes (both internal and external), a velocity of 0.7–0.8 m/s should be aimed at. This should ensure trouble-free operation without harmful deposits. In order to avoid unnecessarily high pressure losses in the system, the velocity should not exceed 2 m/s.

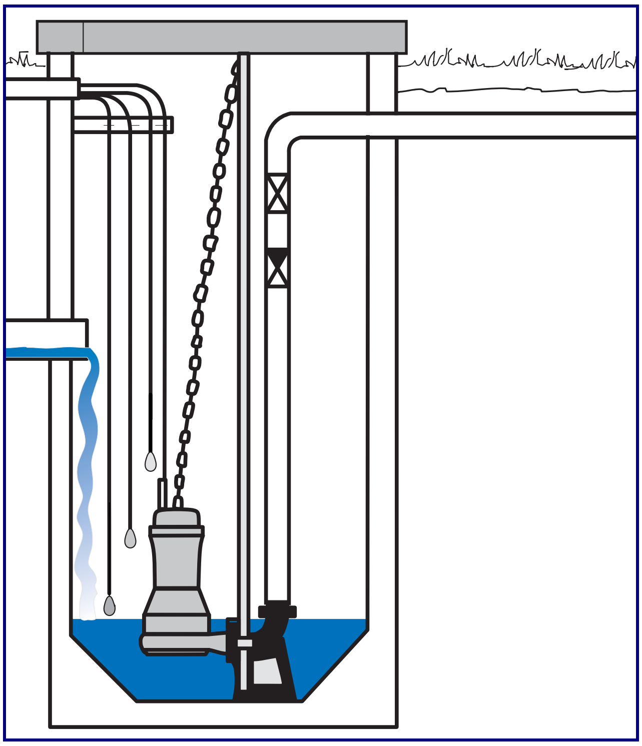


Fig. 19 Installation with vertical and horizontal discharge pipe system

2.3. Determination of system characteristic

The pump pressure must overcome various resistances in the pipe system.

The total head varies with the amount of water in the system. In principle, the counter-pressure consists of three elements:

- Geodetic head
- Losses in individual resistances
- Frictional losses in straight pipes

A graphic illustration of the relation between losses and water flow is called the system characteristic.

2.3.1. Geodetic head

The geodetic head is independent of the flow and is the difference of altitude in metres of the mean water level in the pump sump and the upper side of the external discharge pipe at the outlet of the pump system (final level). This is on condition that no part of the pipe system is at a higher level and that the outlet is not submerged.

If the difference between the upper and the lower water levels in the pump sump is considerable, it may be necessary to check the situation both at pump stop and pump start.

2.3.2. Losses in individual resistances

When water passes through valves, bends, reductions and expansions, etc., energy is lost. This loss varies with the velocity of the water and consequently the flow rate.

These losses can be calculated from the formula

$$He = \xi \times \frac{v^2}{2g}$$

where

He = energy loss in individual resistances (m)
v = velocity of water in individual resistances (m/s)
g = acceleration due to gravity (9.81 m/s²)
ξ = resistance coefficient of individual resistances

It is important to determine the resistance coefficient as accurately as possible, as individual losses can be considerable in cases of high velocity.

2.3.3. Frictional losses in straight pipes

The frictional loss in straight pipes depends on the flow through the pipe system and a number of other factors, of which the most important is the roughness. Here it is important to consider the roughness as the roughness of the pump system, i.e. including the influence of pipe connections, deposits on pipe walls and air pockets. Experience shows that the roughness figures for brand new pipes stated by the manufacturers are not to be relied on. For steel pipes and plastic pipes, the roughness should therefore not be estimated at less than 1.0 mm and 0.25 mm respectively. Often a roughness of 1 mm is used for both pipe types.

If the external discharge pipe is not constantly rising towards the outlet, but has top and bottom points, the risk of air pockets and deposits in the pipe increases and the roughness may increase considerably. In such cases, the pipe characteristic should be determined for alternative roughnesses, e.g. 1.0 mm and 2.0 mm, and the pump selection made according to this.

The external discharge pipe is thus a very important element when dimensioning and selecting pumps. The pump selection task is properly completed only if the external discharge pipe is treated as an integral part of the pump system.

Pipe loss nomograms are very much used and if they are made in a practical way and are used correctly, allow pumps to be selected quickly and safely. It is important that the nomogram is based on recognized resistance formulas, that water temperature and roughness correspond to the conditions in question and that the internal pipe diameter is used in the nomogram.

Grundfos has worked out nomograms (Figs. 81 & 82), by means of which it is easy to determine the frictional loss in straight pipes and individual resistances as well as the velocity.

Constant for system characteristic (C) =

$$\frac{\text{frictional loss in fittings and straight pipes}}{\text{flow squared}}$$

System characteristic, H = geodetic head + C x Q^2.

Roughness of different material surfaces

Type of piping (clean, new pipes if nothing else is mentioned)	**Roughness k** (mm)
Drawn pipes	
(aluminium, copper, brass, glass and various synthetic materials)	**0–0.003**
Plastic pipes	
PVC and PE, new	**0.01–0.005**
PVC and PE, with deposits	**0.15–0.6**
GUP (glass-fibre reinforced polyester)	**0.02–0.05**
Steel pipes	
Drawn pipes	**0.01–0.05**
Welded pipes, new	**0.03–0.15**
Welded pipes, with deposits	**0.15–0.30**
Galvanized pipes, new	**0.1–0.2**
Galvanized pipes, with deposits	**0.5–1.0**
Riveted pipes	**1–10**
Cast iron	
Centrifugal cast, new	**0.1–0.3**
Centrifugal cast, with deposits	**0.5–3.0**
Asbestos cement pipes	**0.02–0.1**
Concrete pipes	
Centrifugal cast pipes	**0.1–0.3**
Vibrated pipes	**0.2–0.8**
Normal pipes	**0.3–1.5**
Other pipes	
Wooden pipes	**0.2–1.5**
Fibre pipes	**0.01–0.05**
Vitrified/enamelled pipes	**0.2–0.5**
Miscellaneous	
Glaze plastered concrete canal	**0.3–1.0**
Raw concrete canal	**1.0–5.0**
Rock tunnel	**70–400**
Canal in earth	**10–200**

2. Sizing of pumps

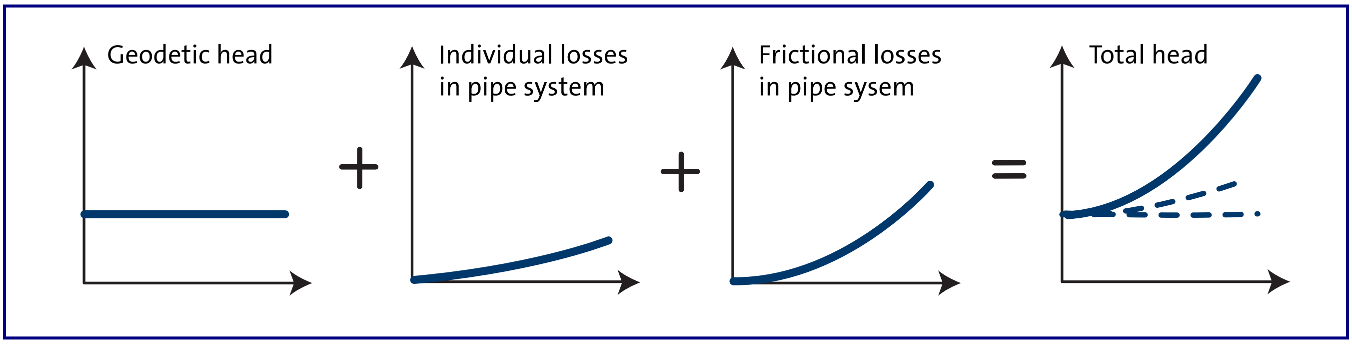


Fig. 20 Calculation of total head

2.4. Pump selection and pump characteristic

2.4.1. Pump selection

Pump suppliers will normally offer several different pumps within a given capacity range and a choice has to be made between these.

The selection should ensure:

- that the pump meets the capacity requirement, possibly by using several pumps.
- that the duty point of the pump is as good as possible. The pump should run at maximum efficiency for as long as possible.
- that good self-cleansing properties are ensured in the pipe system, also during parallel operation when connected to a common external discharge pipe. In this case, the performance of each pump drops compared with the performance at single-pump operation.
- that a pump with a suitably steep pump characteristic is chosen (especially for small pump systems). This ensures sufficient excess pressure, which makes it easier to remove deposits, thus reducing the risk of complete blockage.
- that the passage through the impeller is suitable for the contents of the water to be pumped.

  Normal requirements for free passage through pump and riser main and for water velocity:

  1. Drainage and infiltration water
  Max. particle size 10 mm, self-cleansing velocity in riser main 1 m/s.

  2. Rainwater and grey wastewater (effluent)
  Max. particle size 30–50 mm, self-cleansing velocity in riser main 1 m/s.

  3. Wastewater
  Faecal wastewater from single-family house
  Max. particle size 50–70 mm, self-cleansing velocity in riser main approx. 1 m/s.

  Faecal wastewater from buildings in general
  Max. particle size 70 mm, self-cleansing velocity in riser main approx. 1 m/s.

  Faecal wastewater in main pipes
  Max. particle size 80–100 mm, self-cleansing velocity in riser main approx. 1 m/s.

  Wastewater (effluent) in the industry and at treatment plants after passing a screen
  Particle size 30–50 mm, self-cleansing velocity in riser main approx. 1 m/s.

- that the pump choice is always based on the following curves:

  - Pump characteristic (Q/H curve)
  - Power curve
  - Efficiency curve

For submerged pumps, the power and efficiency curves must be for the whole unit, i.e. pump and motor.

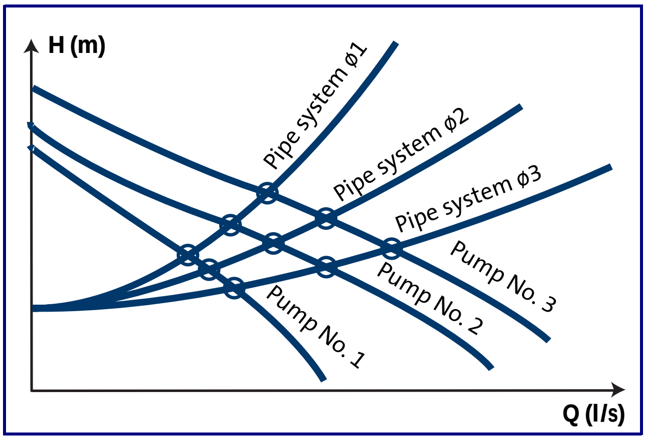


Fig. 21 Relation between pump and pipe system

2.4.2. Pumps in single operation

Fig. 21 shows that it is often necessary to consider different alternatives or to make calculations prior to the final pump selection. Pump selection and sizing is most clearly and easily shown graphically. This is illustrated in the following figures.

The system characteristics, which could be for different geodetic heads or pipe dimensions or materials, are calculated and plotted on a suitable scale. In the same diagram, the pump characteristic for alternative pumps can be drawn, which makes comparison easier. Be careful when plotting the supplier's pump characteristic in the diagram including the system characteristic and think of scale and units on the axes.

The duty point of the pump is the point of intersection between system characteristic and pump characteristic. It is the point where the pump develops exactly the total head required to overcome the geodetic head plus hydraulic losses (individual resistance losses and frictional losses) in internal and external pipes.

It is also possible to draw the efficiency curve in such a way that it can be seen immediately whether a given duty point is acceptable in relation to the efficiency of the pump unit. The optimum pump selection is obtained when the duty point is right above the top point (maximum value) of the efficiency curve (Fig. 22).

If the geodetic head varies, which should be checked, (for instance, with great variation of the water level in the sump, when used as a reservoir), this means vertical parallel displacement of the system characteristic and consequently the duty point will vary within a certain range. In this case also, the pump selection should result in efficiencies around the top point (maximum value) of the efficiency curve (Fig. 23).

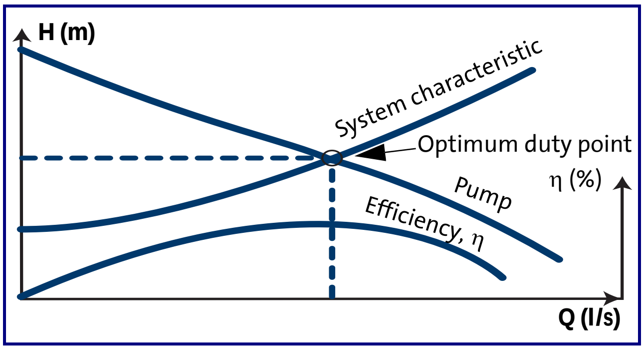


Fig. 22 Optimum duty point for a new pump in a pipe system without deposits

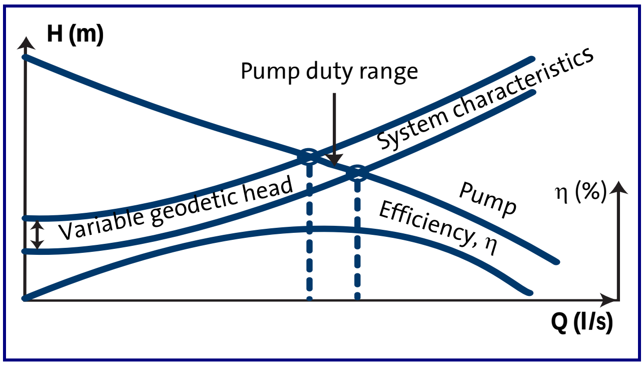


Fig. 23 Duty point for a new pump in a pipe system with variable geodetic head

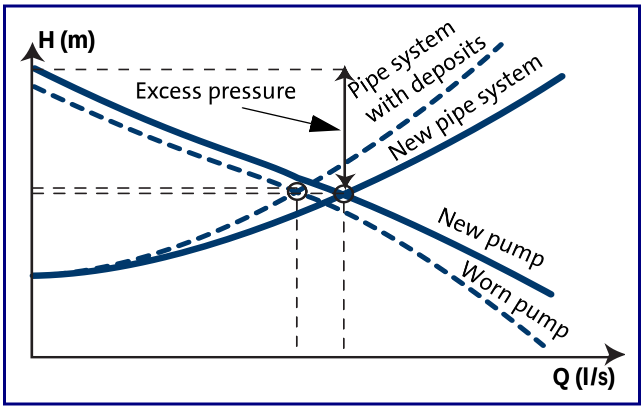


Fig. 24 Moving of duty point over time due to pump wear and deposits in pipe system

Fig. 24 illustrates how the duty point moves if the losses in the pipe system increase, e.g. due to deposits on the pipe walls. It also shows how pump wear gives a declining pump characteristic.

2.4.3. Pumps in parallel operation

Two or more pumps can be installed so that they can run in parallel, connected to a common discharge pipe. The common characteristic for both or all pumps in operation is constructed by horizontal summation (at the same head) of the individual pump characteristics. We only talk about parallel coupling if the pumps are connected to the same discharge pipe so that the pressure loss in the pipes close to the pumps is insignificant compared to the pressure loss in the common discharge pipe.

The individual pump characteristics and the common characteristic can be plotted together with the system characteristic and the efficiency curve - just like in the case of one pump.

The duty point is the point of intersection between the system characteristic and the common pump characteristic. The principle is illustrated in the diagram below.

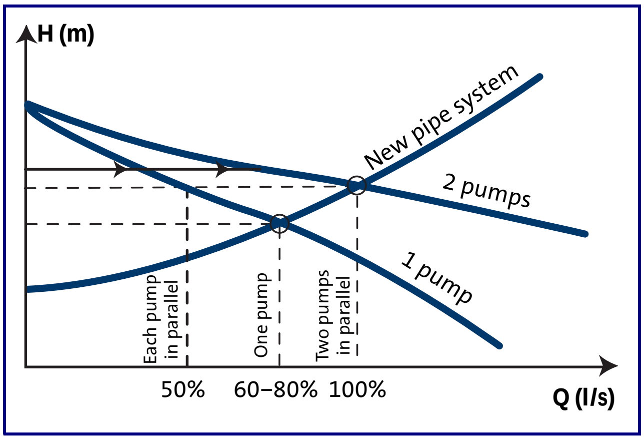


Fig. 25 Principle of graphical determination of duty point with two similar pumps in parallel operation. The characteristics of the two pumps are summed horizontally at the same head.

3. Pump service life

The service life of a pump is the number of hours of operation, or in the case of low usage, the time elapsed, since the previous overhaul or check-up. At each overhaul, bearings and other wearing parts, cables and barrier oil may have to be checked or replaced, but the pump remains fundamentally the same.

Tyical pump service life is between 200 and 2000 hours of operation.

Drainage, effluent and sewage pumps need periodic check-ups as the operating conditions are often tough. The frequency depends on the specific application and the liquid type. In the warranty period it will often be every 2,000 hours of operation or at least once a year. At the check-up, damaged or worn components are replaced.

If properly serviced, the pump may last for 10 years or more, equal to 20,000 hours' operation. The service life of the pump is, however, affected by several factors:

1. Abrasive liquids (Page 23, section 3.1.)
2. Corrosive liquids (Page 24, section 3.2.)
3. Cavitation (Page 26, section 3.3.)
4. Impeller life (Page 28, section 3.4.)

The longest life in connection with heavily abrasive liquids is obtained by using an air compressor operated **air lift pump**. The price of improved durability is a doubling of the power consumption.

3.1. Abrasive liquids

If a standard sewage content existed, it would contain approx. 0.005 vol.% of sand and silt. The sand content is either expressed as

- a **percentage by volume (p_v)** or as
- a **percentage by weight (p_m)**.

The relation between the two is:

$$p_m \sim 3 \times p_v$$

(when density of sand is estimated at 3,000 kg/m³)

This means that if p_v is 0.005%, p_m will be 0.015%. For sewage with this content, any wastewater type of pump and any material could be used. For certain periods, however, the sand content may be much higher, e.g. following heavy rainfall or when snow melts. It may be up to 1,000 times as high for several hours. The amount of sand carried into parts of a sewage system by infiltrating drainwater or groundwater may be so high as to cause extensive pump wear.

Factors that affect the wear of the pump:

1. Sand content
2. Shape of sand grains
3. Pump material
4. Impeller type
5. Pump head

3.1.1. Sand content

Often a sand problem can be traced to a hillside with extensive erosion during heavy rainfall. Rapidly flowing rainwater runoff carries large quantities of humus, sand and silt to roadside gullies and so to the collecting pit. From here, the water is pumped from pumping station to pumping station until trapped at the inlet of the treatment plant. All the way through the system the sand will cause trouble. The sand may also come from a construction site, discharged directly into the sewage system. To reduce the worst problems, a runoff barrier with sand trap or settling basin should be made before the water is led into the sewage system.

Sometimes a sand problem can be traced to an old or incorrectly dimensioned section of the sewage system with collapsed or leaky joints. When it rains, infiltrating water will carry sand and silt into the sewage system. In such cases, the sewage pipe section should be relined or replaced. Generally such problems are best solved by trapping and retaining the sand before it reaches the first pumping station; this is usually the most economic solution also.

3.1.2. Shape of sand grains

Depending on the shape and sharpness of the grains, the pump service life may be much reduced.

3.1.3. Pump material

When pumping abrasive liquids, one way of minimizing practical problems is to select a pump which has impeller and guide vanes of hardened metal or which are rubber-coated, a type of pump which is expensive, both to buy and to service. Mobile contractor pumps are of this type.

3.1.4. Impeller type

Often a good way of solving a sand wear problem is to replace the single-channel impeller pump with a vortex pump.

This pump type will pump most of the sand along the pump housing until it is discharged. This reduces wear on the impeller and the mechanical shaft seal. The price for the improved durability is an increased power consumption of approx. 20%.

3.1.5. Pump head

In case of severe sand problems, a change in the discharge pipe system may be considered in order to reduce the head requirement and to introduce a sand trap. As pump head and velocity through the impeller are related, a lowering of the required head will give longer pump life.

Changing to a pump type with the same flow, but with a lower discharge head, will usually extend service life at the same sand content.

3.2. Corrosive liquids

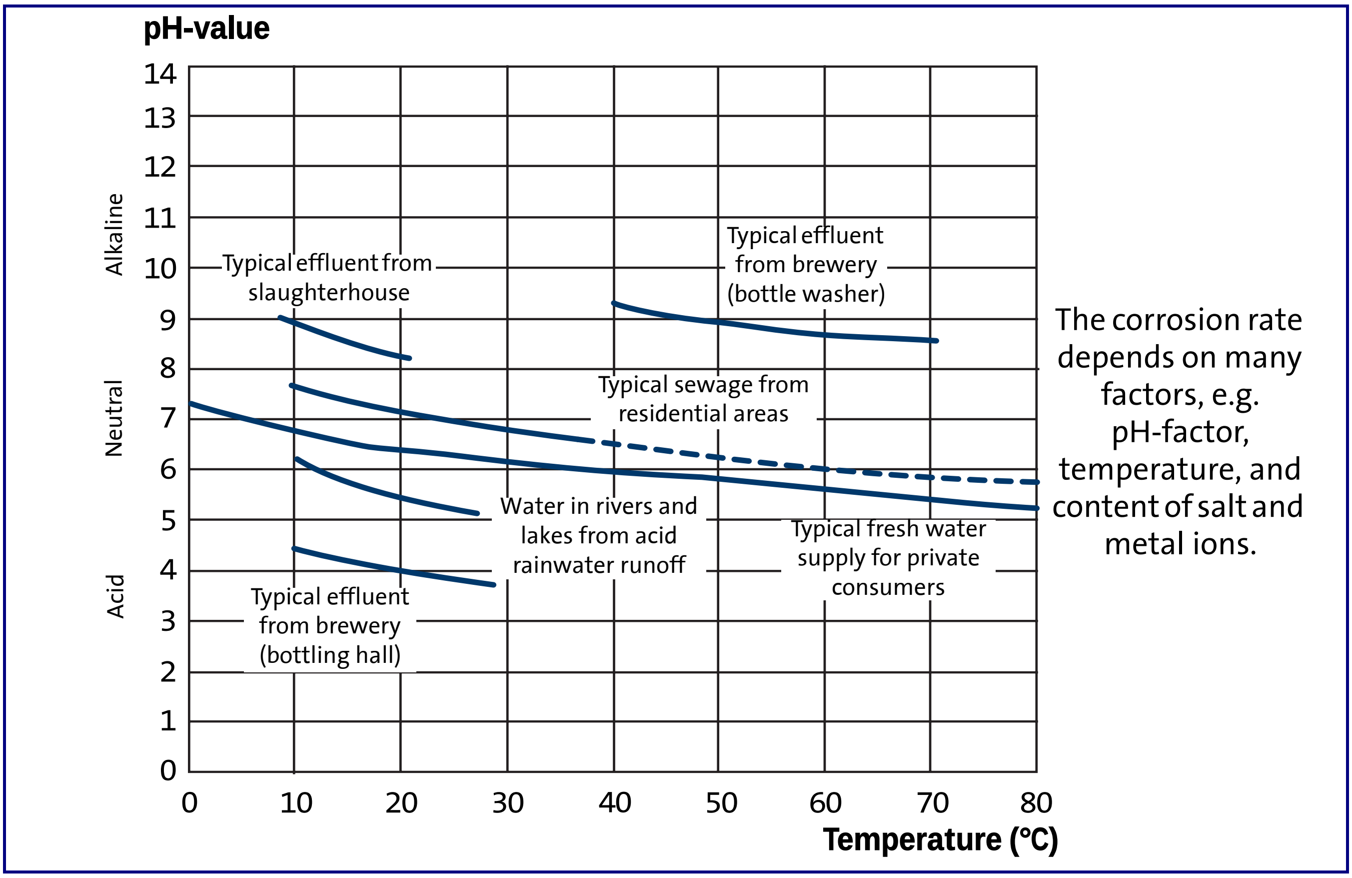


Fig. 26 Acidity of various effluent types

3. Pump service life

Relation between choice of material and service life		
Material	**Reduced service life**	**Acceptable service life**
Cast iron	pH < 6.5	pH > 6.5
Epoxy lining (200 microns) or cathodically protected cast iron	pH < 5	pH > 5
Bronze	pH > 8.5	pH < 8.5
Stainless steel, W.nr. 1.4301	pH < 3	pH > 3
Cathodically protected stainless steel	pH < 1	pH > 1

The above diagram and table show that **cast iron** components have an acceptable service life in "ordinary" sewage at low temperatures. The use of cast iron can be extended by introducing a coating (e.g. of epoxy) and on top of that a layer of wear resistant paint, at least 200 microns thick. To match this increased protection of cast iron components, fabricated steel parts and steel pipes should be hot-dip galvanized.

Bronze should only be considered at a pH value lower than 8.5.

For acid rainwater runoff and hot industrial effluents, the corrosion resistance of cast iron may not be sufficient, especially for components subject to high flow velocities, such as impellers and pump housings. In these applications, the coating and protective natural layer of rust may be eroded, leading to rapid corrosion. Here **stainless steel** will be the obvious choice to obtain acceptable service life.

Because of the risk of corrosion, **aluminium** should only be used for stator housings and inlet screens on portable lightweight contractor pumps.

Submersible pumps made entirely of highgrade stainless steel, protected by an epoxy coating and zinc anodes, are the natural choice for seawater and highly corrosive liquids such as hot industrial process water effluents.

3.2.1. Pit design for corrosive liquids

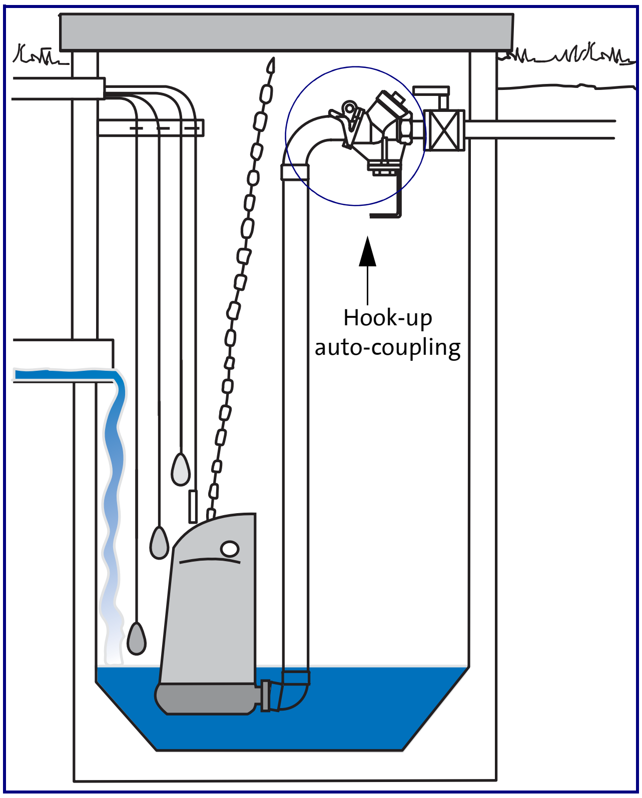


Fig. 27 ***Best installation design*** *for highly corrosive liquids. Any sealing defects are easily detected when the pump is pulled up for service as all piping and gaskets are out of the water.*

3. Pump service life

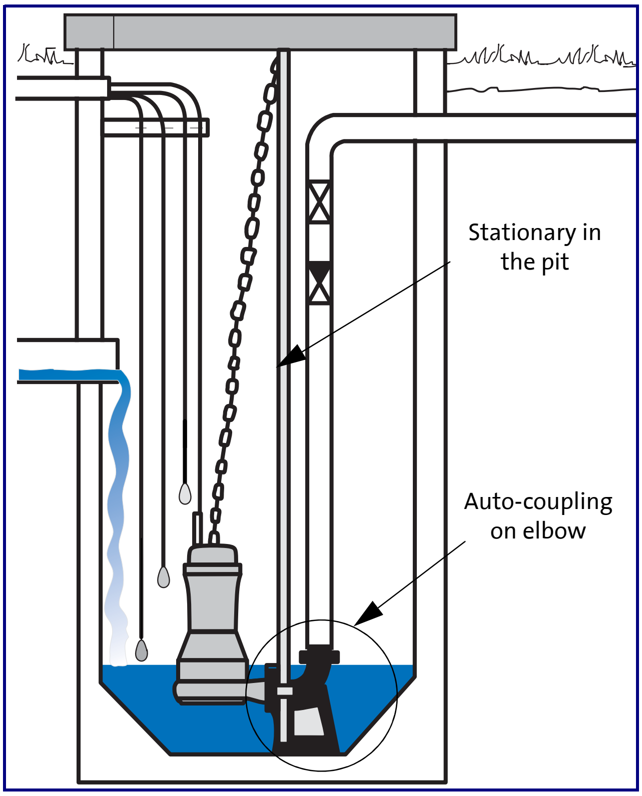


Fig. 28 ***Avoid this installation design*** *for highly corrosive liquids as leaks and pitting holes cannot be detected as they are hidden below liquid level.*

3.3. Cavitation

Cavitation can be considered as being the creation and collapse of vapour bubbles in a liquid along the impeller vanes at low inlet pressure and large flow.

