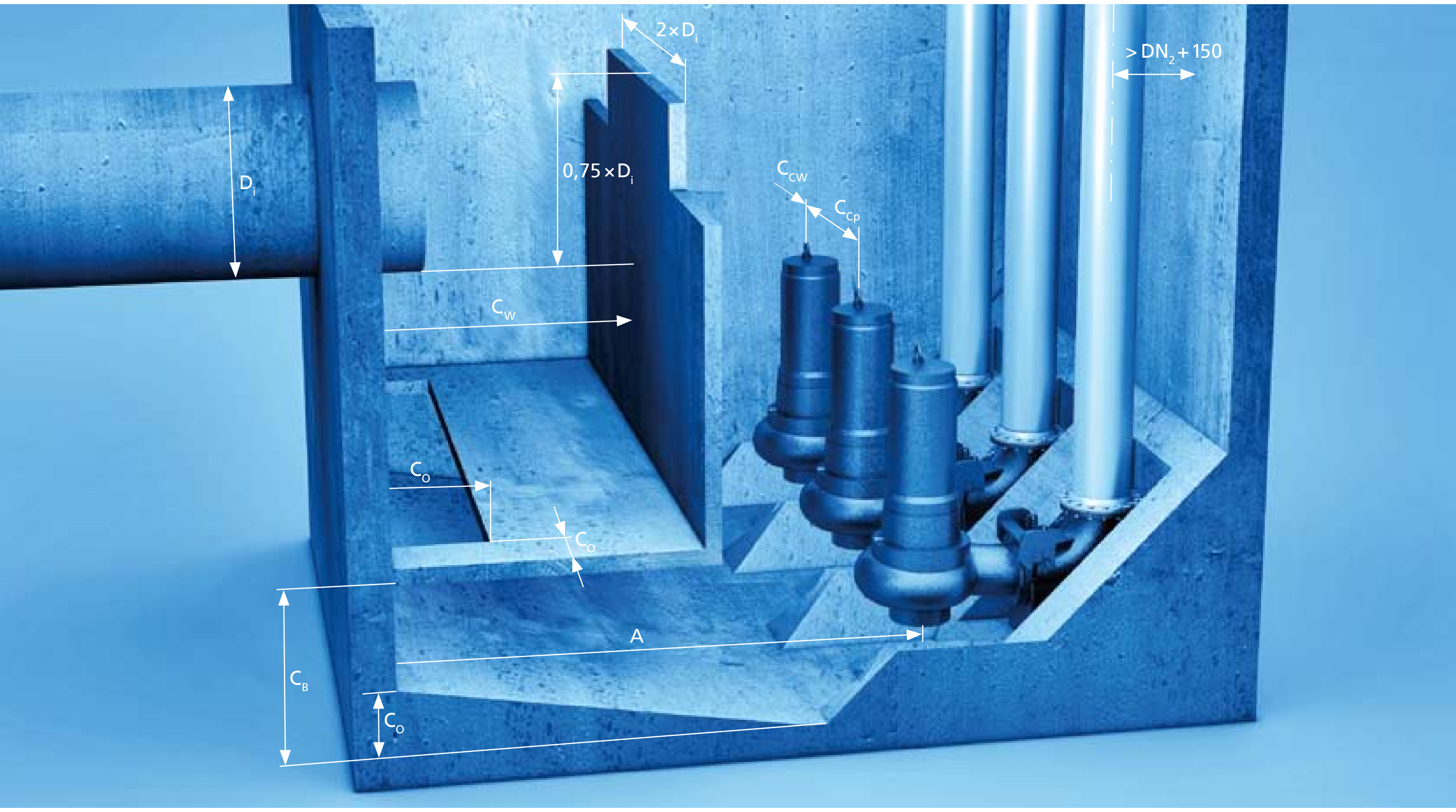
KSB Know-how, Volume 7

KRT Planning Information



Contents

Introduction

This know-how brochure has been created to assist consultants and operators in selecting the most suitable submersible motor pump from the Amarex KRT series.
It further contains detailed advice on dimensioning and operating these pump sets.

KSB designed these submersible motor pumps as a safe, reliable and energy-efficient solution for all centrifugal pump applications in municipal and industrial waste water applications. One of our aims was to provide maximum versatility by offering the pump in a multitude of materials, with a range of robust sensors and flexible installation options. Specially adapted hydraulic systems with wide free passages achieve optimum reliability and make for the optimum economic handling of diverse fluids. Explosion-proof versions are available for potentially explosive atmospheres. Protection against excessive temperature rise in the motor winding, absolutely water-tight cable entries, a special shaft seal and bearings dimensioned to give long service lives are features which provide for long and trouble-free pump operation.

1.
General Pump Selection

1.1
Planning parameters / design data

When planning or dimensioning a pump or a pumping station determining the flow rate and the corresponding head is of paramount importance. Regarding the head, unequivocal assumptions can be made about the losses to be expected. The flow rate is influenced by a number of additional factors which are explained in the following sections.

Pump flow rate

The pump flow rate (also referred to as capacity Q, measured in [l/s] or [m³/h], for example) is the useful volume of fluid delivered by a pump to its discharge nozzle in a unit of time. The useful volume does not comprise any internal flows such as leakages or barrier fluids. The required / actual flow rate needs to be determined as accurately as possible in order to correctly dimension the pump(s) as well as the pumping station. The daily inflow of a waste water pumping station is significantly influenced by the following factors:

- The type of drainage system (combined or separate sewer lines for waste water and storm water)
- Size and structure of the area covered by the treatment plant
- The number of buildings (and inhabitants) connected to the waste water system
- The number and type of industrial and commercial areas connected to the waste water system (expressed in equivalent population

The inflow can be illustrated in a load curve which shows the flow rate of the determined / typical waste water inflow over a day. Significant differences might become apparent not only in the 24-hour load curve, but also when comparing the total inflow of workdays with that of public holidays or weekend days. In the event of precipitation, the inflow is expected to rise.

Enlarged view in the appendix

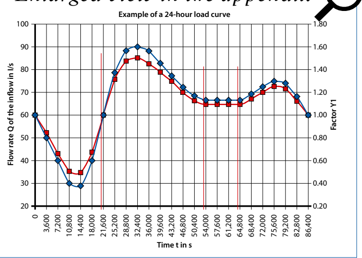


Fig. 1: Example of an inflow load curve for mathematical modelling

This factor is of particular importance in combined sewer systems (which serve to transport both waste water and storm water to the treatment plant).

The load curve forms an important basis for selecting the type and number of pumps, assigning pumps to different operating ranges / conditions, deciding on the pump drives (e.g. fixed or variable speed) and, last but not least, determining the required operating points of the individual pump sets.

Given the large fluctuations of waste water inflow Q shown in the 24-hour load curve, the factor ’time’ needs to be taken into account. The example of the 24-hour load curve in Fig. 1 is expressed as a mathematical function (1). Discrete calculations can be made for 20-second intervals. The calculation is based on the assumption that the load curve is continuously cyclical from commissioning through to decommissioning. The variable factor Y1 describes the varying magnitude of the load curve. The 24-hour load curve reaches its maximum at variable Y1 multiplied by 1.5. The population equivalent is defined in EN 752-6. In Germany, for example, the maximum inflow of 4 l/s is equivalent to a population of 1,000.

$$Q_{in}(t) = Y1 + \frac{1}{2} \cdot Y1 \cdot \sin\left(\frac{\pi}{21600} \cdot (t-21600)\right) \qquad \text{if } 0 \le t \le 54000 \text{ oder } t \ge 64800$$

$$Q_{in}(t) = 1.1 \cdot Y1 \qquad \text{if } 54000 < t < 64800 \tag{1}$$

To determine the nominal flow rate (Q_R = flow rate specified in the pump order for a rated speed n_R, rated head H_R and specified fluid) it can be advantageous for the calculation to be continued on the basis of volumes. Formula (1) for the inflow rate is now used to calculate the inflow volume V_{in} for a specified time interval. Hence:

$$V_{in}(t) = \frac{\left(Y1 + \frac{1}{2} \cdot Y1 \cdot \sin\left(\frac{\pi}{21600} \cdot (t-21600)\right)\right)}{3600} \cdot dt \qquad \text{if } 0 \le t \le 54000 \text{ v } t \ge 64800$$

$$V_{in}(t) = \frac{1.1 \cdot Y1}{3600} \cdot dt \qquad \text{if } 54000 < t < 64800 \tag{2}$$

If the inflow volume V_{in}, the pump volume V_p transported in the specified interval and the sump geometry are given, the new fluid level can be calculated by adding to the previous fluid level the volume difference divided by the cross-section of the sump:

$$\text{Level} = \text{Level}_{old} + \frac{(V_{in} - V_p)}{\frac{1}{4} \cdot \pi \cdot d^2_{sump}} \tag{3}$$

The specified limits of minimum submergence and maximum permissible fluid level must be observed for all pump volumes V_p. The pump volume V_p [1.5] can be calculated as follows:

$$V_p = \frac{Q}{3600} \cdot dt \quad [1.6] \tag{4}$$

1.2
Developed head

The developed head H of a pump (e.g. expressed in [m]) is defined as the useful mechanical energy transferred to the flow per weight of the fluid handled, taking into account the local gravitational constant.

The density ρ of the fluid handled ($\rho = m / V$ [kg/m³], ratio of mass m to a specified volume V of the fluid) does not have any impact on the developed head of a centrifugal pump. It will, however, influence the pump input power.

The kinematic viscosity υ of the fluid handled ($\upsilon = \eta / \rho$ [m²/s] or [cSt], expressing the ratio of dynamic viscosity or factor of proportionality η for shear stress and change of velocity to the density ρ of the fluid handled) only influences the developed head, flow rate and pump input power if it exceeds a specific value. Fluids with a kinematic viscosity equal to or greater than 40 m²/s will affect the pump's operating data. Such fluids are also referred to as viscous.
In waste water engineering, viscous fluids are only found in the sludge treatment processes of sewage treatment plants.

To determine the total head H of a pump station or a pump, the following information needs to be known:

- The height AOD (Above Ordnance Datum) of the invert of the inlet channel or pump sump floor
- The cut-in and cut-out points of the pumps (which equal the minimum submergence and the maximum permissible fluid level in the pump sump)
- The terrain (distance and heights) between the pumping station and the pumping destination
- The valves, fittings and pipes installed, including their nominal diameters DN and their resistance coefficients ζ
- The height AOD of the discharge point.

The basic correlation between the pressure and flow velocity of a fluid in a pipe is described in Bernoullis' equation.

$$\frac{1}{2} \cdot \rho \cdot v^2 + p = \text{const} \qquad (5)$$

Expressed in words the Bernoulli principle states:

"The total pressure of the fluid flowing through a frictionless pipe is the sum of static and dynamic pressure and is constant at all points." [1.8].

This principle applies to the steady, frictionless flow of incompressible fluids. In real life, however, we are dealing with transient flows of incompressible fluids which are affected by friction.
For this reason, Bernoulli's equation must be expanded to include friction and change in velocity. Pressure is generally expressed as developed head H in "metres of fluid".

For submersible motor pumps only the height differences, also referred to as geodetic head H_{GEO}, and the sum of all losses Σ H L have to be considered. The total developed head H can be described using the simplified equation (6) [1.9]:

$$H = H_{GEO} + \Sigma H_{L} \quad (6)$$

Legend:

H_{GEO} Geodetic head, measurable height difference between the fluid level (height above MSL) on the inlet side and on the discharge side

H_{L} Total head loss, equals the manometric head H_{man}

H_{LI} Head losses of valves, fittings and pipes on the inlet side of the pump — not applicable for wet-installed pumps such as KRT and Amacan

H_{LIND} Head losses of valves, fittings and pipes on the discharge side of the pump — for multiple pump systems the losses of individual lines up to the common discharge main

H_{LD} Head losses of valves, fittings and pipes on the discharge side of the pump in the common discharge main

The head loss H_{L} for straight pipes is calculated to [1.10]:

using the equation $\Sigma H_{L} = H_{LI} + H_{LIND} + H_{LD}$

$$H_{L} = \lambda \cdot \frac{L}{d} \cdot \frac{v^2}{2 \cdot g} \quad (7)$$

For valves and fittings the head loss H_{L} is calculated to [1.11]:

$$H_{L} = \zeta \cdot \frac{v^2}{2 \cdot g} \quad (8)$$

Please note:
KSB supplies Piping Calculator software together with its selection program. The Piping Calculator serves to calculate the required heads. Any combination of valves, fittings and pipes can be entered (with nominal diameters and loss coefficients) to calculate the rated head of the planned pumping station [1.12].
Reference literature: KSB publication: Selecting Centrifugal Pumps [1.10]

1.3
NPSH value

The NPSH value (Net Positive Suction Head) is significant in assessing the suction characteristics of a centrifugal pump: It describes the minimum inlet pressure required by each centrifugal pump for reliable and cavitation-free operation [1.13]. We need to distinguish between the permissible cavitation, which causes the developed head of the pump to drop by 3 percent (also referred to as $NPSH_r$ = required) and the NPSH value of the system (also referred to as $NPSH_a$ = available).

Cavitation-free pump operation generally requires the following condition to be met:

$$NPSH_a \geqq NPSH_r \text{ , } NPSH_r = NPSH_{3\%} + \text{safety allowance} \qquad (9)$$

The safety allowance is defined in accordance with ATV (German Association for Water, Waste Water and Waste) and HI (Hydraulic Institute) as 30 % of $NPSH_{3\%}$ of the pump. $NPSH_a$ can be calculated using equation (10a).

$$NPSH_a = z_e + \frac{pe + p_b - pD}{\rho \cdot g} + \frac{v_e^2}{2 \cdot g} - HI \qquad (10a)$$

This equation can be simplified for an open system installed at altitudes up to 1000 m AOD and a fluid temperature of 20 °C:

$$NPSH_a = z_e + 10 \text{ m} \qquad (10b)$$

To be able to document the $NPSH_{3\%}$ value of a pump in the sales literature, pump manufacturers conduct a test run in a test field using a special dry pump installation. In a wet installation this NPSH the value is practically impossible to measure. As the $NPSH_{3\%}$ value changes in relation to the flow rate it is entered as a function of the flow rate $NPSH_r = f(Q)$. This value describes the pressure head in metres required above the vapour pressure of the fluid at the impeller inlet (reference point for NPSH = intersection of pump shaft axis and the perpendicular plane through the extremities of the vane leading edge, sometimes referred to as the impeller eye, see Fig. 1.3).

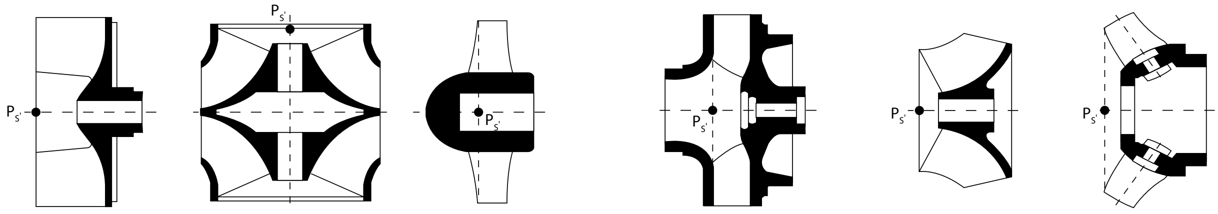


Fig. 1.3: "Position of the reference point Ps' for various impeller types" (Source: KSB publication Selecting Centrifugal Pumps)

The $NPSH_{3\%}$ value can be influenced by the pump manufacturer defining the impeller type and design (impeller eye diameter, number of vanes and design of the vane leading edge) as well as the rated speed of the pump.

The most critical area is the inlet of the vane passage at the impeller, which is the narrowest passage to be passed by the fluid downstream of the suction line for dry-installed pumps and downstream of the pump inlet for wet-installed pumps. The flow around the vane leading edges leads to an unavoidable local pressure reduction in this area. If the pressure falls below the vapour pressure, vapour bubbles develop.

These bubbles are transported along with the flow and implode suddenly when the pressure in the vane passage rises again (see damage shown in Fig. 1.5). The formation and sudden implosion of vapour bubbles is called cavitation.

Enlarged view in the appendix

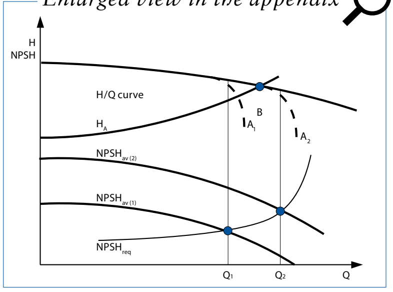


Fig. 1.4: Impact of $NPSH_a$ on the constant speed curve of the pump (Reference: KSB Centrifugal Pump Lexicon)

Cavitation can lead to severe negative conditions, from a drop in developed head and efficiency through to flow separation, rough running, vibrations and loud noise emissions to pitting due to erosion on the impeller or internal pump parts. Cavitation is therefore only acceptable within permissible limits. The permissible cavitation for each individual case also depends on the operating conditions, the period of time the pump is operated outside the permissible range, the fluid handled and, particularly, the materials of the wetted parts (especially the impeller).

Fig.1.4 illustrates the points at which the permissible cavitation is exceeded.

Fig. 1.5: Impeller showing cavitation damage (Source: KSB Centrifugal Pump Lexicon)

At the intersection of $NPSH_a$ and $NPSH_r$ the condition of equation (9) is not fulfilled; to the right of the intersection the flow rate of the fluid no longer rises and the head drops rapidly. This type of curve is referred to as a “head breakdown curve”. Prolonged operation in this condition will damage the pump components (impeller, bearings, shaft seal, etc). To re-adjust operation to operating point B, $NPSH_a$ can be increased (e.g. by increasing the fluid level in the inlet tank).

1.4
Input power

The input power P_2 of a centrifugal pump is the mechanical power delivered by the drive to the pump shaft or coupling.
It can be calculated using equation (11) [1.15]:

$$P_2 = \frac{Q \cdot H \cdot g \cdot \rho}{1000 \cdot \eta_p} \text{ [kW]} \quad (11)$$

η_p efficiency of pump or coupling

The dry solids content TS and any other substances in the fluid handled increase the power requirements at the pump shaft. (The motor must be sized with sufficient power reserve) [1.7]. The input power P_2 must not be confused with the power available at the drive (referred to as drive rating or rated motor power P_R). The rated motor power is indicated by the motor manufacturer on the rating plate.

On submersible motor pumps only the power P_1 consumed by the motor can be measured. This value includes the internal motor losses indicated by the motor efficiency η_M. In this case the pump input power can be calculated from equation (12).

$$P_1 = \frac{P_2}{\eta_M} \text{ [kW]} \quad (12)$$

η_M motor efficiency
When specifying the drive rating for a pump, power reserves to EN ISO 9908 must be added. The reserves will generally compensate for any constructional tolerances and fluctuations in the fluid properties of waste water.
For further details and information on motors in general, refer to the section ’General Description of the Motor’.

1.5
Pumping task

It is very common to name pumps after their purpose of use. The designations are often self-explanatory, relating to the role within the system (e.g. main/booster/base load/peak load pump), the application (e.g. irrigation or drainage pump, circulator, chemical, process, rainfall or dry weather pump) or the fluid handled (e.g. drinking water, seawater, water, waste water, faeces, liquid manure, sludge or solids-handling pump).

Waste water engineering almost exclusively uses centrifugal pumps and positive displacement pumps. Positive displacement pumps are mainly employed in sludge processing (e.g. in digesters where fluids with large dry solids content (> 10 %) need to be transported). Centrifugal pumps cover almost any task in waste water transport and sewage treatment plants.

Centrifugal pumps are characterised by their design features, especially their impeller type, direction of flow and type of installation. An important parameter describing the behaviour of different impellers is the specific speed nq (also referred to as type number K, or N in the USA).

This number, which is based on the affinity laws, can be used to compare impellers of different sizes in combination with various operating data (Q and H at best efficiency point and impeller speed) to determine an optimum impeller type and map its characteristic curves. The specific speed is calculated as follows:

$$n_q = n \cdot \frac{\sqrt{Q_{opt}}}{H_{opt}^{3/4}} \quad [\mathrm{rpm}] \qquad (13)$$

Fig. 1.6 and 1.7 show the correlation between the specific speed and the impeller type as well as the corresponding characteristic curves.

The specific speed of impellers used in waste water applications lies within the range of $n_q \sim 45$ to 200 rpm. Impellers with nq ~ 45 to 90 rpm are mainly used for transporting waste water in and to effluent treatment plants (e.g. main and intermediate pumping stations, effluent plant inlet, return sludge, through to effluent plant discharge).
The entire range is covered by submersible motor pumps of the KRT series, equipped with various impellers.

The activation processes of an effluent treatment plant generally favour large flow rates and low heads (requiring propellers of $n_q \sim 160$ to 200 rpm). Propeller pumps are also used for extracting water from rivers, for transporting cooling water and for flood control, for example. Circulating water for leisure park rides is another task performed by propeller pumps.

Please note:
A separate publication focuses on the selection of propeller pumps and planning of the corresponding intake structures (KSB Know-how, volume 6, 0118.55 10/07: Planning Information Amacan Submersible Pumps in Discharge Tubes).

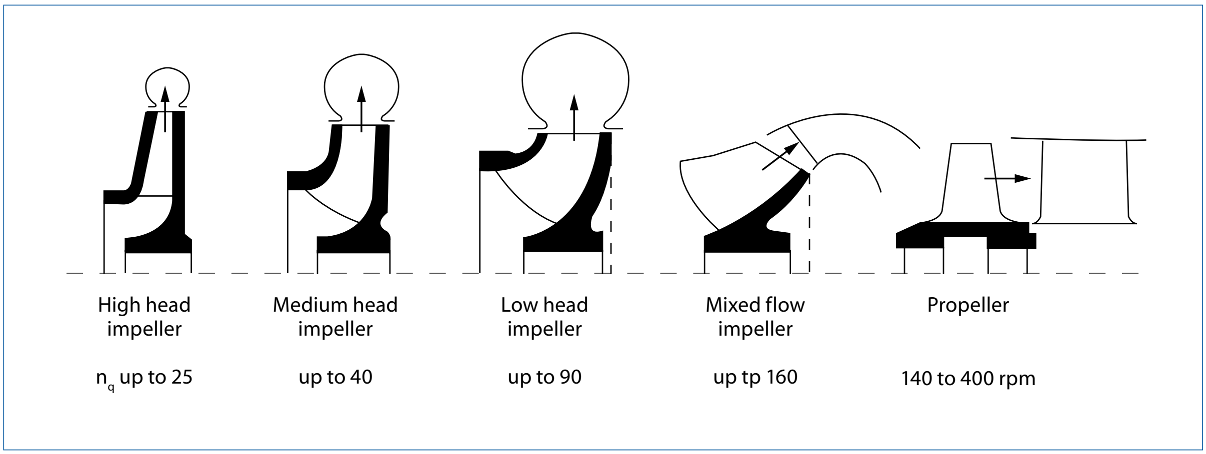


Fig. 1.6: Impellers and their specific speed nq (rpm) Source: KSB Centrifugal Pump Lexicon

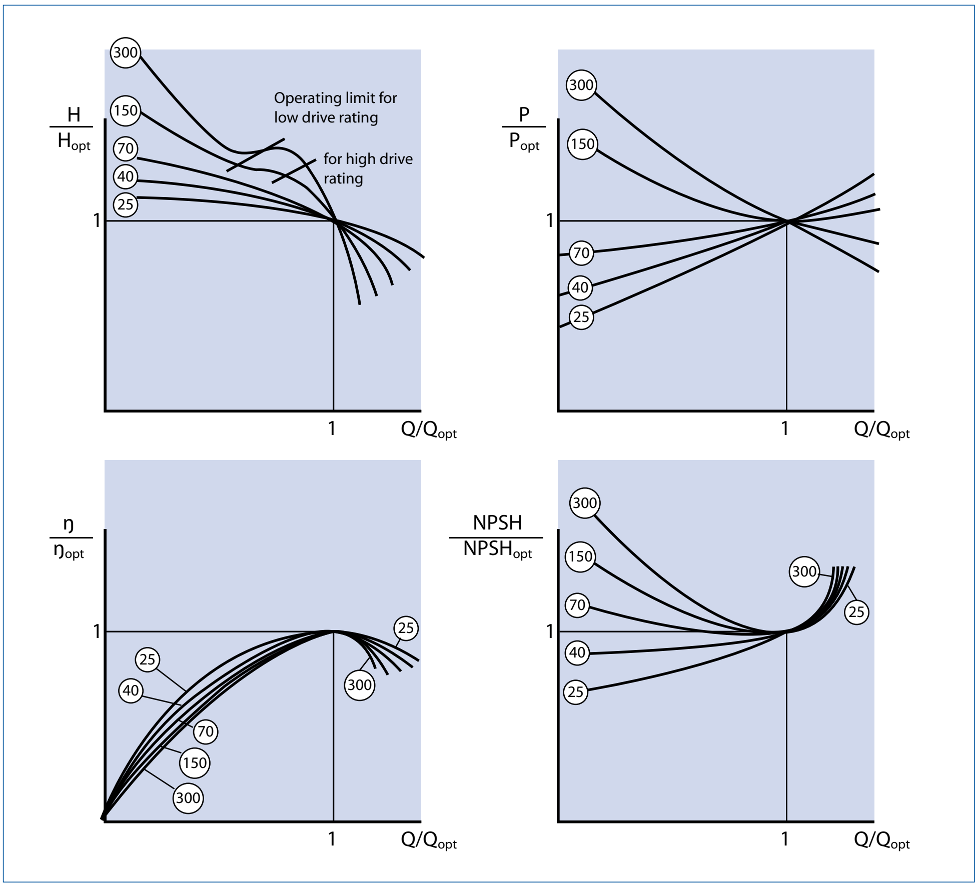


Fig. 1.7: Characteristic curves of centrifugal pumps at various specific speeds. Presented in proportion, based on the best efficiency point (Source: KSB publication: Selecting Centrifugal Pumps)

1.6
Pump selection

Pump selection is primarily determined by the specification of operating conditions – in other words, the operating properties the pumps will be supplied for. The operating conditions primarily comprise data on the fluid handled (e.g. temperature, density, viscosity, dry substance content, sand content or other substances in the fluid), the expected flow rate and the required head, the suction behaviour and the speed of the centrifugal pump. Also required is information on the drive size and rating, the operating mode, the expected frequency of starts as well as any factors determined by the system or environmental regulations such as the maximum permissible noise emission, permissible vibrations, pipeline forces and potential explosion hazards (indication of ATEX zones).

Submersible motor pumps of the KRT series and their waste water specific impeller types (cutter, free flow impeller, one/two/three channel impeller and open single-vane impeller) are specially designed for the particular requirements of waste water transport such as the operating conditions and fluid composition.

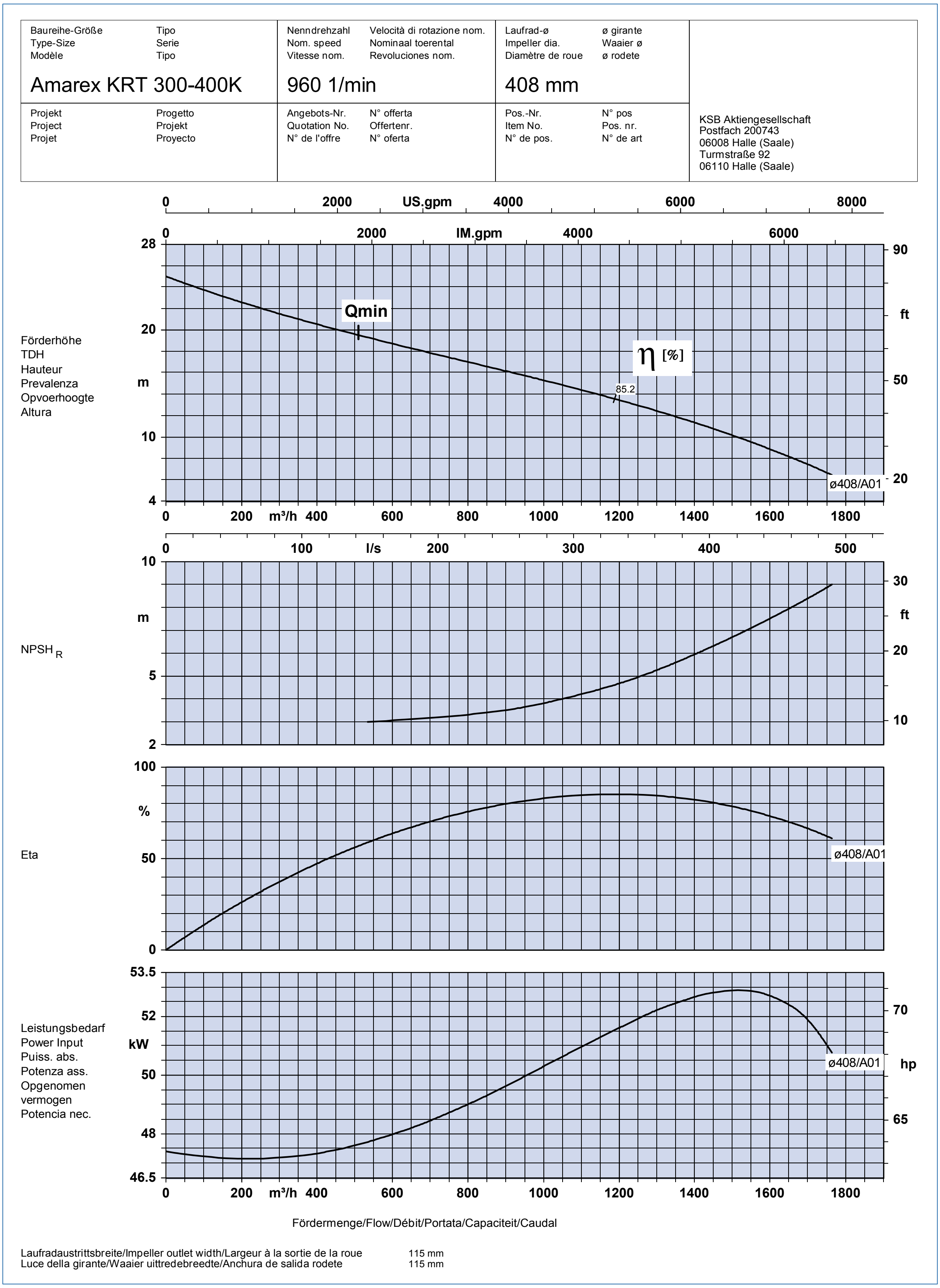
For detailed information on matching impellers to a variety of fluids and on the impellers' application limits refer to the section 'Configuration and Installation'.