Cavitation in sewage pumps may take place if the following applies:

- Vent pipe to sump or tank is too small or partly blocked, combined with a high liquid temperature.
- Long suction pipes in connection with dry-installed pumps.
- Small quantities of air bubbles are sucked in from a vortex when the liquid level is less than 0.5 m above the pump inlet.
- The pump capacity exceeds the operating range shown on the pump curve.
- Pump inlet is blocked.
- Temperature of the pumped liquid is more than 80°C.
- No vent pipe from sump or tank.

Cavitation may destroy impeller, shaft seal or motor bearings after less than 100 hours' operation.

Initial cavitation alone will normally only partly reduce the impeller life, but if installed in an abrasive or corrosive liquid, material loss from the impeller may require replacement of the impeller too often.

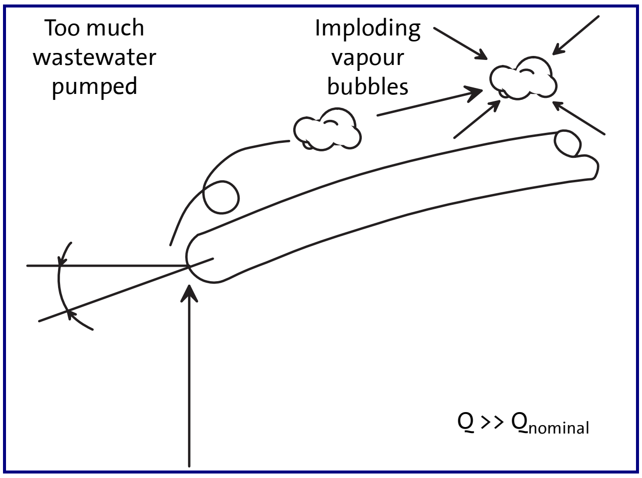


Fig. 29 *Pumped liquid hitting the vane leading edge at an angle different from the vane angle. Eddies and low pressure zones will form on the other side of the vane. If the pressure drops below the vapour pressure, vapour bubbles will form, and being entrained in the flow will be moved to an area of higher pressure where they will collapse (implode). The resulting high pressure impact may lead to pitting and erosion of adjacent surfaces.*

3.3.1. Action

Wet-installed pumps

Raise the start/stop levels by 0.3 m. Check the actual pump flow in the installation. If it exceeds what is recommended on the data sheet, an impeller with a smaller diameter should be fitted.

Dry-installed pumps

Check the suction pipe system for possible air traps, concentric reducers, etc. Raise the start/stop level by 0.3 m. Check the actual pump flow in the installation.

3. Pump service life

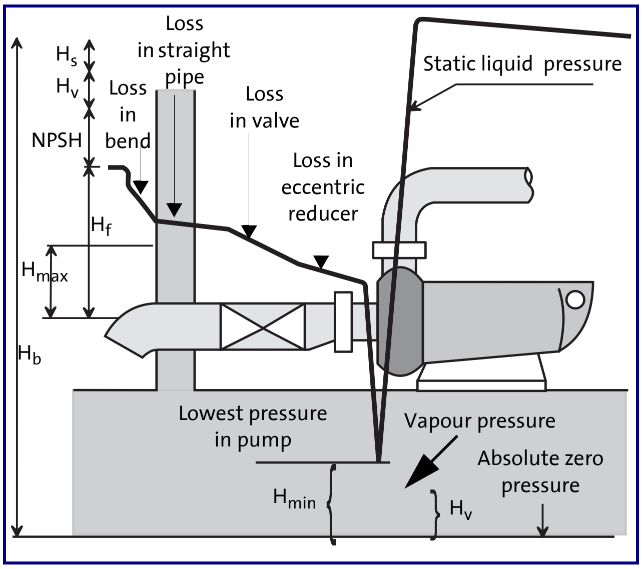


Fig. 30 Friction losses in pipe systems with dry-installed pumps. ***H_{min}* must always be larger than *H_v***

3.3.2. Calculation of maximum suction lift

The theoretical limit of the suction lift $\mathbf{H_{max}}$ is equal to the barometric pressure $\mathbf{H_b}$. At sea level this is 10.3 m, equivalent to 760 mm mercury (Hg). In practice, this value is reduced by the following factors:

H_f: Friction loss in suction pipe and suction valve.

H_v: Vapour pressure of the pumped liquid.

NPSH: **N**et **P**ositive **S**uction **H**ead. Pressure drop from the suction port to the place in the impeller where the lowest pressure occurs (criterion for whether cavitation occurs in the pump).

H_s: Safety. When deciding this value, estimate the possible variations in H_f, H_v and NPSH, e.g. increased friction losses caused by deposits in the suction pipe, changes in liquid temperature and variations in pump capacity (Q).

$\mathbf{H_{max}}$ can then be calculated from the following formula:

$$H_{max} = H_b - NPSH - H_f - H_v - H_s$$

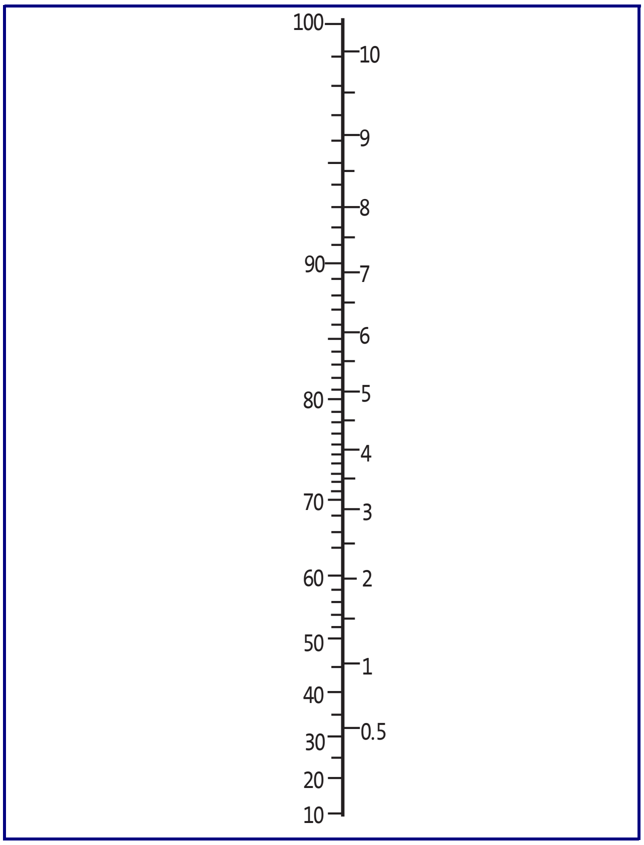


Fig. 31 Vapour pressure

The lowest barometric (atmospheric) pressure which occurs should be used in the calculation. For each pump, an NPSH curve is shown, from which the NPSH value at a given capacity can be read.

P_b: Barometric pressure (Pa)

H_b: Barometric pressure (atmospheric pressure)

$$H_b = \frac{P_b}{\rho \times g} \quad (m)$$

ρ: Density of liquid (kg/m³)

g: 9.81 m/s²

H_f: $\frac{\Delta p}{\rho \times g}$ (m)

Δp: Loss of pressure in suction pipe (Pa)

If H is negative (most relevant for hot liquids), the static inlet pressure must be increased to avoid cavitation.

H_s is usually set at 0.5 m for liquid temperatures up to 60°C. If the temperature is above 60°C the value is raised to 1 m.

Note

If initial cavitation is unavoidable, a vortex pump type should be used, as this impeller type can withstand cavitation better than pumps with semi-open and closed impellers.

The atmospheric pressure at the surface of the sea varies around the value 101325 Pa or 1013.25 mbar = 760 mm Hg = 1 standard atmosphere.

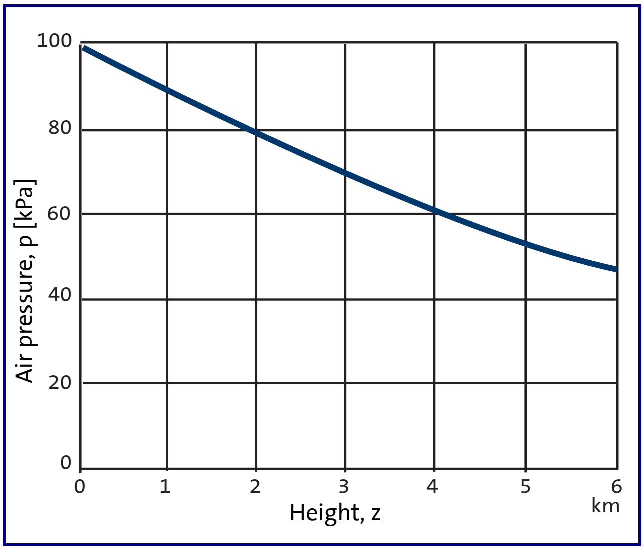


Fig. 32 Variation of atmospheric pressure with elevation

3.4. Combined effect on impeller service life

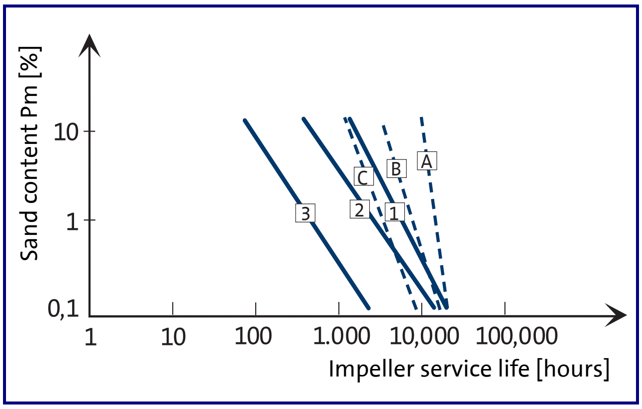


Fig. 33 Comparison of wear structure of two different impeller types operating at 10 m head

Explanation of the diagram above:

1. Semi-open cast iron impeller operating in alkaline sandy sewage with a high pH
2. Semi-open cast iron impeller operating in corrosive sandy water with a low pH
3. Semi-open cast iron impeller operating in corrosive sandy water with a low pH, initial cavitation

A. Same liquid as for curve 1, but with a cast iron vortex impeller

B. Same liquid as for curve 2, but with a cast iron vortex impeller

C. Same liquid as for curve 3, but with a cast iron vortex impeller with initial cavitation

4. Density and viscosity

4.1. Pump performance in high-density liquid

The density of a mixture of water and sand can be written like this:

$\rho = 1 + 0.007 \times p_m$ [t/m³],

where p_m is expressed as a percentage by weight.

If p_v = 15% by volume, p_m will be ~ 45% by weight (see page 19).

$\rho = 1 + 0.007 \times 45 = 1.32$ t/m³.

Using a standard sewage/contractor pump (for densities of up to 1.1 t/m³) to handle this mixture will overload the motor and in case of inadequate motor protection, overheating and burnt out windings will be the result.

Action

1. Fit an impeller with a smaller diameter or a bigger motor. The motor power increase in per cent must at least be equal to the increase in density.

2. Introduce flushing valve operation during startup. This will distribute the solids in the liquid. A mixture with 15% vol. will normally only occur in connection with excavation drainage (contractor pumps) or if the pump flow in vertical discharge pipes is not sufficient to keep the sand suspended.

   In this case, it will settle in the pump housing after pump stop and the life of the motor will be reduced. In that case a pump with higher flow and head should be installed.

Operation at a very small flow with effluent pumps and particularly sewage pumps should be avoided for the following reasons:

1. Sand and other solids collecting in the pump housing.

2. Excessive scaling (build-up of deposits on the walls of the discharge pipe).

3. Periods of heavy vibrations due to uneven balance of the impeller when partly blocked by solids of high density.

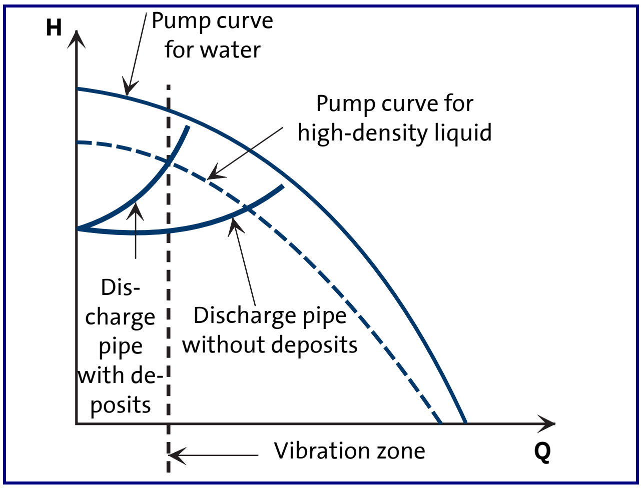


Fig. 34 Effect of high-density liquid

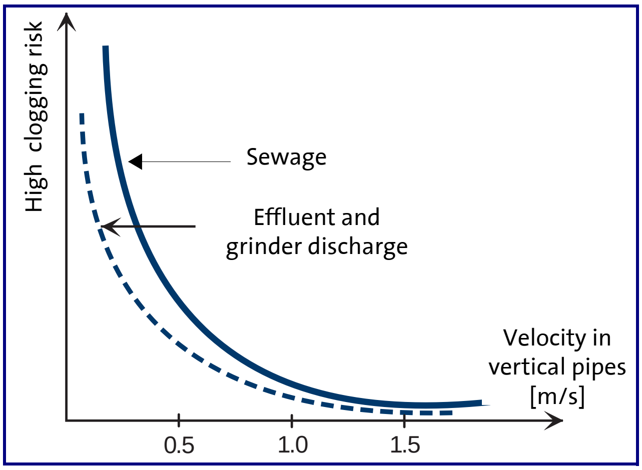


Fig. 35 Scaling and clogging of vertical discharge pipes

Minimum velocity

Sewage: 0.7 m/s, but better with 1 m/s
Effluent: 0.5 m/s, but better with 0.8 m/s

4. Density and viscosity

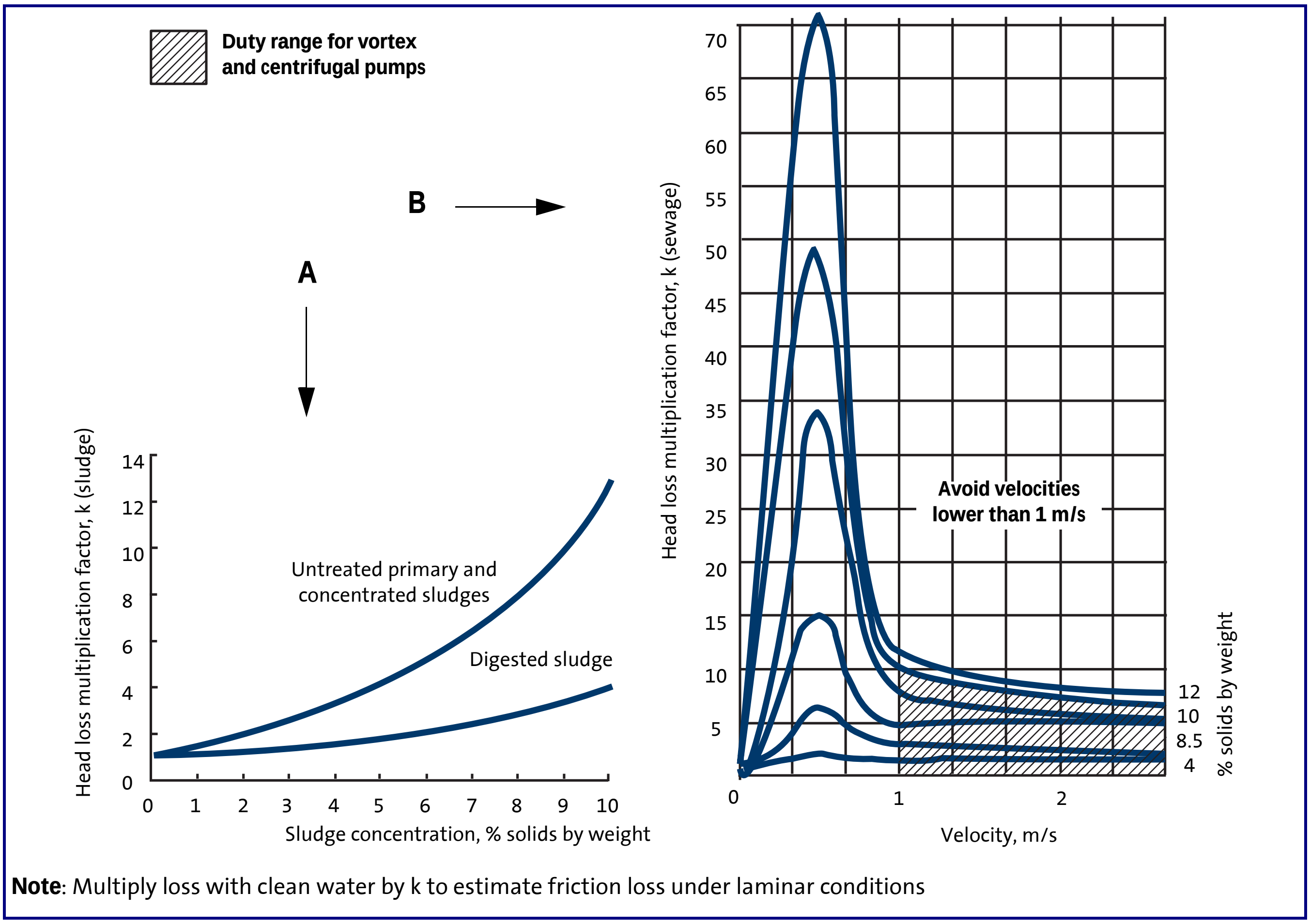


Fig. 36 *Head loss multiplication factors: Diagram A is for different sludge types and concentrations and diagram B is for different pipe velocities and concentrations of solids in sewage*

4.2. Pump performance in highly viscous liquids

The apparent viscosity of unhomogeneous mixtures of water, sludge, fat, leaves and gas can be very high. With an increasing content of solids and sludge, the friction loss in the pipe system will increase while the pump performance decreases, in some cases by up to 40%. This is partly due to the fact that the impeller needs more energy for pumping highly viscous liquids. This will reduce the motor speed by up to 300 RPM which will reduce the capacity considerably.

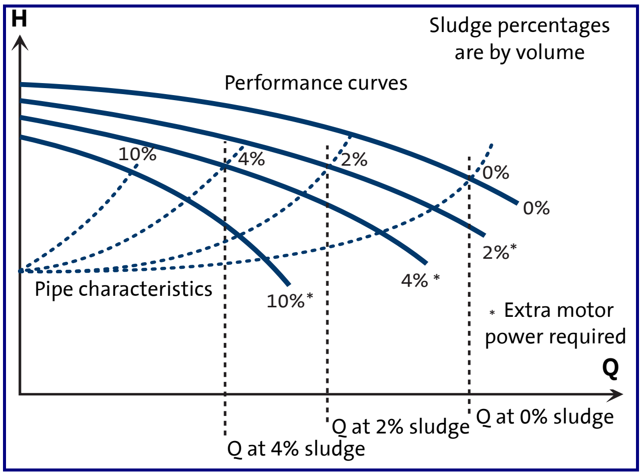


Fig. 37 *Impact of solids in sludge on pump and pipe characteristics. The graph shows only the principle and cannot be used for numeric calculations.*

As a precaution when pumping dense sludge, the pump should be placed as low as possible in order to ensure a good positive suction head. The use of long suction pipes should also be avoided since the pressure drop in these is also increased by the solids content. When the pump starts, a flushing valve should mix the pit content.

Treatment plant sludge may have a high gas content, either dissolved or entrained, and this will have a profound effect on centrifugal pumps. As a rule, sludge with high solids content also has a high content of gas, which will lower the pump performance significantly. In extreme cases, the pump will stop pumping when the liberated gas accumulates at the eye of the impeller, thus preventing it from operating properly. In such cases, a 1/2" vent pipe can be fitted on top of the pump housing or in the discharge pipe system.

Sewage pump impellers with wide channels are generally best suited for sludge pumping. For denser sludge (solids content over 2%), a pump with higher head curve should be chosen in order to ensure the desired performance. Sewage treatment plant sludge is not always uniform, and thus justifies the selection of a pump with an oversize motor to compensate for surges in solids content and consequently in power requirement.

If the sludge contains a lot of sand, a vortex type of pump will often have the longest life.

4.3. Other pump types for handling high-density liquids

4.3.1. Progressive cavity pumps

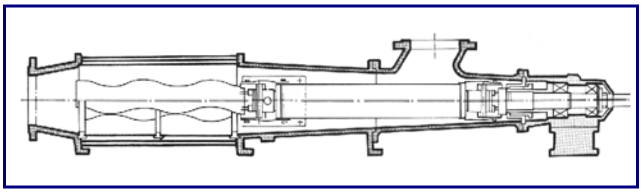


Fig. 38 Progressive cavity pump

The progressive cavity pump has been used successfully for almost all types of sludge. The pump has a single-threaded rotor which operates with a minimum of clearance in a double-threaded helical stator made of rubber. A volume or 'cavity' moves progressively from suction to discharge as the rotor turns.

4.3.2. Rotary lobe pumps

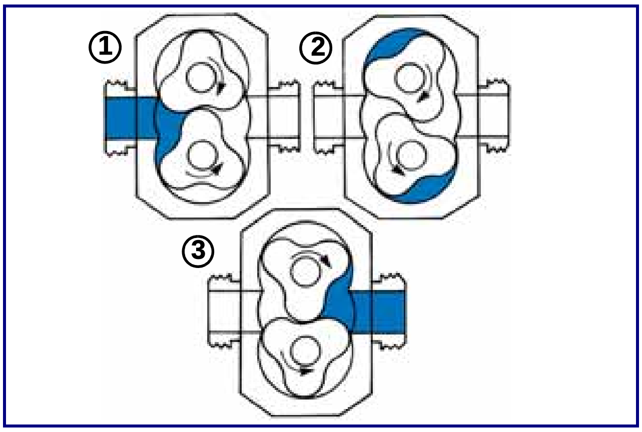


Fig. 39 Rotary lobe pump

Rotary lobe pumps are positive displacement pumps in which two rotating synchronous lobes push the liquid through the pump. Rotational speed and shearing stress are low. For sludge pumping, lobes are made of hard metal or hard rubber. An advantage cited for the rotary lobe pump is that lobe replacement is less costly than rotor and stator replacement for progressive cavity pumps. Rotary lobe pumps, like other positive displacement pumps, must be protected against pipeline obstruction.

4.3.3. Centrifugal torque flow pumps (Vortex)

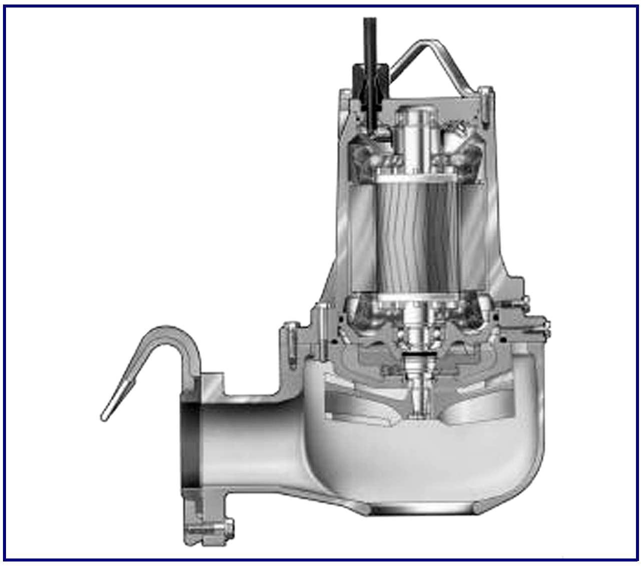


Fig. 40 Centrifugal torque flow pump (Vortex)

This type of pump is very effective for conveying sludge. The size of particles that can be handled is limited only by the diameter of the suction or discharge openings. The rotating impeller develops a vortex in the sludge so that the main propulsive force is the liquid itself. Most of the liquid does not actually pass through the vanes of the impeller, thereby minimizing abrasive contact.

4.3.4. Diaphragm pump

A membrane pump consists of a pump housing with suction and discharge manifold, membrane and a piston connected to a drive unit. The drive unit can be a petrol or diesel engine, a hydraulic engine, an electric motor or driven by compressed air. Both suction and discharge manifold are fitted with non-return valves, which let liquid into or out of the pump, depending on the movement of the membrane.

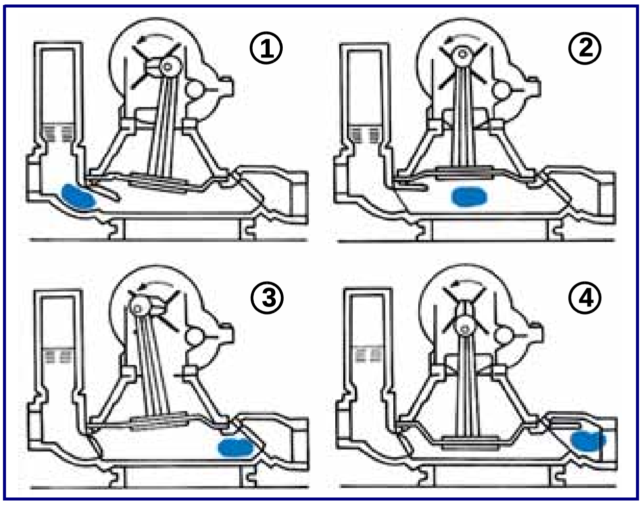


Fig. 41 Diaphragm pump

4.4. Pump selection for different sludge types

Type of sludge or solids	Applicable pump	Comments
Containing grit & sand	• Centrifugal torque flow vortex pump	The abrasive character of grit and sand and the presence of rags make grit difficult to handle. hardened casings and impellers should be used for torque-flow pumps. Air lift pumps may also be used.
Scum (high flow velocity)	• Centrifugal torque flow vortex pump	Scum is often pumped by sludge pumps; valves are manipulated in the scum and sludge lines to permit this. In larger plants, separate scum pumps are used. Scum mixers are often used to ensure homogeneity prior to pumping. Air lift pumps may also be used.
Scum (low flow velocity)	• Diaphragm pump • Progressive cavity pump • Plunger pump	

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4. Density and viscosity

Primary sludge (high flow velocity)	• Centrifugal torque flow vortex pump	In most cases, it is desirable to obtain as concentrated a sludge as practicably possible from primary sedimentation tanks, usually by collecting the sludge in hoppers and pumping intermittently, allowing the sludge to collect and consolidate between pumping periods. The character of untreated primary sludge will vary considerably, depending on the characteristics of the solids in the wastewater and the types of treatment units and their efficiency. Where biological treatment follows, the quantity of solids from waste activated sludge, humus sludge from settling tanks following trickling filters, overflow liquors from digestion tanks, and filtrate return from dewatering operations will also affect the sludge characteristics. In many cases, the character of the sludge is not suitable for the use of conventional non-clog centrifugal pumps, unless the flow rate is high.
Primary sludge (low flow velocity)	• Diaphragm pump • Progressive cavity pump • Rotary-lobe pump	
Chemical precipitation	The same as for primary sludge	
Digested sludge (high flow velocity)	• Centrifugal torque flow vortex pump	Well-digested sludge is homogeneous, containing 5–8% solids and a quantity of gas bubbles, but may contain up to 12% solids. Poorly digested sludge may be difficult to handle. If good screening and grit removal is provided, non-clog centrifugal pumps may be considered, but a vortex pump will be the best choice. It may be necessary to choose an oversize motor.
Digested sludge (low flow velocity)	• Progressive cavity pump • Diaphragm pump • High-pressure piston pump • Rotary-lobe pump • Plunger pump	
Trickle-filter humus sludge (high flow velocity)	• Non-clog and centrifugal torque flow vortex pump	Sludge is usually of homogeneous character and can easily be pumped.
Trickle-filter humus sludge (low flow velocity)	• Progressive cavity pump • Plunger pump • Diaphragm pump	
Return or waste activated sludge (high flow velocity)	• Non-clog and centrifugal torque flow vortex pump	Sludge is diluted and contains only fine solids so that non-clog pumps may commonly be used.
Return or waste activated sludge (high flow velocity)	• Progressive cavity pump	
Ground screenings	Pumping of screenings should be avoided	Pneumatic ejectors may be used.