1.6.1
Characteristic curves

When centrifugal pumps are operated at constant speed, their flow rate Q increases as their head H decreases. In the characteristic head versus flow curve, also referred to as H/Q curve, the head H is plotted against the flow rate Q. Apart from the H/Q curve, a pump is characterised by its efficiency curve, its $NPSH_r$ or $NPSH_{3\%}$ curve and its input power curve, all as a function of the flow rate. When selecting a pump all of these characteristic curves must be considered.

This is illustrated with an example in Fig. 1.8 showing the characteristic curves for a pump with a three-channel impeller with a specific speed nq ~ 80 rpm (low head impeller).

All hydraulic data has been determined to the applicable EN ISO 9906 standard, assuming that clean water is handled. The characteristic curves depend on the specific speed (also see Fig. 1.6). We distinguish between flat and steep curves. For a given change of developed head the flow rate changes much less in a steep curve than in a flat curve. Pumps with steep head versus flow curves are advantageous for flow rate control.



Baureihe-Größe Type-Size Modèle	Tipo Serie Tipo	Nenndrehzahl Nom. speed Vitesse nom.	Velocità di rotazione nom. Nominaal toerental Revoluciones nom.	Laufrad-ø Impeller dia. Diamètre de roue	ø girante Waaier ø ø rodete	
Amarex KRT 300-400K		960 1/min		408 mm		
Projekt Project Projet	Progetto Projekt Proyecto	Angebots-Nr. Quotation No. N° de l'offre	N° offerta Offertenr. N° oferta	Pos.-Nr. Item No. N° de pos.	N° pos Pos. nr. N° de art	KSB Aktiengesellschaft Postfach 200743 06008 Halle (Saale) Turmstraße 92 06110 Halle (Saale)

Laufradaustrittsbreite/Impeller outlet width/Largeur à la sortie de la roue 115 mm
Luce della girante/Waaier uittredebreedte/Anchura de salida rodete 115 mm

Fig. 1.8: Characteristic curves for a three-channel impeller nq ~ 80 rpm at a pump speed of n = 960 rpm (Source: KSB selection program)

1.6.2
Pump characteristic curve

Generally, the curve referred to as the pump characteristic curve is the characteristic head versus flow curve (H/Q curve). As no pump can be operated without losses the internal hydraulic losses of the pump must be subtracted from the theoretical, loss-free head versus flow curve used for selection. The internal hydraulic losses are composed of friction and shock losses. Both loss values can be defined as a function of the flow rate.

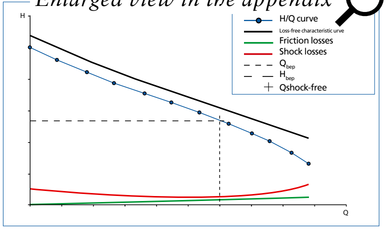
While friction losses rise continuously with increasing flow rates, shock losses rise with both decreasing and increasing flow rates, i.e. when the pump does not run at its rated flow rate or capacity (also referred to as Qshock-free). Fig. 1.9 shows a proportional representation of hydraulic losses.

From zero flow to Q η opt (~ Qshock-free), the efficiency curve (Q/η curve) rises to a maximum value and then drops again. The efficiency curve reflects the internal pump losses and demonstrates the flow rate range in which the pump should be operated for optimum energy efficiency. The curve has been plotted in Fig. 1.10.

Fig. 1.11 and Fig. 1.12 show the curves of $NPSH_{3\%}$ and the pump input power P2. The $NPSH_{3\%}$ curve presents the suction characteristics of the pump (also see the section 'NPSH value'). The pump input power curve is used to determine the required motor rating.

1.6.3
System characteristic curve

The system characteristic curve is also plotted as a function of the flow rate. As shown in Fig. 1.13 the system characteristic curve is composed of a constant static component and a dynamic component which is quadratically proportional to the flow rate (note: this only applies if the dependence of the pipe friction on the Reynolds number is not taken into account).



Enlarged view in the appendix

Fig. 1.9: Characteristic head versus flow curve and its reduction by internal hydraulic losses. Proportional representation based on the best efficiency point.

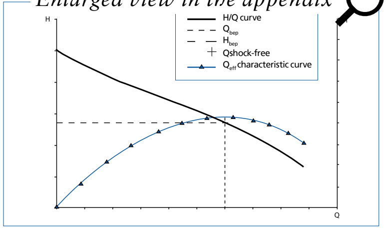


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Fig. 1.10: Efficiency curve η =f (Q). Proportional representation based on the best efficiency point.

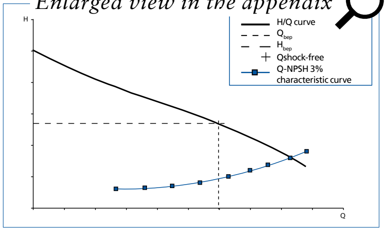

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Fig. 1.11: $NPSH_{3\%}$ characteristic curve, $NPSH_{3\%} = f(Q)$. Proportional representation based on the best efficiency point.

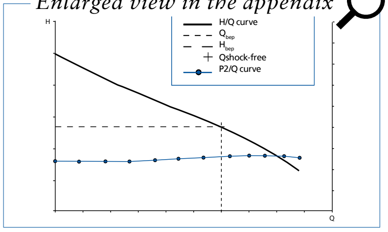

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Fig. 1.12: Electrical pump input power $P_2 = f(Q)$. Proportional representation based on the best efficiency point.

For wet-installed submersible motor pumps the geodetic head component Hgeo equals the measurable height difference between the fluid level on the suction side and on the discharge side. The dynamic head component is composed of the total head losses of any planned or installed valves, fittings and pipes between the discharge side of the pump and the actual discharge point at the fluid level of the discharge-side water body. The section 'Developed head' contains detailed information on this topic.

Enlarged view in the appendix

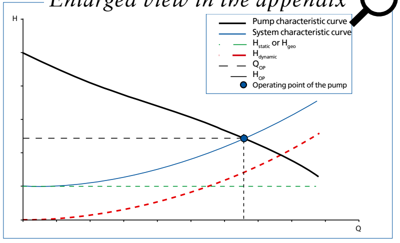

Fig. 1.13: System characteristic curve – Sum of static and dynamic head components

1.7
Permissible pump operating limits

Every centrifugal pump comes with recommended application or operating limits. They denote the maximum and minimum points at which the pump can be used for design, system and drive reasons. Operation within these limits is preliminary for the pump to be able to fulfil its pumping task for the entire duration of its planned service life. The key application and operating limits are discussed in the following sections.

1.7.1
Operating point

The operating point or duty point of a pump system is defined by the intersection (Fig. 1.13) of the system characteristic curve and pump characteristic curve (the characteristic head versus flow curve of the pump shall hereinafter be referred to as pump characteristic curve, the commonly used short form). This point defines the resulting head and the corresponding flow rate. If the operating point needs to be changed, either the system characteristic curve or the pump characteristic curve have to be changed. For further details refer to the section 'Pump operating mode'.

1.7.2
Operating limits Q_{min} and Q_{max}

The (hydraulic, mechanical and acoustic) operating characteristics of a centrifugal pump are mainly defined by the position of the operating point with respect to the point $Q_{\eta\ opt}$.
A pump should be selected with its operating point near the best efficiency point (Q_{OP} approximately 0.8 to 1.2 x $Q_{\eta\ opt}$), if possible. Operation within this range will not only keep down the energy and maintenance costs but also the hydraulic excitation forces. In daily practice, however, certain processes may require the pump set to be run in off-design conditions. The further the operating point from the best efficiency point the less favourable the approach flow at the impeller vanes and the diffuser (casing). If the relative flow can not keep up with the vane profile on the suction side (low flow) or on the discharge side (overload), areas of flow separation will develop, which will increasingly interfere with the energy transfer to the fluid. The hydraulic forces (radial and axial forces) will increase, and so will mechanical vibration, noise and also cavitation, leading to visible/audible effects. Pump manufacturers define the permissible range for continuous operation of their pumps by specifying the limits Q_{min} and Q_{max} (if no limits are given, the end of the illustrated pump characteristic curve is considered Q_{max}).

Usually, the permissible operating range indicated lies between approximately 0.3 and 1.4 x $Q_{\eta\ opt}$.

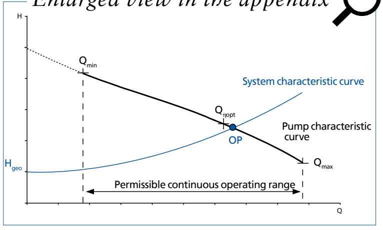

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*Fig. 1.14: Operating limits Q_{min} and Q_{max}– Illustration of the permissible range for continuous operation of a centrifugal pump (Q_{min} approx. 0.3 * Q_{BEP} and Q_{max} approx. 1.4 * Q_{BEP})*

For centrifugal pumps with high specific speeds of approximately nq = 140 rpm or higher, the Q_{min} limit can be significantly higher at approximately 0.6 to 0.7 x $Q_{\eta\ opt}$.

When operating pump sets outside of the permissible operating range, excessive loads and early wear of pump components must be expected. Such conditions will void the manufacturer's warranty.

1.7.3
Special aspects of waste water transport

A centrifugal pump can only be as good as the waste water treatment plant it is integrated in. The pump can only be operated reliably if the peripheral systems of the plant, the fluid to be handled (properties and composition), the control system and the operating mode match the characteristics of the centrifugal pump and its hydraulic system. In this context please beware of the popular euphemism "non-clogging hydraulic system" — It is only a matter of 'load' before every hydraulic system becomes clogged. It would be more accurate to speak of a "low-clogging hydraulic system".

Drawing on our experts' practical experience we have compiled some special aspects of waste water transport. These should be taken into account when planning a waste water treatment plant to make sure it has a high operating reliability ("low-clogging operation").

- Operating point near best efficiency point. The Q_{OP} ~ 0.8 to 1.2 x $Q_{\eta\ opt}$ range is not only the most favourable operating range from an energy point of view, but also the range in which the substances contained in the fluid are transported at higher velocities. The range is marked in Fig. 1.15. Especially under low flow conditions between Q_{min} and 0.8 x $Q_{\eta\ opt}$, the transport of substances in the fluid is more or less restricted due to the low flow rates (low flow velocity). Continuous operation of the pumps in this range can lead to clogging of the impeller channel or to hardened deposits in the clearance between impeller and casing. This characteristic of centrifugal pumps is significant when defining the control and operating range and adjusting the operating point accordingly. Keywords in this context: speed control, change of geodetic head between cut-in and cut-out fluid level in the pump sump, and parallel operation.

Enlarged view in the appendix

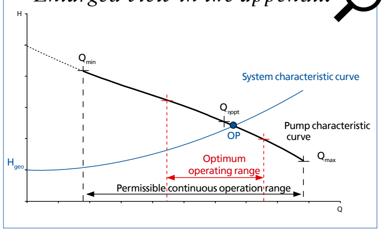

Fig. 1.15: Preferable or optimum operating range for waste water transport

- Make sure the motor has sufficient power reserve. All hydraulic pump data supplied by the manufacturer have been determined with reference to the applicable EN ISO 9906 standard, assuming that clean water is handled. It is impossible for a consultant to predict precisely the actual waste water properties; the trend is towards ever increasing solids and fibre contents in waste water. Operating reliability should be given priority over investment costs (see recommended reserves in ISO 9908).

- Select a suitable impeller. Submersible motor pumps of the KRT series and their waste water specific impeller types (cutter, free flow impeller, one / two / three channel impeller and open single- vane impeller) are specially designed for the particular requirements of waste water transport such as the specific conditions and fluid compositions. For detailed notes refer to the section 'Configuration and Installation'.

- Flow velocities in the pipes and the control regime for operation with frequency inverter. These days, pumps are increasingly controlled via frequency inverters (FI). This makes them more energy-efficient and enables continuous waste water treatment processes. The control ranges are generally independent of the design or engineering characteristics of the pump and drives; they always need to be determined individually with consideration given to the minimum flow velocity for handling solids and fibres. Experience in this field has shown that the flow velocity of waste water should not be below 2 m/s in vertical discharge lines; a minimum of 1 m/s is usually sufficient for horizontal lines. At low pump speeds it must be ensured that any substances in the fluid are transported out of the pump and discharge line. The circumferential speed at the outer diameter D2 of impellers used for waste water applications should not be below 15 m/s.
The start ramps of centrifugal pumps should generally be as short as possible to allow the pumps to quickly reach their highest possible speed.
The speed is then reduced to meet the operating point.
The frequency inverter should not be allowed to operate the pump at the natural frequency of the system (foundation/ pump/piping) and must not occur in continuous operation. In parallel operation all pumps should be operated at the same frequency, if possible, to prevent the flow rate of individual pump sets from decreasing until the pump is operated under impermissible low flow conditions. The swing check valves must open completely at every operating point of the pump to minimise the surface which can be attacked by substances in the fluid and to prevent clogging.

- Approach flow conditions and structural design. Smooth pump operation at the agreed operating data requires hydraulically optimised approach flow conditions (see the section 'Structural Design' for further explanations). For submersible motor pumps of the Amarex KRT series relatively small sumps with inclined sump floors are suitable as they will provide a continuous flow of pollution load along with the fluid handled. At relatively short start-up intervals this sump design prevents the concentration of deposits so that the sumps remain clean.

1.8
Pump operating mode

The pump operating mode depends on many factors. The operating point can be moved by adjusting the impeller diameter or speed, or by changing to parallel or series operation. In this context, the system conditions must also be taken into account, such as the fluid levels in the inlet tank, the inlet conditions and the NPSH available. The fluid properties are also of major importance, for example its composition, density, viscosity and temperature. These factors will be explained in detail in the following sections.

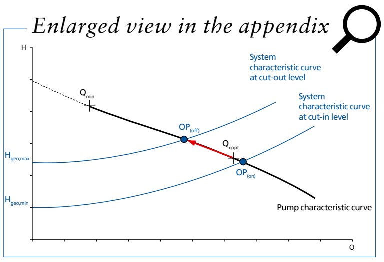

Fig. 1.16: Shifting the operating point of the pump at fixed speed by altering the geodetic head between the suction-side cut-in and cut-out level

1.8.1
Single-pump operation

The system characteristic curve can be adjusted by altering the geodetic head component. The geodetic head can be altered by means of the fluid level in the suction chamber for example, as illustrated in Fig. 1.16. The operating range of the pump on the H/Q curve lies between the two operating points ’pump cut-in’ and ’pump cut-out’.

Please note:
Make sure the operating point is near the best efficiency point, i.e. within the optimum operating range.

1.8.2
Control by throttling

The system characteristic curve can generally be adjusted in two ways. The flow resistance in the piping can be increased or decreased. This will be the intended result of controlling a throttling element or using a different pumping route (pipes with different nominal diameters and lengths) or the consequence of unplanned pipe deposits, corrosion or incrustation.

When closing the gate or throttle valves of a centrifugal pump, some of the pump input power which has been converted into the developed head is knowingly ’destroyed’ (or more accurately: wasted without use). From the point of view of conserving energy, this is the least favourable control option. In waste water engineering in particular, this option should be avoided (apart from start-up and shut-down processes) to prevent the increased risk of clogging at or downstream of the valves.

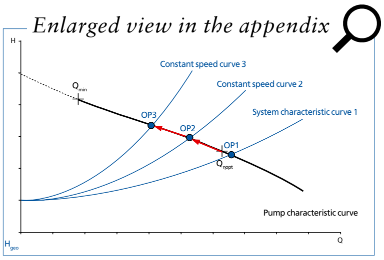

Fig. 1.17: Shifting the operating point of the pump by changing the pressure losses in the piping, e.g. the nominal diameter of pipes, the pumping route or length, or the deposits and incrustations in the piping

1.8.3
Adjusting the impeller diameter

A relatively easy and hydraulically very efficient (but irreversible) measure to reduce both the flow rate and the head at an unchanged speed is to adjust the impeller diameter D_2 by turning down the impeller or cutting back the impeller vane tips (Fig. 1.18). As this measure modifies the vane length or the width and angle of the vane trailing edge, its effect on flow rate, head and efficiency depend on the impeller type (specific speed nq). As a rough rule of thumb, the lower the specific speed nq, the more the impeller can be turned down without major efficiency losses.

Pump manufacturers indicate the possible diameter reduction range for their impellers in the form of a selection chart in the documentation / characteristic curve booklets. Within this range the correlation between impeller diameter, flow rate and head can be shown by using equation (14).

Enlarged view in the appendix

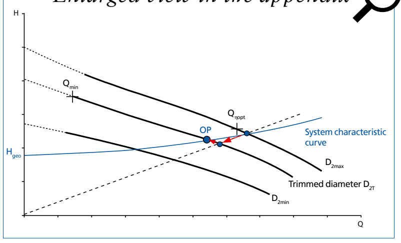

Fig. 1.18: Trimming or adjusting the impeller diameter to meet the required operating point of the pump

$$\frac{Q_{2T}}{Q_{2max}} = \frac{H_{2T}}{H_{2max}} = \left(\frac{D_{2T}}{D_{2max}}\right)^2 \tag{14}$$

The corresponding values for Q and H are positioned along an imaginary straight line which passes through the origin of the H/Q coordinate system (Fig. 1.18). The new operating point of the pump set is the resulting intersection of the characteristic curve of the pump with reduced (trimmed) impeller diameter and the unchanged system characteristic curve.

Please note: Make sure the operating point is near the best efficiency point, i.e. within the optimum operating range. Also, observe a minimum circumferential speed at the impeller outlet of approximately 15 m/s, if possible.

1.8.4
Speed control

Speed-controlled or variable speed pumps will always produce the flow rate / head which is actually required. This is the most energy-efficient type of control. It also keeps the load on the pump components to a minimum. In addition, reducing speed on the suction side makes the system $NPSH_{available}$ more dependable. The correlation of speed, flow rate and head is described by the special affinity laws for centrifugal pumps, assuming unchanged density and constant pump efficiency:

$$\frac{Q_1}{Q_2} = \frac{n_1}{n_2}$$

$$\frac{H_1}{H_2} = \left(\frac{n_1}{n_2}\right)^2$$

$$\frac{P_1}{P_2} = \left(\frac{n_1}{n_2}\right)^3 \tag{15}$$

Enlarged view in the appendix

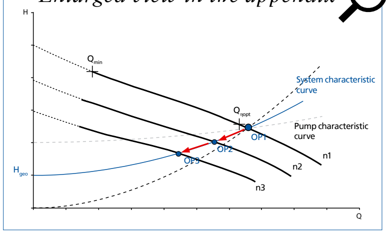

Fig. 1.19: Shifting the operating point of a centrifugal pump by changing the speed

The corresponding values for Q and H are positioned along an imaginary parabola which passes through the origin of the H/Q coordinate system, illustrated by the dashed line in Fig. 1.19. The new operating point of the pump set is the resulting intersection of the characteristic curve of the pump with reduced speed and the unchanged system characteristic curve. For system characteristic curves with a small static component the new operating point remains near the best efficiency point. The following effect is proportional to the static component of the characteristic curve: Speed reduction will cause the pump to operate with small flow rates in a range of poor low-flow efficiencies, and speed increase will cause the pump to operate with poor overload efficiencies.

Please note:
Make sure the operating point is near the best efficiency point, i.e. within the optimum operating range. If using a control regime with frequency inverter operation observe the flow velocities in the pipes, also observe a minimum circumferential speed at the impeller outlet of approximately 15 m/s. If possible provide sufficient motor power reserves for frequency inverter operation.

1.9
Parallel operation of pumps of identical sizes

Parallel operation of two or more centrifugal pumps with a shared suction/collecting line is particularly suitable for flat system characteristic curves. The smaller the dynamic head component, which is quadratically proportional to the flow rate, the larger the attainable increase in flow rate. This correlation is illustrated in Fig. 1.20. If the pump sets are identical, the total flow rate is composed of equal parts of the individual flow rates of each pump at a given head. The heads of each individual pump have to be added to by the dynamic component of head losses occurring in the individual lines up to the collecting line. The system characteristic curve of the collecting line only contains the head losses upstream of the point where the individual lines join.

Please note:
Make sure the operating point is near the best efficiency point, i.e. within the optimum operating range. Observe the flow velocities in the pipes. When selecting a pumping station for parallel operation of two or more identical pump sets, single-pump operation in the collecting line might have to be excluded if the individual pump characteristic curve does not intersect the characteristic curves of the system.

Enlarged view in the appendix

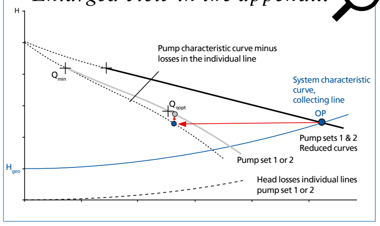

Fig. 1.20: Parallel operation of two identical centrifugal pumps. Losses of individual lines (head losses up to the collecting line) have been taken into account in the reduced pump characteristic curve

1.10

Parallel operation of pumps of different sizes

In principle, the parallel operation of two or more centrifugal pumps of different sizes is in analogy to that of pumps of identical sizes (Fig. 1.21). The pump sets will work together smoothly if they have stable H/Q characteristic curves (the shutoff head is higher than the head at Q_{min}). Preferably, the pumps should have identical shutoff heads.

The total flow rate is composed of the flow rates of the individual pumps at a given head. The heads of each individual pump have to be added to by the dynamic component of head losses occurring in the individual lines up to the collecting line. The system characteristic curve of the collecting line only contains the head losses upstream of the point where the individual lines join.

Please note:
Make sure the operating point is near the best efficiency point, i.e. within the optimum operating range. The pump set with the smaller shutoff head can very quickly be subjected to small flow rates when the total head changes ($H_{geo\ max}$, throttling, etc). Observe the flow velocities in the individual lines. When selecting a pumping station for parallel operation of two or more different pump sets, single-pump operation might have to be excluded if the individual pump characteristic curve does not intersect the characteristic curves of the system.

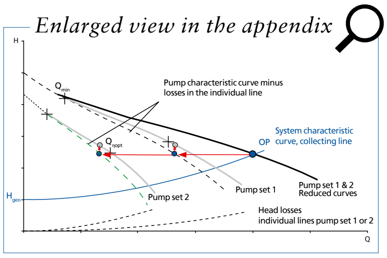
Enlarged view in the appendix

Fig. 1.21: Parallel operation of two different centrifugal pumps. Losses in individual lines (head losses up to the collecting line) have been taken into account in the reduced pump characteristic curve.

1.11

Series operation

Series operation of two or more identical centrifugal pumps with a shared collecting line is particularly suitable for steep system characteristic curves. In combination with flat pump characteristic curves the resulting flow rates only change within a slim margin even when the head changes drastically (e.g. the geodetic head component H_{geo}). The total head is composed of the heads of the individual pumps at a given flow rate.
This correlation is shown in Fig. 1.22.

This operating mode is very rarely used for waste water transport.

Please note:
Make sure the operating point is near the best efficiency point, i.e. within the optimum operating range. Observe the flow velocities in the pipes. The second pump set (downstream of the first one) must be suitable for the pressure increase and an inlet pressure equal to the discharge pressure of the first pump set. Observe the required strength and pressure class of the casings.

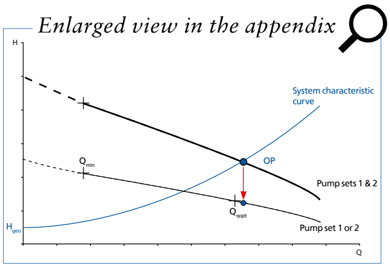
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Fig. 1.22: Series operation of two identical centrifugal pumps

1.12
Assigning pumps to different operating ranges/conditions

Pumping stations which are integrated in larger networks cover a variety of pumping routes at different times and are subject to major fluctuations often require a solution that goes beyond varying the operating modes and control options of one or several identical centrifugal pumps. In Fig. 1.23 different pumps are assigned to different operating ranges/conditions. In this example the pumping routes / characteristic curves are subdivided into the three operating conditions rainfall, day time and night time. All pumps can be adjusted to the current flow rate and pumping route by means of speed control. Each pump is assigned an identical stand-by pump. In addition, the day time pumps are backed up by another set of identical pumps. The day time pumps can also be operated in parallel. During rainfall and day time the waste water can be expected to be diluted sufficiently to be handled by suitably sized centrifugal pumps with multi-vane impellers (number of vanes z = 2 or 3). The night time pumps are fitted with single-vane or free flow impellers as the small flow rates may entail a high concentration of solids in the fluid handled.

Enlarged view in the appendix

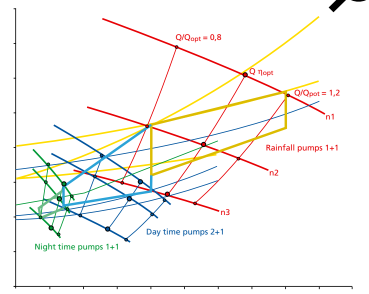


Fig. 1.23: Assigning rainfall, day time and night time pumps to different pumping routes for different fluid levels and events

Please note:
Make sure the operating point is near the best efficiency point, i.e. within the optimum operating range. If using a control regime with frequency inverter operation observe the flow velocities in the pipes, Also observe a minimum circumferential speed at the impeller outlet of approximately 15 m/s. If possible provide sufficient motor power reserves for frequency inverter operation.

1.13 Concept of wet-installed pumps

The most straightforward concept for a pumping station is the installation of wet-installed pumps. The pumps are installed directly in the suction chamber and completely or partly surrounded by waste water during operation. The pumps can either be operated with a vertical shaft driven by a motor mounted above the fluid level, or the entire pump sets can be used under water as submersible motor pumps.

In practice wet-installed pumps were mainly used in smaller pumping stations (flow rates up to approximately 100 l/s); they are called packaged pumping stations [1.17; 1.18].

The benefits of a wet installation are also increasingly employed in large pumping stations (flow rates up to approximately 16,000 l/s). The advantages and disadvantages of this arrangement are listed in Table 1.1 [1.19].

To prevent clogging, the narrowing the pipes in the direction of flow must absolutely be avoided. The inside diameter of the discharge lines must be equal to or greater than the inside diameter of the discharge nozzle [1.20]. Use pipe connections without narrowing
and make sure that open valves do not obstruct the flow [1.21; 1.22]. Calculate the optimum diameter based on the minimum flow velocity and use the next largest pipe diameter available. For longer discharge lines measures to reduce surge pressure have priority over measures to maintain the minimum flow velocity. For discharge line lengths of up to 500 m a maximum velocity of 2.5 m/s applies [1.23].

The piping material must be suitable for the waste water to be transported. Make sure it is corrosion-resistant (hydrogen sulphide!). This also applies to the material of the pipe supports, which need to be closely spaced. The piping must be fastened without transmitting any forces to the pump. The pipes should have a smooth inner surface, be able to withstand cyclical loads and be selected, depending on the discharge head, for an operating pressure of 6 to 10 bar. The discharge line from the pump must be connected to the main line with a horizontal section. Avoid abrupt changes of direction. Pipe connections and fittings must comply with the relevant product standards.

Butterfly valves are unsuitable as isolating valves in the waste water sector (see overview in Fig. 4.2.3a). We recommend soft-seated isolating gate valves with external thread, body made of GGG, stem made of 1.4571, stem nut and seat rings made of 2.1060. Choose actuators whose maximum actuation force cannot damage the gate valve [1.24].

Especially suitable as non-return valves are swing check valves with lever and weight. The body material we recommend is lamellar graphite cast iron (GGL) or nodular cast iron (GGG) [1.25]. For low flow velocities, non-return ball valves can be used [1.26]. The non-return valve should be arranged vertically and as high as possible above the pump to allow the rising fluid level to release the air it displaces in the pump. If this condition is met, a venting device for the pump is not required [1.27].

GGG	nodular cast iron
GGL	lamellar cast iron
1.4517	Stainless steel
2.1060	tin bronze

according to ISO CuSn12Ni2
according to ASTM (USA) C91700

The inlet line of the (minimum of two) [1.28] pumps should be installed with a downward slope, allowing the water to freely enter the pumps (suction head operation) [1.29]. Operation in the unstable zone must be avoided. Cavitation should be limited to the permissible range ($NPSH_{available} / NPSH_{req} \geq 1.3$) [1.30]. The pumps must be suitable for the waste water to be handled and for the pumping task [1.31]. According to European Standards motors without explosion protection can be used. In Germany, however, national regulations require Ex dII B T3 explosion protection; as the suction chambers of waste water pumping stations are classified as potentially explosive atmospheres [1.32].

Operating status messages are to be displayed individually. Individual fault messages are to trigger a visual alarm and general fault messages an acoustic alarm [1.33]. It is further recommended to install measuring devices for the fluid level, discharge pressure and flow [1.34].

Notes regarding the Reynolds number

The flow velocity v is not constant across the pipe cross-section A. Newtonian (viscous) fluids stick to the pipe wall where the flow velocity equals zero. The maximum flow velocity can be found along the pipe axis. The flow velocity over the cross-section can be divided into laminar and turbulent flow (Fig. 1.24) [1.35].

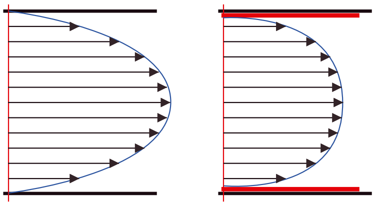


Fig. 1.24: Laminar and turbulent flow

The type of flow depends on the average flow velocity v, the pipe diameter d and the kinematic viscosity ν of the fluid. These variables are expressed by the Reynolds number. KSB AG uses Reynolds number 2320 to distinguish between turbulent and laminar flow.

Notes on the volume of the suction chamber

For fixed speed pumps the available volume in the suction chamber is calculated as follows to worksheet ATV-DVWK-A 134 (German Association for Water, Waste Water and Waste):

$$V = 0{,}9 \cdot \frac{Q_P}{Z} \qquad (16)$$

Standardised values have been defined for domestic waste water quantities. In Germany for example, the standardised waste water quantity used per inhabitant in a day equals 150 to 300 l (without allowing for infiltration); the peak flow equals 4 to 5 l per 1000 inhabitants per second (including an allowance for infiltration) [1.36].

Advantages	**Disadvantages**
Little structural and civil engineering required (some pump sets available as packaged pumping stations)	Internal parts in the suction chamber can lead to deposits
Little space required	Poor accessibility
Little investment required	Unhygienic servicing conditions
Simple systems engineering	
Large NPSH $_{\text{available}}$	

Table 1.1: Advantages and disadvantages of pumping stations with wet-installed pumps (Source: Author's own presentation based on Weismann, D. (1999), page 104 f).

Literature

[1.1] Additional literature: ATV-DVWK –A 134
[1.2] Additional literature: ATV-DVWK –A 118
[1.3] Additional literature: ATV-DVWK –A 134
[1.4] Mathematical expression of the presentation by Turk, W.I. (1954), page 144
[1.5] See PWSIM 02 source code, line 353
[1.6] Mathematical expression of the presentation by Turk, W.I. (1954), page 144
[1.7] Additional literature: KSB Centrifugal Pump Lexicon
[1.8] Hahne, E. (2000), page 397
[1.9] Additional literature: KSB publication: Selecting Centrifugal Pumps
[1.10] Additional literature: KSB publication: Selecting Centrifugal Pumps
[1.11] Additional literature: KSB publication: Selecting Centrifugal Pumps
[1.12] Additional literature: KSB Piping Calculator, Selection Software
[1.13] Additional literature: Brochure Europump 1974 "NPSH bei Kreiselpumpen – Bedeutung, Berechnung, Messung" (NPSH for centrifugal pumps – significance, calculation, measurements)
[1.14] Additional literature: Brochure Europump 1974 "NPSH bei Kreiselpumpen – Bedeutung, Berechnung, Messung" (NPSH for centrifugal pumps – significance, calculation, measurements)
[1.15] Additional literature: KSB Centrifugal Pump Lexicon
[1.16] See KSB AG (1989)
[1.17] See ATV e.V. (editor) (1982), page 443f.
[1.18] See Weismann, D. (1999), page 100ff.
[1.19] Weismann, D. (1999), S.104F.
[1.20] See ATV-DVWK-A 134 (2000), page 20
[1.21] See EN 752-6 (1998), page 6
[1.22] See ATV-DVWK-A 134 (2000), page 23
[1.23] See ATV-DVWK-A 134 (2000), page 10
[1.24] See ATV-DVWK-A 134 (2000), page 21ff.
[1.25] See ATV-DVWK-A 134 (2000), page 24
[1.26] See ATV-DVWK-A 134 (2000), page 24
[1.27] See ATV-DVWK-A 134 (2000), page 24
[1.28] See EN 752-6 (1998), page 4
[1.29] See ATV-DVWK-A 134 (2000), page 7
[1.30] See ATV-DVWK-A 134 (2000), page 15
[1.31] See EN 752-6 (1998), page 6
[1.32] See ATV-DVWK-A 134 (2000), page 18
[1.33] See ATV-DVWK-A 134 (2000), page 30
[1.34] See ATV-DVWK-A 134 (2000), page 30
[1.35] See Hahne, E. (2000), page 395ff.
[1.36] See EN 752-4 (1997), page 14f.

2.
Configuration and Installation

2.1
Selecting the optimum impeller geometry

The number of different impeller types for centrifugal pumps in waste water transport exceeds that of any other application (Fig. 2.1). All these impeller types serve a particular purpose.

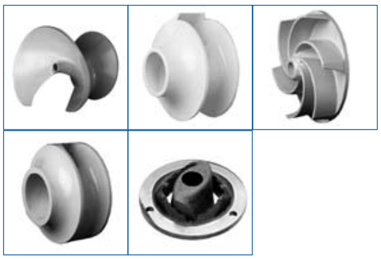


Fig. 2.1: Impeller types

The most important criterion in impeller selection is the operating reliability. This is why the ATV guideline (DVWK-A 134) stipulates a free passage of 100 (76) mm. Also pump efficiency has gained in significance over the last few years.

Factors to be considered for reliable operation are, in particular, the gas content, the fibre content, the size of solid particles, the dry substance content and the sand content. Table 2.1 shows KSB's expected values for common fluids in waste water treatment.
For gas, sand and dry substance content the limits of each impeller type can be defined reasonably accurately; for fibres and other solids in the fluid, quantities are harder to define. The composition of waste water can also change over time. The operator's experience should be considered when selecting an impeller.

The overview in Table 2.2 shows the application limits of each impeller type

High gas content and relatively high fibre content are best matched with open impellers, especially free flow impellers. For pre-screened waste water, closed K impellers are recommended due to their excellent efficiency. The only suitable impeller type for small and medium sized pumps handling fluids with larger solids are free flow impellers and single-vane impellers as they provide the required free passage.

Fluids containing long fibres (textiles, cleaning and hygiene products, plant matter) jeopardise the operating reliability of closed impellers (with impeller shroud) affecting the vane leading edge and the suction-side clearance between impeller and casing.

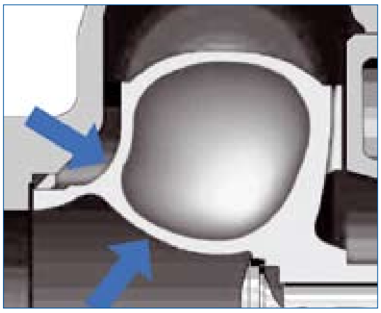


Fig. 2.2: Problematic areas for fluids containing fibres

Due to the flow of leakage volume through the clearance between impeller and pump casing fibres can accumulate in this area (Fig. 2.2) and form "hardened deposits" (Fig. 2.3). This risk is reduced by a narrow clearance. Wear-resistant materials are used to ensure the clearance gap remains unchanged, which has the added benefit of maintaining a stable efficiency.

Fig. 2.3: Hardened deposits

Table 2.1: Expected values of fluids in waste water treatment

	Gas content vol%	Fibre content	Size of solids	Dry substance content (%)	Sand content (g/l)
Storm water and surface water	-	Low	Small	-	0 - 3
Waste water					
- Municipal waste water					
- Domestic waste water	0 - 2	Medium	Medium	-	0 - 3
- Commercial waste water	0 - 2	High	Large	-	0 - 3
- Industrial waste water	0 - 2	High	Large	0 - 5	0 - 3
Water containing a large proportion of sand	-	-	-	-	8 - 10
Sludge					
- Activated sludge	2 - 4	Low	Small	1 - 2	-
- Primary sludge	2 - 4	Low	Small	2 - 6	-
- Secondary sludge	2 - 4	Low	Small	2 - 3,5	-
- Sludge from thickener	3 - 6	Low	Small	2 - 5	0 - 2
- Stabilised sludge	-	Low	Small	5 - 10	-
- Dewatered sludge	-	Low	Small	20 - 30	-
- Dry sludge	-	Low	Small	30 - 50	-

Table 2.2: Application limits of different impeller types

	Gas content vol%	Fibre content	Size of solids	Dry substance content (%)	Sand content (g/l) *
Cutter	-	Medium	-	2	-
Free flow impeller (F impeller)	≤ 8	High	Large	< 8	≤ 10
Closed single-vane impeller (E impeller)	≤ 2	Medium	Large	≤ 6	≤ 6
Open single-vane impeller (D impeller)	≤ 4	High	Large	≤ 13	≤ 4
Closed two-vane impeller (K impeller)	-	Low	Medium	≤ 3	≤ 4
Open two-vane impeller	4	High	Medium	6	≤ 6
Multi-vane impeller (K impeller)	-	None	Small	≤ 5	≤ 6

** Provided the impeller is made of suitable material*

To evaluate pump efficiency simply comparing the “best” efficiency is insufficient. Instead we need to look at the efficiency at the actual operating points. For evaluating the total power input over the pump life cycle, the expected service life of the pump must also be taken into account. In some applications pumps run for more than 4000 hours per year; in others, such as domestic pumped drainage or storm water tanks, the operating time of a pump is often far below 100 hours per year.

This means that, apart from general requirements for operating reliability, the key criteria for selecting a waste water pump differ. For continuous operation efficiency is of major importance whilst the focus for pumped drainage is on investment costs.

2.2

Matching materials to the application

Grey cast iron, especially JL1040, has proven very successful for all main components of wet-installed submersible motor pumps in municipal water and waste-water applications.

This material has several benefits: Its great chemical resistance in neutral and alkaline environments matches its resistance against hydro-abrasive wear. Remarkably, the properties of the casting skin which contains large amounts of carbon, iron oxides and silicon oxide provide great protection against wear and corrosion. Modern designs keep machining to a minimum in order to preserve the casting skin as much as possible.

The material's low modulus of elasticity dampens vibrations at the casing parts and the duck-foot bend. At a reasonably low price per kilogram, manufacturers can offer a stable and reliable design without any risk of the pump lifting off the duckfoot bend even at relatively high pressures.

As a material for the motor housing, grey cast iron has very good thermal conductivity compared to stainless steel, for example. Grey cast iron is the first choice in more than 90 % of applications.

Highly abrasive fluids

In sand traps or in areas where large amounts of sand are present in storm water being transported to the waste water system, the impeller and even the pump casing might have to be made of a material which is particularly resistant to abrasive wear. We recommend high-alloy grey cast iron 0.9635. A comparison in a model wear test showed that the linear material loss rate of JL1040 is 20 times higher than that of 0.9635

For casing parts, coatings have also proved successful in the last few years. Select a coating method which is compatible with the material to be coated. Also make sure that the coating medium can handle the type and concentration of solids in the fluid. Coatings are not recommended for impellers as the coating life would be too short.

Pumps for corrosive fluids

Duplex stainless steels such as 1.4517 and 1.4593 have proven successful many times over. Pure austenitic steel such as 1.4408 are not as wear-resistant and are unsuitable for seawater applications.

Duplex stainless steels with an austenite/ferrite ratio of 1:1 not only offer excellent corrosion resistance but also outstanding mechanical properties, such as strength and elongation at fracture, as well as adequate wear resistance. If a very long service life is required, pumps for seawater applications need to be made of a material with a so-called PREN value of 35 or even 38 (Fig. 2.4).

The effect of coatings is limited in combination with corrosive fluids such as seawater. Even the slightest damage to the coating will lead to uninhibited spreading of the corrosion process underneath the coating.

Special coatings combined with cathodic protection by anodes have resulted in remarkable resistance. Based on this solution, several pumps with JL1040 casings have been in operation in pumping stations at the Red Sea for more than 5 years without displaying any visible signs of corrosion. Prerequisites for this solution are proper maintenance and regular anode replacement (every 1 to 2 years). Electric conductivity between the pump and other components with large surfaces such as pipes or grids must be prevented during installation. Otherwise the anode would be used up early due to an unfavourable anode/cathode ratio, which would impair the pump protection.

Fig. 2.4: KRT for seawater applications, completely made of duplex stainless steel

Casing wear rings (K and E impellers) / wear plate (D impellers)

The clearance between the casing wear ring and the impeller with or without an impeller wear ring determines the flow rate of the leakage volume. The flow rate of the leakage volume significantly influences the pump efficiency. If the clearance remains constant, pump efficiency generally remains constant too. If wear causes the clearance to widen, leakage reduces the effective volume flow rate of the pump, thus reducing pump efficiency. A larger clearance also increases the risk of hardened deposits as described in the section 'Selecting the optimum impeller geometry'.

As K impellers are normally only used for fluids with a low solids content, JL1040 is usually an adequate casing ring material. Materials of higher wear resistance are required for more demanding fluids. As an option, KSB offers wear rings made of semi-austenitic cast CrNi steel (VG 434) for K impellers. Material 1.4464 has comparable properties. Even high-alloy grey cast iron (0.9635) can be used for the casing wear rings of E impellers. The materials on offer for wear plates for D impellers are similar. In addition to JL1040, KSB offers high-alloy grey cast iron 0.9635 as an alternative for higher wear resistance. To increase the wear resistance of edges and surfaces of casing wear rings and impellers under high loads, parts made of JL1040 are successfully hardened to a depth of several millimetres.

Shaft

KSB shafts are made of ferritic chromium steel (1.4021) as a standard. This material is of good mechanical strength. It is corrosion-resistant in more than 90 % of all applications. Highly corrosive fluids such as seawater require duplex stainless steels with a suitable PREN value. In this case, for reasons of magnetisation 2- and 4-pole motors might require friction welded shafts with the motor section being ferritic.

2.3
Shaft seal

Sealing the shafts of submersible motor pumps with two mechanical seals in tandem arrangement (Fig. 2.5) has been the established solution for many decades.

For this arrangement, 85 to 90 % of the space between the two mechanical seals has to be filled with a suitable liquid. The remaining air volume prevents temperature rises leading to excessive pressure increase in the reservoir which could push the inboard mating ring out of its seat. The liquid exclusively serves to form a lubricating film between the rotating and stationary seal faces of both mechanical seals. Lubrication is crucial for keeping wear of the seal faces to a minimum.

Submersible motor pumps in waste water applications can always be affected by dissolved gases in the fluid coming out of solution in the pump casing. Gas always accumulates in the lowest pressure zone, which is around the mechanical seals. Without separate lubrication the mechanical seals would have a very short service life. As a standard, rotating and stationary seal faces are made of silicon carbide / silicon carbide (SiC/SiC). This material has relatively poor anti-seizure properties but is highly resistant to the effects of solids.

NBR or Viton are used for the elastomer elements of the mechanical seals as EPDM is incompatible with oil. PTFE is only required for extreme applications.

The mechanical seals are usually designed as rubber bellows -type seals with a single spring (Fig. 2.6 a). Low investment costs are not the only advantage of bellows -type mechanical seals. The bellows also completely compensate for shaft deflection caused by radial forces in the pump without any relative motion on the shaft. The shaft is thus protected against wear, and no shaft sleeve is required.

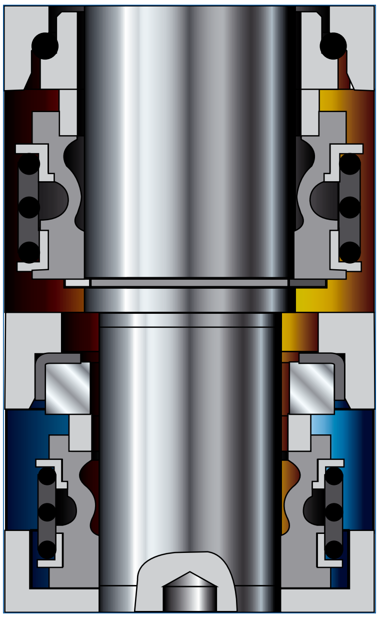


Fig. 2.5: Typical tandem arrangement of mechanical seals with oil reservoir

For pump sizes with shaft diameters larger than 100 mm bellows-type mechanical seals with a single spring are no longer feasible for assembly. Balanced mechanical seals with stationary seat are recommended for these sizes (Fig. 2.6 b). The stationary seat is located in the seal housing with the rotating face being pressed up to it by covered springs that are not in contact with the fluid handled.

Mechanical seals with covered springs are also required for smaller pump sizes if the fluid handled contains long fibres or sharp components, for example pumps handling swarf in machining applications.

Fig. 2.6 a: EagleBurgmann MG1 bellows-type mechanical seal

Fig. 2.6 b: EagleBurgmann HJ mechanical seal

Fig. 2.7: Balanced mechanical seal with stationary head

KSB uses light, non-toxic, biodegradable oil as a lubricant. A water/glycol mixture is used in pumps where the lubricant for the mechanical seals also serves as a coolant.

2.4
Rotor and bearings

It is essential that the shaft and bearings are correctly dimensioned for the loads in the permissible operating range.

Operation under ’off-design’ conditions may not only damage the mechanical seals but also especially the bearings as well as the shaft. The various reasons for the operating limits are described in detail in the section ’General Pump Selection’.

The system conditions may not allow the exclusion of pump operation against a closed gate valve. Apart from high bearing forces this will also lead to forces on the impeller resulting in severe shaft deflection.

Shaft deflection can in turn lead to the impeller rubbing against the casing wear ring. Prolonged operation at this condition will widen the clearance between impeller and casing wear ring.

For submersible motor pumps with drive ratings of 4 kW and above the bearings are generally dimensioned for a calculated minimum bearing life of 25,000 hours within the operating limits Q_{min} and Q_{max}. The bearing life will be normally significantly longer if the pump set is operated within these operating points.

Smaller pumps have a shorter calculated bearing life. If small pumps are intended for continuous operation, this should be mentioned in the specifications.

The bearings are usually grease lubricated. The bearings of pumps with a small to medium pump power output (< 65 kW) are generally lubricated for life. Pumps with a higher pump power output often need their bearings to be re-lubricated. Such pumps are fitted with a special re-lubrication system. For the required grease quality, quantity and re-lubrication intervals refer to the operating manual for the pump.

2.5 Installation

The following three types of installation are common for submersible motor pumps: installation of transportable models (Fig. 2.8), stationary wet installation (Fig. 2.9) and vertical dry installation (Fig. 2.10)

For transportable models the pump must be firmly positioned in the pump sump; suitable hoisting tackle is required to lift the pumps.

Stationary wet installation is effected via a duckfoot bend fastened to the tank floor. The duckfoot bend has to be matched to the permissible load of the pump and the mating dimension of the claw fastened to the discharge nozzle of the pump. The mating dimensions are not standardised. Heavy pumps might need to be fastened to the concrete floor with foundation rails. The duckfoot bend or foundation rails are fastened with chemical anchors (composite anchor bolts) approved for structural engineering. The chemical anchors need to be set in a concrete floor of sufficient strength (minimum C25/C30 to DIN 1045) (Fig. 2.11 a+b). Observe an adequate height of the pump's suction inlet above the tank floor. For details please refer to the section 'Structural Design'. Prior to installing the pump, the complete discharge line and the guide arrangement for the pump have to be fitted. For notes on the piping also refer to the section 'Structural Design'. Two different guide arrangements are available: guide wire and guide rail (Fig. 2.12 a+b + 2.13). A comparison (Table 2.3) shows that the guide wire arrangement has many advantages.

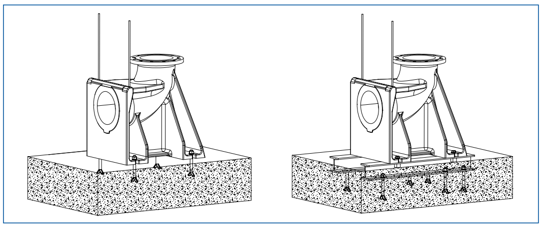


Fig. 2.11 a+b: Fastening the duckfoot bend or foundation rails

Fig. 2.8: Installation of a transportable waste water pump

Fig. 2.9: Stationary wet installation of a waste water pump

Fig. 2.10: Vertical dry installation of a waste water pump

For this reason KSB prefers the guide wire arrangement as a standard; guide rail arrangement is offered as an alternative.

The upper brackets of the guide arrangement are suitably fastened to a concrete wall or ceiling with chemical anchors. Spacers need to be fitted on guide wire arrangements for large installation depths.
For the guide rail arrangement the installation of intermediate supports every 6 m is recommended. The intermediate support brackets are either clamped to the discharge line or mounted directly to the wall of the pump sump.

Dry installations will not be explained in detail in this brochure as it corresponds to the installation of dry-installed pumps in general.

Fig. 2.12 a:
Guide wire arrangement

Fig. 2.12b:
Guide wire arrangement

Fig. 2.13:
Guide rail arrangement

Table 2.3: Comparison of guide wire arrangement and guide rail arrangement

Guide wire arrangement	Guide rail arrangement
Easy and convenient to transport	Rails difficult to transport
Fast to install, saving costs	Inflexible regarding structural deviations
Compensation of structural tolerances without extra work/costs	Very costly for large installation depths
Allows installation with inclined angle of up to + 5°	Corrosion problems of guide rails
Flexible and reliable adaptation to different installation depths down to 85 m	Corrosion-resistant rails are very costly
Guide wire made of corrosion-resistant stainless steel 1.4401 (316)	Problems with sealing (metal-to-metal or shearing of rubber gasket) at the duckfoot bend
Guide wire included in KSB's scope of supply	Access to valves obstructed by inflexible rails
Problems with contamination in cases where powerful flow patterns or floating sludge is present in the pump sump.	Less sensitive to fluids containing fibres

3.
General Description of the Motor

KRT motors are water-tight, three-phase asynchronous squirrel-cage motors, especially designed and selected to drive submersible motor pumps (Fig. 3.1 and Fig. 3.2). The motor is available as a non-explosion-proof or as an explosion-proof model where a “flameproof enclosure” is specified. Pump and motor have a common pump / motor shaft and form an inseparable unit. No defined electrotechnical standards exist for these special pump motors described below; however, the requirements of DIN EN 60034 are complied with as far as possible.

KSB submersible motor pumps are floodable, non-self-priming close-coupled pump sets, which are normally operated completely submerged. They can be operated unsubmerged for a short period of time, during which the permissible motor temperature is monitored by a temperature sensor installed in the motor.
The minimum fluid level indicated in the operating manual generally has to be observed.

A motor variant with a cooling jacket is available for applications which require the pump set to permanently operate with the pump set partly unsubmerged. The cooling jacket provides sufficient motor cooling regardless of the fluid level in the pump sump.

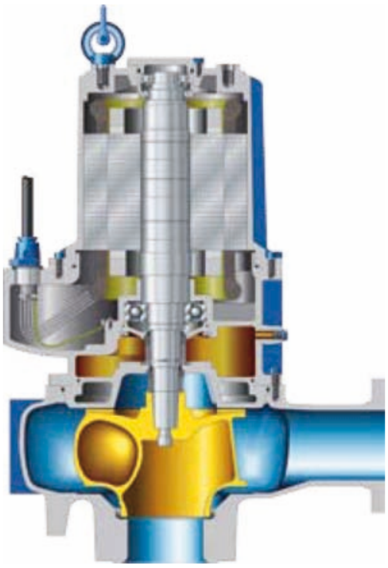


Fig. 3.1: Sectional drawing of a KRT 4 to 60 kW

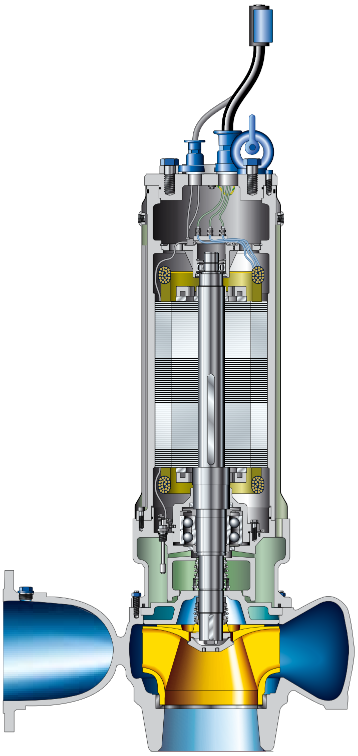


Fig. 3.2: Sectional drawing of a KRT > 60 kW

3.1
Motor sizes

Standard rated power (depending on the number of poles):	4 to 480 kW also up to 880 kW
Standard number of poles (depending on the rated power):	2 to 10 poles
Standard rated voltages:	400/690 V, 50 Hz 460 V, 60 Hz

Note:
1) For 60 Hz rated voltages are available in the range from 200 to 575 V.
2) Higher rated powers and different rated voltages (also high voltage) on request.
3) For the individual motor size refer to the motor data sheets (included with the project documentation or available on request).

3.2
Type of construction

The type of construction of KRT motors is similar to that of IM V10 (to DIN EN 60 034-7).

Motor installation

The motor and the pump are installed directly in the pump sump as a close-coupled unit. During operation the motor is submerged in the fluid to be handled. It can be operated outside the fluid for a short period of time during which the permissible motor temperature is monitored by a temperature sensor installed in the motor. The minimum fluid level indicated in the operating manual generally has to be observed. For large submersible motor pumps the minimum fluid level is usually determined by hydraulic parameters (e.g. air-entraining vortices, NPSH). Fluid temperature: maximum 40°C as a standard.

For operation with fluid temperatures > 40 °C and < 60 °C a hot water variant is available. Operation with fluid temperatures > 60 °C on request.

Sizes

The dimensions for standardised motors to IEC 72 are not applicable for integrated submersible pump sets. Nevertheless, the electrical sheet steel laminations correspond with the so-called IEC dimensions or sizes common on the market.

Immersion depth

KRT submersible motor pumps can be operated up to an immersion depth of 30 m without requiring any special measures to be taken.

3.3
Mode of operation

KRT motors without a cooling system (installation type S) are designed for continuous operation S1 (to DIN EN 60034-1) in a submerged condition. If the motor is operated unsubmerged and dry running is detected, a bimetal switch in the motor winding switches the mode of operation to S3.

KRT motors with a cooling system (installation types K and D) are designed for continuous operation S1 (to DIN EN 60034-1) at all fluid levels.

3.4
Enclosure

KRT motors comply with the requirements of enclosure IP 68 to DIN EN 60 034-5. The pump set also complies with the requirements of enclosure IP 68 to DIN EN 60 529.

3.5
Type of protection and temperature classes

Explosion-proof Amarex KRT motors comply with the requirements of Ex II2G Ex d IIB T3 and, in some cases, T4 type of protection to DIN EN 60079-0 / DIN EN 60079-1 and they are suitable for use in zone 1. The following codes are used in the motor designation: X → T3 and Y → T4.

3.6
Electrical design data

Rating

To ensure a long motor life it is recommended to observe a mains voltage tolerance of ± 5 % and mains frequency tolerances of ± 2 % (Design A) in accordance with DIN EN 60034-1.

Other than that, the power output of Amarex KRT motors in a submerged condition is only restricted by a mains voltage tolerance of ± 10 % and a mains frequency tolerance of ± 2 % compared to the rated values.

Voltage and frequency

KRT motors are fully functional as defined in DIN EN 60034-1 section 12.3 given a mains voltage fluctuation of ± 10 % and a mains frequency fluctuation of up to -5 % /+ 3 % compared to the rated values. They correspond with Design B to DIN EN 60034-1.

Current and starting current

Depending on the motor size the starting current at the motor terminals equals 4 to 9 times the rated current at rated voltage. For individual starting current values refer to the motor data booklet or project documentation.

Start-up and starting method
KRT motors can be started up using either the star-delta or the DOL starting method.
The winding ends are supplied wired for both star and delta operation as standard. If the starting current ratio is limited by the operator, KSB will supply calculated starting curves for the motor (M/ n curves) to facilitate selection, dimensioning and parameter setting of a soft starter or autotransformer as an alternative to star-delta starting at 400 V mains voltage.

When a soft starter is used, the requirements on electromagnetic compatibility to EN 50081 and EN 50082 must be met. When selecting a soft starter observe the information provided by the manufacturer and the electrical motor data, especially the rated current.

Run-up time

The run-up time of Amarex KRT submersible motor pumps on DOL starting at rated voltage should be less than 1.5 seconds.

Permissible locked rotor time

The permissible locked rotor time at rated voltage equals:

For cold start-up: ≤ 25 s

For warm start-up: ≤ 5 s

Moments

For complete pump sets such as submersible motor pumps the moments of inertia, start-up and pull-out torque for the motor do not normally need to be defined. However, for an optimum soft starter setting the corresponding curves can be supplied on request.

Configuration

On KRT motors the six ends of the stator winding strands are always wired to the outside with suitable cables , regardless of the starting method. They can be connected in delta (e.g. 400 V / 50 Hz or 460 V / 60 Hz) or star (e.g. 690 V / 50 Hz) configuration, depending on the voltage. The motor wiring is included in the project documentation or will be made available on request.

Motor rating	Maximum frequency of starts
Up to 7.5 kW	30/h
Above 7.5 kW	10/h

Frequency of starts

To prevent excessive thermal loads on the rotor as well as mechanical loads on the bearings and electrical loads on the insulation the defined frequency of starts per hour must not be exceeded (Table 3.1). In this context, the correlation between flow rates and pump sump volume needs to be considered. It is recommended to limit the frequency of starts to 5000 per year.

Direction of rotation

The shaft must rotate counter-clockwise, seen from the free shaft end.

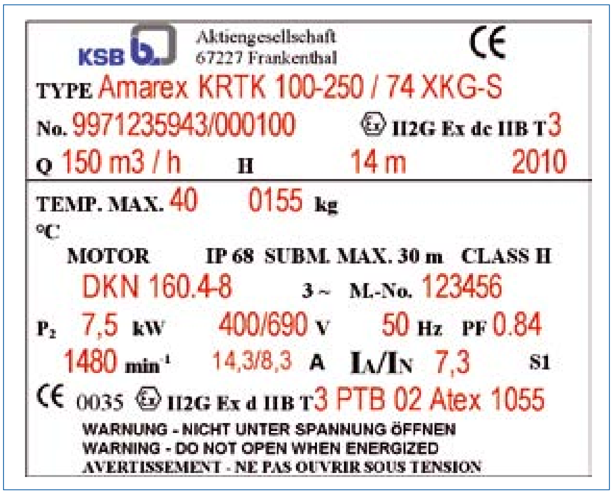
It is highly recommended to check the direction of rotation prior to installing the pump (see operating manual).

Individual motor data

Individual motor data such as the load -dependent efficiencies, power factor, rated current, etc. can be found in the motor data sheets, including load curves, which are provided on request or together with the project documentation.