5. Power supply

5.1. Undervoltage and overvoltage

Power lines are expected to deliver a specific voltage. Near the low voltage transformer, there will often be an overvoltage of 3–5%. When the power lines are loaded, a voltage drop will occur due to ohmic resistance in periods of peak power consumption.

Most power lines are dimensioned so that undervoltage of more than -10% will occur less than once a year at the weakest point. But many consumers still experience periods of considerable voltage drop.

Any motor will suffer if it does not receive the voltage stamped on the nameplate. In case of voltage drop, the motor torque will be reduced and the RPM of the loaded motor will consequently be reduced, too.

As a result of this, the efficiency and induction resistance of the motor drop. This will make the power consumption increase, resulting in increased generation of heat in the motor.

When a motor fully loaded by a centrifugal pump receives 10% undervoltage, the power consumption will increase by approx. 5% and the motor temperature by about 20%. If this temperature increase exceeds the maximum temperature of the insulation material around the windings, these will be short-circuited and the stator destroyed.

This will only be the case if the motor is placed in a hot environment and is badly cooled or in case of voltage asymmetry, current asymmetry or voltage transients at the same time.

Usually, increased winding temperature caused by undervoltage will lead to faster aging of the insulation, resulting in reduced life.

In case of overvoltage from the grid, the power consumption and heat generation in the motor windings will increase as well. Continuously running sewage pumps exposed to overvoltage must have ball bearing grease stable up to 10°C above the insulation class temperature. This means that for insulation class F (155°C), the ball bearing grease must be stable up to 165°C.

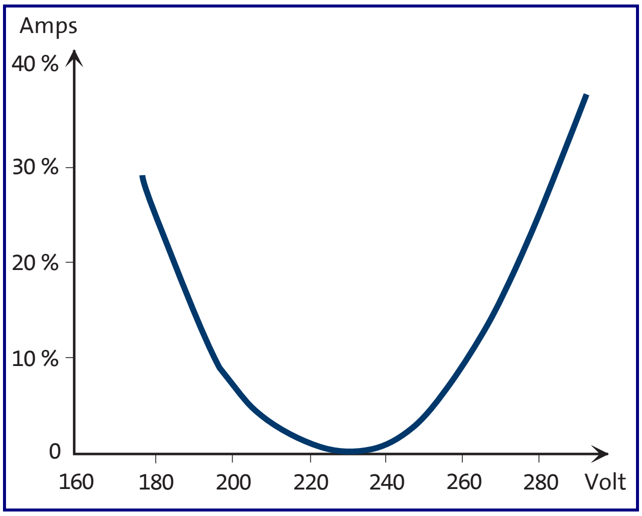


Fig. 42 Additional power consumption at voltage variations

5.1.1. Conclusion

1. For voltage variations of +6% to -10% of the rated value, measured at the motor terminals, normal life can be expected when the power consumption is equal to or less than the full-load current stamped on the nameplate and if the motor cooling is sufficient and no transients or asymmetry occur.

2. For short/periodic voltage variations exceeding +6% to -10% of the rated value, the reduction in life will be moderate until undervoltage/overvoltage variations are so considerable that the stator windings are short-circuited.

3. With permanent or long lasting voltage variations exceeding +6% to -10%, the motor should be derated or a bigger motor chosen in order to obtain acceptable life and efficiency. A thermal overload cut-out should also be fitted.

It is customary to derate a standard motor to ensure long life if overvoltage or undervoltage of more than +6/-10% can be expected at the motor cable entry.

Single-phase motors will often require capacitor adaptation when exposed to low voltage supply.

5.2. Current asymmetry

Low current asymmetry gives the best motor efficiency and longest life. It is therefore important to have all phases loaded equally.

Before measuring takes place, it should be checked that the direction of rotation of the pump is correct, i.e. the one which gives the highest performance. The direction of rotation can be changed by reversing two phases.

The current asymmetry should not exceed 5%. It is calculated by means of the following two formulas:

$$I\,(\%) = \left(\frac{I_{\text{phase max}} - I_{\text{average}}}{I_{\text{average}}}\right) \times 100\ [\%]$$

$$I\,(\%) = \left(\frac{I_{\text{average}} - I_{\text{phase min}}}{I_{\text{average}}}\right) \times 100\ [\%]$$

The maximum value is used as an expression of the current asymmetry.

The current must be measured on all three phases as illustrated below. The best connection is the one which gives the lowest current asymmetry.

In order not to have to change the direction of rotation when the connection is changed, the phases must always be moved as illustrated.

Example
See diagram below and table overleaf.

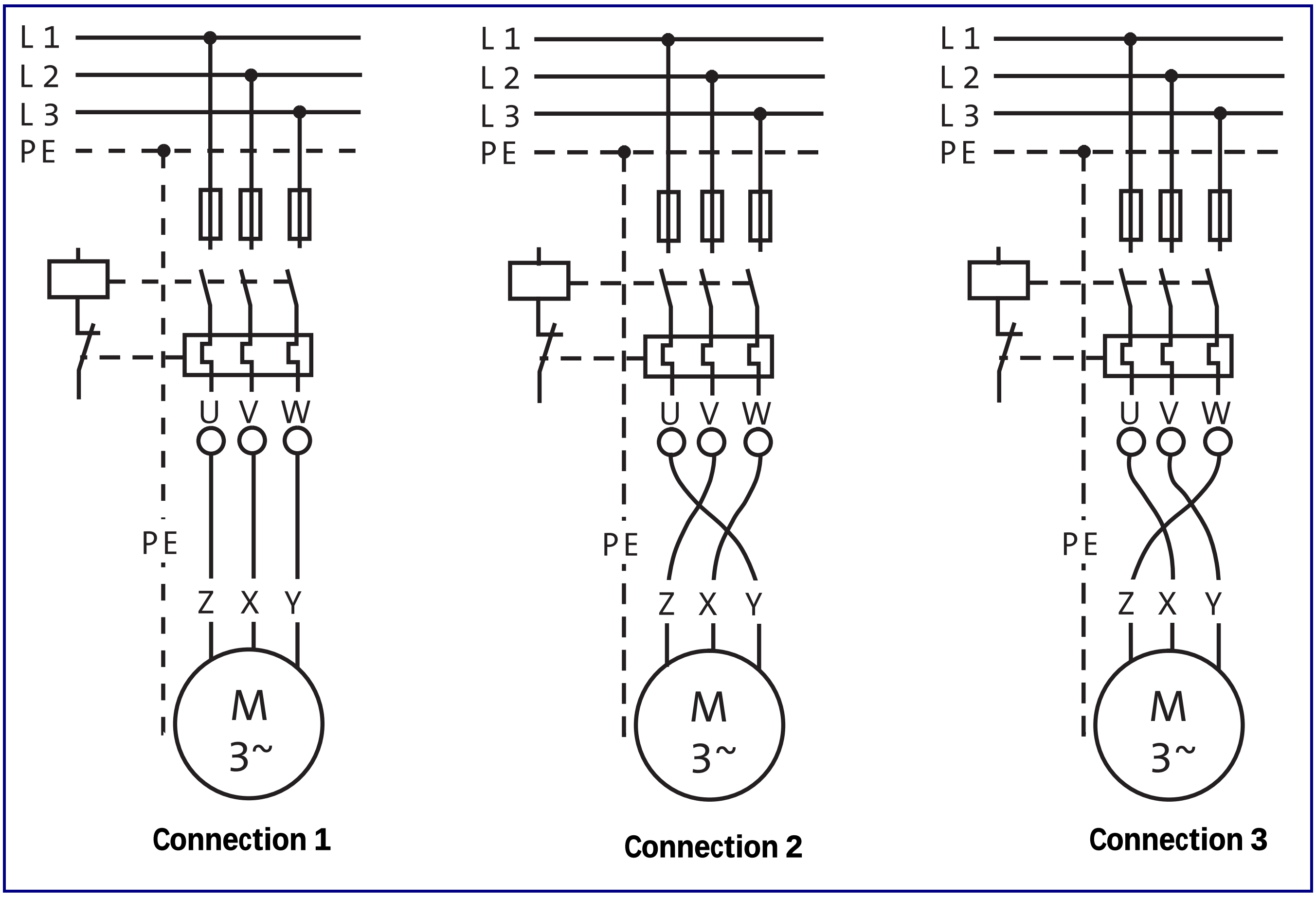


Fig. 43 Correction for current asymmetry for a 3 x 400 V, 30 A, 50 Hz submersible motor

Example (continued)

	Connection 1	Connection 2	Connection 3
Step 1	**U** Z 31 A **V** X 26 A **W** Y 28 A Total 85 A	Z 30 A X 26 A Y 29 A Total 85 A	Z 29 A X 27 A Y 29 A Total 85 A
Step 2	**Average current:** $\frac{\text{Total current}}{3 \times 3} = \frac{85 + 85 + 85}{3 \times 3} = 28.3$ A		
Step 3	**Max. amps. difference from average:**	Connection 1 = 31 - 28.3 = 2.7 A Connection 2 = 28.3 - 26 = 2.3 A Connection 3 = 28.3 - 27 = 1.3 A	
Step 4	**% unbalance:**	Connection 1 = $\frac{2.7}{28.3}$ x100 = 9.5 % - **no good** Connection 2 = $\frac{2.3}{28.3}$ x100 = 8.1 % - **no good** Connection 3 = $\frac{1.3}{28.3}$ x100 = 4.6 % - **ok**	
Step 5	If the current unbalance is greater than 5%, the power company should be contacted. As an alternative, a derated or industrial motor protected by a CU 3 should be used. On the remote control, you will be able to read the actual current asymmetry. A current unbalance of 5% corresponds to a voltage unbalance of 1–2%.		

Even a small voltage unbalance gives a large current unbalance. This unbalance, in turn, causes uneven distribution of heat in the stator windings leading to hot spots and local overheating. The key results are illustrated graphically below.

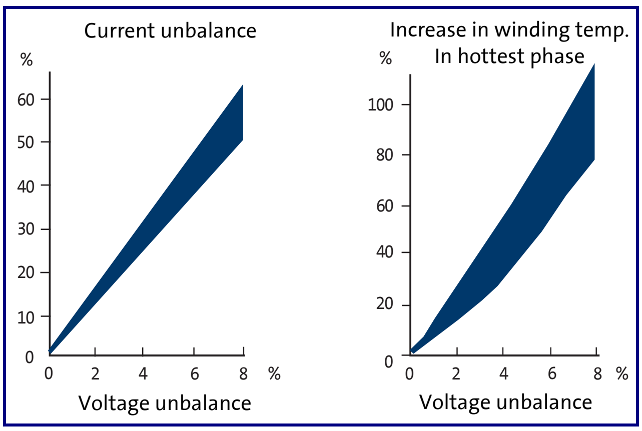


Fig. 44 Relation between voltage and current unbalance and temperature

5.3. Voltage asymmetry

Power lines are expected to deliver the rated voltage on all three phases. Near the low-voltage transformer, this will often be the case.

When the power lines are loaded, all single-phase appliances should be distributed evenly between all three phases in order to avoid voltage drop on a single phase. As single-phase appliances often operate ON/OFF, they may cause unbalance on the grid. Unbalance can also be caused by asymmetrical transformer stations as well as asymmetrical distribution lines or worn or coated contactors. In case of unbalance on the grid before the motor is connected, the supply board should be contacted. A motor seldom loads all phases equally; it is therfore often possible to compensate for the unbalance by connection the winding using less current to the phase with the lowest voltage.

5.4. Frequency

The frequency should always be kept at the nominal value. If the frequency is higher, the pump may overload the motor. If the frequency is lower, the pump performance will drop.

5.5. Voltage transients

Power lines are supposed to deliver sine shaped waves on all three phases. The sine shaped waves produced at the power station are added to the transients in the distribution system.

Transient sources:

1. Frequency converters without filters
2. Soft starters
3. Contactors for big machines
4. Capacitors for process machines
5. Lightning

5.5.1. Frequency converters without filters

Modern frequency converters with an LC or RC filter can be protected so that they do not produce voltage peaks above 850 V in connection with cables of up to 100 m between frequency converter and motor. This is fully acceptable and any Grundfos motor with correct rating and cooling will have an acceptable life.

Frequency converters of the PWM type (Pulse Width Modulation) without an LC or RC filter yield an output voltage which differs much from the ideal sinusoidal curve with transients of 850–1200 V, measured at a cable length of 1 m, depending on the make. These transients will increase with increasing cable length between frequency converter and motor. At 200 m, for instance, the transients will be double at the motor cable plug, i.e. 1700–2400 V. The result will be a reduction of the motor life. Because of this, frequency converters must at least contain an RC filter to ensure optimal motor life.

5.5.2. Soft starters

A soft starter will absorb a non-sinusoidal current and give rise to a certain grid noise. In connection with very short acceleration/deceleration times, this is of no practical importance and does not conflict with regulations concerning grid noise. If the start-up time is longer than three seconds, the non-sinusoidal transients will overheat the motor windings and consequently affect the motor life.

5.5.3. Contactors for big machines

Big machines starting DOL or in star/delta connection may create sparks and send considerable transients back to the grid when the contactors are opened. These transients are only a threat to a submersible motor on very weak grids.

5.5.4. Capacitors for process machines

Process plants may contain complicated controls with many and big capacitors which send transients back to the grid. Transients are only a threat to a submersible motor if the grid is very weak.

5.5.5. Lightning

A severe stroke of lightning directly on a well installation, starter or power supply will generally destroy all living organisms and all electrical installations. The transients from such a stroke of lightning will be at least 20–100 kV and the generation of heat enough to melt the insulation materials.

Lightning striking a high-voltage grid will generate transients which will partly be absorbed by the lightning arresters at the transformer station and be led to earth.

If a low-voltage grid is hit directly by lightning there is a risk of transients of more than 10–20 kV at the pump motor starter.

If starter and motor are not correctly protected by lightning arresters and earthing, the installation may be damaged, as it is installed in electrically conducting groundwater, which is the best kind of earthing there is.

6. Liquid temperature

A standard cast iron wet-installed drainage, effluent, sewage or grinder pump can operate fully submerged in a liquid which is 40°C if the following items are as specified for the pump in question:

1. Power supply
2. Number of starts/stops
3. Pump flow
4. Running time for intermittent duty

If the liquid temperature increases to 50°C for more than five minutes of operation, the motor life will be shortened due to

1. reduced ball bearing life
2. reduced winding insulation life
3. reduced motor cable life

For hot liquid applications with a reasonable service life, it may be necessary to do the following:

- The motor must be derated.
- A heat resistant cable must be fitted or the existing cable derated.
- Service checkup intervals must be halved and the ball bearings replaced more frequently.
- The inlet pressure must be increased.
- All cast iron parts must be protected with a coating of wear resistant epoxy or paint.

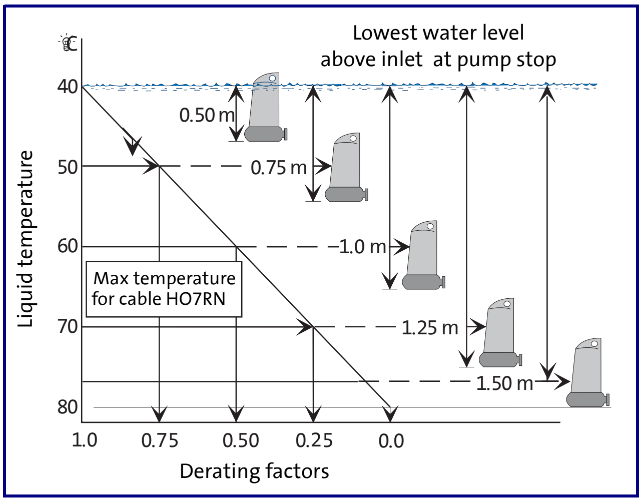


Fig. 45 Derating

A derating factor of 0.5 means that an 11 kW motor is to be equipped only with an impeller requiring a 5.5 kW motor. With a higher load, a reduced motor life is to be expected.

6.1. External cooling

With all these precautions required to maintain a normal pump service life, one might instead consider the use of a cooling jacket, provided cold water is available.

In case of liquid temperatures above 60°C for periods of more than one hour, cooling jackets with connections for external cooling water should be used.

Cooling jackets with connections for external cooling water are used in submerged installations if the pump is not completely submerged during periods of continuous operation.

Relays and timers must be built into the control system to control a cooling water solenoid or motor driven valve during start/stop procedures.

6. Liquid temperature

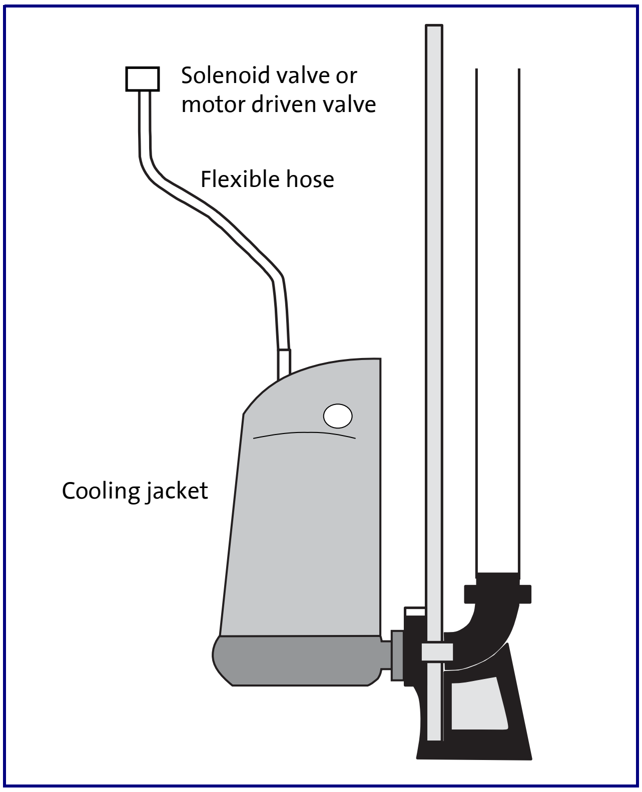


Fig. 46 Installation with external cooling water

The cooling water removes the heat which is developed in the motor during operation. A timer ensures that the cooling water continues to flow even after the pump has stopped. In order to ensure that the motor temperature will never exceed the liquid temperature, cooling water flows for 5 seconds for each kW motor power.

In addition to the cooling water, the pump needs

- a derated or heat resistant cable
- increased inlet pressure
  - 1 m at 60°C
  - 1.5 m at 80°C
- protection of all cast iron components by a coating of wear resistant epoxy or paint

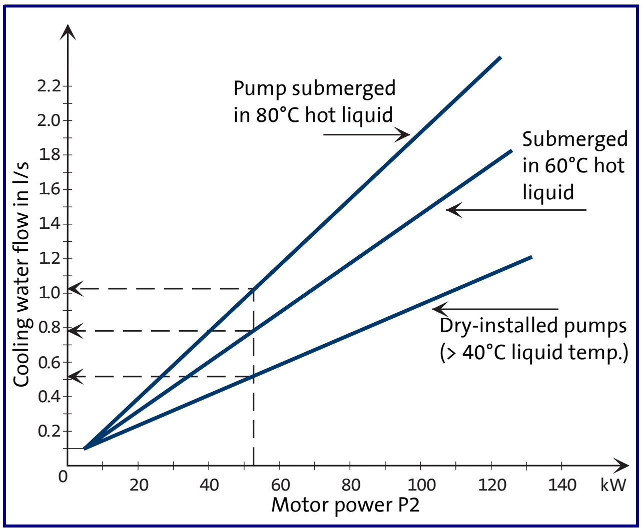


Fig. 47 Required external cooling water flow at maximum 20°C

6.2. High-temperature cable derating

Cable type	H07RN-F PLUS	H07RN
Insulation material	NR/SR	NR/SR
Ambient liquid temperature (°C)	**Correction factor**	**Correction factor**
10	1.30	1.29
15	1.25	1.22
20	1.20	1.15
25	1.15	1.08
30	1.10	1.00
35	1.05	0.91
40	1.00	0.82
45	0.90	0.71
50	0.80	0.58
55	0.70	0.41
60	0.60	-
65	-	-
70	-	-

7. Pump sump

7.1. Layout of pumping station inlet

7.1.1. Gas/air/wave effects

Pump operating problems are frequently caused by entrainment of air and the formation of eddies in the liquid when it splashes into the pit.

Air in sewage water has a tendency to remain there for a long time because air bubbles will stick to the solid particles in the liquid.

The liquid inlet splash velocity is a function of the fall height. Direct fall should always be minimized and if it is more than one metre, an impact breaker should be installed (Fig. 48).

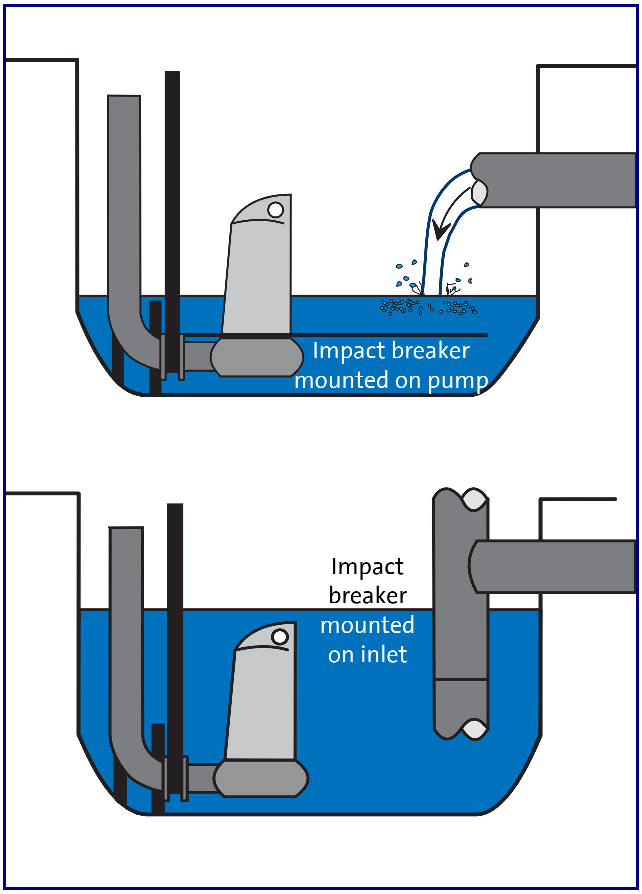


Fig. 48 Location of impact breaker

In addition, pumps should be installed at a depth low enough to avoid vortexes from the pump inlet sucking air in from the water surface (Fig. 49).

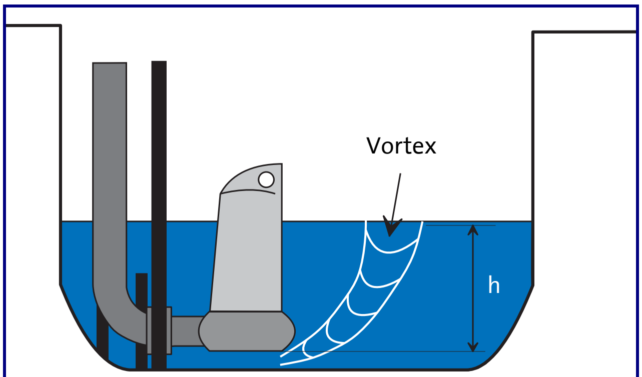


Fig. 49 Minimum submergence to avoid vortexes

7.1.2. Calming chamber

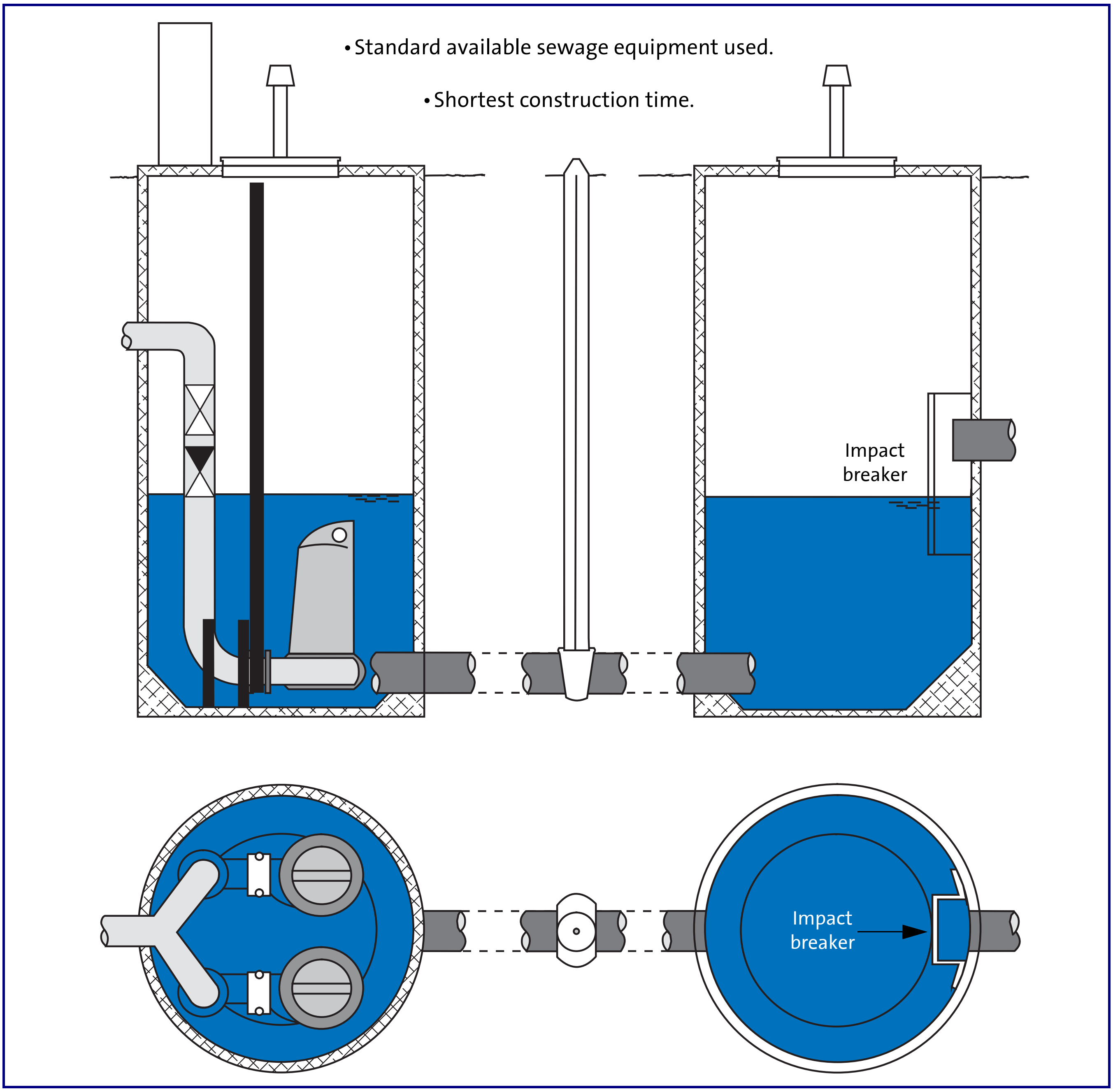


*Fig. 50 For inlet flows bigger than 50 l/s and up to 200 l/s, a **calming chamber** or pit should be considered.*

The solution above is often practically and economically the best as

- extra and often necessary effective volume is obtained
- a shut-off valve can be installed
- mechanical impact on discharge components and guide rail is reduced.