Name plate

A name plate for the complete submersible pump set is shown in Fig. 3.3.



KSB Aktiengesellschaft
67227 Frankenthal
CE
TYPE Amarex KRTK 100-250 / 74 XKG-S
No. 9971235943/000100 Ex II2G Ex de IIB T3
Q 150 m3 / h H 14 m 2010
TEMP. MAX. °C 40 0155 kg
MOTOR IP 68 SUBM. MAX. 30 m CLASS H
DKN 160.4-8 3 ~ M.-No. 123456
P_2 7,5 kW 400/690 V 50 Hz PF 0.84
1480 min⁻¹ 14,3/8,3 A I_A/I_N 7,3 S1
CE 0035 Ex II2G Ex d IIB T3 PTB 02 Atex 1055
WARNUNG - NICHT UNTER SPANNUNG ÖFFNEN
WARNING - DO NOT OPEN WHEN ENERGIZED
AVERTISSEMENT - NE PAS OUVRIR SOUS TENSION

Fig. 3.3: Name plate

3.7
KRT motors with frequency inverter

When operating KRT motors with a frequency inverter observe KSB's notes on operating submersible motor pumps with a frequency inverter or the relevant EUROPUMP papers.

KRT motors are suitable for frequency inverter operation. Select any commercially available IGBT frequency inverter with DC link. Any make can be used, even for explosion-proof pumps. The motor insulation is suitable for pulse voltages of up to 1600 V. Higher pulse voltages are frequent if the rated voltage exceeds 500 V. In this case, fit a dV/dt filter to the frequency inverter or use motors with a special insulation (available on request).

To minimise the risks involved in freely matching frequency inverters to motors KSB recommends an additional power reserve of 5 %. This power reserve will definitely be able to compensate for any increased losses caused by harmonics in the output voltage of the frequency inverters.

3.7.1
Selecting a frequency inverter

When selecting a frequency inverter observe the manufacturer's information and the electrical motor data. Consider the rated current of the motor rather than the rated power of the motor, especially for motors with a high number of poles and low cos phi.

3.7.2
Explosion-proof drives

The following conditions must be met when operating explosion-proof KRT motors with a frequency inverter:

- The individual operating points must be within a range of 50 to 100 % of the rated frequency. Operation above the rated frequency is excluded in the available type test certificates.
- The current limiter of the frequency inverter must be set to 3 x I_N as a maximum.
- The thermistor tripping unit must bear the PTB 3.53 - PTC/A conformity mark.

3.8
Design details of the motor

KRT submersible pump sets are fitted with a water-tight, three-phase asynchronous squirrel-cage motor, especially designed and selected to drive submersible motor pumps. Pump and motor have a common pump/motor shaft and form an inseparable unit.

Stator
The stator of the KRT motor consists of a stator core into which a three-phase current winding made of copper wire has been inserted. High-quality enamelled wire and insulating materials (in the slot and end windings) combined with polyester resin impregnation provide high mechanical and electrical strength.

Insulation materials and thermal class
The insulation system of the motor is exclusively made of market-proven components of well known manufacturers. All insulation materials comply with the requirements of thermal class H. A variety of binding methods is available for the winding ends. Within the rated conditions the motor winding temperatures comply with thermal class F.

Rotor
The rotor is a squirrel-cage motor. The cage in the rotor core is either made of die-cast aluminium or of soldered copper bars and rings, depending on the motor size.

Bearings
The drive end and non-drive end are fitted with rolling element bearings. Up to pump size 280 the bearings are greased for life; the bearings of pump sizes 315 and above come with a re-lubrication system. The lubricants used are high-temperature lithium soap base greases. The grease quality is defined in the operating manual.

3.9
Cooling

The motor is primarily cooled with air. Inside the motor the air is circulated in a closed system by fan blades on the two ends of the rotor. The heat generated in the motor is dissipated via the casing to the water which acts as a secondary coolant. EN 60034-6 code: IC 4 A 1 W 8

3.10
Monitoring equipment

Overcurrent protection
The motor must be protected from overloading by a thermal time-lag overcurrent relay in accordance with DIN VDE 0660 / IEC 947 (Fig. 3.5). The relay has to be set to the rated current of the motor as indicated on the name plate (see the section ’Name plate’ or the project documentation, or place a request).

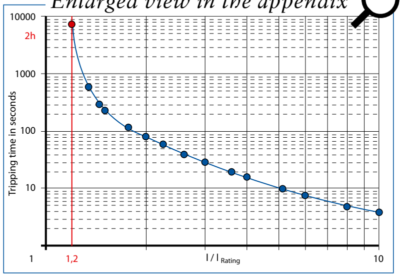
Anti-condensation heater
The motors of KRT submersible motor pumps do not require an anti-condensation heater (see the section ’Moisture protection of the motor’). The water-tight design prevents condensation inside the motor. Any residual humidity in the air is absorbed by silica gel sachets.

Sensors in the motor pump set

Winding temperature monitoring without explosion protection (installation types S and P / wet)
The windings of KRT motors are protected by a temperature monitoring circuit. Two bimetal switches connected in series or three PTC thermistors connected in series monitor the temperature. They trip the pump when the permissible winding temperature is exceeded and automatically re-start the pump once the windings have cooled down. For this purpose they have to be wired directly into the control circuit of the motor contactor.

Winding temperature monitoring with explosion protection (installation types S and P / wet)
Explosion-proof KRT motors have to be monitored by two independent temperature sensors in the winding.

- Two bimetal switches connected in series monitor the temperature. They trip the pump when the permissible winding temperature is exceeded and re-start it automatically once the windings have cooled down. The bimetal switches protect the motors against overloading and dry running.
- In addition, three PTC thermistors connected in series (with a tripping temperature 20 Kelvin above the maximum winding temperature) are fitted. In the event of a failure of the bimetal temperature sensors, these additional thermistors will trip the pump before the permissible temperature limits for explosion protection at the surface of the motor housing are exceeded.



Enlarged view in the appendix

Fig. 3.5: Tripping curve for class 10 thermal time-lag over-current trips to EN 60947-6-2

For explosion-proof KRT pumps the additional thermistors must be connected and fully functional. Automatic reset and start-up is not permitted. For this purpose a commercially available thermistor trip device with manual reset must be integrated in the control circuit of the motor contactor.

The winding temperature of dry operated submersible motor pumps (installation types K and D) is exclusively monitored by PTC thermistors.

Moisture protection of the motor

A conductive moisture sensor is fitted to check the motor space for integrity. If any moisture penetrates into the motor space a current will flow through the sensor to the earth conductor. The sensor can be combined with any commercially available electrode relays which trigger an alarm when the electrode resistance falls below 6 kΩ.

For small pumps, a commercially available 30 mA FI RCD can be used as an alternative.

Bearing temperature monitoring

The temperature of the motor bearings is monitored as follows, depending on the motor size:

- Motor rating > 30 kW: monitoring of pump-end fixed bearing optional
- Motor rating > 60 kW: monitoring of pump-end fixed bearing as standard, monitoring of motor-end radial bearing optional

Each monitored bearing is protected by a temperature monitoring circuit (Table 3.2). The temperature is monitored by PT100 temperature sensors installed in the bearing housing. The sensors change their resistance proportionally with temperature.

Calculation formula:

$$R = 100\ \Omega \cdot \left(1 + 0.00383 \cdot \frac{T}{°C}\right) \qquad (17)$$

Monitoring of mechanical seals

The mechanical seals of motors with ratings > 60 kW are monitored as standard. An integrated float switch (NC contact) opens when water penetrates into the leakage chamber as a result of defective mechanical seals. The contact may either trigger an alarm signal or shut down the motor. The NC contact is suitable for a maximum of 250 V a.c./ 1.5 A.

Monitoring of the vibration velocity

Motors with a rating of 60 kW and above can be fitted with a sensor at the upper bearing to monitor the effective vibration velocity. The sensor transmits an analog 4 –20 mA measuring signal. It must be supplied with a voltage of 15 to 32 V d.c.

For KSB submersible motor pumps with multi-vane impellers (K impellers) observe the limits in Table 3.3.

On submersible motor pumps with single-vane impeller (E impeller) higher vibration velocities of up to 17 mm/s can be caused by hydraulic imbalance, depending on the operating point. Pumps of this variant are always fitted with a shielded control cable.

Table 3.2: Bearing temperature monitoring

20°C	107.7 Ω	Test
110°C	142.1 Ω	Warning
130°C	149.8 Ω	Stop
Special lubricant		
130°C	149.8 Ω	Warning
150°C	157.0 Ω	Stop

Table 3.3: Vibration velocity limits for submersible motor pumps with multi-vane impellers

Vrms	Vrms	Vpeak	Output current	Comment
mm/s	inch/s	inch/s	mA	
0	0.00	0.00	4.0	Sensor min.
9	0.35	0.50	11.2	Preferably lower
11	0.43	0.61	12.8	Alarm
14	0.55	0.78	15.2	Stop
20	0.79	1.11	20.0	Sensor max.

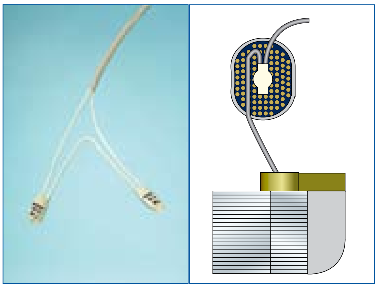
(Also see EUROPUMP-Leitfaden / Schwingungen bei Kreiselpumpen [Europump Guidelines / Vibrations of Centrifugal Pumps], Table A.1 / Flexible installation, vertical)

3.11

Connection and description of monitoring equipment

Thermal motor monitoring

Brief description of the sensors



20 21
21 22

Bimetal switch

- Temperature-sensitive miniature contact
- Glued into the motor winding
- Volt-free NC contact, 250 V ~, 2 A

Closed	Temperature O.K.
Open	Temperature too high

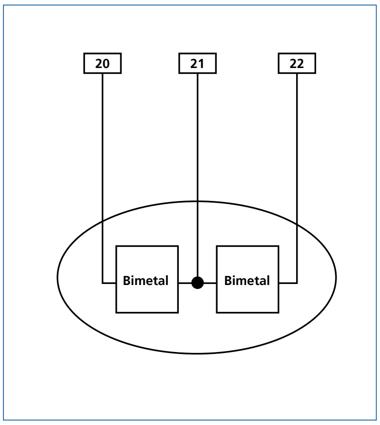
10 11

PTC thermistor

- Temperature-dependent semiconductor resistance with positive temperature coefficient
- Glued into the motor winding
- Maximum voltage 30 V

R < 1250 Ω	Temperature O.K.
R > 4000 Ω	Temperature too high

Connection for motor ratings up to 4 kW
(For submersible motor pump type Amarex N only)



20 21
21 22

Motor version U / W
No direct connection to the control circuit required; connect to dummy terminal

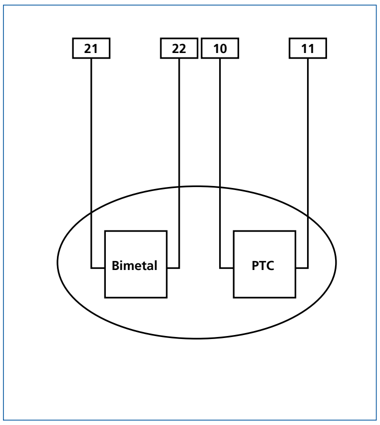
20 21
21 22

Motor version Y
ATEX

To be wired directly into the control circuit

Connection via thermistor tripping unit with manual reset

Sensors for motor ratings > 4 kW
(installation types S and P)



20 21
10 11

Motor version U / W / UN / WN
No direct connection to the control circuit required; connect to dummy terminal

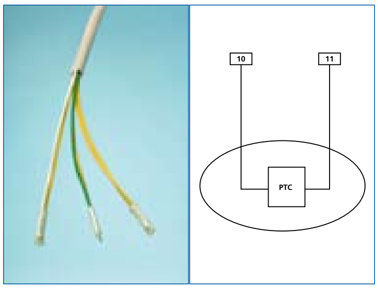
20 21
10 11

Motorversion X / Y / XN
ATEX

To be wired directly into the control circuit

Connection via thermistor tripping unit with manual reset

Connection for motor ratings > 30 kW
(installation types K and D)



10 11

Motor version UN
Connection via thermistor tripping unit with manual reset

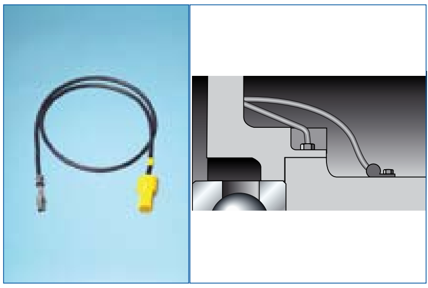
10 11

Motor version XN
ATEX

Connection via thermistor tripping unit with manual reset

Monitoring by moisture protection electrode (in the motor space)

Brief description of the sensors

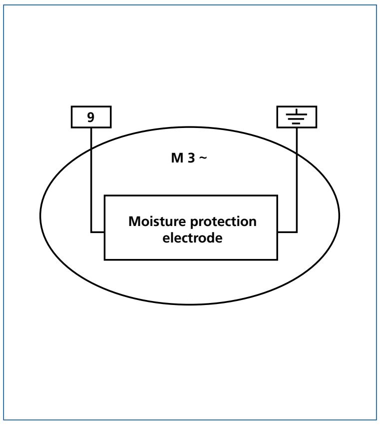


9 MP

Leakage sensor
Conductive sensor
Screwed to the lower bearing bracket
For motors >65 kW additionally at the upper bearing bracket
A.c. voltage sensors shall be used to prevent the formation of insulation layers.
Maximum voltage 250 V

To be triggered at a leakage resistance of approximately 6 kΩ.

Connection for all motor types



9 MP

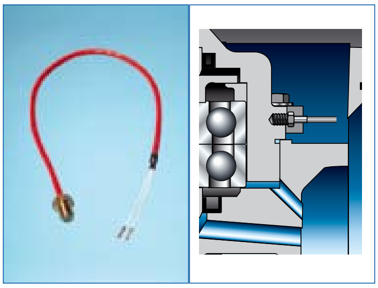
Motor version U / X / Y / W / UN / XN / WN
With and without ATEX

Connection to an electrode relay with the following parameters

Sensor circuit	10 - 30 V~
Tripping current	0,5 - 3 mA

Thermal bearing monitoring

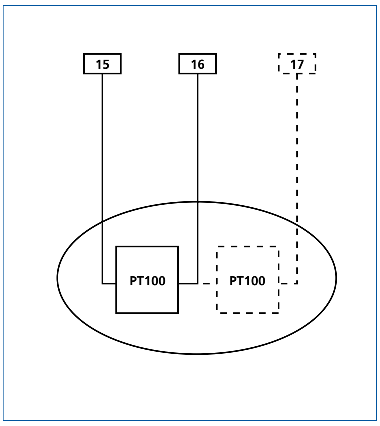
Brief description of the sensors



PT100 – ball bearing
PT100 resistance thermometer
M8 thread in the bearing housing
Analog, continuous temperature signal
Maximum voltage 6 V

15	16	Lower bearing
16	17	Upper bearing (motors >65 kW optional)

Connection for motor ratings
> 30 kW



15 16
16 17

Motor version U / X / Y / W
With / without ATEX

Connection to a PT100 switching relay with the following parameters

Alert temperature:	110°C
Cut-out temperature:	130°C

15 16
16 17

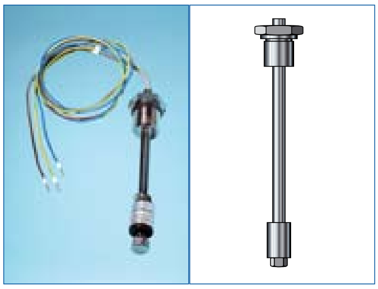
Motor version UN / XN / WN
With / without ATEX

Connection to a PT100 switching relay with the following parameters

Alert temperature:	130°C
Cut-out temperature:	150°C

Monitoring of mechanical seal with float switch

Brief description of the sensors

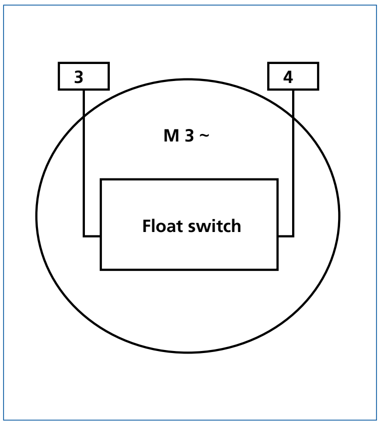


3 4

Float switch
Volt-free NC contact, 250 V ~, 2 A

Closed	Leakage chamber empty
Open	Leakage, check mechanical seal

Connection for all motor types



3 4

Motor version U / X / Y / W / UN / XN / WN
With / without ATEX

Connection for alarm and cut-out

3.12

Power and control cables with cable entry

Amarex KRT submersible motor pumps are supplied fitted with flexible cables suitable for use in waste water. The special cable glands are connected in the motor as follows:

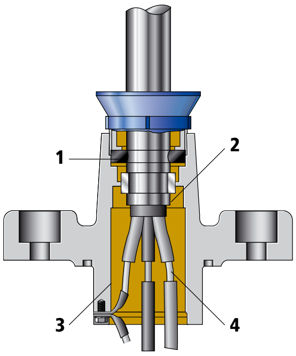
- For motor ratings < 60 kW with plug-type connections or crimp connections
- For motor ratings > 60 kW with terminal board and cable shoes

Cable gland
The cable glands are absolutely water-tight when submerged up to 30 m with multiple safety provided (Fig. 3.7):

1) Long rubber gland
2) Resin-embedded cable sheath
3) Individual cores stripped, tinned and sealed in resin

The power and control cables are suitable for use in waste water and are of especially high mechanical strength.
Depending on the operating conditions the following cable types are available for selection:

- S1BN8-F / standard
- S07RC4N8-F / shielded version optional
- Tefzel with ETFE cable sheath / optional for chemically aggressive fluids



1 Long rubber gland
2 Outer cable insulation
3 Individual core insulation sealed in resin
4 Individual cores stripped, tinned and sealed in resin

Fig. 3.7: Cable gland of a KRT

For the number of conductors and cross-sections refer to the project documentation or motor data sheet, or request details.

Benefit:
Long service life of the motor due to an absolutely waterproof design (also see the section 'Shaft seal'). Only high quality flexible cables are used for submerged operation to ensure reliable continuous operation of submersible motor pumps and a long service life. Together with a renowned cable manufacturer KSB has developed cables optimised for waste water applications.

3.13
Power cables

Technical data

Finely stranded class 5 copper conductors to DIN VDE 0295

EPR insulation

Inner sheath made of rubber

Special outer sheath made of synthetic rubber, colour: black

90°C	Continuously permissible conductor temperature
200°C	Permissible conductor temperature with short circuit (up to 5 seconds)
	Fire protection to DIN EN 50265-2-1
	Resistant to UV radiation, weather and ozone
	Oil resistant to DIN VDE 0473-811-2-1, part 10
	Flexible
0	Laying and transport temperature: -25 to + 80 °C
V	0.6/1 kV: green/yellow conductor identification
	For application in water / not drinking water

Brief description

OZOFLEX (PLUS) S1BN8-F rubber-sheathed cables have been developed for KSB's standardised and explosion-proof pumps. They are designed to flexibly connect KSB submersible motor pumps up to a cable cross-section of 50 mm².

Given the variety and changing composition of waste water the cables must only be used in easily accessible and controllable areas.

If aggressive water or water of special composition is handled, the resistance of the cables must be checked in each individual case.

The cables can be used indoors, outdoors, in potentially explosive atmospheres, in areas with a high fire risk, in industrial plants, in commercial and in agricultural facilities.

The regulations stipulated in DIN VDE 0298-300 must generally be observed.

Design based on DIN VDE 0828-16

VDE Reg. No. 7586

3.14

Tefzel cable (TEHSITE)

Technical data

Finely stranded class 5 copper conductors to DIN VDE 0295

TE400 insulation

Inner sheath made of silicone

TE-400 outer sheath, colour: black

135°C	Continuously permissible conductor temperature
270°C	Permissible conductor temperature with short circuit (up to 5 seconds)
	Fire protection to DIN EN 50265-2-1
	Resistant to UV radiation, weather and ozone
	Oil-resistant / general chemical resistance
	Flexible
V	450/750 V: green/yellow conductor identification
	For application in water / not drinking water

Brief description

TEHSITE cables (TEFZEL) are resistant to heat and chemical components. They are designed to flexibly connect KSB's submersible motor pumps if the temperature of the fluid handled and/or the ambient temperature exceed 60 °C or if high chemical resistance is required.

The scope of application is defined in the corresponding VDE report of 30 November 1983 and its amendment of 14 October 1987.

Due to their design and materials TEHSITE cables are less flexible than rubber-sheathed cables.

The regulations stipulated in DIN VDE 0298-300 must generally be observed.

Design based on DIN VDE 0828-16

3.15
Shielded rubber-sheathed cable

	Technical data
	Finely stranded class 5 copper conductors to DIN VDE 0295 EPR insulation Inner sheath made of rubber Braided shield made of tinned copper wires Special outer sheath made of synthetic rubber, colour: black
90°C	Permissible conductor temperature
250°C	Permissible conductor temperature with short circuit (up to 5 seconds)
	Fire protection to DIN EN 60332-1-2
	Resistant to UV radiation, weather and ozone
	Oil-resistant to DIN EN 60811-2-1
	Flexible
	Laying and transport temperature: -25 to + 80 °C
V	450 / 750 V: green/yellow conductor identification
	Application in water / not drinking water DIN VDE 0282-16 HD 22.16

Brief description

OZOFLEX (FC+) S07RC4N8-F rubber-sheathed cables have been developed to flexibly connect submersible motor pumps to frequency inverters. They meet the requirements of the EMC directive and can be supplied up to a cable cross-section of 50 mm².

Given the variety and changing composition of waste water the cables must only be used in easily accessible and controllable areas.

If aggressive water or water of special composition is handled, the resistance of the cables must be checked in each individual case.

The cables can be used indoors, outdoors, in potentially explosive atmospheres, in areas with a high fire risk, in industrial plants, in commercial and in agricultural facilities.

The regulations stipulated in DIN VDE 0298-300 must generally be observed.

Design based on DIN VDE 0282, part 16

3.16

Quality assurance and test logs

Standard routine test

Standard routine tests of KRT motors are conducted to KSB’s works standards, which comprise:

- Winding resistance test
- Insulation resistance test
- High-voltage test on the winding
- Earth conductor check
- Check of monitoring devices
- No-load current
- Direction of rotation check

Sample type test

In addition to the above routine tests a type test composed of the tests listed below is conducted for one sample of each motor type in accordance with the works standard:

- Measurement of winding resistances
- Motor temperature rise test to DIN EN 60034
- Short circuit test to determine the starting current at reduced voltage (alternative DOL starting with oscillographic measurement)
- Efficiency determined by the loss summation method to DIN EN 60034

Optionally, pumps can be supplied with a so-called 2.2 certificate of a motor of the same design.

4.
Piping and Valves

General

Detailed planning is a prerequisite for proper installation and maintenance, trouble- free operation and a high availability of technical equipment. This also applies to the piping and valves within and outside the pumping station.
The discharge lines transport the fluid handled from the pump to the pumping destination.
The pump and discharge line should be seen as a technical/ hydraulic unit. Correlations of this unit can be graphically illustrated as pump and system characteristic curves, also referred to as pipe characteristic curves.

We will refer to the piping inside the pumping station as inner piping. The discharge lines outside of the pumping station right up to the actual discharge will be referred to as outer discharge lines

In general, the inner piping of a pumping station consists of suction lines and discharge lines. Suction lines do not apply to submersible waste water motor pumps which are generally operated as a stationary wet installation, like the KRT.

In the field the outer discharge lines are also called waste water discharge lines or transport lines. They are usually laid underground in frost free conditions. When planning the piping layout extreme high and low points should be avoided in the waste water discharge lines, if possible. If any constraints require such high and low points, additional technical measures must be taken, such as fitting flushing connections and drains at low points, and vent valves at high points.

To reliably transport municipal waste water a free passage of 100 mm is recommended through the pump impeller, the valves and the discharge line. The inside diameter of the piping should measure 80 mm as a minimum.

4.1
Planning the piping

4.1.1
Piping

4.1.1.1
Dimensioning

Starting parameters for the dimensioning of discharge lines:
- Flow rate
- Operating pressure

The dimensioning or calculation of the inner (nominal) diameter depends on the:
- Flow velocity

If the nominal diameter is known, the following parameters can be calculated for a specified flow rate:
- Head losses or pipe friction losses
- Head loss of the piping

The formula “geodetic head + head losses = manometric head” can be used to determine the
- Operating pressure

A transient flow analysis can be used, if required, as an approach to calculate the operating pressure, nominal pressure and conduct static calculations of the pipes (see the relevant section below for further details).

This section explains the selection parameters in further detail.

Determining the flow velocity and selecting the nominal diameter

Based on the required or planned flow rate, the nominal diameter is directly dependent on the flow velocity. The pipe friction losses can be derived from the flow velocity.

From an economic point of view (investment and operating costs) the following aspects need to be taken into account when specifying the flow velocities and nominal diameters of the pipes.

Flow velocities below the specified minimum can lead to failures (clogging, etc). Flow velocities above the specified maximum can also lead to operational failures. In addition, they generate high pipe friction losses, consuming unnecessary energy.

Nominal diameter / inside diameter of the pipes

The nominal diameter of the discharge line can be derived from the maximum planned flow rate, the piping length and the fluid handled with consideration of the reference values mentioned above. The selection of an optimum nominal diameter should be based on a profitability analysis, i.e. the investment costs should be compared to the operating costs and the energy costs in particular. Small nominal diameters with high flow velocities will cause high flow losses in longer pipes. As a result, pumps with a higher head and higher pump input power (Fig. 4.1.1.1a) will be required.

The nominal diameter of the pipes should be equal to or greater than the nominal diameter of the corresponding pump connection.

For small pumping stations the pumps must not only be dimensioned for the inflow; resistance to clogging and the minimum speed also have to be considered. If the recommended flow velocity in the vertical discharge line is not reached, measures should be taken to prevent clogging (e.g. a flushing connection).

A special case is the drainage of individual properties (e.g. pumped drainage) that are to be connected to a central waste water system. If pumps with cutters are used smaller diameter pipes can be selected.

Enlarged view in the appendix

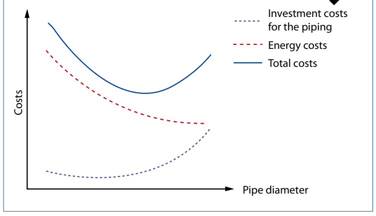


Fig. 4.1.1.1a: Cost structure for designing and operating a piping system

Flow velocities

Waste water pipes differ considerably from drinking water pipes as they need to reliably transport a large variety of substances and fluid compositions, including fibres, mineral solids of various sizes (sand, grit and stones) and organic contaminants.

For this reason, the minimum flow velocities must be observed. The following aspects need to be considered:

- Different flow velocities for vertical and horizontal pipes
- Inside diameter of the pipe, considering that larger diameters require higher flow velocities
- Fluid composition (analysis of fibre content, solids content and particle size)
- Operating mode of the piping (discontinuous or continuous)
- Total length of the piping

KSB conducted some research on the transport of substances contained in waste water at the Berlin Technical University. The results are documented in the diagram “Minimum flow velocities” (Fig. 4.1.1.1b). The nominal diameter range of DN 100 to DN 250 was examined in more detail and the nominal diameter range of DN 500 to DN 1000 was extrapolated. The substances in the fluid handled are those commonly contained in waste water, such as fibre, gravel 0/4, gravel 16/32 and granite gravel 2/5.

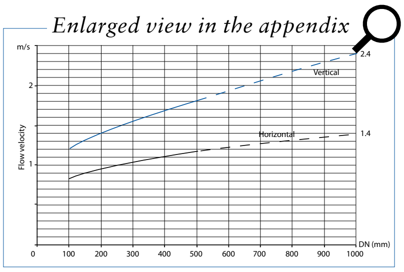
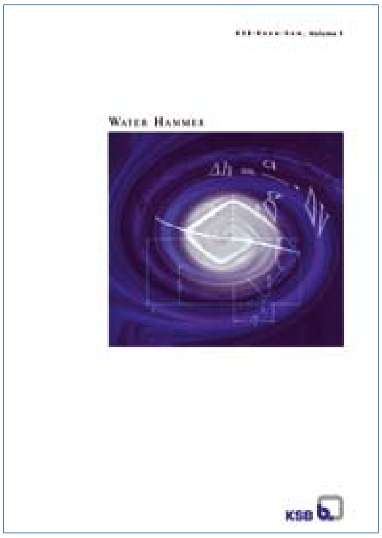

Enlarged view in the appendix

Fig. 4.1.1.1 b: Minimum flow velocities n

Surge analyses

In water supply and waste water systems any change in the operating conditions also leads to dynamic changes of pressure and flow. These transient processes in piping systems for the extraction, treatment, transport and distribution of water have to be taken into account and examined when planning a pumping station as they can cause significant damage to pipes, valves and other internal parts. Transient operating conditions can have many causes and are generally unavoidable. They can be the result of pump failure, start-up or shutdown of pumps, cutting in or cutting out of pumps in addition to already operating pumps, also of variable speed pumps or of closing/opening valves, control valves, pressure-reducing valves, etc. Given the complexity of surge pressure, the use of the numerous proximation’ calculation methods should be avoided as their scope of validity is very limited and cannot be applied in general. The use of such methods outside their scope of validity can lead to significant dimensional errors.



In this context we would like to refer to the DVGW booklet, technical rules, worksheet W 303 “Dynamic pressure variations in water supply systems” and to the KSB Know-how volume 1 “Water Hammer”. We recommend consulting experts in this field to assess the surge pressure and define preventive measures.

Static calculation of the piping

The pipes must be able to continuously and reliably withstand the internal and external pressures acting on the system. This includes the pressures of transient processes (e.g. surge pressure), unless preventive measures have been taken.