7.1.3. Dry pit installation (see also chapter 8)

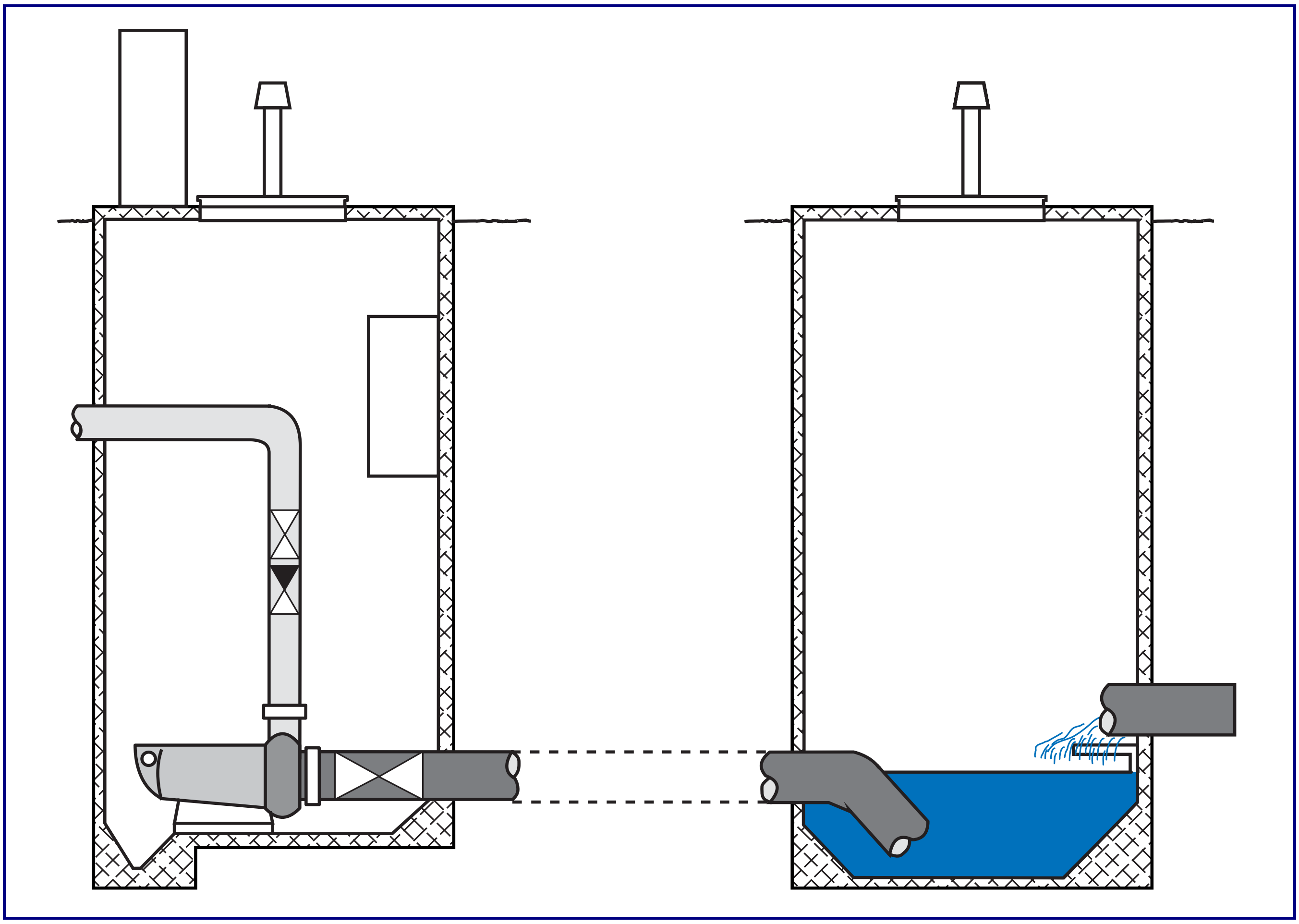


Fig. 51 *For inlet flows between 50 and 200 l/s,* ***dry pit installations*** *should be considered. They are often more expensive to construct, but allow much quicker access for servicing or in case of failure. This is especially so as the weight of the pump is far above 100 kg and manpower is not sufficient so that a powered lift is required.*

7.1.4. Deceleration stretches

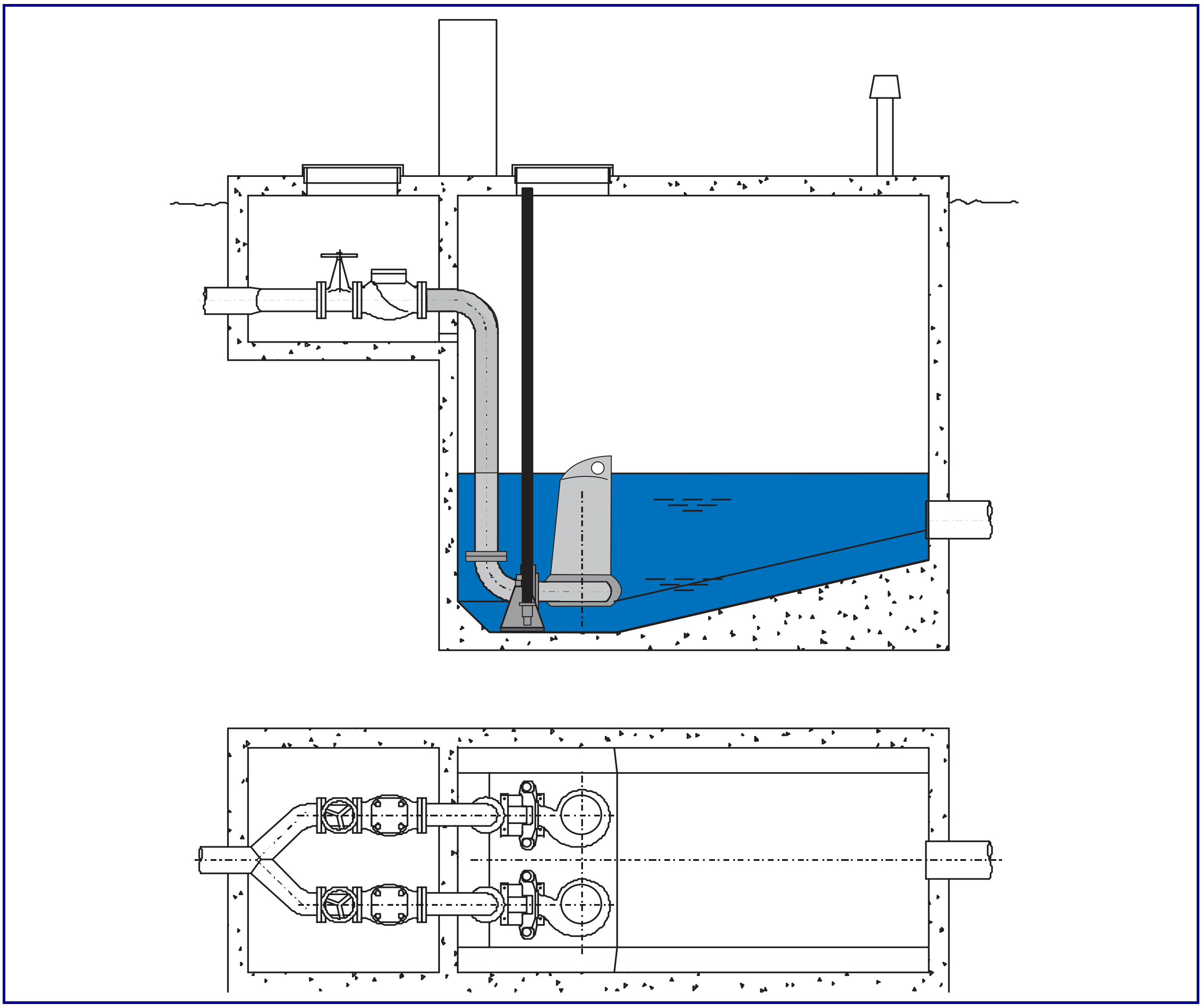


*Fig. 52 For peak inlet flow greater than 200 l/s, a non-splash widening **deceleration stretch** may be considered to absorb the energy of the incoming water, to avoid turbulence vortexes and frequent repair and replacement of worn concrete slabs and other equipment. A wave breaker is often required to calm the water of the level control zone.*

If the peak inlet flow exceeds 200 l/s, the local authorities, a technical adviser or the pump supplier should be contacted for advice about the best pit design.

7.1.5. Multiple pump pit

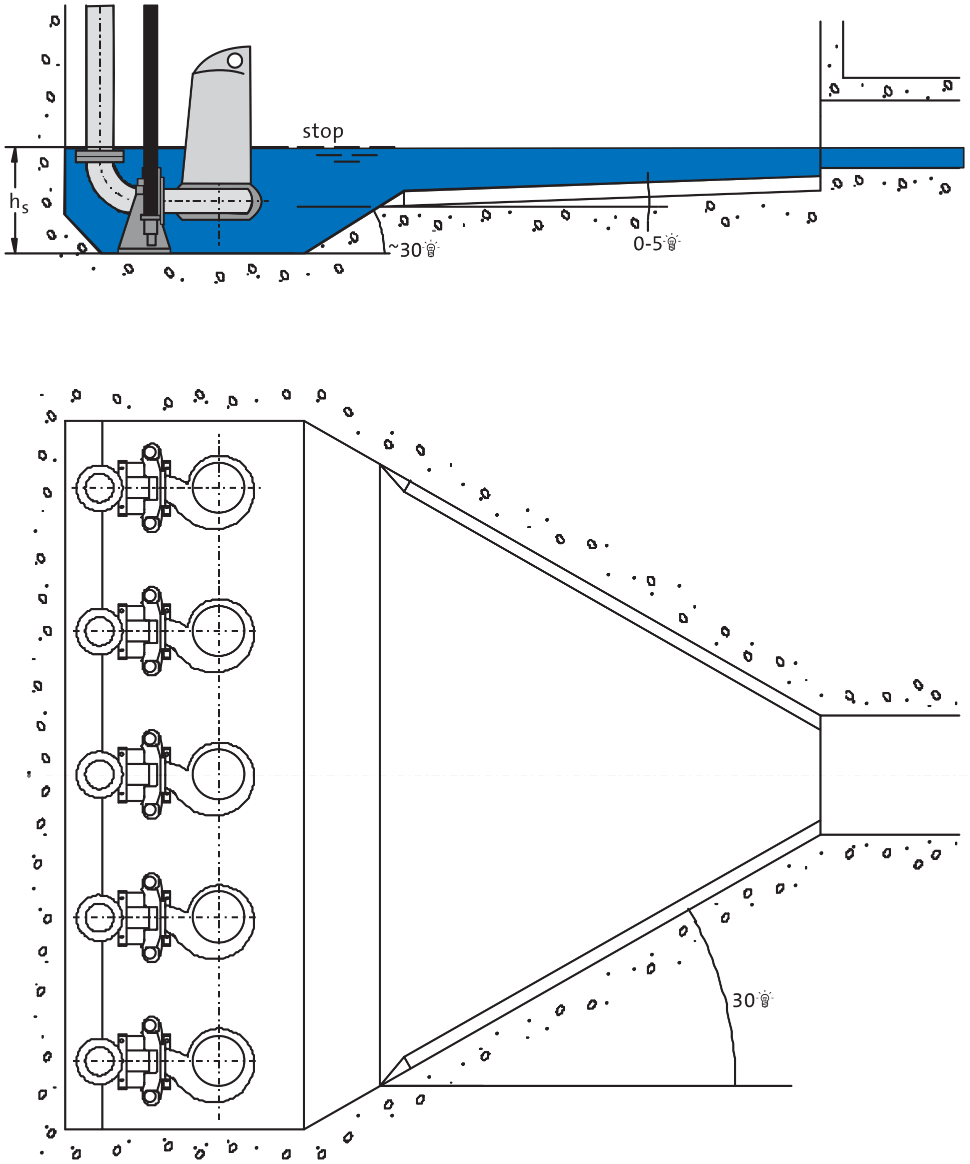


Fig. 53 Pumping station design for several submersible pumps and large flows.

7.2. Sizing of pump sump

When starting a pump, a lot of heat is developed in stator and rotor.

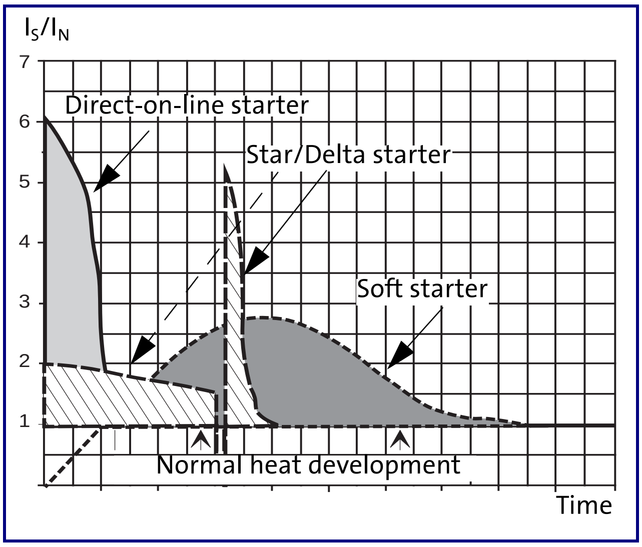


Fig. 54 Development of heat during startup

When exposed to this "overheating", the motor needs a normal operating and cooling period before the next start, because the pumps have been designed for intermittent operation with a maximum of 20 starts per hour. Long periods with a higher starting frequency will affect the service life.

7.2.1. starting frequency and pump capacity of pumping station

In a pumping station the water volume comprises the volume below the lowest pump stop level and the pumpable volume above this level, fluctuating with pump usage and incoming flow rate. The starting frequency of the pumps depends on the available pumpable volume and the incoming flow rate.

The starting frequency Z is a function of the ratio between Q_{in}/Q and V_h, where

Q_{in} = incoming flow rate (l/s)
Q = pump capacity (l/s)
V_h = accumulated (pumpable) volume between start and stop (m^3)

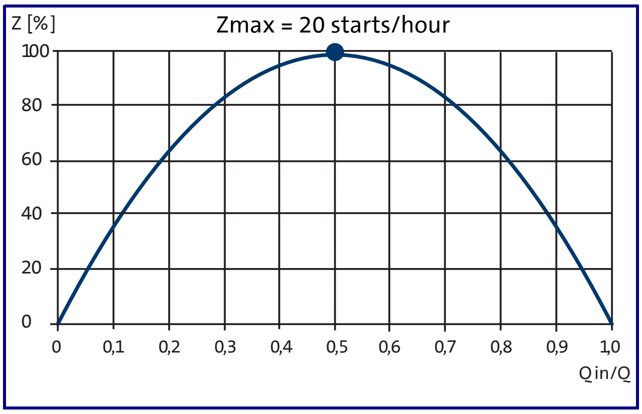


Fig. 55 Starting frequency curve Z for a single-pump pumping station as a function of the ratio between incoming flow rate Q_{in} and pump capacity Q.

Note that when the maximum inflow is equal to the pump capacity, the pump runs permanently. When the actual pump capacity for single-pump operation is equal to maximum peak inflow, Z_{max} will always appear when the inflow is half the pump capacity.

$$Z_{max} = \frac{Q \times 3.6}{4 \times V_h} \quad (Z_{max} = \text{maximum starts per hour})$$

By isolating V_h we get:

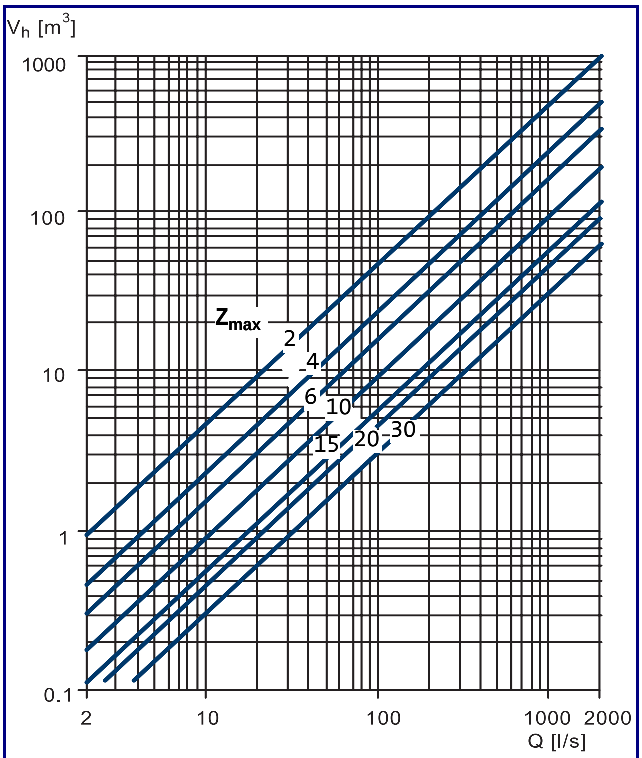
$$V_h = \frac{Q \times 3.6}{4 \times Z_{max}}$$

Example
Q = 10 l/s
Z_{max} = 20 starts/hour

Necessary minimum accumulated volume between start and stop:

$$V_h = \frac{10 \times 3.6}{4 \times 20} = 0.45 \text{ m}^3$$

With two alternating pumps, V_h can be halved.



Q = pump capacity [l/s]
Z_{max} = maximum starting frequency [1/h]
V_h = accumulated volume between start and stop [m³]

Fig. 56 Nomogram for the determination of the accumulated volume V_h between start and stop for a single-pump pumping station

Note
In practice there may be situations where the incoming flow to a pumping station is very small and only momentary, for instance in pumping stations serving only a few households. In such cases, the pump capacity is selected much larger than Q_{in} in order to attain a flow velocity in the rising main high enough to prevent sedimentation. In this situation the Q_{in}/Q ratio remains small, and the Z_{max} value is not reached at all or only very seldom.

In installations where expected maximum incoming flow Q_{in} is less than 60% of the selected pump capacity, the accumulated sump volume is chosen in such a way that there will be at least two pump starts a day in order to prevent sedimentation in the sump.

Example

	Sump volume (V_h) [m³]
Single-family house	0.1
Two-family building	0.15
Four-family building	0.2
Eight-family building	0.25

The above effective sump volume will normally ensure a pump start after morning toilet visit and shower and again after preparation of dinner.

Minimum total effective sump volume			
6 pumps in parallel alternating operation (factor 0.2)	4 pumps in parallel alternating operation (factor 0.25)	2 pumps in parallel alternating operation (factor 0.5) $Q_{in}/Q < 1$	Single pump $Q_{in}/Q \leq 1$
$V_h = \frac{Q \times 3.6}{24 \times Z_{max}}$	$V_h = \frac{Q \times 3.6}{16 \times Z_{max}}$	$V_h = \frac{Q \times 3.6}{8 \times Z_{max}}$	$V_h = \frac{Q \times 3.6}{4 \times Z_{max}}$

7.2.2. Permanent duty

Standard drainage, effluent and sewage pumps are designed for a maximum of 20 starts per hour and 3000 hours' maximum operation between major overhauls.

For some industrial applications, permanent duty is required. This will result in more than five times the usual running hours per year. These pumps are to be serviced every 3000 hours of operation. At these intervals, the oil must be changed and all wear parts checked and replaced if tolerances have been exceeded.

For permanent duty, the preferred pump types are

- special-designed heavy duty pumps with 4-pole or 6-pole motors
- vortex pumps with lightweight impeller
- semi-open multi-vane impeller pumps

7.2.3. Intermittent duty of submersible pumps in dry installations (air cooled)

For dry installations, a liquid cooled cooling jacket is always to be preferred.

If, however, the relation between pump sump volume, inlet flow and pump capacity is perfectly matched, it is possible to install ordinary air-cooled sewage pumps. The calculations for this arrangement are complicated. If the installation is designed in accordance with the following diagrams, a long service life can be expected.

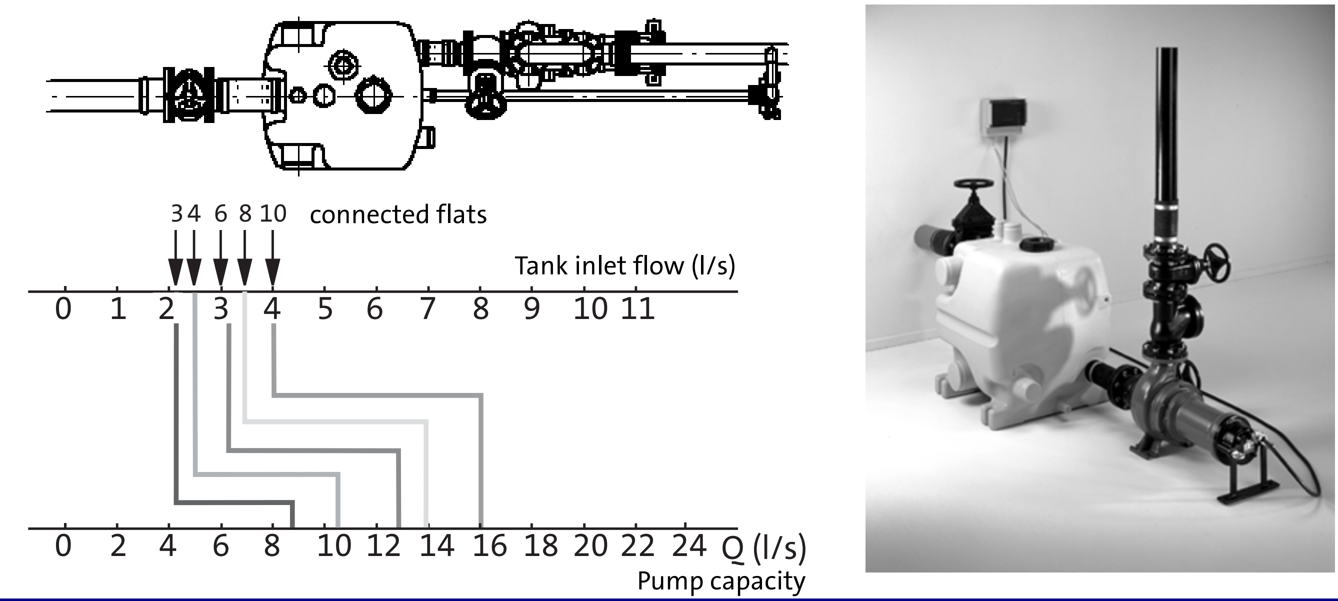


Fig. 57 ***APL**: One 400-litre tank and one air-cooled duty pump*

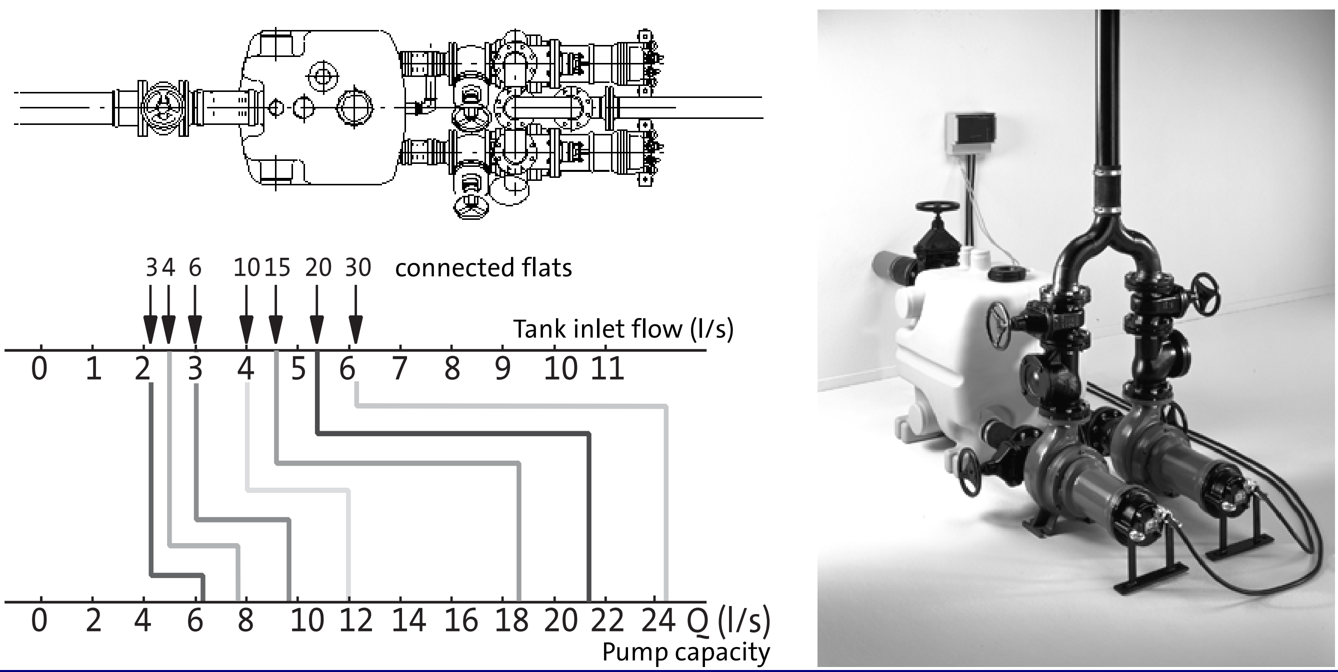


Fig. 58 ***APLD**: One 400-litre tank and two air-cooled alternating duty pumps*

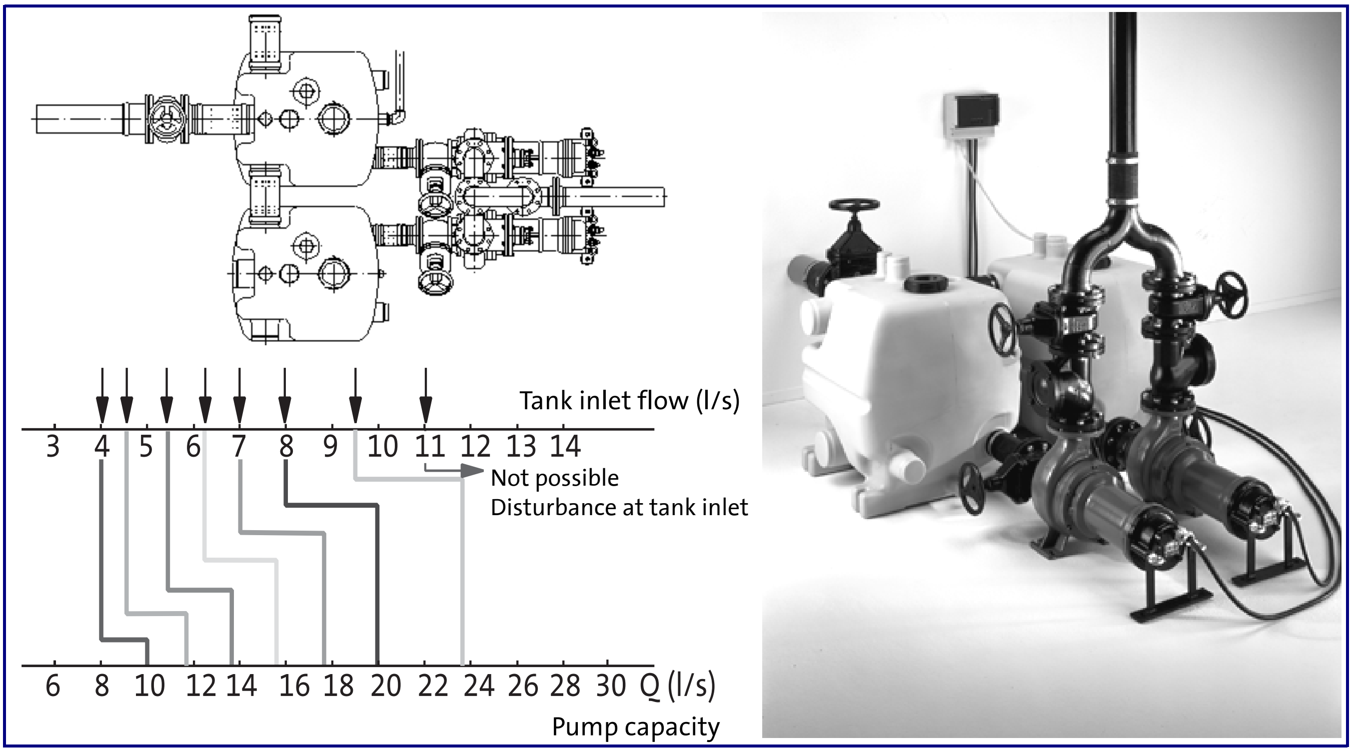


Fig. 59 ***APLD/2***: *Two 400-litre tanks and two air-cooled alternating duty pumps*

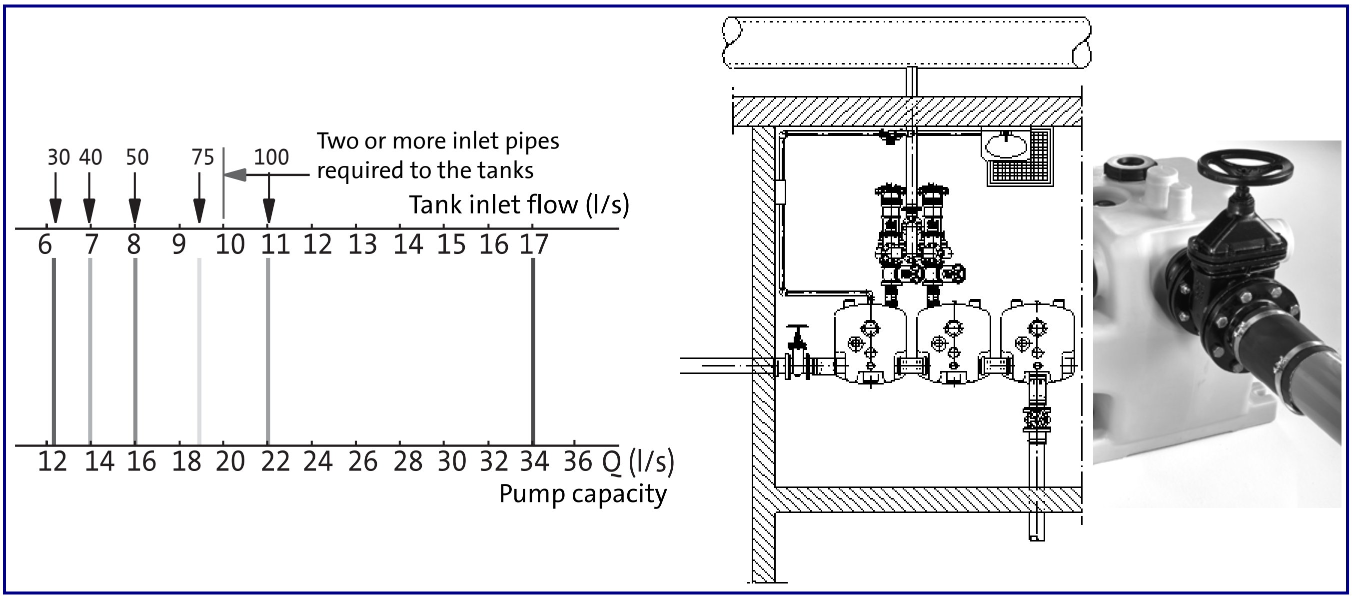


Fig. 60 ***APLD/2 plus***: *Three 400-litre tanks and two air-cooled alternating duty pumps. Two or more tank inlet pipes required.*

7.3. Auto-coupling sealing

Avoid using auto-couplings with a metal to metal seal surface at the discharge as this will result in a flow loss of 3–10%, depending on the discharge pressure. This means extra power consumption, reduced self-cleansing of discharge pipe and constant wear of the coupling surfaces.

The auto-coupling should have a 100% effective sealing consisting of a built-in L-seal or a pressure backed up membrane seal. This will improve the operating economy considerably. With this type of seal, however, it is important not to lower the sewage level so much that air will enter the pump as it cannot get out.

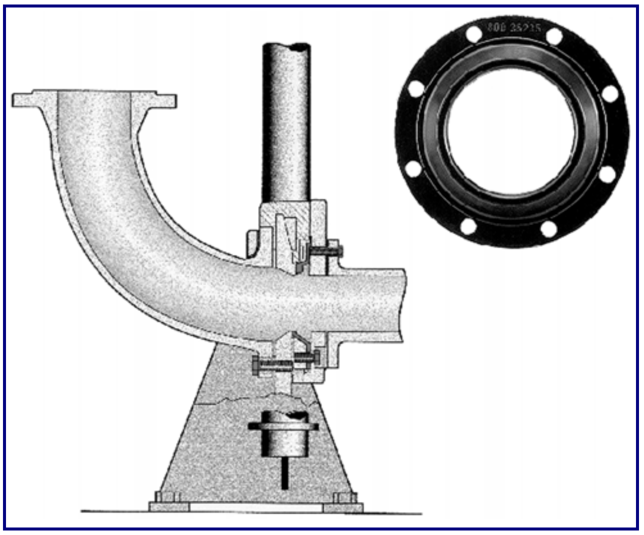


Fig. 61 Energy saving discharge connection

8. Dry pit installation

The number of dry pit pump installations has gone up year by year. For this application, Grundfos wastewater pumps are being increasingly used, although originally developed for submerged use.

Main reasons for choosing Grundfos pumps for dry pit installations:

1. Thoroughly tested, reliable pump
2. Compact design
3. Option of internal cooling
4. Flood-proof

However, submerged wastewater installations are still the commonest. When old pump installations are refurbished or upgraded, they are often changed into a dry pit type. Compared with submerged pump installations, dry pit installations require a different design approach described below in respect of aspects such as vibration, noise, cavitation and inlet arrangements.

8.1. Vibration and noise

One of the major advantages of submerged installations is that the liquid helps to reduce vibrations and noise.

In case of dry pit pumps, you have to be extra careful with the design of the complete pump installation. A rotating machine will always be a source of noise.

Generally, in dry pit installations, a pump should be chosen whose duty point is within 50–125% of the flow for optimal efficiency. In this range, noise from the impeller, cavitation and other sources is minimized.

The most usual installation for dry pit Grundfos pumps is a rigid installation. In some cases, however, it is necessary to isolate the pump from the foundation and piping. This can be done by introducing anti-vibration feet between pump and foundation and a flexible flange connection between piping and pump inlet and outlet.

8.2. Cavitation

8.2.1. Net Positive Suction Head, NPSH

The positive head required on the suction side of the pump to secure safe operation in terms of cavitation is determined by the NPSH curve. When the pump is moved from the sump and a suction pipe is introduced, two points should be considered: firstly, the losses in the inlet pipe will cause a head drop which the pump will witness as a drop in suction head. Secondly, the level difference between sump and pump inlet.

See chapter 3.3 for a more detailed description of the subject.

8.3. Suction pipework: dimensions and design

Design and dimensioning of the suction pipe is important to avoid vibrations, reduced pump efficiency and risk of cavitation.

The suction pipework should be dimensioned so that the flow velocity does not exceed 2.0 m/s for vertical pumps and 2.5 m/s for horizontal pumps.

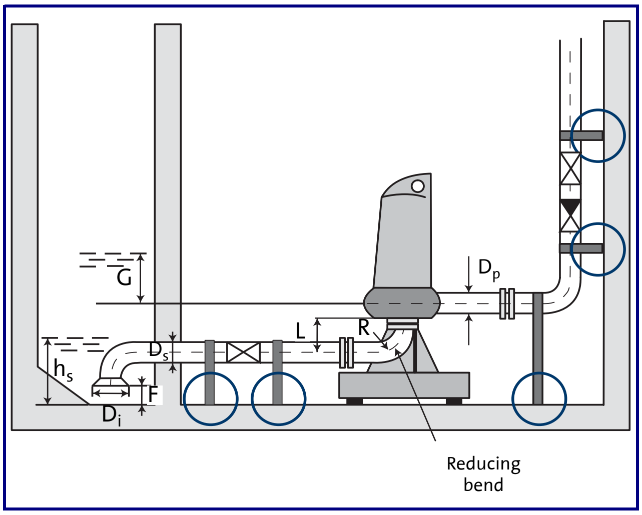


Fig. 62 Recommended installation dimensions for vertical dry pit submersible pumps. $F \geq 0.5 \times D_i$ and minimum equal to free passage of pump, $v_{max} = 2.0$ m/s, min. start level $G \geq D_p$, $L \geq D_s + 100$ mm, $R \approx L$.

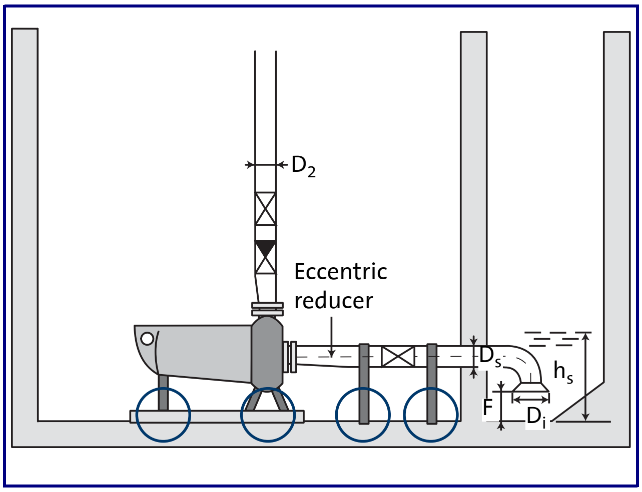


Fig. 63 Recommended installation dimensions for horizontal dry pit submersible pumps. $F \geq 0.5 \times D_i$ and minimum equal to free passage of pump, $v_{max} = 2.5$ m/s

Recommended suction pipe inlet designs are shown in Figs. 62 and 63. The downward suction exerts a sucking effect on the pit floor, and is less prone to suck air from the surface.

In **vertical pumps**, the suction pipe will have to turn 90° to reach the pump inlet which will lower the pump efficiency because the flow around the perimeter of the impeller eye will be uneven. If the pump inlet dimension is smaller than the suction pipework, a reducing bend is recommended. The increasing flow velocity in the reducing bend will alleviate the disadvantage of the bend and the pump will run more smoothly.

The narrowing of the straight inlet pipe to a **horizontal pump** should be eccentric so as to avoid air from collecting and possibly blocking the impeller.

An inlet design with unfavourable flow characteristics may cause a pressure drop large enough to use up the available NPSH and lead to pump cavitation. The recommended NPSH margin should be observed in installations where the suction pipe geometry gives reason for concern. See 8.3.1. concerning how to reduce inlet losses.

8.3.1. Inlet bells

Inlet bell mouth

To accelerate the flow smoothly into the inlet pipe and reduce inlet losses, the inlet should be provided with a bell mouth. Sump and intake should be designed to avoid build-up of sediments.

Bell diameter

The bell diameter (D_i) should be chosen to keep the inlet velocities as follows:

Q < 300 l/s	**0.6 < v < 2.8 m/s**
300 < Q < 1200 l/s	**0.9 < v < 2.4 m/s**
Q > 1200 l/s	**1.2 < v < 2.1 m/s**
Optimum velocity: 1.7 m/s	

At the optimum velocity of 1.7 m/s, the following formula can be used for calculating the bell diameter (D_i):

$$D_i = 0.027 \times \sqrt{Q} \text{ (m)}$$

where Q = pump flow rate in l/s.

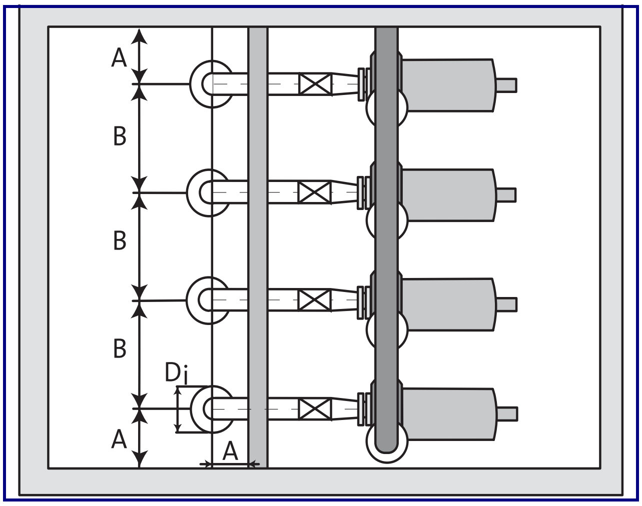


Fig. 64 Recommended installation dimensions for suction pipes in sump ($A_{min} \geq 1.5 \times D_i$ and $B_{min} \geq 3 \times D_i$)

Stop levels

The stop level setting for dry-installed pumps is dependent on suction pipe inlet height, shape and flow velocity. 200 mm above the suction pipe inlet is a good rule-of-thumb for this height, and useful for the designer. The shape of the suction pipe inlet is important, and good designs are shown in Figs. 63 and 64. For this inlet shape a provisional pump stop level height can be calculated using the following formula:

$$h_s = 0.2 + 0.04 \times \sqrt{Q}$$

where
h_s = stop level height, m
Q = pump flow rate, l/s

8. Dry pit installation

In pumping stations with several different stop levels, such as in frequency-controlled installations, it is important to program the control sequence to pump down to lowest stop level at least once per day to clean out the bottom.

Start levels
In pumping stations with dry-installed pumps the starting levels have to be set above the pump casing in order to ensure that the casings fill up when the pumps start pumping. For vertical pumps, this height may be considerable and should be set with a margin according to Fig. 62.

General rules
Although an inlet pipe for a dry pit pump acts as a flow straightener, it can in itself cause unsteady flow. Where bends have to be introduced where for example a vertical pump or a bell parallel to the sump floor is used, such bends should be selected with care to minimize disturbances to the flow.

Smooth bends are always preferred to sharp ones. As a general rule, 5–10 pipe diameters of straight pipe between bends and between bend and pump are required to reduce the disturbances. This, however, is often not practicable.

8.4. Pumping station internal pipework

The internal discharge pipework in a pumping station should be selected for a flow velocity of 2–3 m/s. The pressure pipework should have a dimension of at least 100 mm but can be 80 mm in small pumping stations, provided that the pump free passage is 80 mm or less.

In multi-pump installations, the pump discharge pipes should be joined by branches designed to prevent settling of solids into the individual pipes when the pumps are not running, which may lead to valve blockage. Good branch designs are shown in Fig. 65.

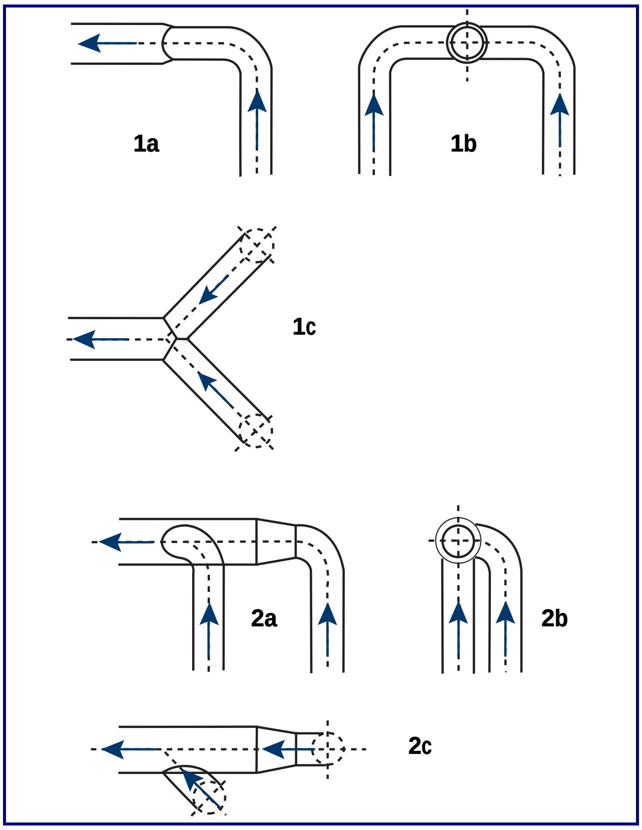
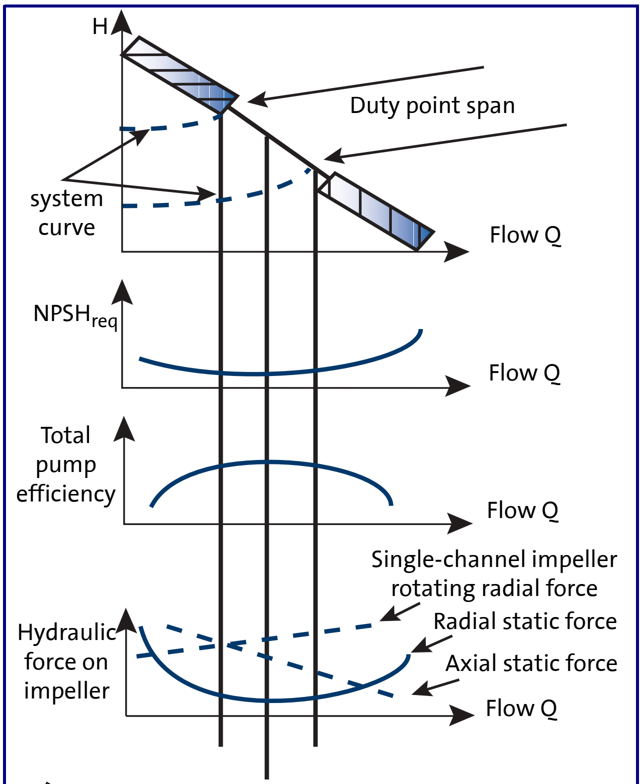


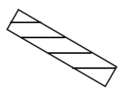
Fig. 65 Discharge pipework branch design. The design should emphasize smooth transition and prevent rising main sludge from settling on valves in pump risers when the pumps are stopped.

8.5. Importance of duty point and problems with off-duty pumps

To achieve the best possible pump operation and to minimize disturbances from the pump in the system, it is of great importance to select the correct unit for the duty point in question.

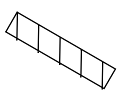
Some of the factors are examined overleaf.





- Recirculation
- High radial and axial forces compared to Q_{opt}
- Low efficiency
- Instability (unstable operation due to recirculation)
- Higher $NPSH_{av}$ is required than at Q_{opt}

Recirculation causes unstable operation of the pump which creates a rumble or banging low frequency noise. Cavitation can cause cavitational erosion which may affect the performance.



- Higher $NPSH_{av}$ is required than at Q_{opt}
- Low efficiency
- High radial forces compared to Q_{opt}

Fig. 66 Factors affecting pump performance

8.6. Vibrations

8.6.1. Introduction

Vibrations from machinery and other equipment can have serious consequences. Knowledge of the phenomena involved, together with design rules for pump installations, are necessary to reduce these unwanted effects and pump installations can be designed to achieve this.

Whenever machinery with rotating parts is used, vibrations occur. The designer's goal is to keep these vibrations within accceptable levels, particularly at points where they can affect the performance of the equipment. Consequences to be avoided include fatigue failures, noise and wear.

8.6.2. Disturbances

The most common disturbances resulting in unwanted vibrations in submersible pumps are listed below in order, with the most likely first.

- Imbalance in rotating parts
- Hydraulic forces caused by the volute
- Hydraulic forces caused by a single-vane impeller

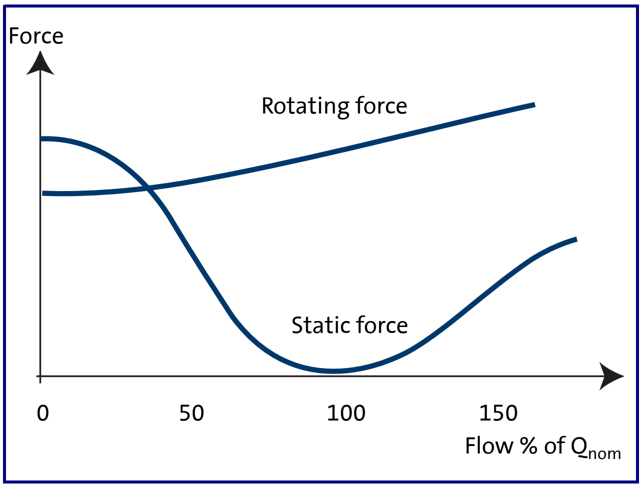


Fig. 67 The magnitude of the forces is dependent on the duty point

- Hydraulic forces that occur when a vane passes through zones of uneven pressure in the volute.
- Pressure impulses caused as the impeller vanes pass guide vanes.
- Other vibrational disturbances often come from the electric motor; they may cause noise, but are normally harmless in their impact on the structure involved.

8.6.3. Installation

Vibrations can be kept at acceptable levels if a number of general rules are followed.

All parts of a system should be sufficiently stiff and firmly anchored so that the primary disturbances have frequencies below the lowest natural frequency of the system. The entire system must be considered, including piping, valves, pump, support etc.

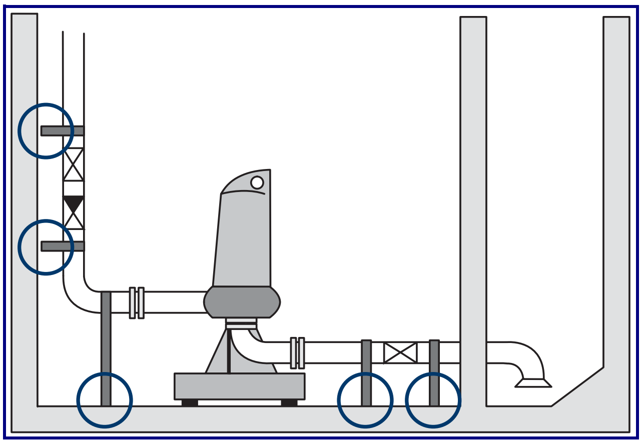


Fig. 68 Typical anchorage points

The pump can be insulated from the structure by:

- Including a base of adequate mass, at least twice the mass of the rotating parts.
- Anchoring the pump firmly to the base.
- Using a flexible support, e.g. anti-vibration feet or a rubber mat between base and floor.
- Using flexible joints for the pipes.
- Anchoring the pipes to floor or other solid structure.

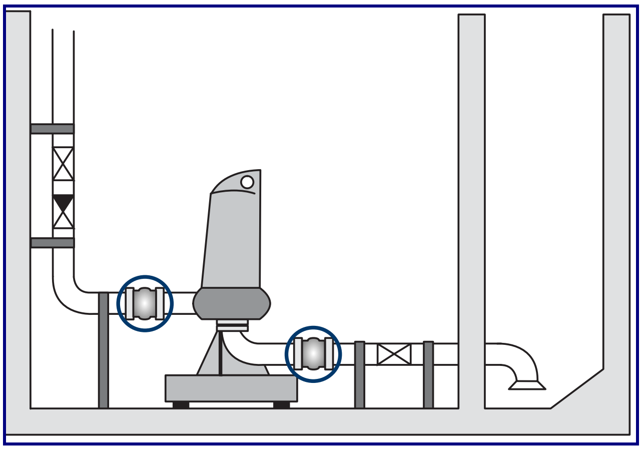


Fig. 69 Ways of minimizing vibrations

Because vibrations are independent of gravity, horizontal supports should be provided since they are as essential as vertical supports.

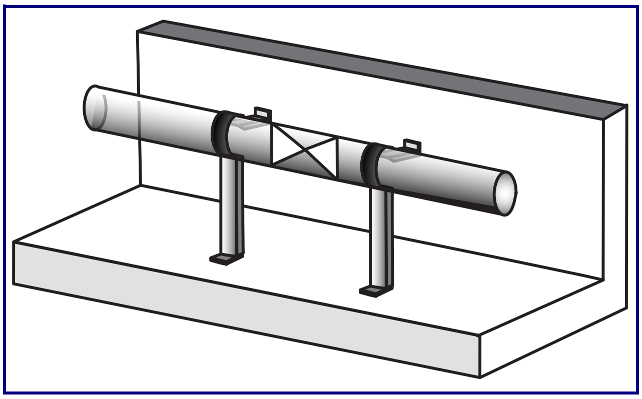


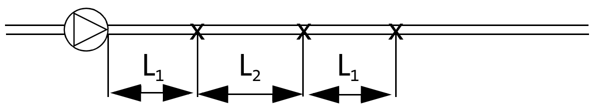
Fig. 70 Horizontal anchorage

Heavy parts of the piping, like valves, must be properly supported.

The piping must be anchored if bellows are used. Bellows between pump and pipe can transform pressure fluctuations into disturbances, causing severe vibrations in the piping.

8.6.4. Anchoring distances

To avoid vibrations in the piping system, varying distances between the anchoring points are necessary. The maximum distances between the anchoring points should be as follows:



L_1 = DN × 14
L_2 = DN × 16

where

L = max. distance between anchoring points
DN = nominal pipe diameter

8.6.5. Variable speed drive

The use of a variable speed drive can excite a broader range of frequencies. If problems with high levels of vibration occur, one should scan the frequency range involved to see if any peaks occur. If so, the installation has natural frequencies that are being excited and the installation should be altered or certain speed ranges avoided.

8.6.6. Conclusion

Unwanted vibrations in installations with machinery like pumps can be avoided or reduced to acceptable levels if certain practices are followed. Any improvements must be based on an understanding of the phenomena involved. Proper anchoring at correct positions is vital. With flexible installations the mass ratio, (total to rotating mass), must be high enough to ensure low vibration levels. If a variable speed drive is used, it might be necessary to avoid certain speed ranges.