For calculating, the required wall thickness of the piping the required pressure class, the external loads and the material must be considered.

Check the necessity of conducting a static calculation of the pipes for each project. The static calculation of the piping comprises:

- Primary loads (internal pressure, weight of pipe/valves/water fill)
- Secondary loads (stresses or forces caused by the impacts of temperature differences in relation to the design temperature)
- Occasional loads (for example wind, ice, snow)
- Dynamic loads
- Stress analysis
- Vibration behaviour (showing excitation and natural frequencies)
- Earthquake stability

The calculation helps determine, for example:

- Required pipe wall thickness for the selected material
- Forces and moments for planning the construction or supporting structures (for wall penetrations, foundations and other fastening points)
- Type (fixed bearings, plain bearings, guides) and position of pipe fixtures
- Forces and moments for pipe fixtures (bearing loads for fixed bearings, plain bearings, guides)
- Design details for pipe fixtures (selection of fixed bearings, plain bearings, guides)

Note:
Secondary loads (forces and moments), also called “thermal loads”, are often larger than primary loads (weight and pressure), especially if the piping is rigidly connected between two anchorage points. This often leads to the permissible force limits in parts of the structure (e.g. wall ducts) being exceeded. Additional preventive measures must be taken, such as fitting bellows or other expansion joints.
The piping layout can also be adjusted to reduce stresses and forces. In a straight piping layout between two wall penetrations the pipe cannot “give way” unlike an angled piping layout, where stresses and forces are much lower.
It is also important to properly select and arrange plain and fixed bearings as well as guides.

4.1.1.2
Piping layout

Inner piping

For installation in the pump sump the submersible waste water motor pump is supplied with a duckfoot bend, a guide arrangement (guide wire or guide rail) and a lifting chain or rope.

The discharge line is connected to the duckfoot bend which is fastened to the floor of the pump sump. The discharge line consists of a vertical riser with a horizontal discharge line branching off. If the pumping station consists of several pumps with the same pumping destination, each pump has its own discharge line. For longer pipe lengths the individual discharge lines are united in one or several collecting discharge lines (sometimes called the discharge manifold).

The discharge line coming from the pumping station should be laid with a rising slope towards the discharge (termination).

If the topographic conditions require the piping to be laid with distinct high and low points, air could collect at the high points, or sediments could accumulate at the low points. If this is the case the flow velocity needs to be checked. Air accumulation leads to increased pressure losses. This could reduce the volume flow rate of the pump and its self-venting capacities might need to be looked at.

If self-venting is restricted or excluded vents and aerators must be fitted at the high points and drains and flushing connections at the low points. Aerators and vents are also effective vacuum breakers, should an undesired and uncalculated siphon effect occur.

The valves are either arranged vertically in the risers in the pump sump or horizontally in a separate valve pit.

Fig. 4.1.1.2 a: Valve pit

Fig. 4.1.1.2 b: Valve chamber

When installing the valves in the risers, install them in the upper part of the pump sump. Benefit: The valves are more easily accessible and the risk of solids depositing on the check valve is reduced. If the valves are installed in a lower position a minimum distance to the duckfoot bend must be observed otherwise air pockets could lead to problems when starting up the pump. When installing the shut-off valves make sure that the position of the operating elements (e.g. handwheel) allows the pump to freely draw in the fluid.

Risers above the swing check valve should be kept as short as the site conditions allow to prevent possible solid deposits. Risers must always be integrated into the collecting discharge lines (discharge manifold) in the horizontal axis. Their integration should be designed to be as hydraulically optimised as possible. Depending on the site conditions, saddle connections, weld-in elbows, Y-pipes and specific connecting angles can be used (Fig. 4.1.1.2 c).

Fig. 4.1.1.2 c: Integration of the individual discharge lines in the direction of flow

If the cross-section needs to be increased, select suitable expansion tapers (referred to as “reducers” in piping contexts). Choose the smallest possible diffuser angle. In the riser use eccentric reducers to allow the pump to freely draw in the fluid.

If an absolutely tight seal is required to guide the discharge line through the wall of the structure, a flanged wall pipe (sometimes referred to as a puddle flange) or a flexible wall duct can be used. When sealing the wall penetration with a modular seal, make sure that the pipe is correctly centred and fastened in the opening.

Expansion and dismantling joints or bellows expansion joints should be installed in the piping as required to allow for proper installation without stresses or strains, compensation of length tolerances and dismantling for any repair work. These tasks can usually also be covered by flanged pipe bends installed in a suitable position in the piping layout.

The number of flanged connections should be kept to a minimum to facilitate assembly and repair of the piping. Provide the required flanged connections for repair and to install prefabricated piping units. Keep welding at the site to a minimum. Select suitable flanged connections for the fluid handled, the chosen pipe material and the maximum system pressure. Gaskets of DN 200 and larger should be selected with a steel insert. When using fasteners made of stainless steel, use bolts of quality V2A and hexagon nuts of quality V4A.

If space is at a premium, the collecting line can also be installed outside the civil structure.
A separate structure for the gate valve structure (also referred to as valve chamber or valve pit) might be a useful option for space or operating reasons (Fig. 4.1.1.2 a + b).

If high points in the pumping station cannot be avoided, a venting option must be provided. Waste water treatment plants should generally be fitted with a vent as gas emissions are to be expected. If the external piping is laid with a downward slope, an automatic aeration and vent valve should be fitted at the highest point of the pumping station. If switching off the pump causes a siphon effect, start-up problems of the pump caused by entrapped air cannot be excluded.

If required, provide drain options and flushing connections (e.g. nozzle, ball valve or Storz coupling with blind cap).

If the pumping station is to be installed as an open structure (tank), frost protection measures must be taken as necessary.

Outer piping

The outer pipes must comply with the legal requirements and the recommendations of the specialist associations (see ATV worksheet 134). Significant high points must be vented. Air pockets in the pipes can lead to reduced flow rates and operating faults such as sudden valve closure and vibrations in the piping.

Note:

The problem of deposits must be taken into account when planning to fit a pipe joint at the transition from the inner to the outer piping, which is the point immediately upstream of the outer wall.

4.1.1.3
Pipe fasteners / brackets

General

Pipe fasteners/brackets:

- Double pipe clamps
  - with floor support
  - with wall bracket
  - suspended from the ceiling
- Saddle bearings with and without pipe clamp
- Special structures

With the static calculation of the pipes in mind, fixed bearings or plain bearings should be selected for the pipe brackets.

Fasteners / brackets in KRT pumping stations

The risers are directly and tightly fastened to the duckfoot bends. The duckfoot bend is used as an anchorage point within the load limits indicated by the manufacturer. Duckfoot bends are designed for higher permissible vertical forces, as indicated, to handle the weight of the pipes. The weight of the riser pipe can usually be accommodated by the duckfoot bend. The permissible forces and moments must be observed also during operation.

Pipe brackets should be closely spaced and particularly stable. The fasteners should be suitable for the weight of pipes and fluid. They should also prevent any impermissible loads (forces and moments) at the connecting points as well as any impermissible vibrations.

Impellers with a small number of vanes which are fitted in waste water pumps cause a pulsation of the fluid.
Excitation frequency =
speed x number of vanes

The most critical hydraulic “vibrations” occur in pumps with single -vane impellers. The excitation frequencies equal 25 Hz at 1500 rpm, and 17 Hz at 1000 rpm.

The natural frequencies of steel pipes often fall within this range.

Pulsation in the flow causes the discharge line of the pump to vibrate. Resonance must be avoided and occurs when the excitation frequency of the pump equals the natural frequency of the piping. Resonance will lead to maximum vibration amplitudes and very high forces acting on the bearings (supports).

To reliably rule out resonance make sure that these two frequencies differ from each other by at least 10 % of the excitation frequency.

The excitation frequency can usually not be changed (as this would mean changing the pump speed by more than 30 %).
For this reason it is the natural frequency of the pipe which has to be adjusted.

The natural frequency of the piping depends on:

- The mass distribution within the system (valve position, wall thickness, material)
- The bracket concept

The bracket concept influences the natural frequency decisively. Unfavourable natural frequencies can be adjusted by changing the position of or adding individual bearings (supports) preferably near valves, outlets, etc. The position of large individual masses (valves) also has an impact on the natural frequency.

The exact bearing (support) positions and their natural frequencies can only be determined by a special static calculation of the pipes.

To a lesser extent the natural frequency can also be influenced by the wall thickness. Thicker walls cause higher natural frequencies than thinner walls assuming the same pipe material (elasticity) and excitation.
The vibration forces acting on the bearings (supports) can be derived from the harmonic excitation.

The natural frequencies can only be determined by a static calculation of the pipes. Select robust pipe brackets which are able to safely transmit the forces to the structure.

4.1.1.4
Wall ducts

If pipes are to be laid through internal and external walls of the civil structure, one of the following two types of wall ducts must be used.

Rigid wall ducts

Rigid wall ducts consist of the pipe transporting the fluid (wall pipe) and a puddle flange which is welded on to the pipe in the centre of the wall penetration and integrated into the wall. This type of wall duct serves as an anchorage point. Determine the forces at this point by means of a static calculation of the pipes and verify them against the permissible forces for the structure. Rigid wall ducts can be designed as either:

- Wall pipes with weld ends
- Wall pipes with flanged ends

Wall pipes with weld ends need to protrude from the wall cladding. In special cases, wall pipes can be retrofitted in a wall penetration. In this case, they need to be grouted with a second concrete pour. If this option is chosen, discuss the structural details with the construction consultant. Wall pipes with flanged ends can be either flush with the wall or protruding from the wall. When wall pipes are fitted flush with the wall, their installation between wall reinforcement and wall cladding requires utmost precision regarding the height of the pipe axis and the horizontal alignment of the pipes.

Flexible wall ducts

A flexible wall duct is composed of a pipe sleeve with puddle flange; the pipe containing the fluid handled is guided through this flexible wall duct. The space between the pipe sleeve and the fluid pipe can generally be sealed by either:

- Modular seals, or
- Compression-type gasket inserts

Instead of using a pipe sleeve a core hole can be drilled into the reinforced concrete wall. Core holes are uncommon for larger diameters. If axial thrust has to be prevented when using flexible wall ducts, a pipe bearing/bracket must be fitted as an anchorage point (axial thrust protection) in a suitable position upstream of the wall duct.

4.1.1.5
Pipe materials

The pipes within the pumping station should preferable be made of steel. With consideration of corrosion resistance the steel pipes are designed with thick walls and either coated (e.g. hot-dip galvanised or a coating system) or made of stainless steel (material number 1.4571 / V4A). When using cast pipes, the availability of fittings and the weight have to be taken into account.

For any other materials, e.g. plastic, especially when used for industrial waste water, particular attention should be paid to providing sufficient pipe fasteners and separate supports for fittings such as valves.

Pipe materials for the inner piping:

- Steel (e.g. coated or galvanised)
- Stainless steel (e.g. 1.4301 or 1.4571)
- PE-HD
- Cast (bitumen or EKB coated)

The selection of material for pipes outside of the pumping station depends on the local conditions (ground, corrosion), design criteria for the structure and piping technology as well as economic aspects.

Pipe materials for the outer piping:

- Cast (bitumen or EKB coated, lined with cement mortar)
- PE-HD
- GFRP
- Bitumen -coated steel
- Steel lined with cement mortar

A technically and dimensionally matching joint/adapter has to be fitted between the inner and the outer piping of the pumping station.

4.1.1.6
Fitting measuring devices in the pipes

Measuring devices have to be fitted in the discharge lines (usually the inner piping) in accordance with the monitoring and control concept.

Devices fitted directly in the piping
The only measuring devices which are generally fitted in the pipes are

- Magnetic-inductive flow meters (MID)

Devices fitted at or integrated in the pipes
Devices which are fitted at the pipes measure the following:

- Pressure (pressure gauge or transmitter)
- Flow (flow switch as dry running protection)
- Temperature (uncommon in waste water pipes)
- Flow measurements using ultrasonic sensors

Please note
In this context we would like to mention that in practice additional measurements are required for controlling the pumping station, such as the fluid level in the pump sump and possibly also at the outlet. These measurements are not linked with the piping system.

Notes on the position of MID measuring points
When fitting or positioning MIDs:

- Provide sufficient pipe lengths upstream and downstream of the MID to calm the flow. Observe the information provided by the corresponding manufacturer.
- Select the installation position in accordance with the manufacturer’s instructions. E.g. provide inverted siphons to completely fill the measuring section of devices which are unsuitable for partially filled pipes

Notes on the position of measurement points for pressure measurement, flow switches and ultrasonic measurement
Always select pressure measurement points on the sides of the pipe at the level of the pipe axis. Measurement points should always be located in pipe sections with a calm flow. Avoid measurement points at reducers, adapters, diversions, fittings, etc. Also avoid pipe inverts or crowns as contamination and entrapped air can lead to inaccurate results.

4.2
Selecting valves

4.2.1
General

Valves are a functional part of the piping system and required to implement the pumping process. They mainly fulfil the following functions:

- Shutting off and opening the pipe passage
- Preventing backflow
- Controlling the flow (problematic in waste water applications)
- Aerating and venting the piping

The valve industry offers the following valves for the above functions:

- Gate valves (wedge gate valves, slide gate valves), shut-off butterfly valves, globe valves
- Control gate valves (piston valves, spectacle valves, slide gate valves)
- Swing check valves (with lever and weight or with internal stem), check valves (with diaphragm or discs), ball check valves
- Aeration and vent valves of various designs

4.2.2
Selection criteria

Key criteria for selecting a valve:

- Fluid handled
- Compatibility of design and function with the fluid handled
- Compatibility of materials with the fluid handled
- Nominal diameter depending on the flow velocity and the resulting head losses

4.2.2.1
Fluids handled

When handling waste water the operating conditions depend on the type of waste water:

- Storm water
- Pre-screened surface water
- Industrial waste water
- Grey water without any stringy substances
- Domestic waste water with stringy substances
- Raw sludge
- Return sludge
- Excess sludge
- Clean waste water without contamination
- Service water

See the table “Suitability of valve types for types of waste water” (Fig. 4.2.3 a).

4.2.2.2
Valve design

The use of valves in waste water applications requires a design which is suitable for handling fluids contaminated with coarse or clogging material as well as abrasive and other substances. Such contamination requires the following design features, among others:

- Flow cross-section of the valves as clear as possible
- Clogging when the valve is actuated should be ruled out or largely prevented
- Suitable constructional features such as sealing design and material

4.2.2.3
Installation position and direction of flow

The direction of flow and the installation position often depend on the particular design of a valve. For swing check valves and all other check valves, for example, the design implies the direction of flow. In many cases valves are designed for either vertical or horizontal installation. Observe the manufacturer's information (e.g. installation and operating instructions) right from the planning stage.

4.2.2.4
Materials

Select suitable materials for the types of waste water described above. Materials are usually indicated by the valve manufacturers for each part, such as body, disc, seat, seal, shaft, nuts and bolts/screws, etc. Coated grey cast iron is suitable for surface water / storm water and municipal waste water. Electrostatic plastic coating is particularly suitable. Highly abrasive fluids require hard cast materials with a special coating. Choose suitable elastomers for the seals. EPDM and NBR are generally suitable for municipal wastewater. For industrial wastewater Viton (FPM) may be necessary.

Depending on the industrial waste water, stainless steel valves could be required. Always select materials for use with industrial waste water for each individual case, based on the information provided on substances contained in the fluid handled.

Valve manufacturers or distributors should always be informed of the substances contained in the fluid handled so they can match the valves to the operating conditions.

4.2.2.5
Nominal diameter

As with pipes the nominal diameter of valves depends on the flow velocities (see section 4.1.1.1). Usually, pipes and valves have matching nominal diameters. Please note that nominal diameters smaller than DN 80 are unsuitable for waste water applications.

When selecting the nominal diameter for a valve, pay particular attention to the head losses through the valve.
Swing check valves in particular can have such high loss coefficients that the next size up should be selected for the nominal valve diameter. The pipe selection has to be adjusted accordingly.

Table "Suitability of valve types for types of waste water"

Suitability of valve types for types of waste water

Valve type , Type of waste water	Storm water, pre-screened surface water	Industrial waste water, grey water without stringy substances	Domestic waste water with stringy substances, raw sludge	Return sludge, excess sludge	Clean water without contamination, service water
Shut-off valves					
Ball and plug valves					
Ball valve with reduced port	🟨	🟩	🟥	🟨	🟩
Ball valve with full port	🟩	🟩	🟩	🟩	🟩
Drain ball/plug valve	🟨	🟩	🟥	🟨	🟩
Ball/plug valve with tapered seat	🟨	🟩	🟥	🟨	🟩
Ball/plug valve with cylindrical seat	🟨	🟩	🟥	🟨	🟩
Globe valves					
Horizontal seat globe valve	🟥	🟨	🟥	🟥	🟩
Slanted seat globe valve	🟥	🟨	🟥	🟥	🟩
Angle globe valve	🟥	🟨	🟥	🟥	🟩
Annular piston valve	🟥	🟨	🟥	🟥	🟩
Gate valves					
Metal-seated gate valves					
Round body gate valve	🟨	🟩	🟨	🟨	🟩
Oval body gate valve	🟨	🟩	🟨	🟨	🟩
Slide disc valve	🟨	🟩	🟨	🟨	🟩
Wedge gate valve	🟨	🟩	🟨	🟨	🟩
Soft-seated gate valves					
Wedge gate valve	🟩	🟩	🟩	🟩	🟩
Slide gate valve	🟩	🟩	🟩	🟩	🟩
Penstock valve (sluice gate valve)	🟩	🟩	🟩	🟩	🟩
Shut-off butterfly valves					
Centred-disc butterfly valve	🟩	🟩	🟥	🟨	🟩
Offset-disc butterfly valve	🟩	🟩	🟥	🟨	🟩
Diaphragm shut-off valves					
Straight-through diaphragm valve	🟩	🟩	🟨	🟩	🟩
Weir-type diaphragm valve	🟥	🟨	🟥	🟥	🟩
Diaphragm pinch valve (hydraulic or pneumatic)	🟩	🟩	🟩	🟩	🟩
Diaphragm valve with annular diaphragm	🟥	🟥	🟥	🟥	🟩
Check valves					
Non-return valves					
Spring-loaded non-return valve	🟥	🟥	🟥	🟥	🟩
Foot valve with inlet and suction strainer	🟩	🟩	🟥	🟥	🟩
Nozzle check valve	🟥	🟥	🟥	🟥	🟩
Swing check valves					
Swing check valve with/without lever and weight	🟩	🟩	🟩	🟩	🟩
Multiple swing check valve	🟨	🟩	🟥	🟥	🟩
Slanted-seat swing check valve with/without lever and weight	🟩	🟩	🟥	🟩	🟩
Check valve	🟩	🟩	🟩	🟩	🟩
Ball check valve	🟩	🟩	🟩	🟩	🟩
Dual-disc check valve	🟥	🟩	🟥	🟥	🟩
Wafer-type check valve	🟨	🟩	🟥	🟥	🟩
Diaphragm check valves					
Nozzle check valve	🟥	🟨	🟥	🟥	🟩
Diaphragm non-return valve	🟥	🟨	🟥	🟥	🟩
Other valves					
Discharge valve with float switch	🟥	🟨	🟥	🟥	🟩
Vent/aeration valve	🟩	🟩	🟥	🟥	🟩
Vent/aeration valve for waste water applications	🟩	🟩	🟩	🟩	🟩
Safety valve	🟨	🟩	🟥	🟥	🟩
Minimum flow valve	🟥	🟩	🟥	🟥	🟩
Discharge and end-fitting valve, backflow trap	🟩	🟩	🟥	🟥	🟩

Key
Not suitable 🟥
Partly suitable 🟨
Suitable 🟩

Fig. 4.2.3 a: Overview

4.2.4
Installation

4.2.4.1
Installation type

For the direction of flow and the suitability for vertical and/or horizontal installation, please refer to section 4.2.2.3.

4.2.4.2
Installation position

The installation position is determined by:

- The function of the valve
- Functional framework conditions
- Accessibility and operability

These three criteria are of equal importance when selecting an installation position for a valve. All of them have to be taken into account for an acceptable project solution.

Function of the valve
The first point to consider when selecting an installation position for a valve is its operational function.

The following examples serve to illustrate this point:

- The gate valve at the discharge side of the pump serves to close the pipe if the pump or swing check valve need to be repaired. It should ideally be located immediately downstream of the pump and swing check valve. However, the functional framework conditions (maximum fluid level in the pump sump) and the operability require a different (higher) position.

- The swing check valve should ideally be located directly downstream of the pump, as mentioned above. Again, the fluid level and accessibility demand a more practical location in the piping.

- The position of the aeration and vent valve should always be selected from an operational point of view, which is at the highest point of the piping. Suitable structures to provide accessibility must be provided.

Functional framework conditions
The installation position can be determined by functional framework conditions.
For example:

- Installation criteria provided by the valve manufacturer (vertical/horizontal)

- Routing of the discharge line

- If the discharge line has a long vertical section, the swing check valve must not be installed at a low position in the vertical pipe axis as the function of the swing check valve will be impaired by deposits of contamination (sand, stones, sludge). Stones falling back down onto the valve could also cause some direct damage. In this case, the swing check valve should to be fitted in a horizontal pipe section which has to be planned for in the piping layout.

- Maximum fluid level
- Individual discharge lines joining collecting lines

Accessibility and operability

Accessibility is a very important issue for the operators to ensure operability as well as access for maintenance and repair work. The applicable occupational safety and accident prevention regulations also need to be considered at the planning stage.

Operability and accessibility can generally be achieved as follows:

- Position the valve in a part of the structure which allows easy operability.
- Install ladders and platforms.
- Design the access structure to ensure easy operability and maintenance.

Suitable structural solutions for accessibility and operability:

- **Valve pits**

A prefabricated pit can be provided for the valves, so that they are separated from the pump sump. With the correct positioning of the access covers installation and replacement will be straightforward.

- **Valve chambers**

Valve chambers are a practical solution for large pumping stations with large nominal pipe and valve diameters. Valve chambers provide favourable working conditions as they accommodate the complete piping including individual and collecting (manifold) lines as well as all valves and measuring equipment.

4.2.4.3
Technical solutions for installing and removing valves

The initial design should provide ease of installation and possible later removal plus maintenance. The installation of expansion and dismantling joints next to valves or groups of valves should to be considered.

Installation without expansion and dismantling joints

If pipe bends are included in the piping upstream and/or downstream of the valve or valve group generally expansion and dismantling joints will not be necessary. Dismantling the pipe bend will make the corresponding pipe section accessible for valve replacement.

Installation with expansion and dismantling joints

In many cases the piping layout obstructs the fitting and dismantling of pipe elements and valves. If this is the case, expansion and dismantling joints should be installed next to the valve or valve group. Expansion and dismantling joints come with a length adjustment range to enable fitting and dismantling of the valve or valve group without transmitting any stresses and strains.

The main types of joints are:

- Expansion and dismantling joints with lockable length adjustment

This type of expansion and dismantling joint can generally be supplied:
- with continuous threaded rods
- with discontinuous threaded rods

- Expansion and dismantling joints without lockable length adjustment

Expansion and dismantling joints with discontinuous threaded rods are particularly installation-friendly as the joint length is very easy to adjust. Expansion and dismantling joints without lockable length adjustment can be used as expansion joints as well as dismantling joints.

Pipe coupling as a fitting / dismantling aid
Using a pipe coupling might be a straightforward solution. A pipe coupling is a steel collar which connects two pipe ends with a small clearance. For small to medium nominal diameters the clearance can be sufficient to allow fitting or dismantling a pipe section and to replace valves. Pipe couplings are available as “tension-proof” and “non tension-proof” models.

5
Structural Design

5.1
General

The structural requirements of a pumping station are largely determined by its purpose. Alongside purely structural and mechanical requirements consideration must also be given to hydraulic aspects (fluid dynamics) in the planning and execution of the construction work. The hydraulic areas to be designed start with the inlet upstream of the pumping station, followed by the pump sump contours if required and the actual pump(s) arrangement, ending with the discharge line or discharge system.

The pump manufacturers' aim is to specify in his technical product literature the dimensions (e.g. geometry of the structure) required for installing centrifugal pumps. These reference values are essential for the planning process, in particular for establishing the main dimensions of the pumping station. Successful planning of a pumping station is a complex task. Apart from specifications such as the minimum clearance between pumps and between pump and floor or the dimensions of the floor contour, the planning phase also encompasses the design of the area between the intake and the pump(s).

If the requirements regarding the dimensions, minimum fluid levels or geometry of hydraulic areas within the pumping station are not met, i.e. deviations occur during the planning or construction phase, proper functioning of the entire station can no longer be guaranteed. In such a case it is irrelevant whether these problems are caused by single or multiple deviations. The conditions for pump operation have not been met due to these modifications or deviations and the problems arising as a result are reflected in either the operating behaviour or the performance of the centrifugal pump.

If the pump manufacturer's specifications for the hydraulic and mechanical design aspects of the pumping station are taken into account in the overall layout at an early stage, malfunctions such as falling short of the required performance data or operating problems can be eliminated.

According to Prosser [5.1], the criteria for an unsatisfactory pumping station design can be clearly defined and assessed. Poorly performing pump sumps can arise from the following:

1) Undersized control gates and valves

2) Abrupt changes in flow direction (e.g. sharp corners)

3) Submerged high velocity flow areas (e.g. diffusers with an excessive angle of divergence)

4) Steep slope

5) Weirs with no provision for dissipating the energy of the falling fluid

6) Blunt pillars, piers and guide vanes

7) Any design or mode of operation which leads to asymmetric distribution of the flow in the sump

8) Sump inlet above fluid level

Items 1, 2, 3, 6 and 7 may cause swirls at the pump's inlet. Air-entraining surface vortices and submerged vortices may form in extreme cases (Fig. 5.1). Items 4, 5 and 8 can lead to air intake in the fluid handled, and items 3, 4 and 5 may cause transient flow conditions within the sump.

The purpose of a pump sump is to store fluid in order to provide good conditions for the flow approaching the pump. The following undesirable hydraulic conditions must be avoided:

1) Jets (high flow velocities) discharging into stagnant or slowly moving fluids (as these form large, transient eddies as downstream wakes)
2) Areas affected by flow separation
3) High flow velocities (v > 2 m/s)
4) Transient flows
5) Large surface waves
6) Free falling fluids

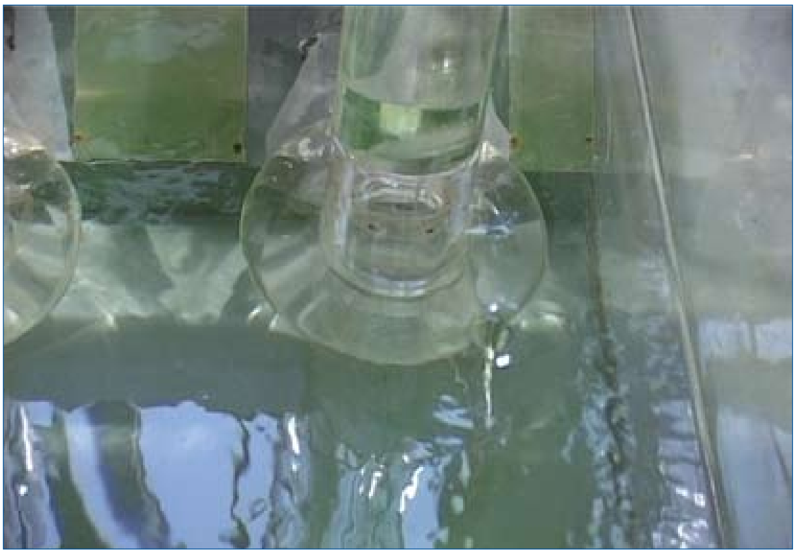


Fig. 5.1: Air-entraining vortex at a model pump

Observing the above criteria at the planning and construction stage is an important step towards creating a smoothly functioning pumping station.

KSB's dimensions compare favourably with those specified in the literature of other pump manufacturers and internationally recognised research institutions. The geometries suggested in KSB's type series booklets and software tools allow smaller pumping stations to be built, thus reducing building costs.

5.2
Screens

The installation of screening equipment is required for trouble-free pump operation. Depending on the type and origin of the fluid handled it is desirable to install coarse screens (the distance between bars should be between 5 and 30 cm) and/or fine screens (the distance between bars should be between 5 and 20 mm). Shingle traps should be mounted upstream of the screens, if needed. The screens and traps should be cleaned automatically during pump operation using appropriate mechanical equipment. In applications extracting surface water from rivers, lakes and canals as well as in storm water pumping stations the installation of screening equipment is an absolute must.

The fact that river water in particular contains shingle and sediment is often overlooked. Under conditions of long-term operation, however, failure to fit the appropriate screening equipment upstream of a pumping station will lead to sand accumulation and considerable sedimentation in stagnation zones at and within the structure. It further leads to increased centrifugal pump wear. Mechanical damage to the impeller and other pump parts cannot be ruled out.

The location of the screens in the pumping station concept is selected by the plant consultant. The screening equipment is either mounted upstream of the pumping station or pump sump to prevent coarse material from entering the structure, or single screens can be fitted at the individual pumps. A sufficiently large distance between the screen and the suction nozzle(s) of the pump(s) must be maintained as the screen slightly reduces the free cross-section and material trapped in the screen can lead to rather uneven flow downstream of the screen. If the screen bars are free from trapped material, the velocity distribution downstream of the screening equipment developing across the flow cross-section should be even and therefore favourable for pump operation.

When establishing the minimum fluid level t_1 in the pump sump, it is also necessary to take into account that a screen filled with trapped material creates flow resistance resulting in different fluid levels upstream and downstream of the screen. The fluid level downstream of the screen must not fall below the permissible minimum fluid level t_1 for the pump's operating point (Fig. 5.2 a).

Fig. 5.2 a: Screen with automatic cleaning system

A value of 0.3 to 0.5 times the impeller free passage should be used as a reference value to determine the permissible maximum distance between the screen bars. This value can be taken from the corresponding pump characteristic curve (see type series booklet or selection software).