9. Grinder pump application

When pumping sewage at a flow less than 4–5 l/s at a required pump head higher than 5 m, a grinder type of pump should always be considered for the following reasons:

- It has a low-weight, semi-open multi-vane impeller. Compared with heavy 70–80 mm free passage single-channel impellers, this leads to reduced vibration and bearing load when lumps of solid matter disturb the balance.
- Cuts solids up into pieces of maximum 10 mm. These float better than big ones and are less likely to block the sewage pipe during periods of low flow.
- Mixes inlet solids better at low flow due to the pre-rotation developed by the special cutter at the inlet.

For discharge pipe sections which are only flushed at low flow, check that the effective sump volume and the pump discharge flow are big enough to create self-cleansing flushing during the pumping cycle and small enough to ensure at least two pump starts per day in order to avoid sedimentation in sump and discharge pipes.

A few rules are to be observed for successful grinder pump operation:

1. When all grinder pumps connected to the same manifold or common discharge pipe are in operation, none of these must exceed the acceptable pressure for the actual pipe.
2. When all grinder pumps connected to the same manifold or common discharge pipe are in operation, the vertical pipe from each pump must have self-cleansing velocity.
3. The common horizontal discharge pipe or manifold should be flushed at self-cleansing velocity by simultaneous running of a sufficient number of pumps at least twice a day in the dry season.

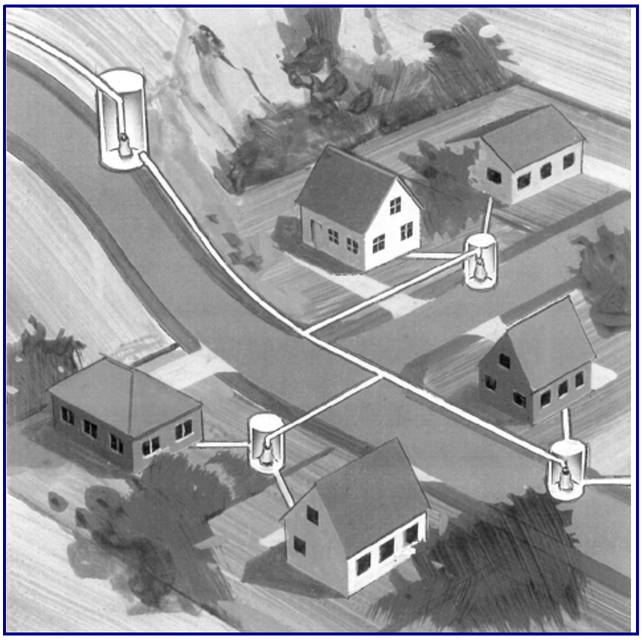


Fig. 71 Typical grinder pump layout

Grinder pumps with a DN 65–80 delivery pipe discharging to a gravity pipe or collecting pit are the ideal solution for summer houses, vacation areas, single-family houses, beach entertainment installations, sporting facilities, etc.

Independent of the activity level, this sewage system will always be self-cleansing.

10. Discharge flow velocity

10.1. Minimum

Minimum water velocity in the discharge pipe from pumping stations is determined by the pumped liquid and the kind of pump cycle used.

In grinder pump and sewage pump discharge pipes protected by a sand trap, a flow velocity of 0.5 m/s is sufficient to obtain self-cleansing when the volume of the pump sump allows complete replacement of the contents of the discharge pipe during one pump cycle daily. Otherwise, a velocity of 0.7–0.8 m/s is required.

Ordinary mixed sewage which may contain sand requires a velocity of 0.7–0.8 m/s to ensure self-cleansing when the volume of the pump sump allows complete replacement of the content of the discharge pipe during one daily pump cycle. In other cases, a velocity of 1 m/s is required.

Application	Minimum velocity [m/s]
Grinder pumping with complete replacement of the liquid in the discharge pipe	0.5
As above, but with only partial replacement of the liquid in the discharge pipe. Mixed sewage with complete replacement of the liquid of the discharge pipe	0.7–0.8
Mixed sewage with small pump sump and only partial replacement of the liquid of the discharge pipe	1.0

In the case of parallel pump operation, it is desirable to discharge a sufficient volume of water through the system during each daily pumping cycle to ensure complete replacement of the contents of the discharge pipe. This is achieved either where the pump sump volume is adequate or where the daily peak inflow is large enough to keep several pumps operating simultaneously. Where such complete replacement cannot be achieved, it is advisable to have a minimum flow of 1 m/s.

In the case of a large volume discharge pipe and piping more than 1000 m long, the flow velocity should be as low as possible before switching off the last pump in order to avoid excessive water hammer; however it should not be less than 0.7 m/s (see chapter 11).

10.2. Maximum

The maximum flow velocity in discharge pipes is limited both technically (max. 5 m/s) and economically (max. 1.0–1.5% frictional loss is acceptable).

The **distribution of total costs** of a pump system over a 10-year period could typically be as follows:

Initial costs:	20%
Service/repair:	30%
Power consumption:	50%

The **initial costs** are heavily influenced by the size of solids the system must be able to handle. Using a system which is able to handle solids of a diameter of 100 mm as base (100%), an increase of the size of solids to 130 mm will result in an increase of initial costs to approx. 160% as this will require not only bigger pumps, but also bigger sump, pipes, bolts, motor, etc. Furthermore, the minimum flow requirement must be observed. On the other hand, a decrease of the diameter of solids to 80 mm will reduce the initial costs to approx. 65%.

The cost of **power consumption** is heavily affected by

- energy price
- annual running hours
- efficiency of pumps and motors
- friction loss in pipework

For small domestic sewage pumps, the annual running time will often be as low as 20–50 hours which makes the cost of energy a minor issue.

For pumps with an annual running time of more than 500 hours, the cost of energy to overcome friction losses becomes of major importance.

The diagram overleaf shows guidelines for optimal velocity at intermittent and constant duty respectively at two different levels of energy prices.

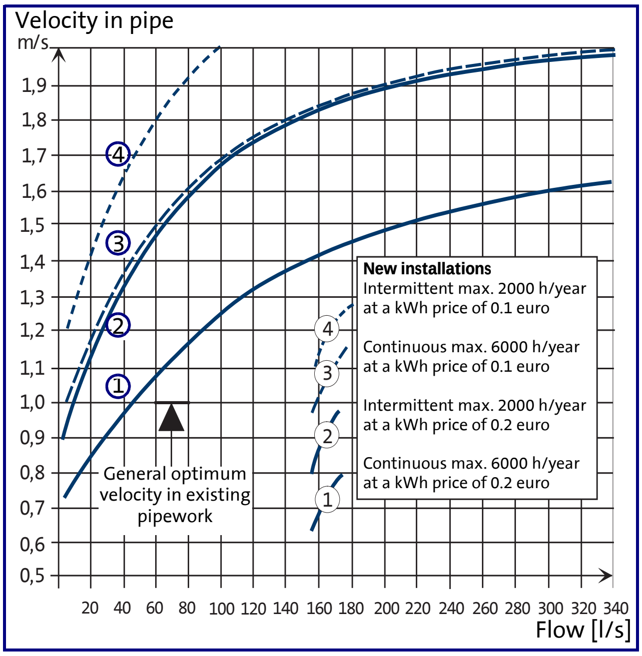


Fig. 72 Velocity for pump selection

10.3. Launcher

In order to reduce the development of hydrogen sulphide in deposits in discharge pipes and to ensure proper system flow including low friction loss, all pumping stations should include a launcher, i.e. a place in the installation through which a cleansing pig or sponge can be inserted into the pipe system.

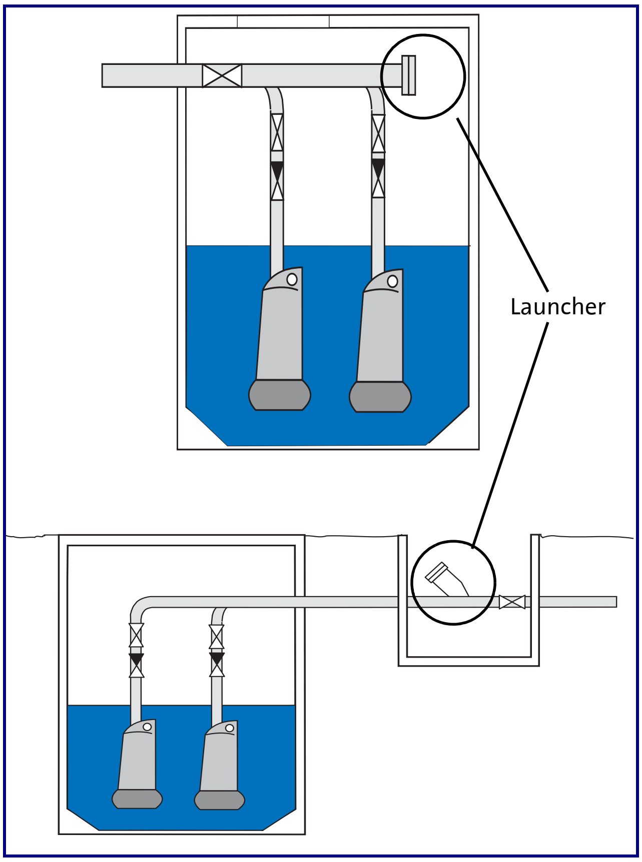


Fig. 73 Launcher

Annual sponge cleansing will remove the bad odours arising from hydrogen sulphide and methane and will remove pockets of gas from the highest points in the installation.

11. Water hammer

Direct-on-line and star/delta pump starts as well as pump stops can result in water hammer in large pump installations. In many cases, water hammer is the most severe impact which the pressure pipe is exposed to. Many pipe bursts are caused by water hammer. Often, seal rings have been worn out or displaced by water hammer as water hammer also creates vacuum. The phenomenon is often not discovered till there is a noise problem. It is possible to make an estimate of water hammer by means of a PC program.

This chapter gives a description of what can typically be observed in the pressure pipe of a sewage pump during starting and stopping. The figure below shows the longitudinal profile of a discharge pipe at a pumping station equipped with two alternating operational sewage pumps and one spare.

Example (approximate figures)

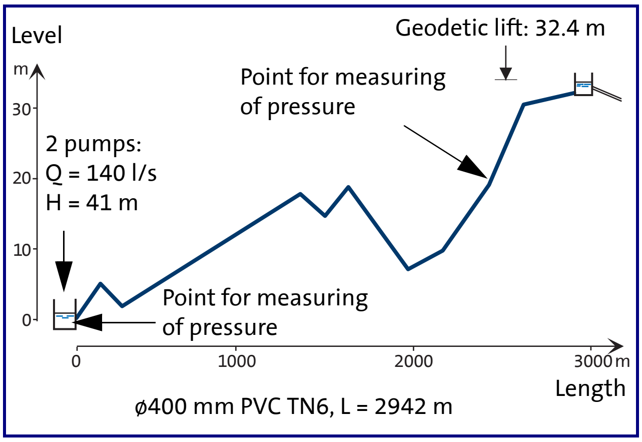


Fig. 74 Longitudinal profile of pressure pipe

Common starting signal for the two pumps, where pump No. 2 is started six seconds later than pump No. 1 in order to reduce the starting current.

Common simultaneous stop signal.

Duty point $P_1 + P_2$ = 140 l/s at 41 m.

Pressure against closed valve: 55 m

Non-return ball valves: DN 200

As the sewage water contains gas it can be compressed somewhat.

DN 400, PN 6 bar PVC pressure pipe with a velocity of propagation of the pressure wave of 250–350 m/s.

Friction loss at 140 l/s: 12 m

Velocity at 140 l/s: 1.3 m/s

Minimum velocity for self-cleansing is 0.7 m/s equal to 75 l/s during continuous operation. However, this installation has an effective sump volume of 8,000 l and a discharge pipe volume of 330,000 l. A pumping cycle therefore replaces about 2.5% of the volume of the discharge pipe. For self-cleansing reasons, the flow velocity should therefore be not less than 1 m/s if no detailed calculations have been made.

The frictional resistance when pump No. 1 is running alone at 84 l/s will be 4.4 m at a flow velocity of 0.75 m/s.

This means that single-pump operation is not possible unless the discharge pipe is cleansed by means of a pig or sponge approx. twice a year.

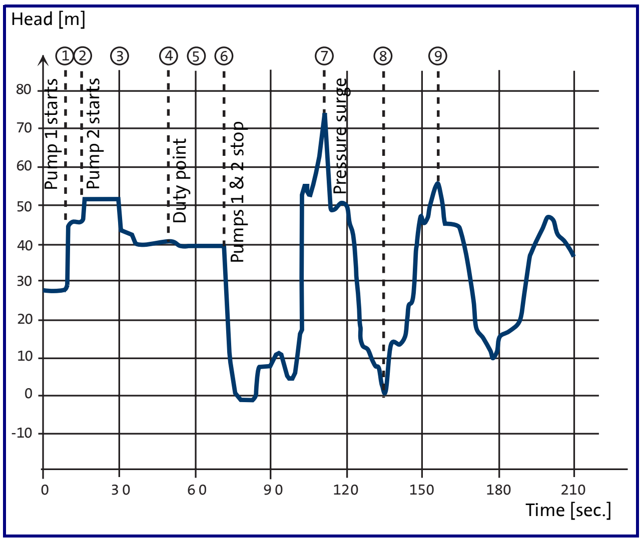


Fig. 75 Pressure in discharge pipe at pump

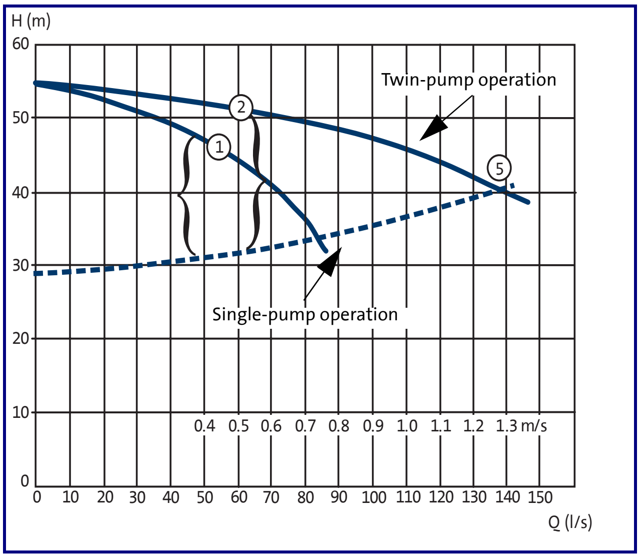


Fig. 76 Pump performance at single-pump and twin-pump operation

Observations during pump start (see Figs. 75 & 76)

1. Start of pump No. 1 (see "1") does not result in a flow of 84 l/s as could be expected, but only 55 l/s (see "1") as 17 m head is used to accelerate the 330,000 litres of sewage in the discharge pipe from zero to 0.4 m/s.

2. After a delay of six seconds, pump No. 2 starts (see "2"). This does not result in a flow of 140 l/s as could be expected, but only 60 l/s as 20 m of the pump head is used to accelerate the 330,000 litres of sewage in the discharge pipe from 0.4 to 0.7 m/s.

3. Approx. 20 seconds after the first pump was started, the pumps have accelerated all 330,000 litres of sewage to a velocity of approx. 1 m/s (see "3"). After this phase, the pressure drops. This decrease is disturbed by the water hammer from the starting of pump No. 1 with a delay of approx. 25 seconds.

4. Approx. 25 seconds after the start of pump No. 2, the resulting water hammer can be seen (see "4").

5. Approx. 45 seconds after the start of pump No. 1, all 330,000 litres are accelerated to a velocity of 1.3 m/s, equal to 4.7 km/h. As expected, the performance of the pumps is approx. 140 l/s. The pump pressure is constant (see "5").

Comments on water hammer after startup:

- No water hammer has been higher than the maximum value of the pressure pipes (PN 6 bar).

- The water hammer caused by the starting of pump No. 2 could have been reduced to the level of pump No. 1, if it had been postponed by 10 seconds. In that case, pump No. 1 would have accelerated the water to 0.75 m/s where the pressure at the lower measuring point would be 34 m when pump No. 2 is started.

- Item 4 above is of minor importance as the content of gas in the water is high. This will absorb the main water hammer during startup.

  70 seconds after the start of pump No. 1, 8,000 litres will have been removed from the pump sump and the common stop level control is activated and both pumps are switched off. Only 2.5% of the contents of the discharge pipe has been replaced during this pumping cycle. To avoid sedimentation at the lowest points of the discharge pipe, the flow velocity must be at least 1 m/s. The discharge pipe should be prepared for insertion of a cleansing pig.

Observations after pump stop (see Fig. 75)

- When the pump stops, the 330,000 litres of sewage (see "6") will try to continue at a speed of 1.3 m/s. This will create a vacuum at the lower end of the discharge pipe. This will force the non-return valve at the pump to open and sewage from the sump will be sucked in via the pump for approx. 15 seconds. The lowest part of the discharge pipe will now be under vacuum which may cause PVC pipes to burst longitudinally and make worn seal rings burst at pipe joints.

- Approx. 25 seconds after the closing of the non-return valve, the first and largest water hammer blow will occur with a peak of 7.5 bar (see "7") or 25% more than acceptable for the pipe. This pressure will force all lip seals in pipe joints back in normal position (if they are not already fully worn out).

  The duration of the water hammer will be prolonged by a high gas content. Often water hammer will only last for a split second and sound like a blow on a barrel.

- 25 seconds after the first and largest water hammer blow, the first and largest vacuum surge will occur, which will also affect the lip seals in the pipe joints (see "8").

- After this, the intensity of the water hammer decreases (see "9").

Comments on water hammer after pump stop:

- All maximum and minimum limits for application of lip seals in PVC PN 6 pipe joints have been exceeded.

- Vacuum and water hammer could have been more than halved if the stop of pump No. 2 had been delayed. In that case the pump would have replenished the pipe and consequently counteracted the first full development of the vacuum surge resulting from the stopping of pump No. 1. When pump No. 2 stops after 25 seconds or longer, the velocity of the water in the discharge pipe will have dropped from 1.3 to 0.75 m/s. This means that the water hammer caused by the stopping of pump No. 2 will have been halved compared with the situation when both pumps are stopped at the same time.

- Simultaneous stopping of both pumps can be a disaster in cases where the volume of water in the discharge pipe is large.

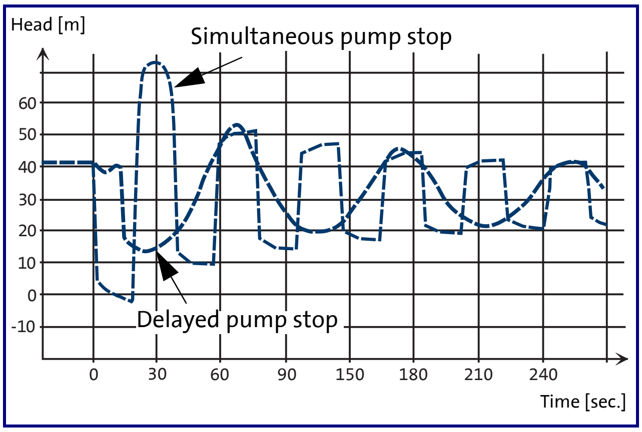


Fig. 77 Water hammer in discharge pipe with simultaneous and delayed pump stop respectively

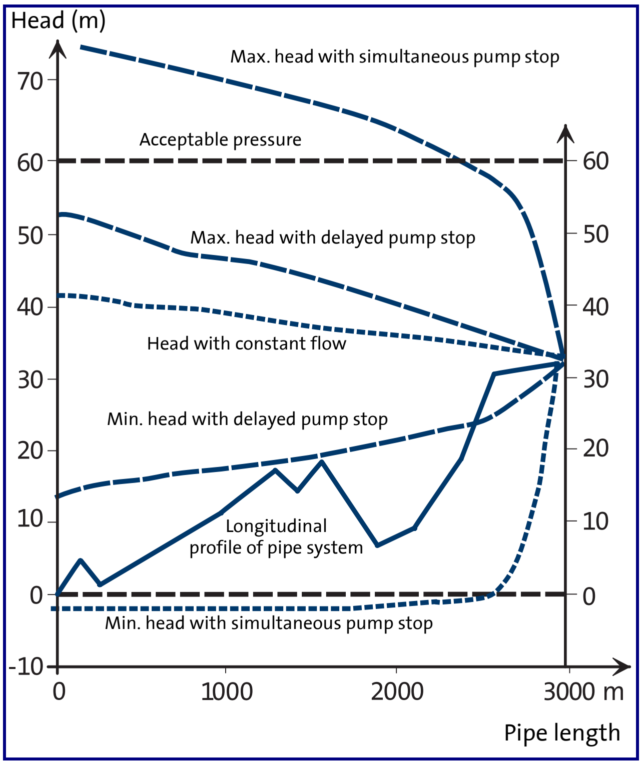


Fig. 78 Longitudinal profile of minimum and maximum water hammer pressure in discharge pipe with simultaneous and delayed pump stop respectively

11. Water hammer

Positive effects of water hammer in sewage pipes
The blow releases sludge and encrustations from the pipes. This means that moderate water hammer can be positive if it is kept to a level where it does not create a vacuum (with the risk of sucking in ground water) or pressure peaks close to the PN for the chosen pipe system including the joints.

The risk of water hammer rises with increasing pump pressure and with the amount of water in the discharge pipe and with the flow before the last pump stop.

The diagram below makes it easy to identify potentially risky installations.

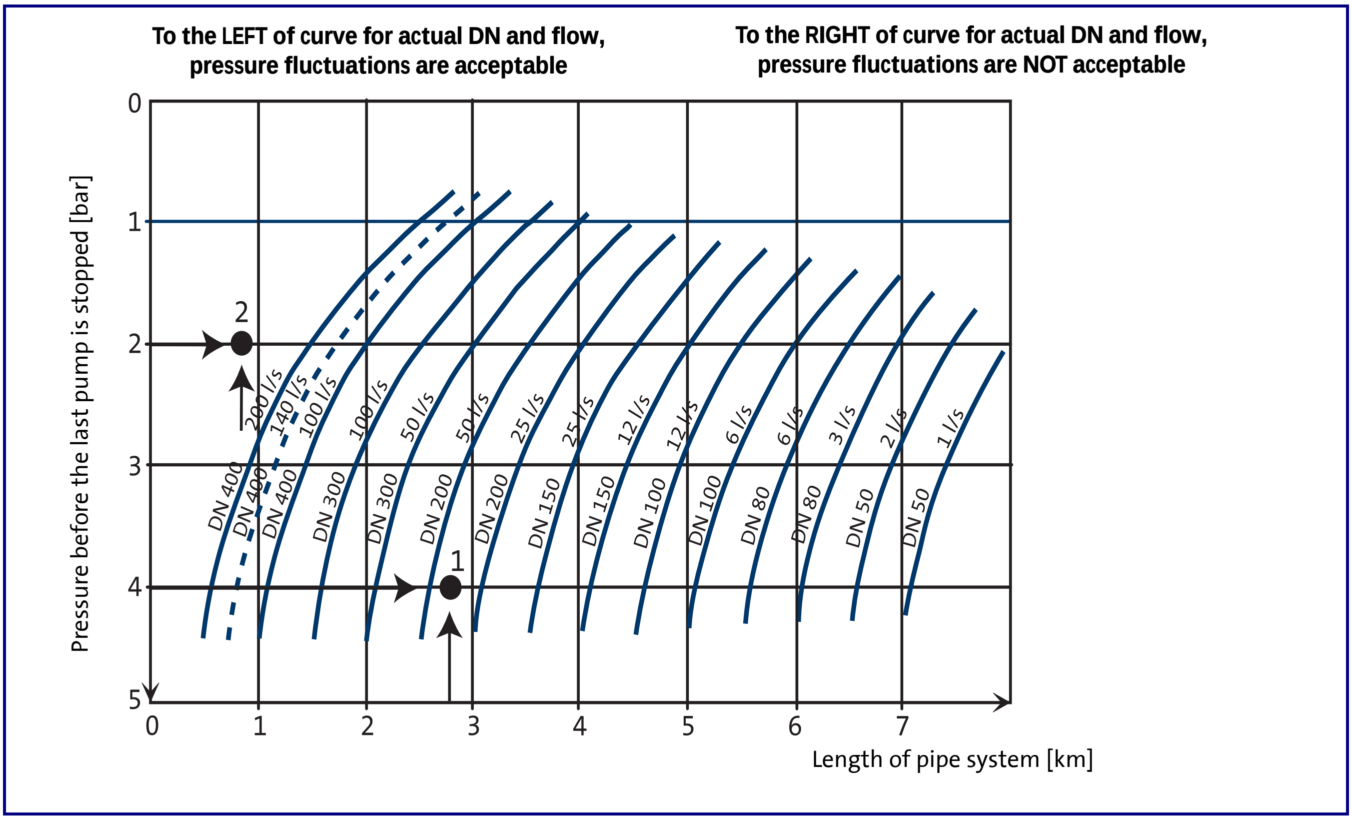


*Fig. 79 Diagram for estimating the limits for **simultaneous** pump stop*

How to use the diagram

Example 1
The length of the discharge pipe is 2942 m, DN 400, flow before simultaneous pump stop is 140 l/s. Pump pressure before stop is 4 bar.

Result:
We are far to the right of the curve DN 400, Q = 140 l/s at point 1. Calculation of water hammer is necessary. The risk of water hammer can be reduced by installing diaphragm tanks on the discharge pipe after the non-return valves.

Example 2
The length of the discharge pipe is 800 m, DN 400, flow before simultaneous pump stop is 140 l/s. Pump pressure before stop is 2 bar.

Result:
We are to the left of the curve DN 400, Q = 140 l/s at point 2. There is no risk of water hammer of destructive character when using simultaneous pump stop as we are on the Q = 140 l/s curve or to the left of it.

11. Water hammer

How to eliminate water hammer

1. Introduce parallel operation of up to four sewage pumps, each with its own level stop or time delay. During pumping, however, the minimum flow to ensure self-cleansing must be observed; it may be necessary to have two pumps in operation. In this case, operation of one pump alone should only take place before the last pump is stopped in order to allow the flow to slow down gradually.

2. Introduce pressure equalization by means of diaphragm tanks of a total capacity of 1% of the hourly performance of the smallest pump or 1% of the content of the discharge pipe, whichever is the larger. Make sure that the smallest pump stops last.

3. If item 2 above is not possible, fit a return bypass to the sump controlled by a motor-driven valve with 30 seconds' minimum opening and closing time.

4. If items 1–3 above are not possible, soft starts and stops over a period of 15–30 seconds should be introduced.

12. Key figures and diagrams

12.1. Inlet flow

12.1.1. Wastewater flow (Qs,r)

The rated wastewater flow is calculated from the assumed wastewater flows qs,a from the individual installations, taking the probability of simultaneous use into consideration.

12.1.1.1. Assumed wastewater flow (qs,a)

Installations	Assumed wastewater flow (l/s)
Bathtub	0.9
Bidet	0.3
Shower	0.4
Floor drain in buildings	0.9
Wash basin	0.3
Kitchen sink, single or double	0.6
Kitchen sink, single or double (industry)	1.2
Urinal	0.3 per stand (max 1.8)
Urinal with flushing valve	0.4
Washing machine (private)	0.6
Dishwasher	0.6
Washing trough	0.4 per metre or 0.3 per tap point
WC with cistern or flushing valve (6–9 l per flush)	1.8

Note: Particularly for flats and single-family houses with only one household, the rated flow, Qs,r must be minimum 1.8 l/s, corresponding to Sqs,a = 12 l/s when toilets are connected. The minimum flow velocity (1 m/s) in the riser main must, however, be observed.

12.1.1.2. Collecting pipes where $12 \leq \Sigma qs,a \leq 4000$ l/s

The rated wastewater flow can be found from the diagram overleaf (Fig. 80), based on the sum of assumed wastewater flows.