To evaluate the screen's influence on the fluid level directly upstream of the pumps it is advisable to use Hager's simplified calculation [5.2], if a detailed screen selection procedure is not being undertaken (Fig. 5.2 b).

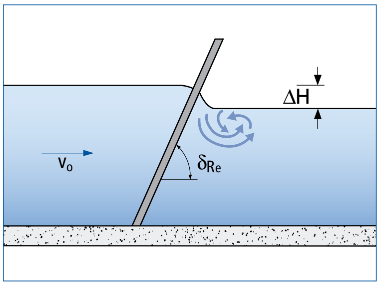


Fig. 5.2 b: Flow through screen, without lowered floor

Applying this calculation will result in the lowering ΔH of the fluid level downstream of the screen as expressed in the equation:

$$\Delta H = \xi_{RE} \times \frac{P1}{\eta_M} \qquad (18)$$

Here v_0 is the flow velocity upstream of the screen. The total loss coefficient $ß_{RE}$ is a function of the angle of inclination of the screen δ_{RE} in relation to the horizontal position as well as of the correction factor for the cleaning method c_{RE} and the coefficient ζ_{RE}. For a clean screen this correction factor is 1, with mechanical cleaning it ranges between 1.1 and 1.3 and with manual cleaning between 1.5 and 2. The coefficient ζ_{RE} comprises the shape of the screen bars and the ratios between the free flow area $\bar{a}$ and the area between the bar centrelines $\bar{b}$ (Fig. 5.2 c).

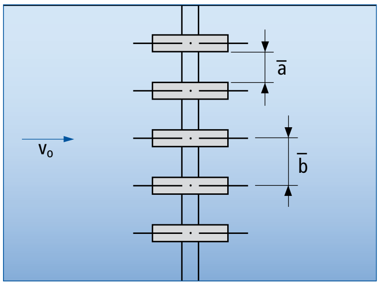


Fig. 5.2 c: Screen layout drawing

Hence:

$$\xi_{RE} = \beta_{RE} \times \zeta_{RE} \times c_{RE} \times \sin \delta_{RE} \qquad (19)$$

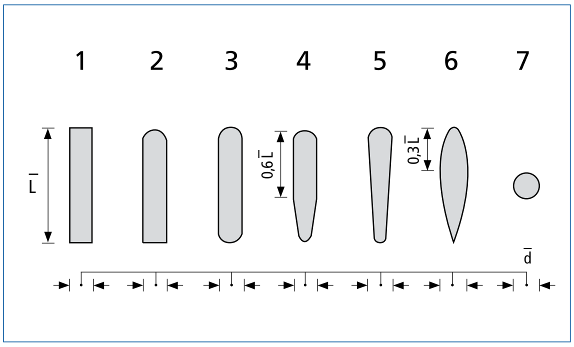


Fig. 5.2 d: Different shapes of screen bars

The following values can be assigned to the different shapes of screen bars (Fig. 5.2 d):

Form	1	2	3	4	5	6	7
$ß_{RE}$	1	0,76	0,76	0,43	0,37	0,3	0,74

$\bar{L}$ is the length of the screen bar profile, a is its width. If the ratio $\bar{L} / \bar{a} \approx 5$ and the condition $\frac{\bar{b}}{\bar{a}} > 0.5$ is met, the formula for ξ_{RE} can be simplified as follows:

$$\xi_{RE} = \frac{7}{3} \beta_{RE} \times \left[\frac{\bar{b}}{\bar{a}} - 1\right]^{\frac{3}{4}} \times c_{RE} \times \sin \delta_{RE} \qquad (20)$$

In order to compensate for the losses ΔH occurring as the flow passes through the screen, the floor of the intake structure or channel is often lowered by the value Δz downstream of the screen.
(Fig. 5.2 e):

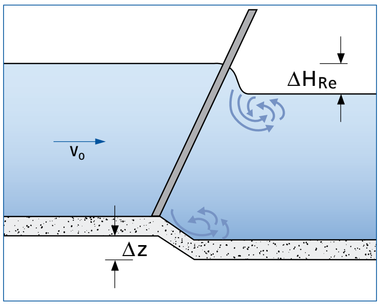


Fig. 5.2 e: Flow through screen with lowered floor

$$\Delta H = \Delta z \tag{21}$$

The values for losses through screens usually range between approx. 5 cm for mechanical cleaning to approx. 10 cm for manual cleaning

For detailed screen selection the method according to Idelchik [5.3, S. 504 ff] is recommended.

This method is most appropriate when the influence of oblique flow to the screen is also to be taken into account or if the screen bars are markedly different from those illustrated in Fig. 5.2 d.

Screens are often planned to be in the direct vicinity of the suction nozzle. The distance between the screening equipment and the suction nozzle should be at least Y = 4 x D for simple straight screens (D = outside diameter of the suction nozzle). The use of differently shaped screening equipment can lead to jet formation downstream of the screen. In this case the minimum distance should be Y = 6 x D to be verified in detailed model testing, if necessary.

Cleaning of the screen should preferably take place automatically. To activate the cleaning process it is possible to make use of the difference in fluid levels upstream and downstream of the screen. This ensures that the cleaning process is activated when required.

Manual cleaning is not favoured for pump systems in continuous operation as the fluid level has to be regularly checked and the screen cleaned by the operating staff. Timer controlled cleaning is not sufficiently reliable.

The decision on fitting a screen upstream of the pumping station or pumps and the required spacing of screen bars also needs to be checked against the impeller type and size as well as against the type of fluid handled.

5.3
Formation of scum in waste water pumping stations

Layers of scum frequently occur when operating waste water pumping stations. This process is caused by the substances contained in the waste water. Substances which are lighter than water rise to the surface and collect in areas with low flow velocities. Substances whose density is similar to that of water will initially be suspended. This suspended condition can, for example be changed by air intake caused by falling water. In this case small air bubbles will form a compound with the suspended solids. These compounds also rise to the surface. Substances whose density is considerably higher than that of water sink to the floor of the pump sump. Depending on the composition of the sedimentation flow velocities far exceeding the usual 0.7 to 0.8 m/s might be required to break the sedimentation [see section 5.5]. If the waste water remains in the inlet tank for a prolonged period of time and a surface layer of scum is formed, the waste water will be closed off from any oxygen supply. This will end the aerobic oxidation process and accelerate anaerobic digestion. The reaction products from the digestion process should be considered as very problematic. Hydrogen sulphide compounds are a particular nuisance. They are hazardous to health, flammable, corrosive and malodorous. Substances contained in waste water such as faeces, oils, greases, hair and other fibres contribute towards the formation of scum.

To prevent the formation of sulphides in waste water the oxygen intake at the boundary layer between air and waste water should equal the oxygen consumption. This condition will only be met if the waste water surface is largely kept free from floating solids or if the formation of a layer of scum is prevented by appropriate means.

Measures to prevent or reduce layers of scum:
- Prevent floating solids in the waste water, if possible.
- Critically assess the effects of waste water falling into in a pump sump.
- Manually remove any incrustations (with a high-pressure water jet).
- Coat the surfaces (prevent corrosion of concrete).
- Optimise (reduce) the period the waste water remains in the pump sump, maximum of 6 to 8 hours, with consid eration of the 24-hour load curve.
- Break any forming layers of scum by creating turbulences at the water surface (with flushing lines or mixers).

Fig. 5.3: Formation of a layer of scum in the pump sump

- Avoid using control systems to achieve a constant fluid level as it will create favourable conditions for the formation of layers of scum.
- Optimise the pump selection. If possible do not use pumps with cutters as cutters upstream of the pump will suppress suction-side turbulences. Also set the cut-out point to low flow operation as inlet recirculation will generate a good mixing process of the fluid in the sump.
- Define flushing cycles for the pump sump, using the installed duty pumps if possible.
- Optimise the pump sump geometry (smallest free surface in relation to the maximum sump volume).
- Make maximum use of the pump sump volume as a switching volume for the pumps.

Additional devices such as collecting devices for clogging material, mixers or screens always increase maintenance and investment costs. The proper disposal of any separated material also needs to be taken care of.

5.4
Installing benching in pump sumps

As waste water and surface water usually do contain solids, the transport of these solids should also be addressed when planning a pump sump.

When the fluid leaves the inlet line the flow velocity decreases. Depending on the velocity distribution in the structure sedimentation might occur. The pump or pumps cannot draw in sediment and transport it out of the structure together with the water.

If the structure has not been fitted with suitable slopes (benching), sedimentation will continue and can eventually change the flow through the structure and/or clog the pump(s). This situation can be prevented by fitting sufficiently large areas of sloping floor and/or benching (structures along the sides). The angles can vary depending on the surface finish of the structure. Angles of around 60 degrees are recommended according to worksheet ATV-DVWK-A 134. Please note that this will considerably increase the building costs as the structure will become much deeper for the same inlet tank volume. Smaller angles are sufficient if the surfaces are coated, which reduces the required depth of the structure (see recommendations by the Hydraulic Institute 9.8, 1998).

If the floor of the pump sump has a very flat design consideration can be given to providing a flow gulley (possibly by using internal fittings) to ensure sufficient flushing. Varying the cross-section at some points, for example, will increase the flow velocities so that solids/sediment are transported with the fluid. Rule of thumb: Fill all areas of low flow or no flow (dead volume) with concrete to generally prevent deposits.

To prevent any deposits in low-flow areas suitably designed benching can be used to close the area between the duckfoot bend of the pump and the wall of the structure (in the direction of the approach flow) (Fig. 5.4 a). When installing benching in this location, provide for later installation work around the duckfoot bend (allow enough space for aligning and bolting down).

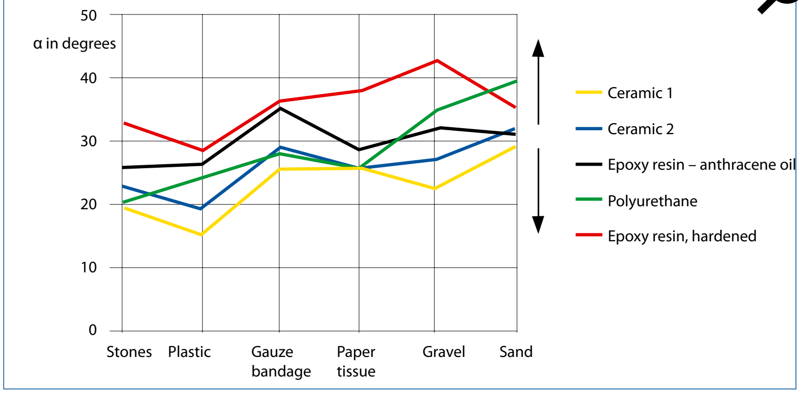
Coating the concrete contours not only improves the gliding behaviour of solids in the waste water, but also protects the structure against so-called concrete corrosion. This issue is of major significance, but will not be covered in further detail in this brochure.

KSB commissioned comprehensive research on this topic at the Berlin Technical University. The results demonstrate the impact of the inclination angle of variously coated benching on the gliding behaviour of individual substances contained in the fluid (Fig. 5.4 a).

Fig. 5.4a: Model for a waste water pumping station with benching and bottom flow splitters

If established flow velocities in the pump sump are assumed for Fig. 5.4 b, the inclination angle might be able to be reduced without any sedimentation forming in the floor area.

This would again influence the costs for the structure. A more precise prediction of the situation in the pump sump can be made by means of a CFD simulation (see section 5.11 'The significance of CFD simulations'). Surface deterioration (increased roughness) by solids contained in the waste water or increased gliding resistance (sticking) of greases and oils were not part of the research conducted. These factors have to be estimated depending on the local composition of the waste water.



Enlarged view in the appendix

Fig. 5.4 b: Gliding angle of various solids contained in waste water combined with various coatings (without considering the flow)

5.5
Splitters preventing submerged vortices

When installing pumps, unfavourable approach flow conditions can lead to the formation of submerged vortices, which have a negative effect on the performance or smooth running of the pumps. This can be taken care of at the planning stage of the pumping station: Fitting (bottom) flow splitters between the pumps will actively prevent the formation of such vortices (Fig. 5.5 a). Bottom flow splitters fitted underneath the suction cross-section (inlet) will directly influence the formation of vortices in the inlet flow. Flow splitters are intended to prevent the formation of submerged vortices between the pumps. The required geometric dimensions can be derived from the geometry of the selected pump size. The bottom flow splitters have to be fitted absolutely symmetrical in relation to the inlet section of the pump; otherwise the approach flow towards the impeller will be asymmetrical, causing well-known effects. Adjust the calculated dimensions to the shape of the pump sump or increase them, depending on benching and wall contours. This will reduce the occurrence of impermissible low flow velocities in the direct vicinity of the pump and prevent undesirable deposits.

Enlarged view in the appendix

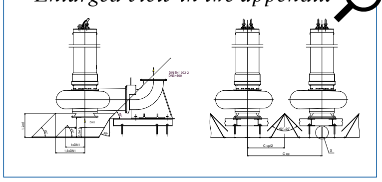


Fig. 5.5 a: Geometric design of (bottom) flow splitters

The flow splitters can either be made of concrete or of (stainless) sheet steel. An advantage of sheet steel fabrications is that they can be installed after the concrete work and pump installation has been completed. This makes it easier to fit the flow splitters symmetrically with regard to the suction nozzle of the pump.

The position of the flow splitters between the pumps is based on the minimum distances derived from the required maximum volume flow rates of the individual pumps (Fig. 5.5 b).

The visual asymmetry of this flow splitter arrangement can be ignored. It is caused by the offset position of the inlet section in relation to the volute-shaped pump casing.

Enlarged view in the appendix

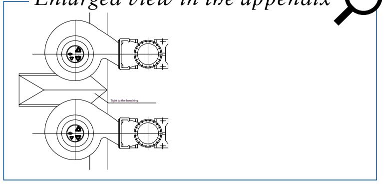


Fig. 5.5 b: Top view – flow splitter between two pumps

5.6
Dimensions for the pump sump and pump installation

The required minimum dimensions for installing pumps in a pump sump are a function of the maximum volume flow rates of the individual pumps and the maximum number of pumps in the pumping station. The individual volume flow rate of a pump can be used to calculate the required distance between pump and wall, adjacent pumps and the inlet channel or line.

The given approach flow in relation to the pump installation and the height of the intake are key criteria for deciding on further procedures or selecting a structural design. In addition, the total volume flow rate of the pumping station and/or the maximum individual volume flow rates of the pump(s) should be assessed regarding the necessity of model testing [see section 5.8].

The required minimum dimensions for the pumping station can be clearly identified by means of table 5.1. The definitions are based on the terminology of the internationally renowned standards of the Hydraulic Institute H.I. 9.8 – 1998 [5.6]. Diagrams 5.6 a to 5.6 c provide the required dimensions depending on the flow rate of the individual pumps.

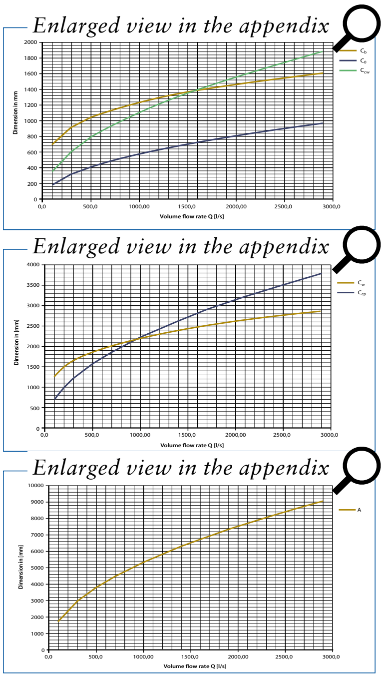

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Fig. 5.6 a - 5.6 c: Minimum dimensions for the pump sump

These diagrams only apply to a maximum number of 5 individual pumps. If this number of pumps per pump sump is exceeded, the pump sump dimensions have to be validated using CFD and possibly also model testing.

If more than 5 pumps are positioned next to each other, the distribution of the intake impulse in the pump sump and its effects are hard to predict, especially when waste water is handled.

If the flow approaches the pump in the precise direction of the pump installation, the intake impulse has to be destroyed by means of a curtain wall with a floor opening. The height difference between the pipe invert and the minimum fluid level in the pump sump can be compensated by a type of balcony construction. The inflow cross-section has to be compatible with the maximum inlet flow velocity of 2.0 m/s. The length of the inlet channel should be at least 5 x diameter of the inlet pipe to compensate for any negative effects from diversions or

Dimension variable	Definition
A	Distance between the centreline of the suction nozzle of the pump and the inlet or the opposite wall
C_{cp}	Distance between the centrelines of adjacent suction nozzles / pumps
C_{cw}	Distance between side walls and the centreline of the suction nozzle
C_o	Opening in the curtain wall or balcony
C_w	Width of the stilling basin or balcony
C_b	Height of the balcony above the floor of the pump sump
Y	Minimum distance from the centreline of the suction nozzle to the outlet of a screen upstream of the suction nozzle
α	Inclination angle of the floor upstream of the suction level

Table 5.1: Definition of variables and dimensions

fittings upstream of the pump sump. The same applies to longitudinal approach flow in relation to the pump installation (see examples 5.6.1 a, 5.6.1 b and 5.6.2 c).

Enlarged view in the appendix

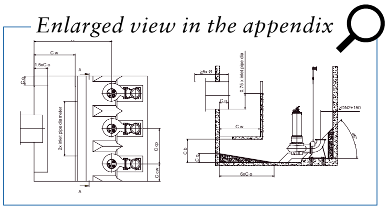

Fig. 5.6.1 a: Example of a KRT (wet installation) with direct approach flow and height difference between pipe invert and pump sump

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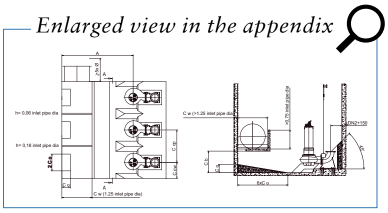

Fig. 5.6.1 b: Example of a KRT (wet installation) with longitudinal approach flow and height difference between pipe invert and pump sump

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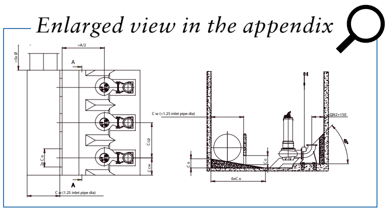

Fig. 5.6.1 c: Example of a KRT (wet installation) with longitudinal approach flow and no height difference between pipe invert and pump sump

Wet-installed submersible motor pumps

The position of the inlet channel or line is decisive for determining the minimum dimensions of the pump sump. Check if the inlet will be at the same height as the floor of the pump sump or if an additional height difference has to be overcome (water falling onto a free surface increases the risk of additional air intake in the fluid) and the direction of the approach flow in relation to the pump installation.

5.7

Pump sumps with major pollution loads

Temporary or even permanent high pollution loads can be handled by today’s modern waste water pumping station without any major difficulties. The following conditions need to be fulfilled as a prerequisite:

- The pump sump is correctly dimensioned in size and shape.
- The operating mode will not overload the hydraulic system (e.g. concentrated pollution loads from a storm water stand-by retention tank causing a brief peak load of a few minutes).
- The pollution load or the fluid are not extreme in their characteristics.

Over the last few years experience has shown that problems with retained pollution loads, solids or sludge occur in no more than 3 % of all pumping stations worldwide. In these cases the use of a small submersible motor mixer has proven absolutely successful (Fig. 5.7).

Fig. 5.7: Submersible motor mixer in a pump sump

With regard to time the mixer can be switched on briefly prior to the actual pumping process, if a longer operating period is not required. This will distribute the total pollution load over the total fluid volume to achieve optimum pumpability. Right from the start the pollution load will be transported with the fluid rather than retained.

With regard to location, local deposits can be mixed in by pointing the jet core of the mixer directly at them. No action is required for zones in which adequate suspension is provided by the structural design or approach flow.

The mixer can also be positioned to mix in floating sludge, so that it can be transported with the fluid. Key benefits are:

- The mixer can be selected for the specific situation, e.g. the fluid composition, and the size and design of the sump.
- The total sump volume can be covered by one small mixer.
- Flexibility (see above)
- No reduction of the volume flow rate of the pump and complete transport of the substances without any additional cleaning procedures.

5.8
The necessity of model testing

The object of model testing is to simulate the flow of a planned pumping station in a scale model. It helps identify precisely where problematic conditions (vortex action, uneven velocity distribution, etc.) might arise and how to then influence these positively, where necessary. The high transparency of acrylic glass makes this material an excellent choice for the construction of suitable models. In order to be able to transfer the flow conditions to the full-size structure dimensionless numbers are applied in the design of the model. These characteristic coefficients describe the forces acting in the flow. They should be as identical as possible for both the model and the full-size structure. The most relevant forces are those resulting from gravity, dynamic viscosity, surface tension and the inertia of the fluid in motion. The dimensionless numbers applied here are as follows:

REYNOLDS number $$Re = \frac{vd}{\nu}$$

FROUDE number $$Fr = \frac{v}{\sqrt{gl}}$$

WEBER number $$We = \frac{\rho\ v^2 l}{\sigma} \qquad (22)$$

Key:
v = flow velocity in m/s
d = hydraulic diameter in m
ν = kinematic viscosity in m^2/s
g = gravitational constant in m/s^2
l = characteristic length (in the hydraulic system) in m
σ = surface tension in N/mm^2.

As these characteristics are to a degree interdependent it is impossible to apply them all at the same time in a scale model. It is therefore important to find a compromise that provides an optimum solution for a given application.

Model testing is absolutely necessary when one or more of the criteria listed below apply to the intake structure or pump sump:

- The volume flow rate per pump is higher than 2.5 m^3/s or 6.3 m^3/s for the entire pumping station.
- The inflow is asymmetrical and/or not uniform.
- Alternating pump operation in multiple pumping stations involves significant changes in flow direction.
- An existing pumping station has already created problems.

5.9
Test set-up

The geometry of the model must correspond to the original structure, taking into account the selected scale and the characteristic coefficients mentioned previously. This applies to the hydraulic part of the civil structure and the pumps. Both the structure of the building and the pumps are constructed from transparent material. A model of the impeller is not required as the test aims to simulate only the flow approaching the impeller.

Instead of an impeller a vortometer is fitted, whose rotational speed provides information on the development of vortices in the intake.

The flow velocities are measured at reference points across the model pump's entire suction cross-section via Pitot tube or laser. To judge vortex development the fluid surface as well as the wall and floor areas are observed. Vortex intensity in a given flow cross-section is visualised by means of dyes. Their size is measured by the swirl angle θ of the vortometer.

The following equation is applicable:

$$\Theta = \tan^{-1}\left(\frac{\pi^{\circ} d_m n}{u}\right) \tag{23}$$

Key:

d_m = pipe diameter (here: suction inlet of the pump) in m
n = revolutions of vortometer in 1/s
u = axial flow velocity in m/s

According to Hecker, the surface vortices are classified into six categories (1 = low, 6 = very high, Fig. 5.9 a) and the submerged vortices into three categories (Fig. 5.9 b).

If one were only to look at the diagrams, these vortex formations appear relatively harmless. Vortex formation observed in model tests give an idea of what could happen in a real structure. Unlike laboratory situations the real pumping station rarely deals with clear water and it is therefore difficult to identify vortex action as the source of the problem, especially when submerged vortices are involved.

The criteria which apply to this method of investigation may vary slightly depending on the pump type and the size and design of the pumping station.

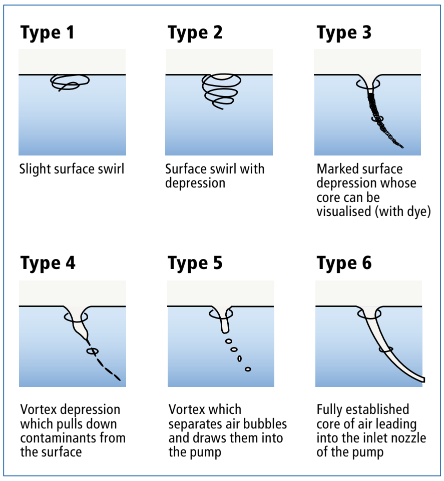

Fig. 5.9 a: Classification of surface vortices according to Hecker (Types 1 to 6)

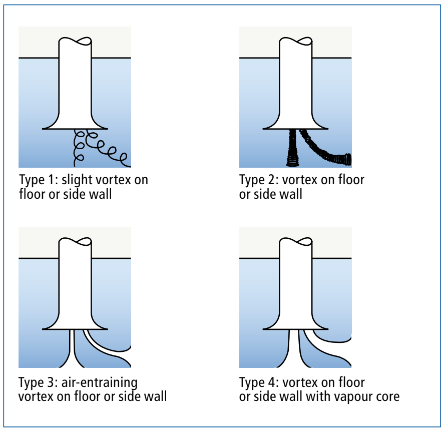

Fig. 5.9 b: Classification of submerged vortices according to Hecker (Types 1 to 4)

5.10
Assessing results

Before the design is finalised the measurement results should be confirmed by all parties involved: pumping station designer, end customer, pump manufacturer and the institution which conducted the tests.

Key criteria:

1. The mean flow velocity at the defined measuring points of the suction cross-section should not deviate from the mean value by more than 10 %.

2. The swirl angle should not exceed 5 degrees. A swirl angle of 6 degrees can be tolerated if it occurred during less than 10% of the period of observation.

3. Surface vortices may only be accepted up to type 2 and submerged vortices up to type 1. They can be tolerated in exceptional cases, if they occurred during less than 10 % of the period of observation.

In general the following applies: Occurrences that have a minor effect in the model may be considerably more significant in the full-size structure!

The tests must be concluded with a detailed report on the operating conditions investigated. The vortex formations and operating conditions observed (for the tested fluid levels in the civil structure) have to be documented on video and made available to the party commissioning the tests.

KSB will support and co-ordinate project related model testing upon request.

5.11
The significance of CFD simulation

Intake structures often have to be adjusted to the local conditions, which means they are hard to standardise. This is why model testing is frequently carried out at the planning stage to ensure reliable operation of the full-scale version. The main objectives of these tests are to exclude any air-entraining surface vortices and submerged vortices, and to secure a reliable velocity distribution in the intake area of the pump. As the tests relate to a flow with free surface, scaling is based on the affinity laws defined by Froude.

Detailed local analysis of flow behaviour is only possible by means of complex measurements of the local velocities or by using dyes. The often desired evaluation of the sedimentation behaviour of solid particles or an overview of the velocities in any given place in the intake structure can only be provided to a limited extent.

KSB offers to examine and predict any possible problems which might occur when using pumps in waste water applications by means of proven CFD simulation software.

KSB numerically analyses all model tests conducted at KSB and their results, thus drawing on a wealth of experience. The quality of relevant pump problems has proven to be reflected correctly. Such problems generally include all types of vortices which occur under water. The establishing characteristic type of flow is generally also displayed correctly, for example transient flows in the intake area which are hazardous to the pumps, the occurrence of pre-swirl and the analysis of flow separation zones.

If flow separation zones affect the water surface, they can have a significant impact on an early occurrence of air-entraining vortices. The formation and distribution of these vortices which often have a large volume caused by air intake are hard to determine in numerical studies. A numerical prediction, however, is quite possible based on relevant experience.

Even though the free surface is usually assumed to be a frictionless wall in the simulation the reasons for air-entraining vortices can be detected. In this context a connection between the simplified assumption and the actually occurring air-entraining vortices is sought.

The objective of the calculations is met when the conclusions from the numerical analysis match the results of model testing also in the case of extreme approach flow conditions. If this is confirmed reliable pump operation can be guaranteed. In KSB's experience this has been shown to work.

Due to their complexity, the calculation results generally provide more information on problematic flow patterns than model testing. The correct interpretation of the calculation result is decisive in distinguishing between important and unimportant information and quantify the risk factors. Checking the intake conditions by means of CFD simulation is an established method these days. This is reflected by customers increasingly requesting such calculations for their specific intake structures.

To be able to use CFD calculations effectively the points to be clarified by the simulation should be discussed in detail with the customer prior to conducting the calculations. CFD is a reasonably complex tool and can only be used efficiently if the problems to be analysed are clearly defined.

Benefits of the CFD analysis

CFD analyses are not primarily aimed at replacing model tests. CFD should be used when it is best suited to the character of expected operating problems. Flow patterns of a transient character or the sedimentation behaviour in a pump sump, for example, can be analysed easier with CFD than with model testing.

First of all, potential problems and their character should be logically analysed. Based on this analysis a decision can be made on how best to examine and prevent the expected operating problems – by means of model testing, CFD analysis or both.

Software used

A software program has been developed to solve the general Navier-Stokes equations which describe the flow. This software is now commercially available. KSB uses the software from the provider ANSYS as an efficient instrument to predict the flow conditions with relative precision. The time and costs of such a simulation depend on:

- The size of the flow area to be modelled
- The desired geometric resolution
- The computer performance
- The presentation of results (report) and scope of results

Fig. 5.11 a: Flow patterns in a KRT pumping station.

Methodology

The mathematical description of fluid flows is based on the Navier-Stokes equations. They describe the processes at each point of a flow by means of partial differential equations for the mass, energy and momentum.

The calculation of each spatial point in a flow is not feasible as this would result in an infinite number of calculations. A grid is generated instead, whose nodes are calculated. The grid model is then processed further to provide information on the pressure and velocity distribution, which can then be subjected to numerical and/or graphical analysis.

To make the calculations comparable, a turbulence model is used which accurately reflects the real conditions based on experience.

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}=f_x-\frac{1}{\rho}\frac{\partial p}{\partial x}+v\left[\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right]$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}=f_y-\frac{1}{\rho}\frac{\partial p}{\partial y}+v\left[\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right]$$

$$\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}=f_z-\frac{1}{\rho}\frac{\partial p}{\partial z}+v\left[\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right] \tag{24}$$

Fig. 5.11 b: Navier-Stokes equation system describing the flow

Air-entraining vortices caused by the qualitative flow in the chamber can be predicted fairly accurately. An approach flow tangential to the chamber is most likely to generate a vortex in the chamber with an air-entraining vortex at its centre. This flow pattern is illustrated in Fig. 5.11 c.

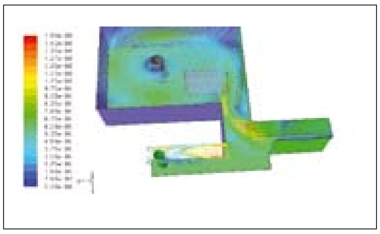

Fig. 5.11 c: Structural design

Objectives

Model testing is particularly valuable when diagnosing surface vortices and swirl values for various pump inlet positions. The velocity distribution at the impeller level can be examined by thorough testing. Recognising the flow quality of complicated inlet chamber geometries in a model test requires vast experience.

This is where a CFD analysis is advantageous. The flow can be made visible over the entire volume. The flow quality can easily be analysed in areas of constant velocities and cross-sections.

The following severe problems can occur in the intake chamber:

- Transient flows in the pump area
- Sedimentation in large waste water treatment plants
- Air-entraining vortices and submerged vortices
- Swirling approach flows to the pumps (pre-swirl leads to increased cavitation or changed heads)
- Air intake (here: air transport by the flow)

Transient flows are time-dependent flows. If the flow quality changes over time the required acceleration forces have to be generated by the pump, which usually causes vibrations. Pumps with a high specific speed are especially at risk.

Sedimentation is extremely detrimental to the operation of a waste water treatment plant. Removing deposited sediment can be very costly. The risk of sedimentation in the pump chamber can be analysed by examining the velocities near the floor.

Swirling flows influence the developed head and the pump input power. They also have an effect on the cavitation characteristics. The air intake cannot be calculated, but the transport of air entering the structure with the flow can be estimated by examining the velocity distribution in the volume.

Summary

If any problems are expected during operation, every possible option should be used to analyse these potential problems and thus prevent the costs they could incur.

CFD simulation is perfectly suited to evaluating flows in intake structures and pump sumps. The aim is to prevent any operating problems in the water system or waste water treatment plant that is to be built. A logical analysis of the plant under consideration is the basis for efficient model testing and CFD analyses.

At KSB CFD simulation is a well-established engineering tool that has been used for years. For some pumping stations it makes sense to use a combination of CFD simulation and model testing to optimise the plant and find the best solution.

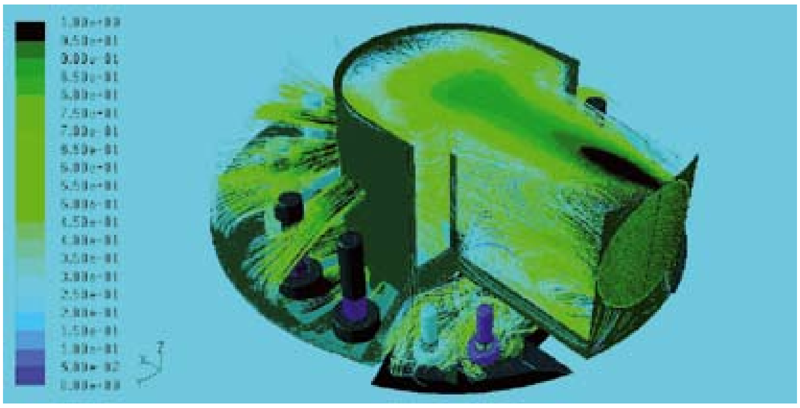

Fig. 5.11 d: Simulation of a pumping station with several pumps

Fig. 5.11 e: Structural design of a KRT pumping station based on calculation

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Diagrams

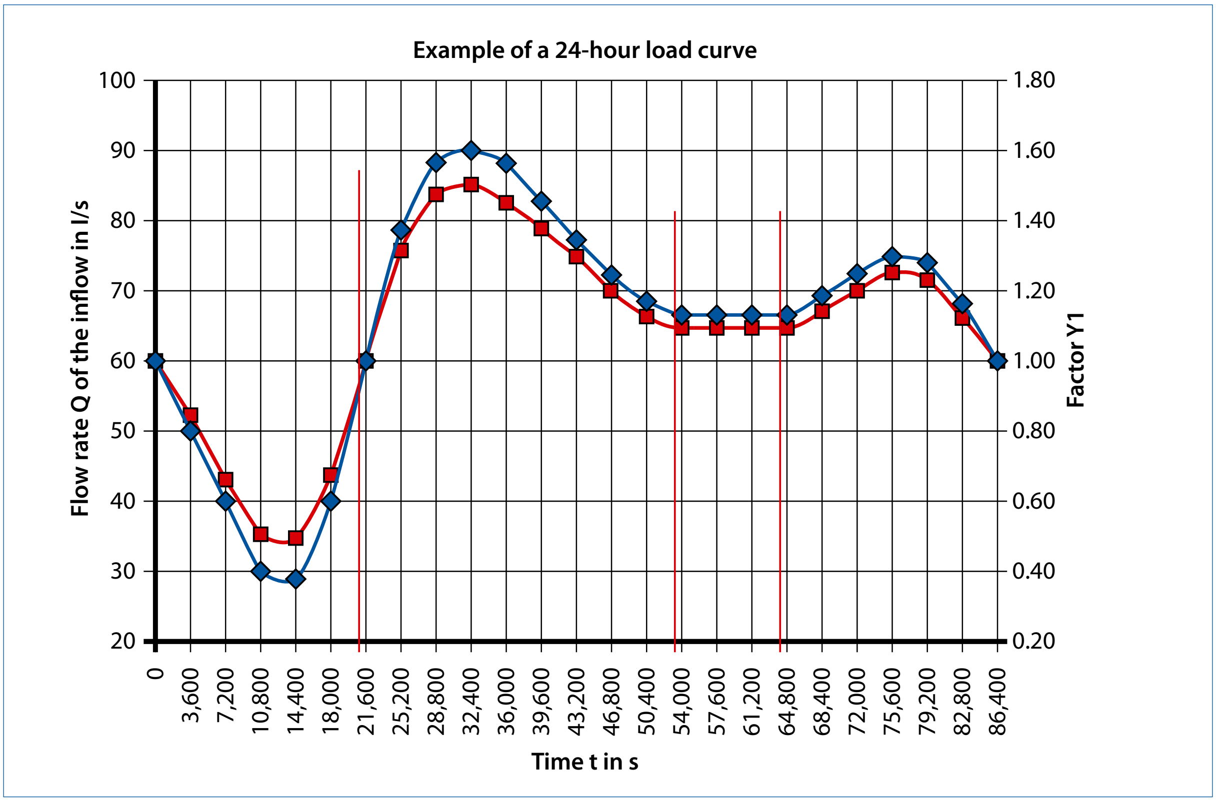


Fig. 1: Example of an inflow load curve for mathematical modelling

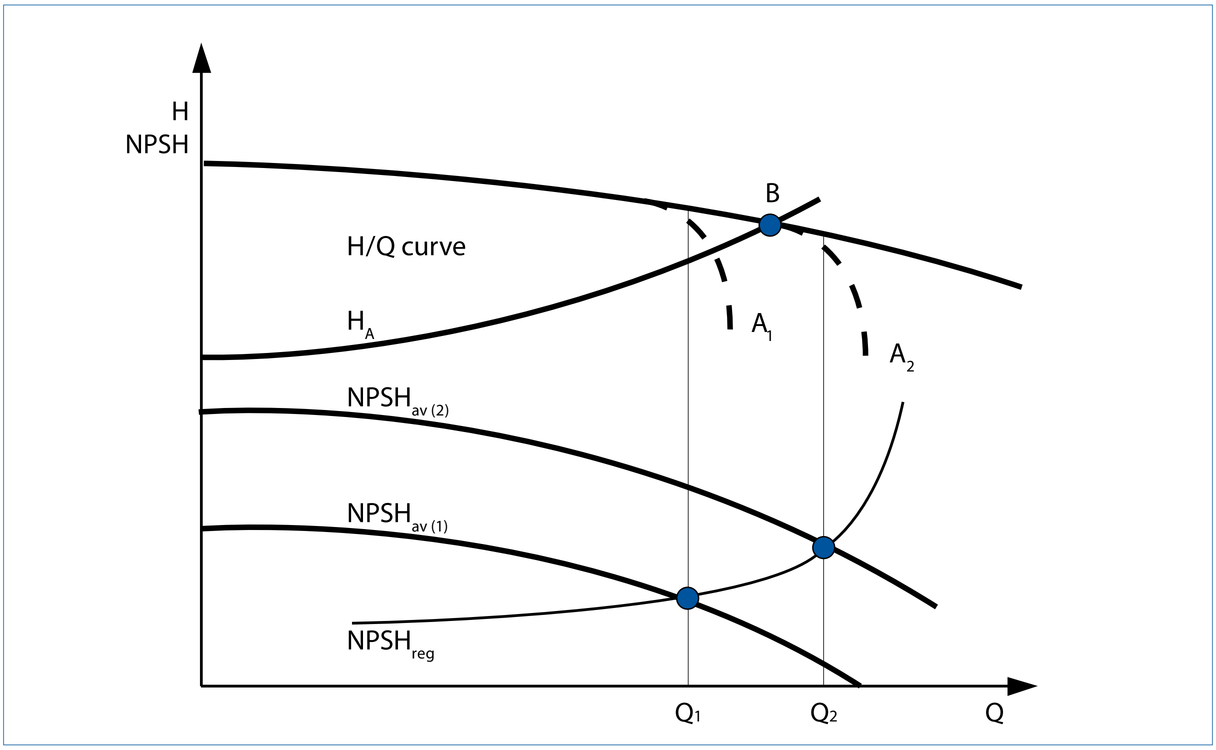


Fig. 1.4: Impact of NPSHa on the constant speed curve of the pump (Reference: KSB Centrifugal Pump Lexicon)

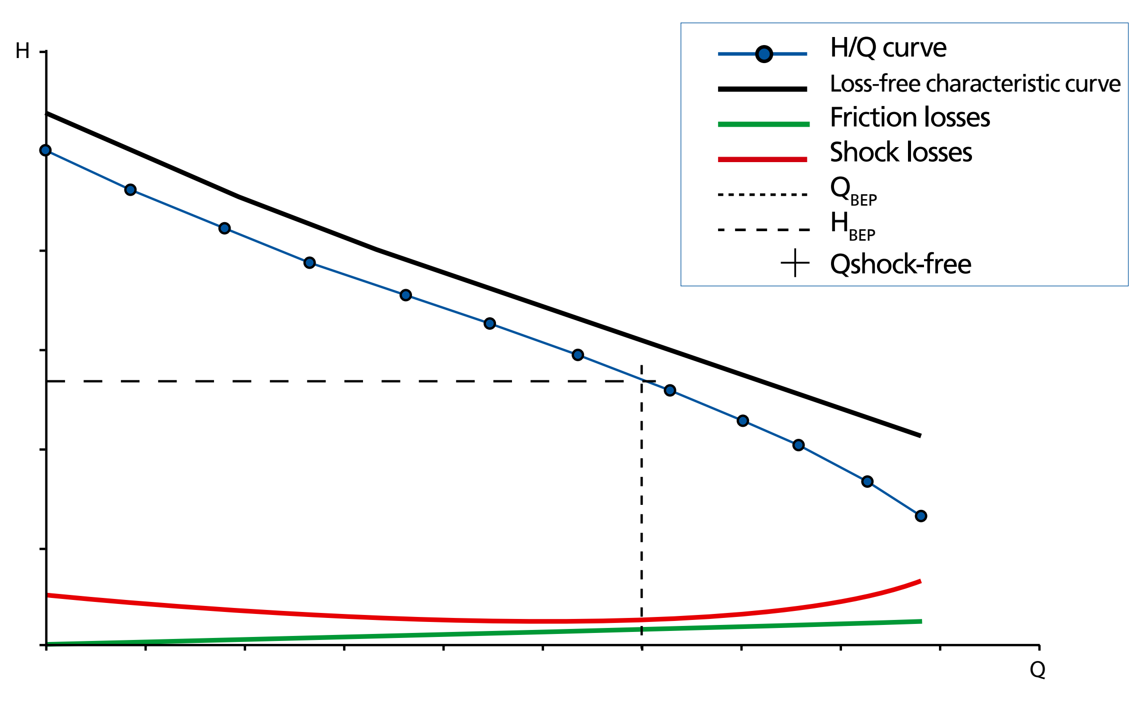


Fig. 1.9: Characteristic head versus flow curve and its reduction by internal hydraulic losses. Proportional representation based on the best efficiency point.

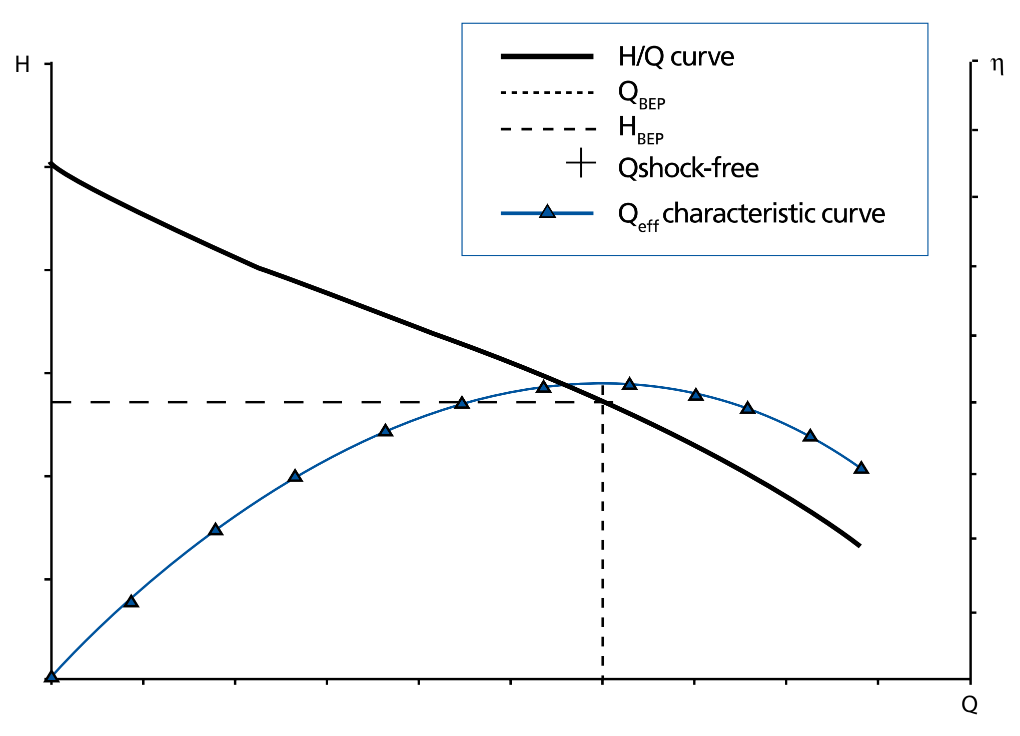


Fig. 1.10: Efficiency curve η =f (Q). Proportional representation based on the best efficiency point.

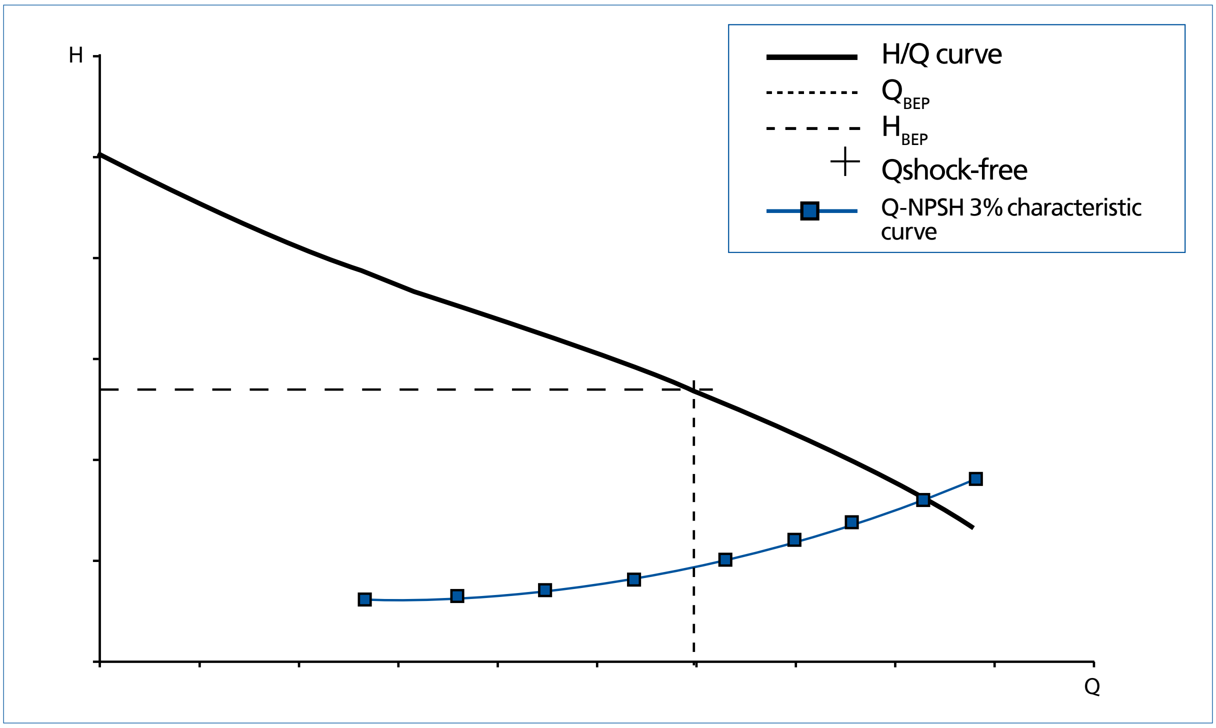


Fig. 1.11: NPSH$_{3\%}$ *characteristic curve, NPSH*$_{3\%}$ *= f (Q). Proportional representation based on the best efficiency point.*

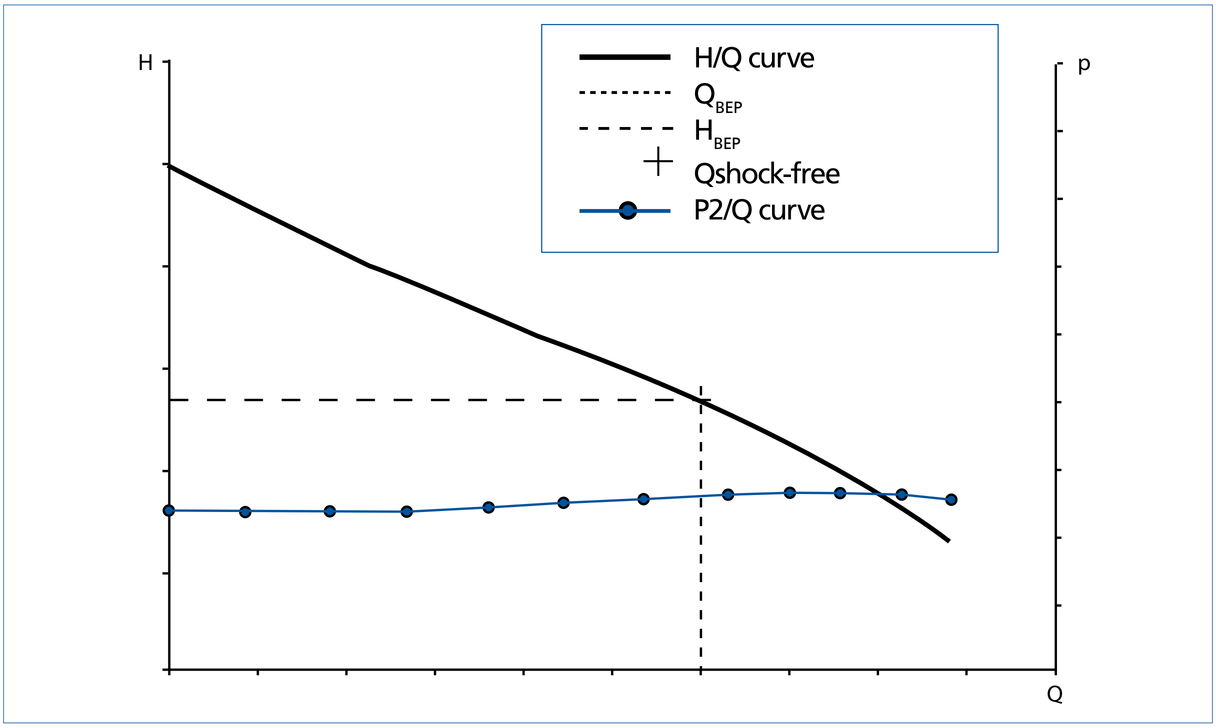


Fig. 1.12: Electrical pump input power $P_2 = f(Q)$*. Proportional representation based on the best efficiency point.*

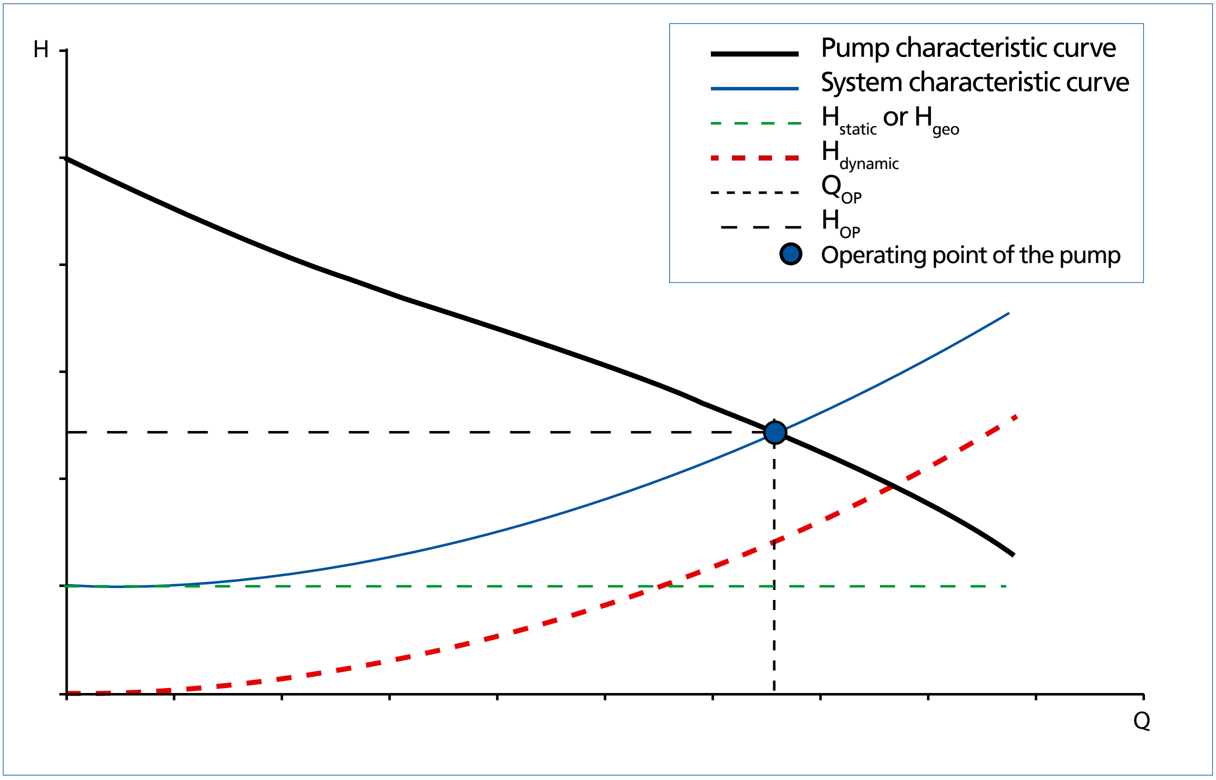


Fig. 1.13: System characteristic curve – Sum of static and dynamic head components

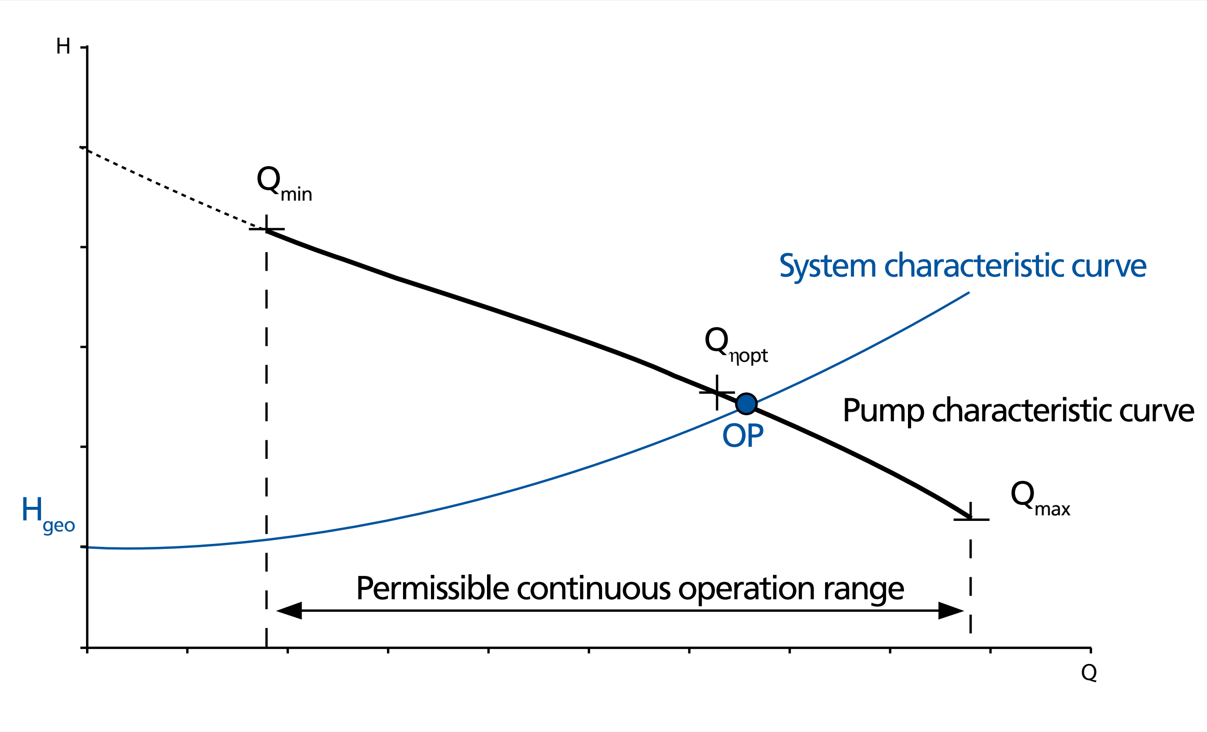


*Fig. 1.14: Operating limits Q_{min} and Q_{max} – Illustration of the permissible range for continuous operation of a centrifugal pump (Q_{min} approx. 0.3 * Q_{BEP} and Q_{max} approx. 1.4 * Q_{BEP})*