The diagram is based partly on measurements and partly on probability considerations. It is drawn in such a way that the rated wastewater flow can be expected to occur once a day. Allowance has been made for the fact that the probability of simultaneous use of several installations is bigger at hotels, hospitals, schools, barracks, cinemas, meeting rooms, factory changing rooms, nursing homes, etc. than in private homes, offices and nursing homes.

12.1.1.3. Collecting pipes where $\Sigma qs,a > 4000$ l/s

The rated wastewater flow can be determined after agreement with the authorities.

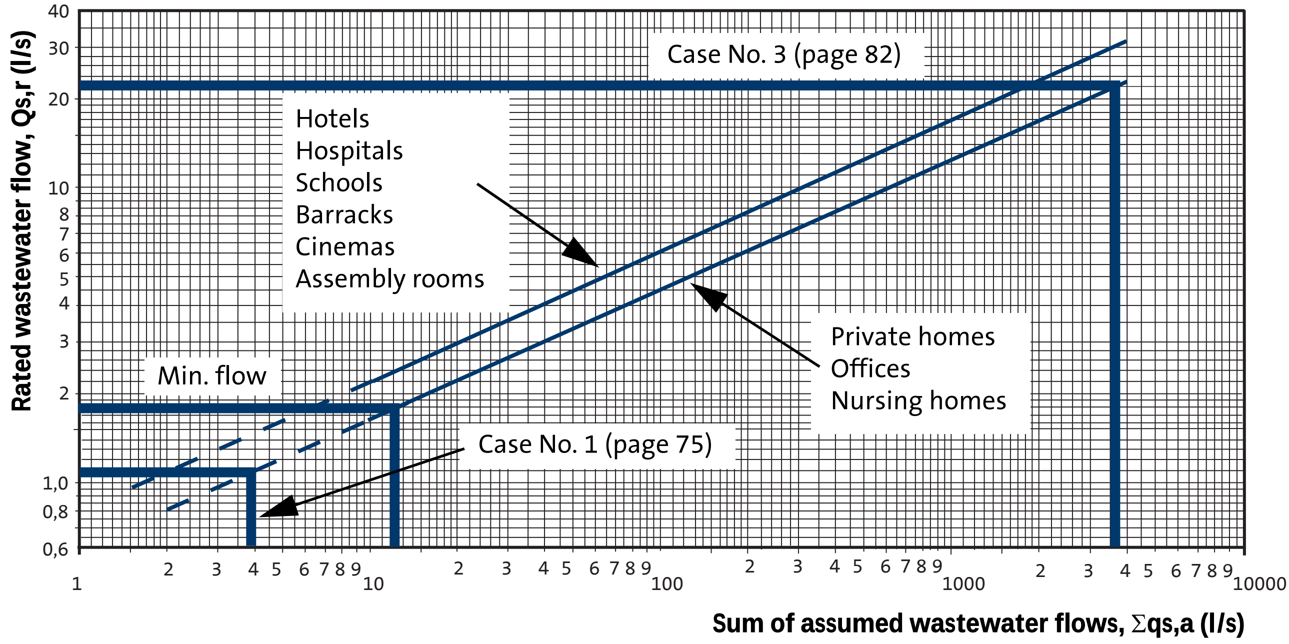


Fig. 80 Diagram for estimating the assumed wastewater flow

12.1.2. Rainwater flow (Qr,r)

The rated rainwater flow is calculated like this:

Qr,r = i x ϕ x A, where

i = the rated rain intensity (l/s/m²)
A = the catchment area (m²)
- measured in horizontal projection
ϕ = discharge coefficient

12.1.2.1. Rated rain intensity

Shower intensity is normally based on a duration of 10 minutes.

In relatively big installations, it will usually be possible to base calculations on reduced intensities, i.e. longer periods of rain.

12.1.2.2. Discharge coefficients

Guidelines for calculating discharge coefficients	
Surface	**Discharge coefficient**
Roofs and impermeable surfaces, e.g. bitumen, concrete or surfaces with tight joints	**1.0**
Surfaces with joints of gravel and grass	**0.8**
Gravel	**0.6**
Garden areas and similar places	**0.1**

The average discharge coefficient must normally not exceed the one stipulated by the authorities for the installation in question. If it does, a delay basin or something similar should be established in agreement with the authorities.

12. Key figures and diagrams

n*	Rated rainwater intensity in l/s/m² (l/s/ha)	Application	
		Separate systems	Common systems
1	0.011 (110)	Where there is only a risk of inconvenience, e.g. flooding outside building.	Where there is only a risk of inconvenience, e.g. smell. Flooding is not acceptable.
1/2	0.014 (140)	Where there is a risk of minor damage to buildings, furniture, machines or equipment. It should be possible to normalize things by ordinary cleaning and short-term drying. Flooding should occur only in rooms with watertight floor constructions.	
1/10	0.023 (230)	Where there is a risk of severe damage to buildings, machines or equipment.	
- 0		Where there is a risk of accidents or health hazards to animals or human beings.	
*** n** is the annual probability of showers with an intensity bigger than the rated one.			

12.1.2.3. Catchment area

The catchment area (A) is calculated as the sum of

- horizontal areas
- horizontal projections of sloping surfaces
- 1/3 of vertical surfaces hit by heavy showers, i.e. normally the surfaces pointing towards the prevailing wind direction.

It is recommended that the rated rainwater flow is calculated assuming that all possible extensions to a building have been constructed.

12.1.3. Drainage water flow (Qd,r)

The rated flow of drainage water in collecting and discharge pipes is usually small. In areas with porous soil and drainage under the groundwater level, the rated drainage water flow should be based on hydrogeologic tests.

12.1.4. Rated discharge flow in common systems

This is calculated like this:

Qr = Qs,r + Qr,r + Qd,r

12.1.5. Rated discharge flow in separate systems

This is calculated like this:

- Qr = Qs,r in wastewater pipes
- Qr = Qr,r + Qd,r in rainwater pipes

12.2. Pressure loss in pipes

Diagrams for pressure losses in different kinds of pipes are shown on the following two pages.

12. Key figures and diagrams

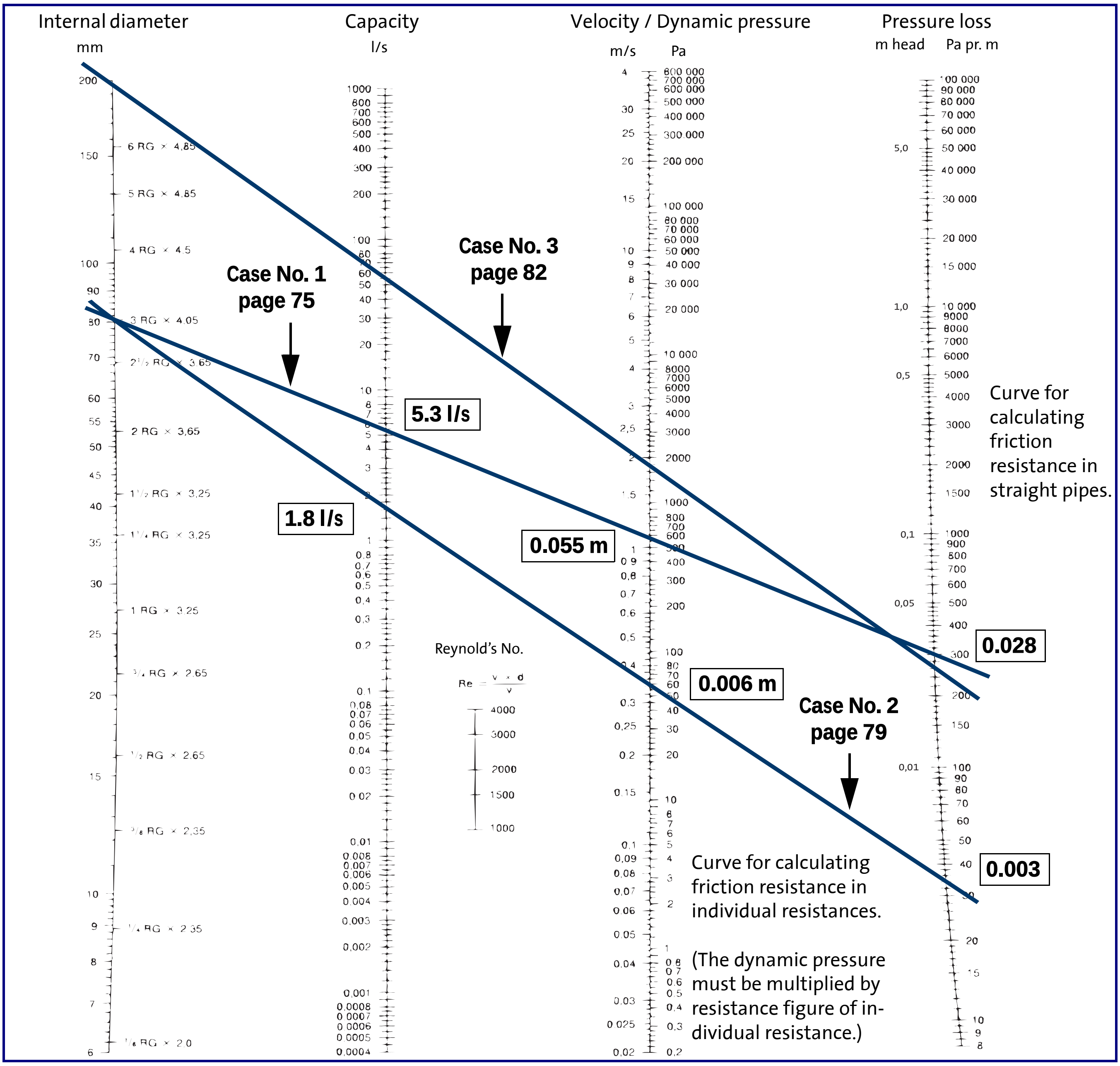


Fig. 81 Nomogram showing friction loss in straight galvanized steel pipes with deposits

Temperature range
The nomogram is valid for water at 10°C. At 0°C the friction loss error will be no more than +10% and at 55°C no more than -25%.

Basis
Colebrook's formula at a water temperature $t = 10°C$, absolute roughness $k = 1.0 \times 10^{-3}$ m, and a deposit layer $a = 0.3 \times 10^{-3}$ m.

Diameters
On the right hand side of the diameter scale, the internal diameter of medium thick threaded pipes, steel 00, according to DS 540, 3rd edition, are stated.

According to this standard these diameters are indicated with the thread that can be cut in the pipe, plus the wall thickness in mm.

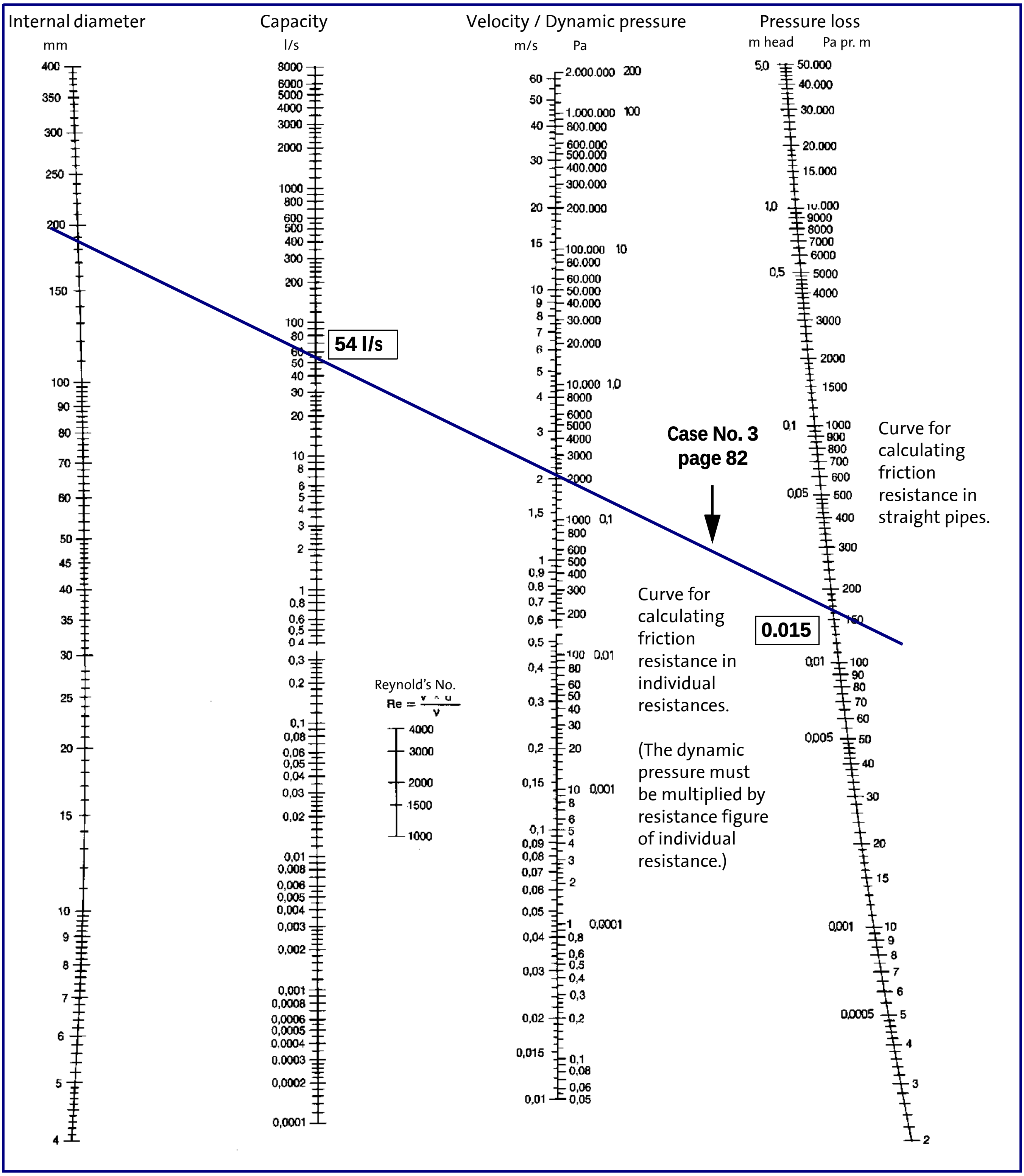
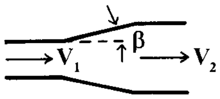
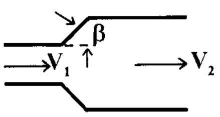
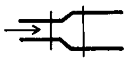
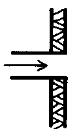
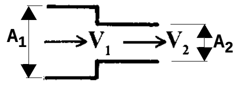
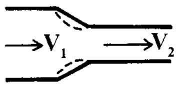
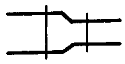
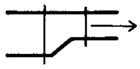
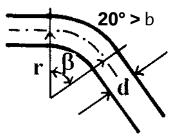
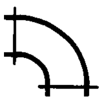
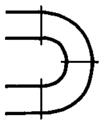
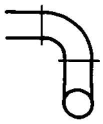
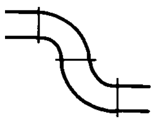


Fig. 82 Nomogram showing friction loss in PVC ground sewage pipes with deposits

12.3. Friction loss in individual resistances (ξ-values)

Widening	
	$\beta < 20°$ $\Delta H = \xi \dfrac{(V_1 - V_2)^2}{2g}$ β | 5° | 10° | 15° ξ | 0.2 | 0.5 | 0.85
	$\beta \geq 20°$ $\Delta H = 1.1 \dfrac{(V_1 - V_2)^2}{2g}$ for turbulent flow
	Standard widening ξ = 1.0
	Outlet ξ = α

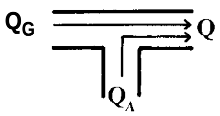
Narrowing	
	Sudden narrowing A_2/A_1: 0 | 0.2 | 0.4 | 0.6 | 0.8 | 1.0 ξ: 0.5 | 0.4 | 0.3 | 0.2 | 0.1 | 0
	Conical or rounded narrowing ξ ~ 0–0.1
 	Standard narrowing ξ ~ 0 Eccentric reducer ξ ~ 0.5

Change of direction	
	Bends β = 90° r > 4d: ξ ~ 0.2 (rough pipe) ξ ~ 0.1 (smooth pipe) r = d: ξ ~ 0.5 (rough pipe) ξ ~ 0.2 (smooth pipe) β < 90° $\xi = \xi_{90} \sin\beta$
	Standard bends ξ ~ 1.0 d ≤ 20 mm ξ ~ 0.5 d > 20 mm
  	Two 90° bends $\xi = 2 \times \xi_{single}$ $\xi = 3 \times \xi_{single}$ $\xi = 4 \times \xi_{single}$

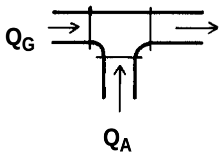
12. Key figures and diagrams

Confluence

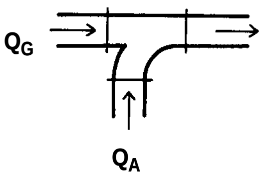
A = branching
G = straight flow



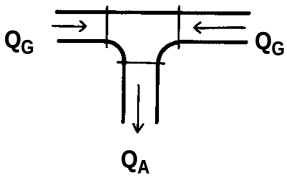
Q_A/Q	0.2	0.4	0.6	0.8
ξ_A	0	0	0.5	0.8
ξ_G	0.2	0.3	0.4	0.5



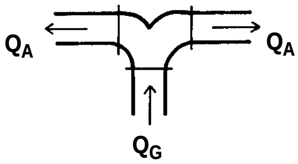
T-piece, confluence
$\xi_A \sim 1.0$
$\xi_G \sim 0.5$



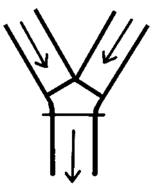
T-piece, confluence
$\xi_A \sim 0.5$
$\xi_G \sim 0$



T-piece, symmetrical branching or confluence
$\xi_A \sim 3.0$



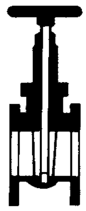
T-piece, symmetrical branching or confluence
$\xi_A \sim 1.5$



Y-piece, symmetrical branching or confluence
$\xi \sim 0.6$

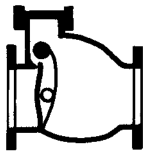
Valves and taps

ξ-values strongly depend on shape.
Factory values should be used.

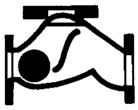


Slide valves **without** narrowing: ξ = 0.1–0.3

Slide valves **with** narrowing: ξ = 0.3–1.2



Flap non-return valve
ξ = 0.5–1.0 (fully open)



Ball non-return valve
$\xi \sim 1.0$ (fully open)

ξ-values above are valid for fully open valves.
At half-open postition, ξ may be 2–3 times as big.
Depending on shape and position, a certain minimum flow velocity through the valve is necessary for it to be regarded as fully open.
Information must be obtained from the supplier.

13. Practical examples

13.1. Case No. 1: Effluent pumping

The wastewater, drainage water and rainwater from the basement of this building must be pumped away. The toilet water from the upper floor is discharged by gravity.

Find a proper solution.

Grey wastewater
- Wash basin
- Floor drain
- Bathtub
- Washing machine
- Dishwasher
- Kitchen sink

Rainwater

Horizontal area:	100 m² roof,	$\phi = 1.0$
	50 + 50 m² gravel,	$\phi = 0.6$
Vertical area:	150 m² x 1/3,	$\phi = 1.0$

Drainage water
From sandy soil, 40 m pipe,
drainage zone width 30 m on each side of the pipe.

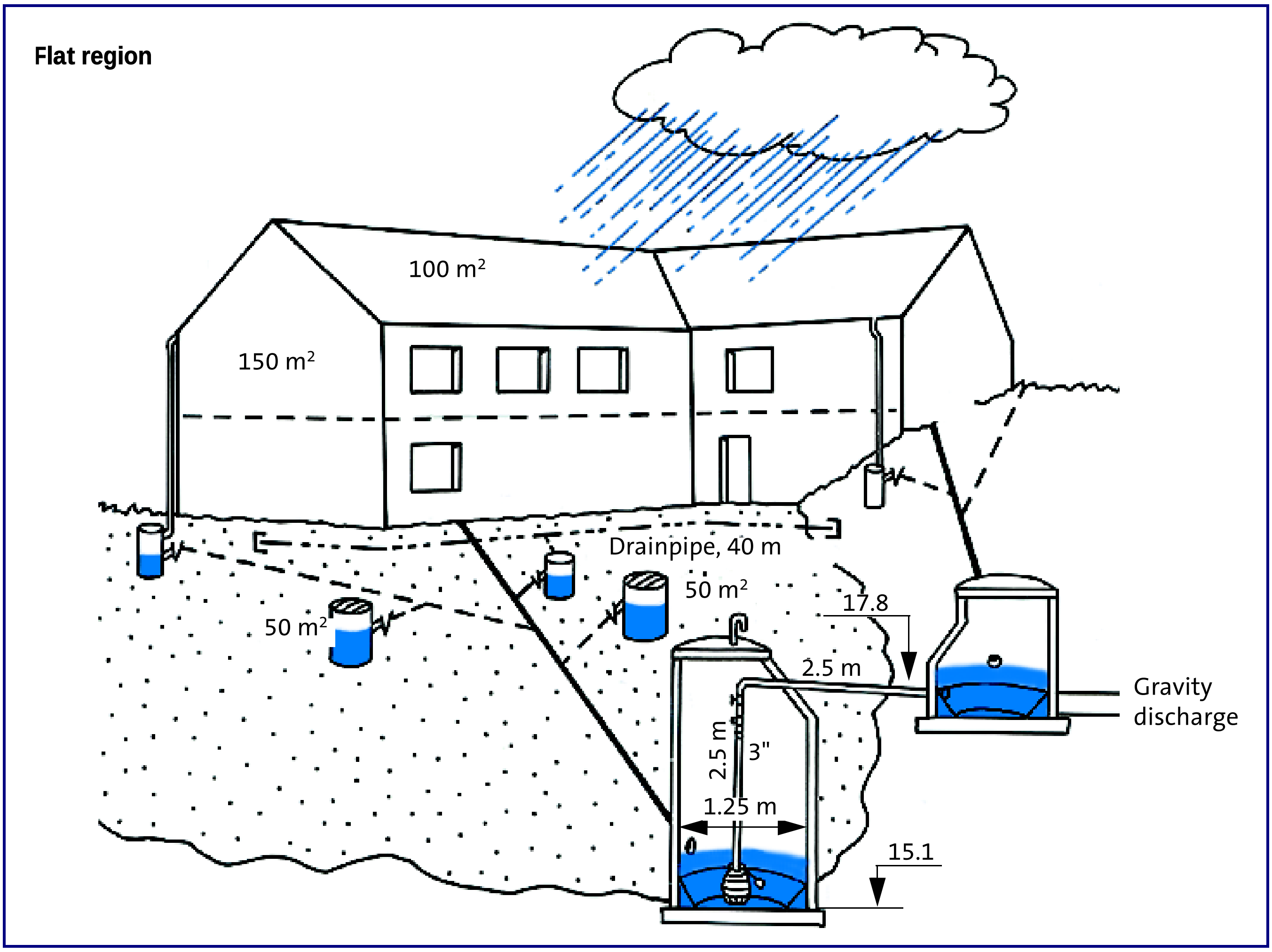


Fig. 83 Installation diagram

13. Practical examples

13.1.1. Determination of discharge flows

13.1.1.1. Wastewater flow

Installations (See 12.1.1.1.)	Assumed wastewater flow (l/s)
Wash basin	0.3
Floor drain	0.9
Bathtub	0.9
Washing machine	0.6
Dishwasher	0.6
Kitchen sink	0.6
Total (Σqs,a)	**3.9**

The diagram on page 68 shows that an assumed total wastewater flow of 3.9 l/s gives a rated total wastewater flow, Qs,r, of 1.05 l/s. However, as mentioned in section 12.1.1.1, the minimum rated wastewater flow of a single-family house is 1.8 l/s.

13.1.1.2. Rainwater flow

n*	Rated rainwater intensity in l/s/!m^2 (l/s/ha)	Application	
		Separate systems	Common systems
1	0.011 (110)	Where there is only a risk of inconvenience, e.g. flooding outside building.	Where there is only a risk of inconvenience, e.g. smell. Flooding is not acceptable.
1/2	0.014 (140)	Where there is a risk of minor damage to buildings, furniture, machines or equipment. It should be possible to normalize things by ordinary cleaning and short-term drying. Flooding should occur only in rooms with watertight floor constructions.	
1/10	0.023 (230)	Where there is a risk of severe damage to buildings, machines or equipment.	
- 0		Where there is a risk of accidents or health hazards to animals or human beings.	

*** n** is the annual probability of showers with an intensity bigger than the rated one.

Catchment area (m^2)	Rated rainwater flow (l/s)
Roof 100 x 1.0 x 0.014	1.4
Gravel surface (50 + 50) x 0.6 x 0.014	0.8
Vertical area 150 x 1/3 x 1.0 x 0.014	0.7
Total (ΣQr,r)	**2.9**

13.1.1.3. Drainage flow

Ground: Sandy soil
Drainage area: 40 m x (30 + 30) m = 2400 m^2.

The rated drainage flow (Qd,r) from this area is estimated at 2 m^3/h ~ 0.6 l/s (see Fig. 10, page 11).

13.1.2. Determination of pipework system

13.1.2.1. Status of pump system (see 1.1)
Pumping from individual building means that there are no layout restrictions from general sewage regulations.

13.1.2.2. Rated discharge flow in common system (see 1.4.1)

Qr = Qs,r + Qr,r + Qd,r
Qr = 1.8 + 2.9 + 0.6 = 5.3 l/s ~ 19 m^3/h

13.1.2.3. Calculation of pipe size
Flow rate = 5.3 l/s = 0.0053 m^3/s.
For self-cleansing ability, minimum velocity = 1.0 m/s (see page 59).

$$\text{Maximum pipe area} = \frac{0.0053}{1.0} = 0.0053\ \text{m}^2$$

Therefore maximum pipe diameter =

$$\sqrt{\frac{0.0053 \times 4}{\pi}} = 0.082\ \text{m, or say DN 80.}$$

This size of pipe will be suitable for any pump likely to be chosen, since the latter will have clearances of 35 mm or 50 mm. No additional safety calculation is required.

13.1.2.4. Pipe layout (see 2.2)
A discharge pipe with a 3" union for dismantling from horizontal sewage pipe can be chosen. This means that an auto-coupling system is not necessary.

13. Practical examples

13.1.2.5. Frictional loss in individual resistances (see 2.3)

Individual resistances	ξ-values
Standard widening from pump to DN 80 discharge	1.0
One 90° bend (r = d)	0.5
Union	0.3
Valve	0.3
Standard widening from horizontal 3" discharge pipe to gravitational sewage pipe	1.0
Total	**3.1**

Dynamic head in a DN 80 pipe, flow rate 5.3 l/s, is 0.055 m (see Fig. 81).

Δp = 3.1 x 0.055 m = 0.17 m in individual resistances.

Frictional loss in 5 m (2.5 + 2.5 m) DN 80 straight pipe:

Δp = 0.028 x 5 m = 0.14 m

Total frictional loss:
0.17 + 0.14 m = 0.31 m at a flow of 5.3 l/s.

13.1.2.6. System characteristic

$$\frac{H}{Q^2} = \frac{0.31}{5.3^2} = 0.0110$$

The system characteristic is H = 2.7 + 0.0110 x Q^2.

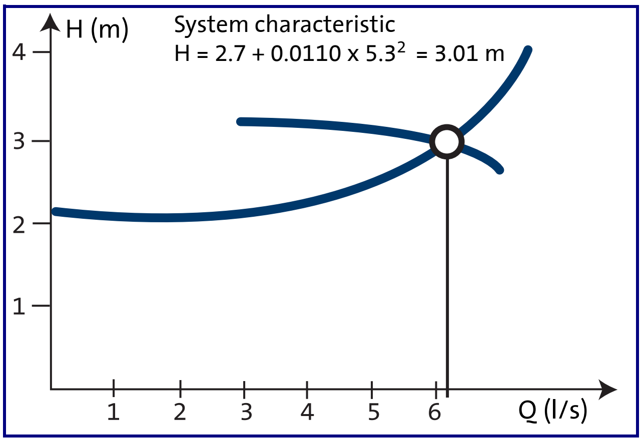


Fig. 84 Determination of duty point

From Fig. 81 it can be seen that the velocity in vertical DN 80 pipes is 1.05 m/s at a flow of 5.3 l/s. As the minimum self-cleansing velocity is 1 m/s (see table on page 59) a reduced flow cannot be accepted unless the pipe dimension is reduced.

13.1.3. Pump selection

13.1.3.1. Suitable Grundfos effluent pumps

AP 35.40.08.3, 50 Hz, 3 x 400 V, I_n = 2.1 A

AP 50.50.08.3, 50 Hz, 3 x 400 V, I_n = 2.1 A

AP 30.50.09.3, 50 Hz, 3 x 400 V, I_n = 2.2 A

AP 51.65.07.3, 50 Hz, 3 x 400 V, I_n = 1.9 A

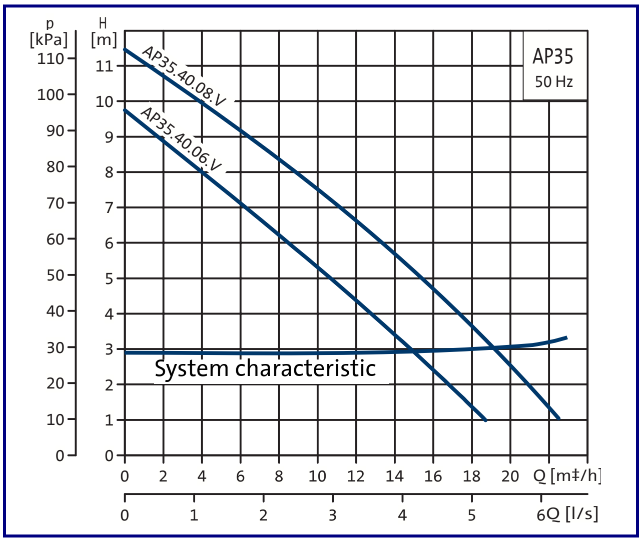


Fig. 85 AP 35 pump characteristics

AP 35.40.08 with a vortex impeller will be the most cost-effective purchase and the AP 30 requires the least total energy (see overleaf).

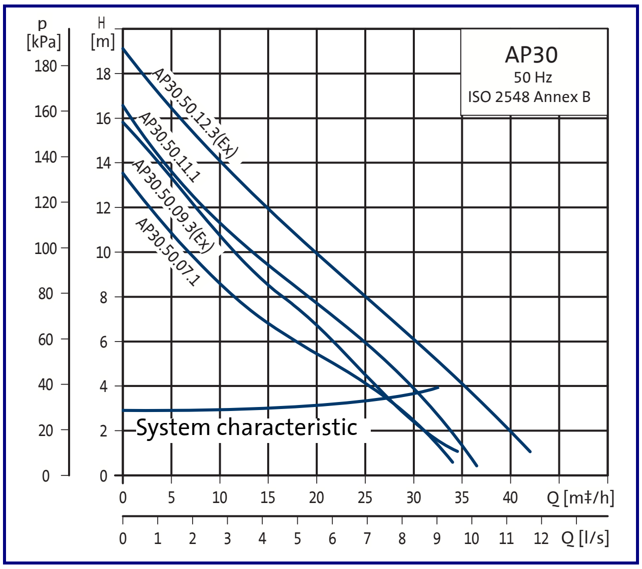


Fig. 86 AP 30 pump characteristics

13.1.3.2. Pump operation (see 2.4.2)
A Danish household like the one in the example will typically have

- a **wastewater discharge** of 300 m³/year,
- a **rainwater discharge** of 0.7 m³/m² x ϕ x A = 0.7 × 1.0 × 100 + 0.7 × 0.6 x (50 + 50) + 0.7 × 1.0 × (150 × 1/3) = 147 m³/year at a precipitation of 700 mm/year, and
- a **drainage discharge** of 0.1 mm³/m²/year x A, totalling 240 m³/year.

This means that the total annual discharge flow will be 300 + 147 + 240 m³ = 687 m³.

The **operating time of AP 35.40.08.3** will be

$$\frac{687 \text{ m}^3\text{/year}}{19 \text{ m}^3\text{/hour}} = 36 \text{ hours/year}$$

The **power consumption** P_1 will be

$$P_1 = \sqrt{3} \times 400 \times 2.1 \times 0.86 \times 36 \times 10^{-3} = 45 \text{ kWh/year}$$

The **operating time of AP 30.50.09.3** will be

$$\frac{687 \text{ m}^3\text{/year}}{27 \text{ m}^3\text{/hour}} = 25 \text{ hours/year}$$

The **power consumption** P_1 will be

$$P_1 = \sqrt{3} \times 400 \times 2.2 \times 0.83 \times 25 \times 10^{-3} = 32 \text{ kWh/year.}$$

As the annual operating time is as low as 25 and 36 hours respectively, the pump could remain in the pit for 55 years before the 2000-hour oil change interval was reached. This means that the only argument for installing a double pump has to do with safety.

If the pump should fail, there is still an accumulation volume in pipes and pit of approx. 1.5 m³, corresponding to one or two days' discharge from the house.

The traditional pump selection for this application would be a pump with a 30 mm clearance.

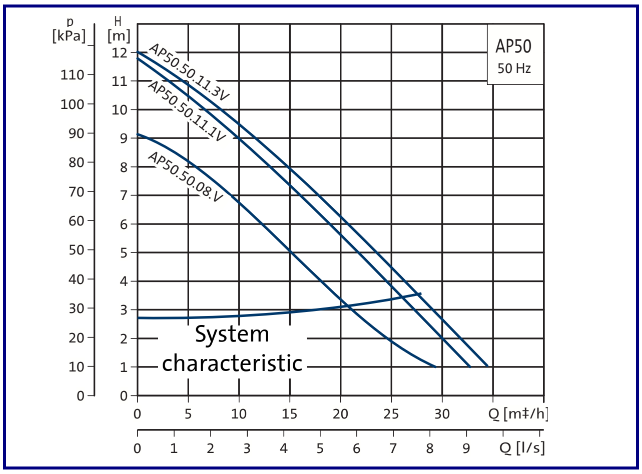


Fig. 87 AP 50 pump characteristics

This tradition is partly based on availability and price. Today, an AP 50.50.08.3 with non-clogging vortex impeller, which can handle solids of up to 50 mm, should be considered.

The **operating time of AP 50.50.08.3** will be

$$\frac{687 \text{ m}^3\text{/year}}{21 \text{ m}^3\text{/hour}} = 33 \text{ hours/year}$$

The **power consumption** P_1 will be

$$P_1 = \sqrt{3} \times 400 \times 2.1 \times 0.87 \times 33 \times 10^{-3} = 42 \text{ kWh/year}$$

13.1.3.3. Pump sump volume
Pit diameter: 1.25 m.
Acceptable number of starts: 20 per hour.

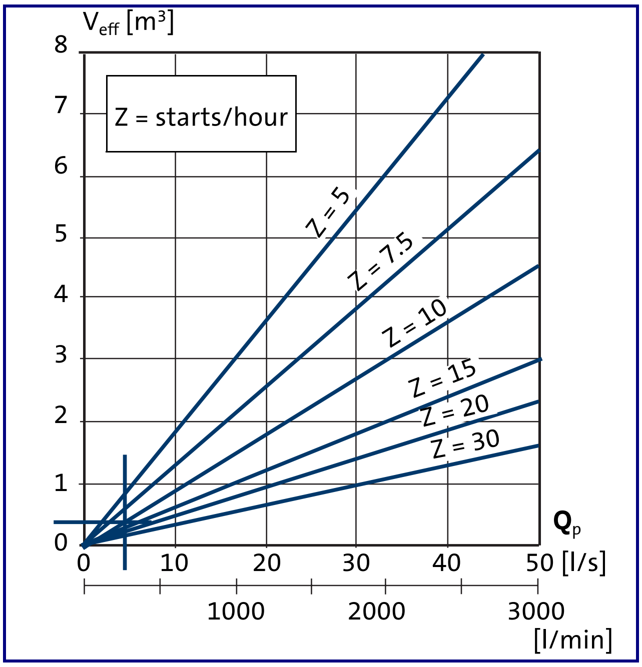


Fig. 88 Determination of effective sump volume based on number of starts and flow

AP 50.50.08.3 pumps in a 1.25 m pit at a flow of 5.3 l/s. Distance between stop and start position of float switch is

$$\frac{0.25 \text{ m}^3 \text{ (volume)}}{\pi/4 \times 1.25 \text{ m}^2} = 0.21 \text{ m}$$

13.1.3.4. Energy consumption
The energy consumption of AP 50.50.08.3 will be 42 kWh per year for a DN 80 discharge pipe at a flow velocity of 1 m/s. The selection of a pump which would have a lower energy consumption would be approx. 50% more expensive. The energy saving will never make up for the additional investment.

13.1.3.5. Selection of discharge point
As the wastewater is pumped directly into the gravitational pipe, no special precautions have to be taken.

13.1.3.6. Pump control and panel
An LC 108, DOL 2.9 A with three standard level switches, weights, brackets and necessary fittings should be offered.

13.2. Case No. 2: Lifting station for domestic sewage

The wastewater discharge from a flat in the basement of a building cannot run out into the wastewater pipe outside the house by means of gravitation. A pump system must therefore be installed.

The discharge from the pump can be connected to the vented gravitation pipe in the discharge installation from the ground floor.

The wastewater from the flat comes from

- 2 WCs
- 1 bathtub
- 2 showers
- 2 wash basins
- 2 kitchen sinks
- 2 floor drains
- 1 washing machine
- 1 dishwasher

13.2.1. Position and layout of pump system
The pump can be located in the building and a closed pump unit consisting of collecting tank, pump and level switch is required. This is a convenient solution as far as space, smell, etc. are concerned.

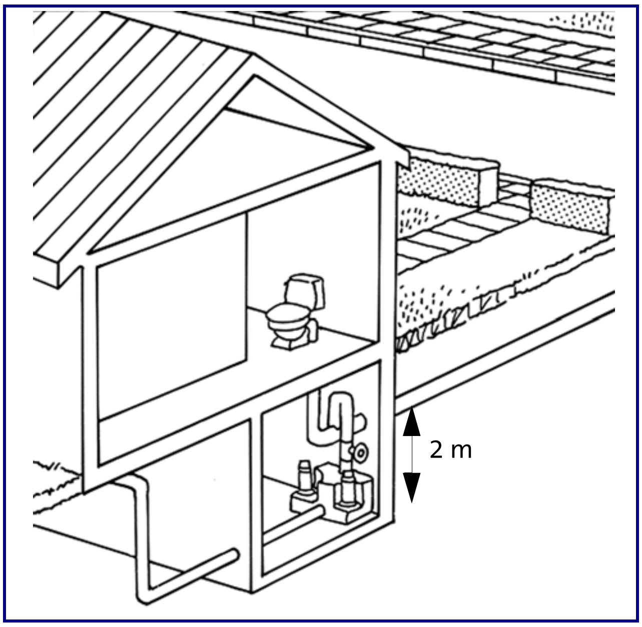


Fig. 89 Installation

13.2.2. Inflow

Installations	Assumed wastewater flow (l/s)
2 WCs	3.6
1 bathtub	0.9
2 showers	0.8
2 wash basins	0.6
2 kitchen sinks	1.2
2 floor drains (75 mm)	1.8
1 washing machine	0.6
1 dishwasher	0.6
Total	**10.1**

This flow is smaller than 12 l/s (see 12.1.1.1.). As the discharge comes from all rooms of the building, the rated wastewater flow can be estimated at 1.8 l/s, which is the maximum inflow to the pump.

13.2.3. Pump capacity, number of pumps and duty mode

For operating safety (small accumulation capacity), a pump unit consisting of 2 pumps is chosen, which gives 100% reserve.

Alternating duty mode is chosen and in such a way that both pumps can run in parallel at high water level in the accumulation tank.

13.2.4. Pump and pipe layout

A non-return valve is built into the pump unit. A slide valve is fitted immediately above the pump discharge (common for both pumps) followed by a vertical discharge pipe, which is connected to the top of the gravitational discharge installation below the ground floor level by means of two 90° bends and a T-piece.

For the discharge, a DN 80 mm steel pipe is chosen. This is an acceptable dimension when pumping discharge water from toilets. It is the same dimension as the standard discharge port of the Grundfos pump unit.

The difference between the level in the pump unit tank and the discharge installation which the discharge pipe is connected to is 2.0 m and the total length of the discharge pipe is 2.8 m.

13.2.5. Data for discharge pipe

DN 80 mm galvanized steel pipes with an internal diameter of 82.5 mm.

Roughness assumed to be 1.0 mm (see table page 18).

13.2.6. Geodetic head

2.0 m plus the pipe loop, 0.2 m (assumed), total 2.2 m.

13.2.7. Individual losses

As all pipes have the same dimension, no separate calculation of individual losses has to be made.

Loss type (see pages 72–73)	Resistance coefficient (ξ)
Slide valve	0.3
90° bend	0.5
90° bend	0.5
Outlet	1.0
Total	**2.3**

13.2.8. System characteristic

Geodetic head: 2.2 m.

Individual resistances (see page 70)	Loss (m)
Frictional loss in valve, bend and outlet. Resistance coefficient 2.3 x dynamic pressure, 0.006 =	0.014
Frictional loss in straight pipes: 2.8 x 0.003 =	0.008
Total	**0.022**

Constant C for calculating frictional loss characteristic:

$$C = \frac{H}{Q^2} = \frac{0.022}{1.8^2} = 0.007$$

Formula for calculating system characteristic:

H = geodetic head + C x Q^2

At Q = 1.8 l/s:	H = 2.2 + 0.007 x 1.8^2	= 2.22 m
At Q = 5 l/s:	H = 2.2 + 0.007 x 5^2	= 2.38 m
At Q = 10 l/s:	H = 2.2 + 0.007 x 10^2	= 2.90 m
At Q = 15 l/s:	H = 2.2 + 0.007 x 15^2	= 3.78 m

The four points are plotted on the APL pump data sheet (Fig. 90).

13.2.9. Pump selection

APL 81.12.3 will yield approx. 11 l/s in the pipe system in question which is more than peak inflow, which means that this pump is suitable.

13.2.10. Check self-cleansing

From Fig. 81 on page 70, it can be seen that a flow rate of 11 l/s in a 82.5 mm (DN 80) pipe gives a velocity of approx. 2.1 m/s, which is sufficient to guarantee self-cleansing.

13.2.11. Conclusion

A Grundfos pump unit APL 81.12.3 with DN 80 discharge pipe.

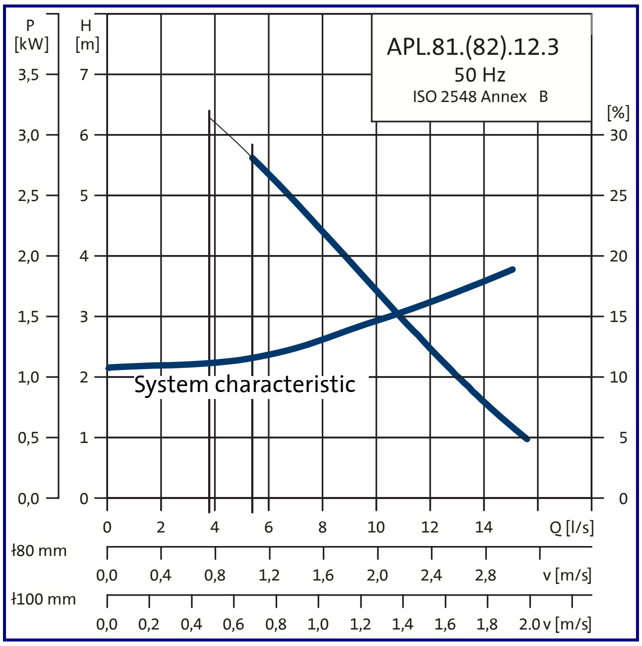


Fig. 90 APL pump characteristic

13.3. Case No. 3: Pumping station for municipal sewage

The sewage water from a town and the pumped sewage from a hospital is to be pumped to the gravity main.

A pump system must therefore be installed.

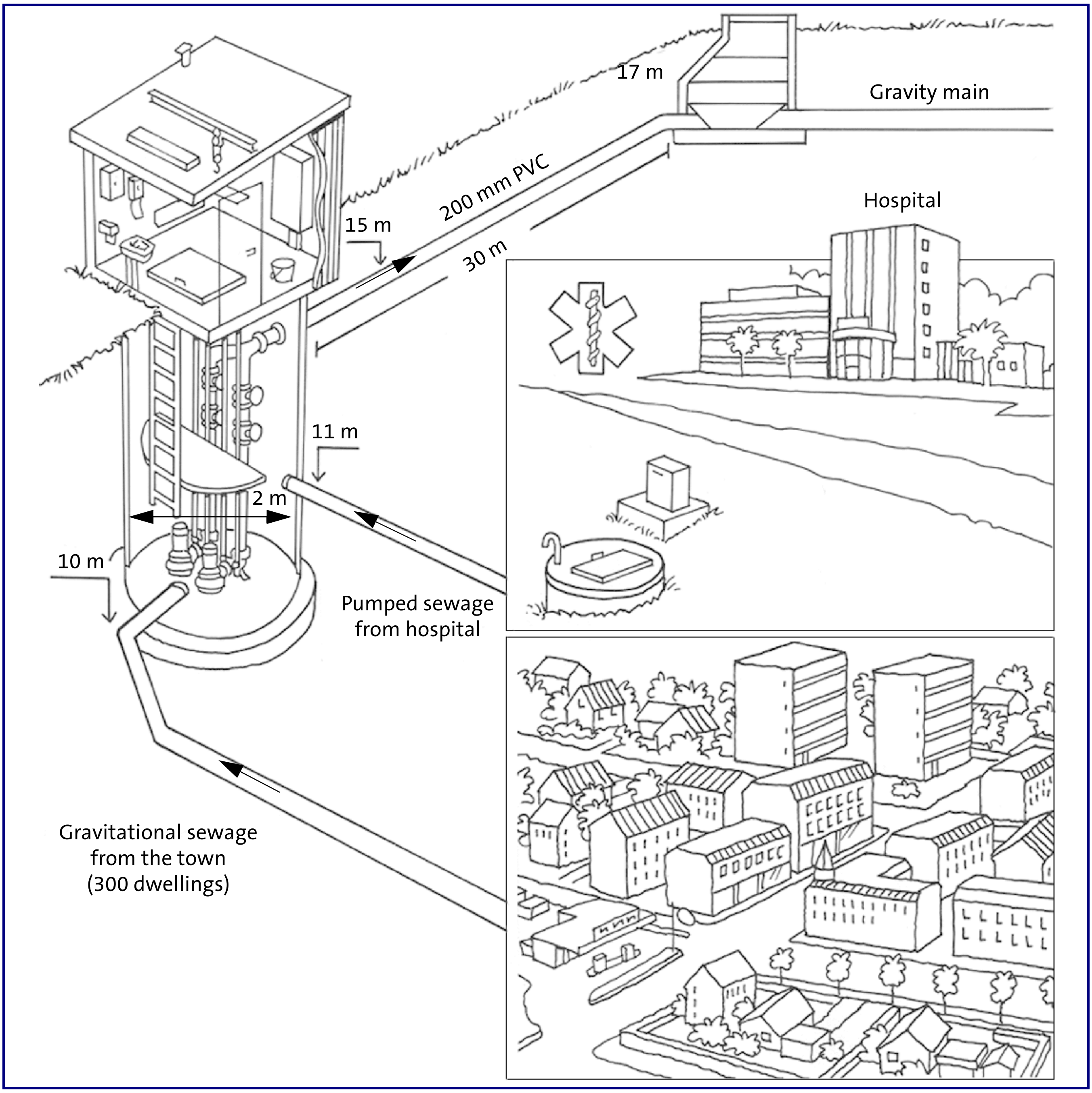


Fig. 91 Principal diagram of installation

13.3.1. General (see 1.)

The pump installation is located in a pit with a diameter of 2 m at the side of a service road.

The inflow is sewage from a pumping station at a hospital and gravitational sewage from a town with 300 dwellings, consisting of blocks of flats and single-family houses.

Dimensioning and selection of pumps (see 2.)

100% spare capacity with two alternating pumps is preferred. Safety margin over maximum inflow should be approx. 15% and the pipe dimension DN 200.

13.3.2. Inflow

Pump peak load, Qs,r, from the hospital is 25 l/s.

Gravitational sewage from dwellings. Rated sewage flow per dwelling is 1.8 l/s, which gives an assumed flow per dwelling of 12 l/s (see 12.1.1.1., page 67).

Sum of assumed wastewater and sewage flow:

Sqs,a = 300 x 12 l/s = 3,600 l/s.

Rated sewage and wastewater flow, Qs,r, from the town = 22 l/s (see Fig. 80 on page 68).

Required pump capacity, Qs,r = 25 + 22 l/s = 47 l/s = 170 m^3/h.

Safety margin 15%.

Total pump requirement: 47 l/s x 1.15 = 54 l/s equal to 195 m^3/h.

13.3.3. Pump selection (see 2.4)

The selected pump is to handle 100 mm solids.

13.3.4. Geodetic head

$$\text{Outlet} - \frac{\text{min. level + max. level}}{2} =$$

$$17 - \frac{10 + 11}{2} = 6.5 \text{ m (Fig. 91)}$$

13.3.5. Frictional loss in individual resistances

Individual resistances (pages 72–73)	ξ-values
1 elbow in coupling foot	0.5
1 widening 150/200 mm	1.0
1 non-return flap valve	1.0
1 slide valve	0.3
1 90° bend at manifold	0.5
1 Y-piece	0.6
1 outlet	1.0
Total	**4.9**

Dynamic pressure for DN 200 at 54 l/s is 0.2 m head (Fig. 81, page 70).

Frictional loss in individual resistances is 0.2 x 4.9 m = 0.98 m (Fig. 81).

Frictional loss in DN 200 vertical pipe at 54 l/s = 0.03 m/m (Fig. 81).

Frictional loss in PVC 200 horizontal pipe at 54 l/s = 0.015 m/m (Fig. 82, page 71).

13. Practical examples

One pump running, Q = 54 l/s	
	Head (m)
Geodetic head	6.5
DN 200, dynamic loss in individual resistances	0.98
DN 200, vertical pipe loss 5 x 0.03 (Fig. 81, page 70)	0.15
PVC 200, horizontal pipe loss 30 x 0.015 (Fig. 82, page 71)	0.45
Total	**8.08**

13.3.7. System characteristics

One pump running, Q = 54 l/s

Frictional loss: 0.98 + 0.15 + 0.45 = 1.58 m

Constant C for frictional loss:

$$\frac{H}{Q^2} = \frac{1.58}{54^2} = 0.00054$$

System characteristic

$H = 6.5 + 0.00054 \times Q^2$

At Q = 0 l/s:	$H = 6.5 + 0.00054 \times 0^2$	= 6.50 m
At Q = 10 l/s:	$H = 6.5 + 0.00054 \times 10^2$	= 6.55 m
At Q = 20 l/s:	$H = 6.5 + 0.00054 \times 20^2$	= 6.72 m
At Q = 30 l/s:	$H = 6.5 + 0.00054 \times 30^2$	= 6.98 m
At Q = 40 l/s:	$H = 6.5 + 0.00054 \times 40^2$	= 7.37 m
At Q = 50 l/s:	$H = 6.5 + 0.00054 \times 50^2$	= 7.86 m
At Q = 60 l/s:	$H = 6.5 + 0.00054 \times 60^2$	= 8.45 m
At Q = 70 l/s:	$H = 6.5 + 0.00054 \times 70^2$	= 9.16 m

The data are plotted on the AP 100.150.80, 50 Hz, data sheet (Fig. 92).

13.3.8. Performance curves

The curves apply to clean water at +20°C.

Tolerances of Q and H are +/- 10%.

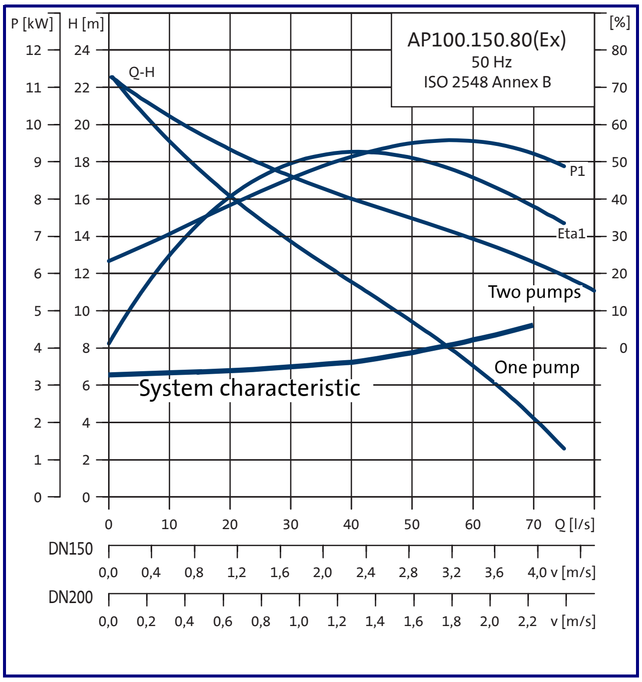


Fig. 92 Duty point for one or two pumps, respectively

Actual duty point with **one AP 100.150.80 in operation**:

Q = 54 l/s
H = 8.15 m
h = 48%
P1 = 9.5 kW

Actual duty point with **two AP 100.150.80 in operation**:

Q = 84 l/s ~ 42 l/s per pump
H = 10.3 m
h = 54%
P1 = 18.4 kW ~ 9.2 kW per pump

13.3.9. Check of self-cleansing

Velocity in vertical pipe at Q = 42 l/s is 1.34 m/s, which is more than the required velocity for self-cleansing of 1 m/s.

Velocity in horizontal pipe at Q = 54 l/s is 1.95 m/s, which is more than the required velocity for self-cleansing of 0.8 m/s.

13.3.10. Pump sump layout (see 7.)

When going for maximum 10 starts (n) and stops an hour per pump, the sump volume must be at least 2.43 m^3 as

$$V_h \geq \frac{Q\,(m^3/h)}{4 \times Z} = \frac{54 \times 3.6}{8 \times 10} = 2.43\ m^3$$

13.3.11. Position of level switches

Stop level: 0.20 m above pump inlet.
Start level of first pump:

$$\frac{V_h}{A} = \frac{V_h}{\pi/4 \times D^2} = \frac{2.43}{\pi/4 \times 2^2} = 0.77 \text{ m above stop level.}$$

Second pump starts 0.1 m above start level of first pump, i.e. 0.87 m above pump stop level.

Alarm 0.97 m above pump stop level.

Note: The starting level is always to be at least at the top of the motor housing to ensure efficient motor cooling.

13.3.12. Energy consumption

Energy consumption is typically calculated in KWh/m^3 or in KWh/1000 m^3. The energy consumption of the AP 100.150.80 for pumping 1000 m^3 will be as follows:

$$P = \frac{P1 \times 1000\ m^3}{3.6 \times Q\,(l/s)} = \frac{9.5 \times 1000}{3.6 \times 54} = 48.87\ kWh$$

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