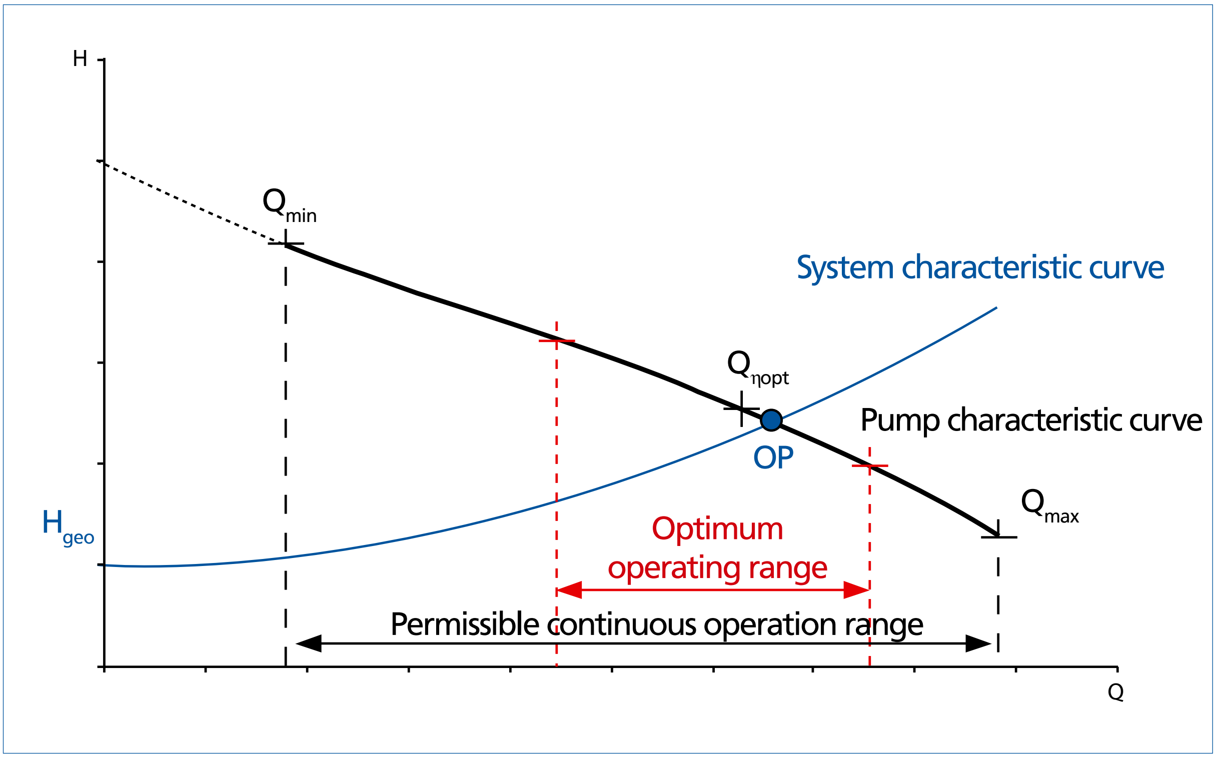


Fig. 1.15: Preferable or optimum operating range for waste water transport

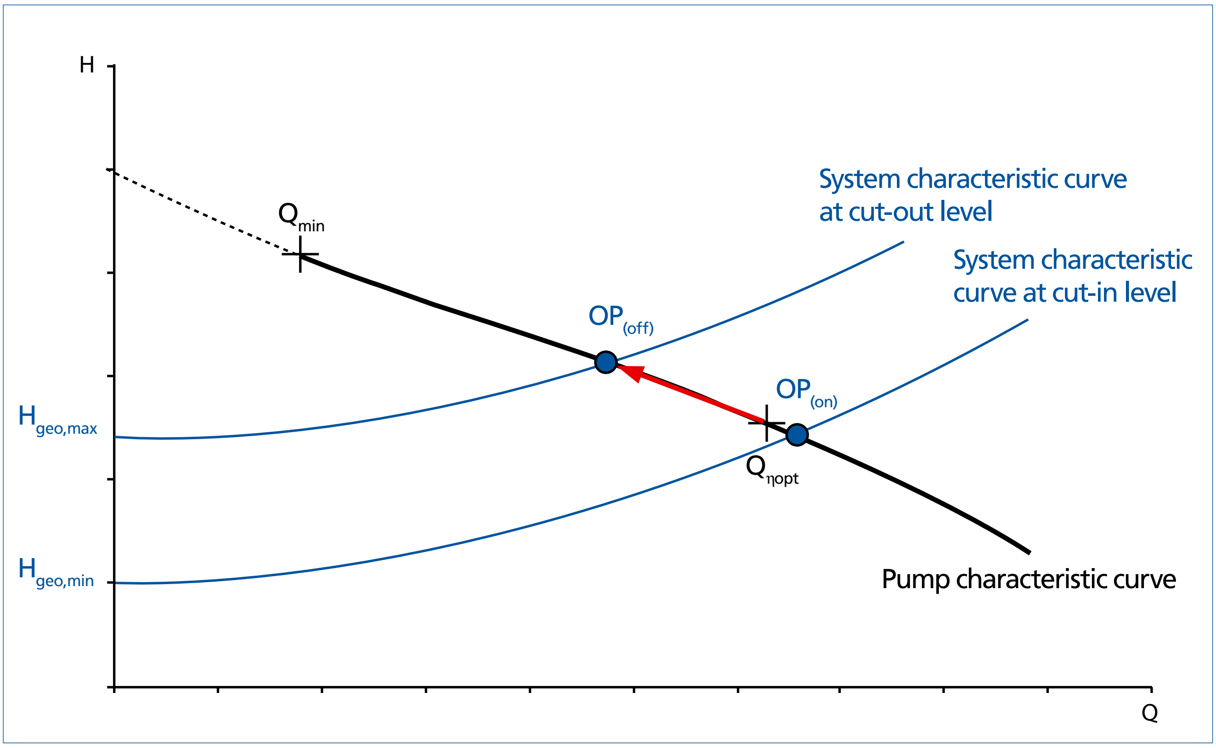


Fig. 1.16: Shifting the operating point of the pump at fixed speed by altering the geodetic head between the suction-side cut-in and cut-out level

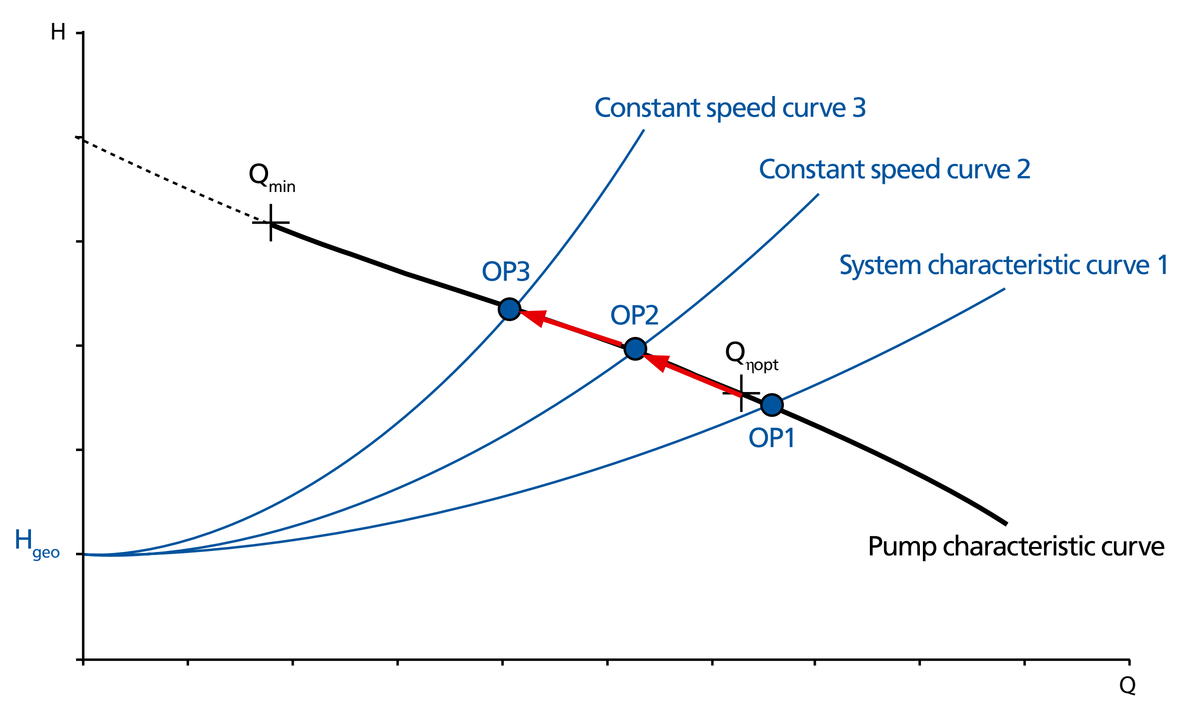


Fig. 1.17: Shifting the operating point of the pump by changing the pressure losses in the piping, e.g. the nominal diameter of pipes, the pumping route or length, or the deposits and incrustations in the piping

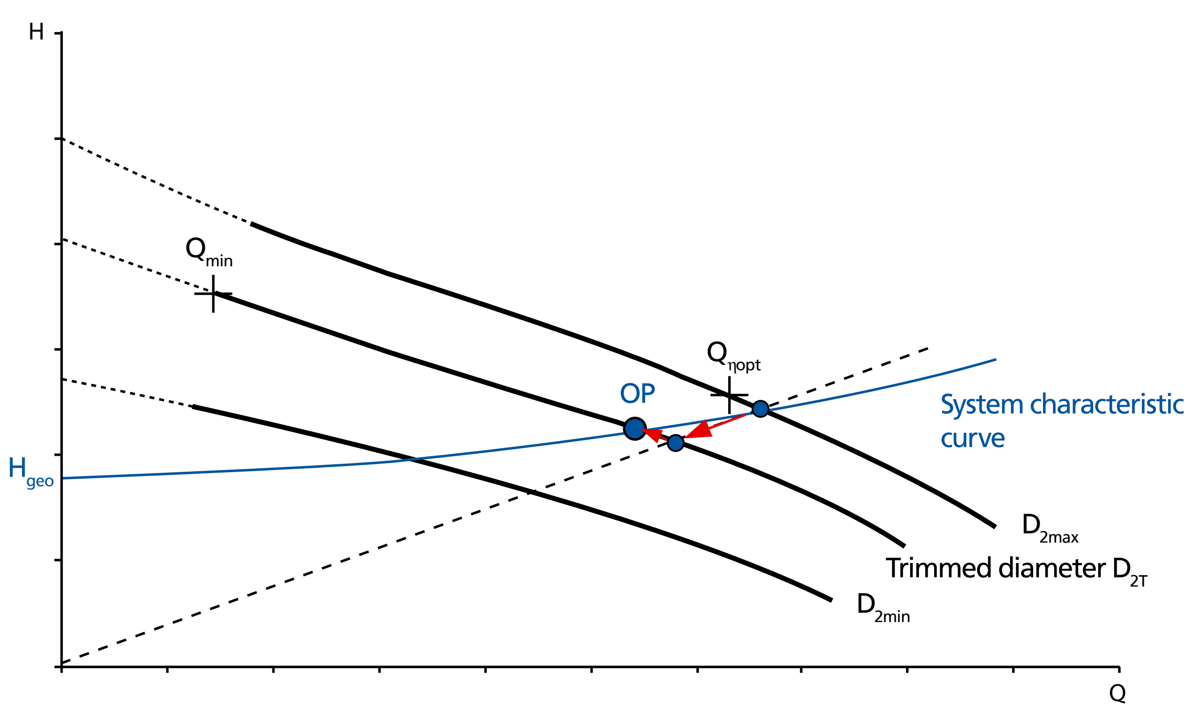


Fig. 1.18: Trimming or adjusting the impeller diameter to meet the required operating point of the pump

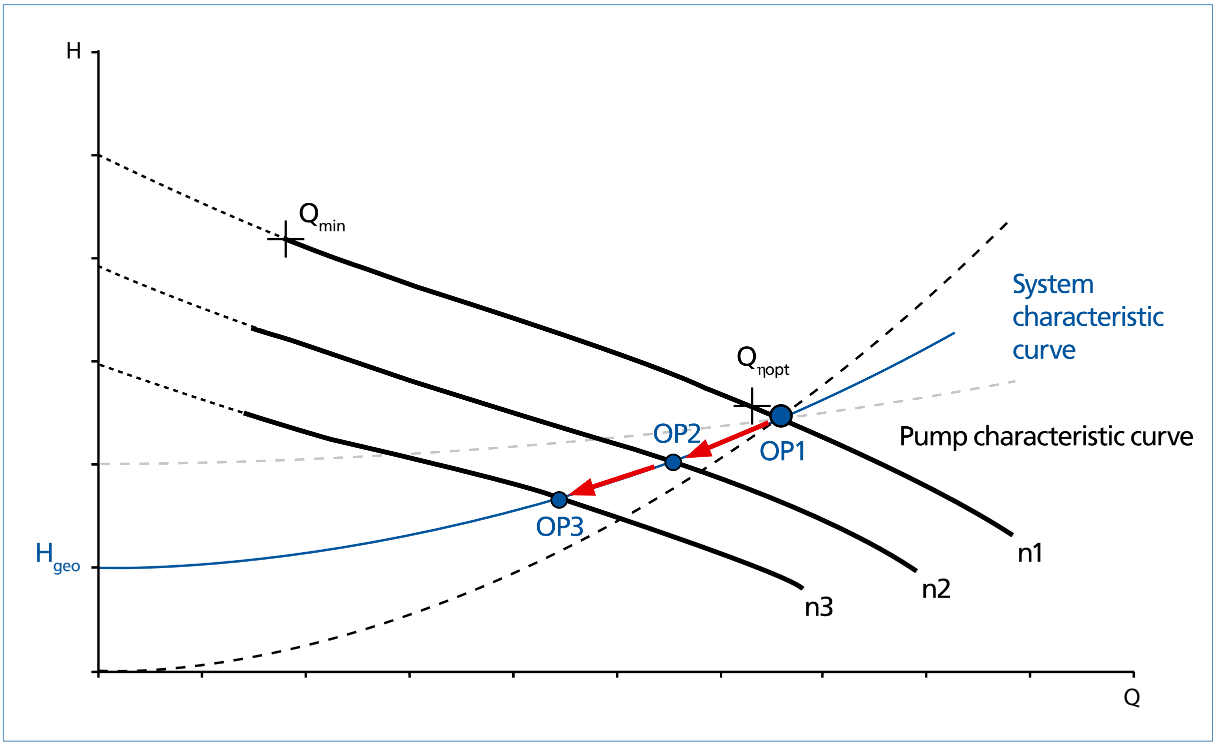


Fig. 1.19: Shifting the operating point of a centrifugal pump by changing the speed

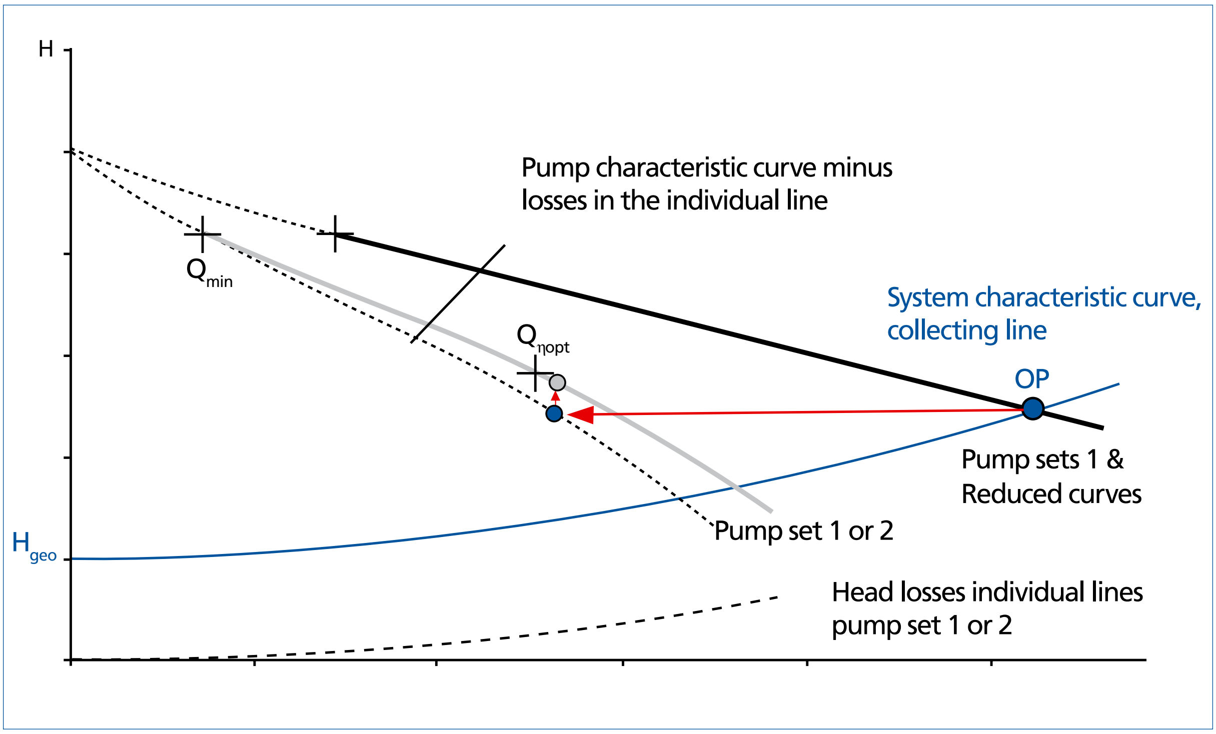


Fig. 1.20: Parallel operation of two identical centrifugal pumps. Losses of individual lines (head losses up to the collecting line) have been taken into account in the reduced pump characteristic curve

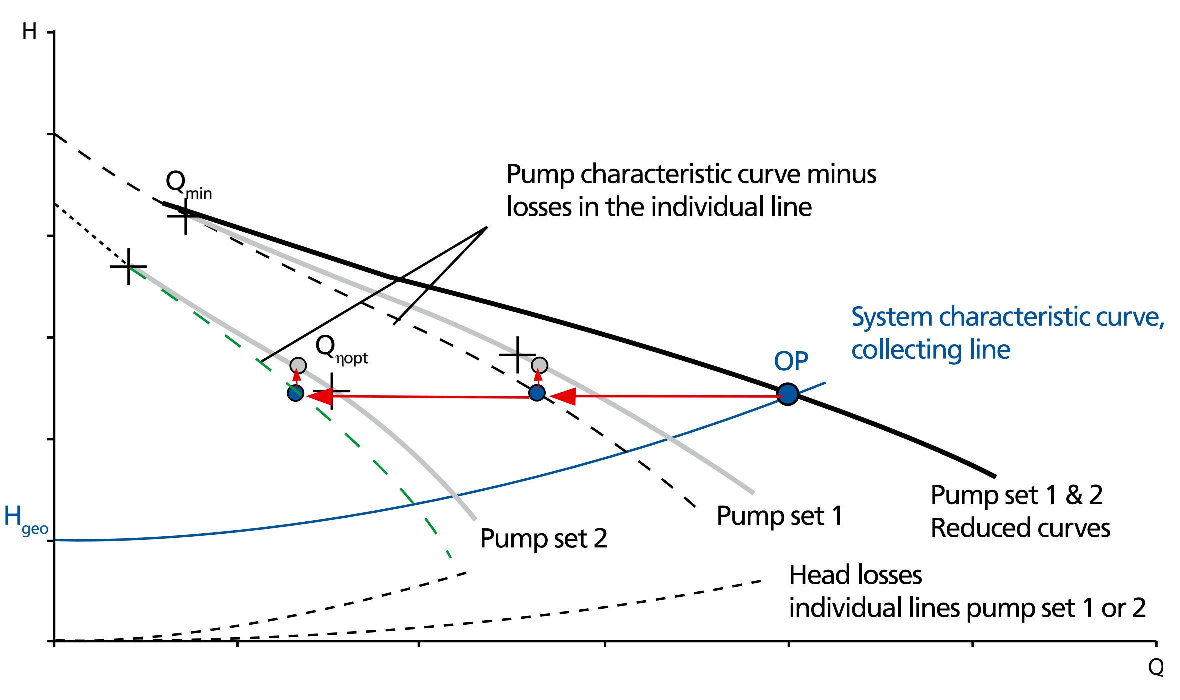


Fig. 1.21: Parallel operation of two different centrifugal pumps. Losses in individual lines (head losses up to the collecting line) have been taken into account in the reduced pump characteristic curve

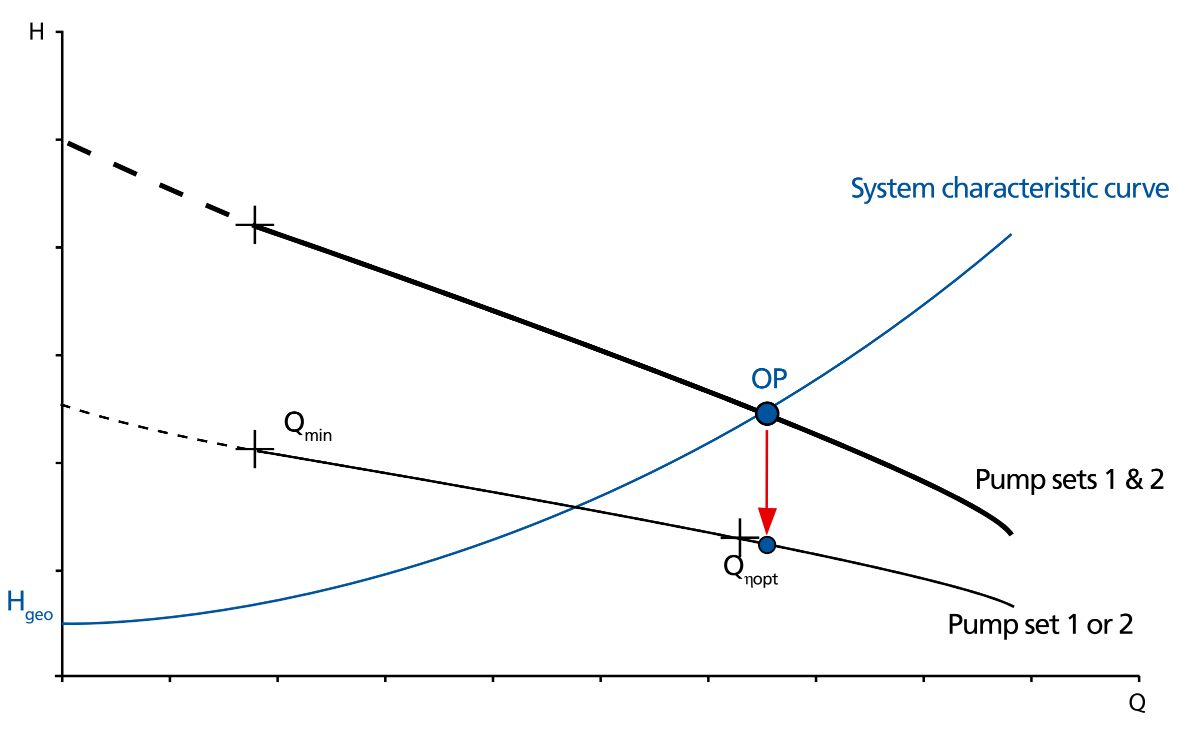


Fig. 1.22: Series operation of two identical centrifugal pumps

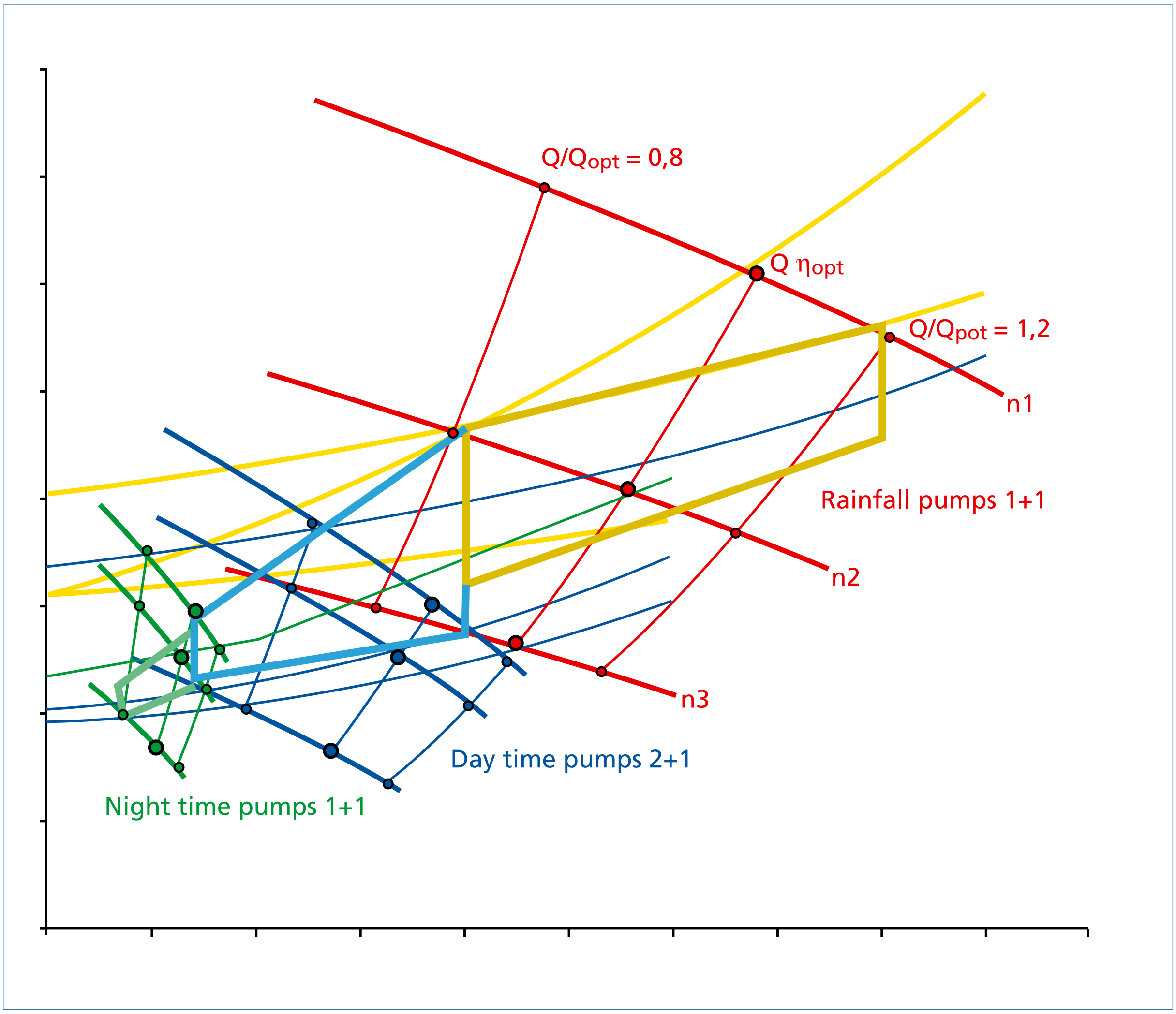


Fig. 1.23: Assigning rainfall, day time and night time pumps to different pumping routes for different fluid levels and events

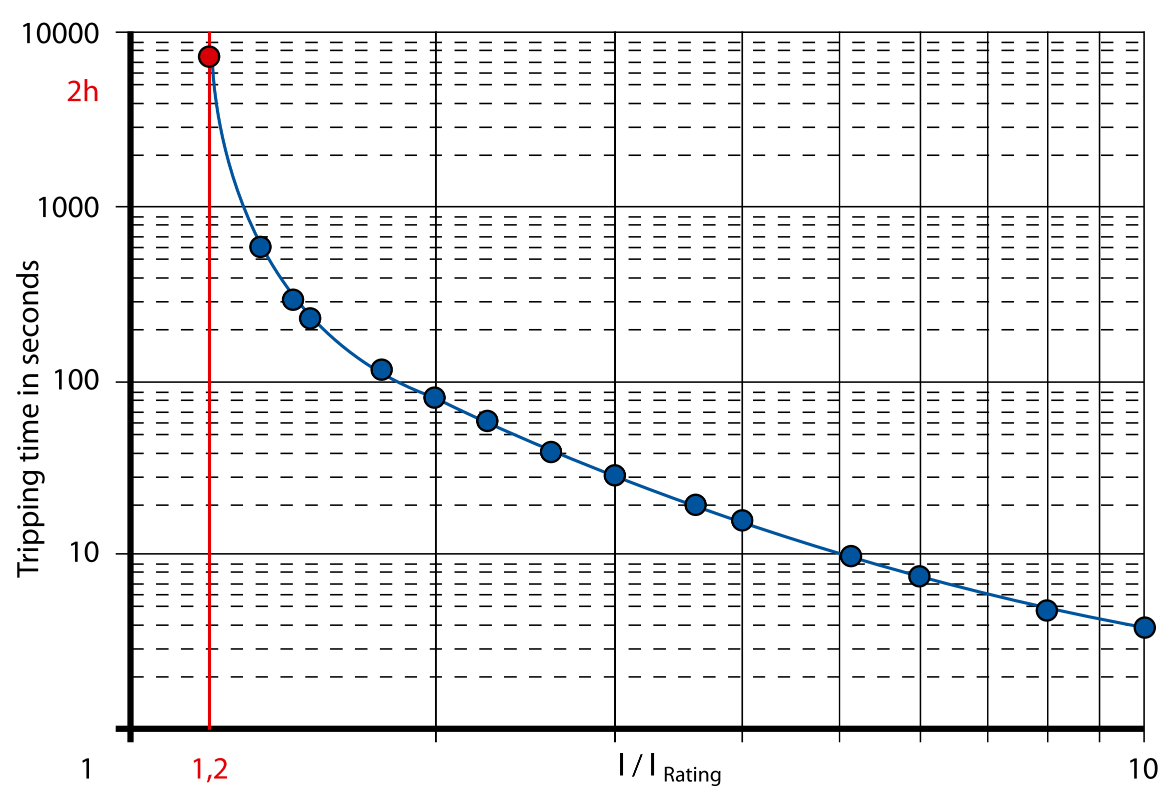


Fig. 3.5: Tripping curve for class 10 thermal time-lag over-current trips to EN 60947-6-2

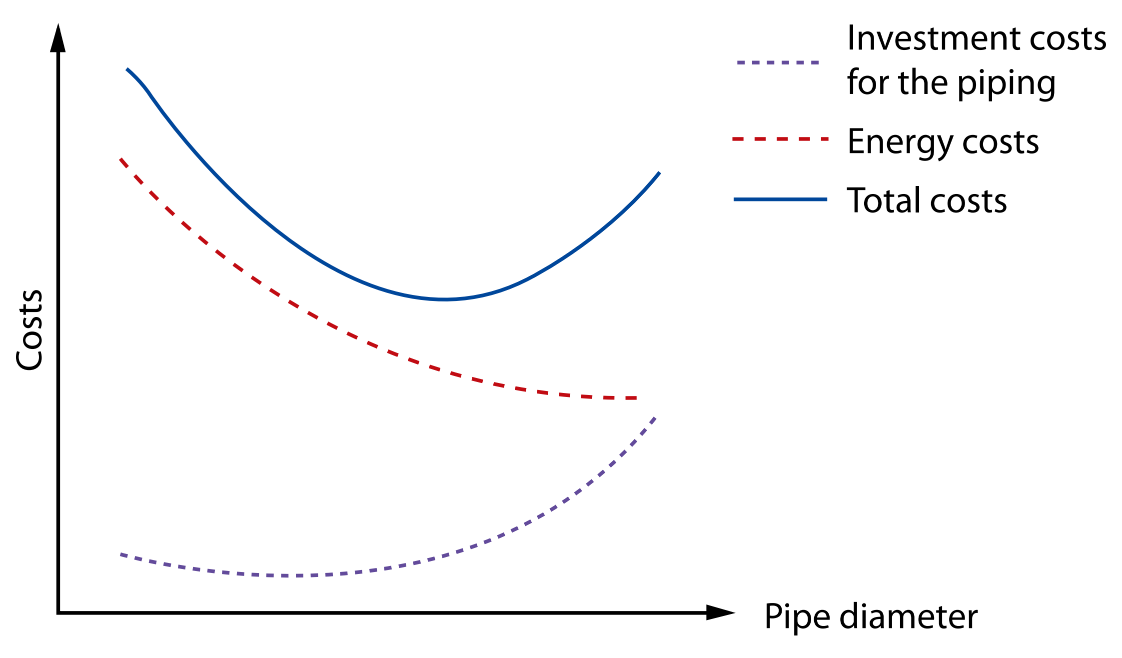


Fig. 4.1.1.1a: Cost structure for designing and operating a piping system

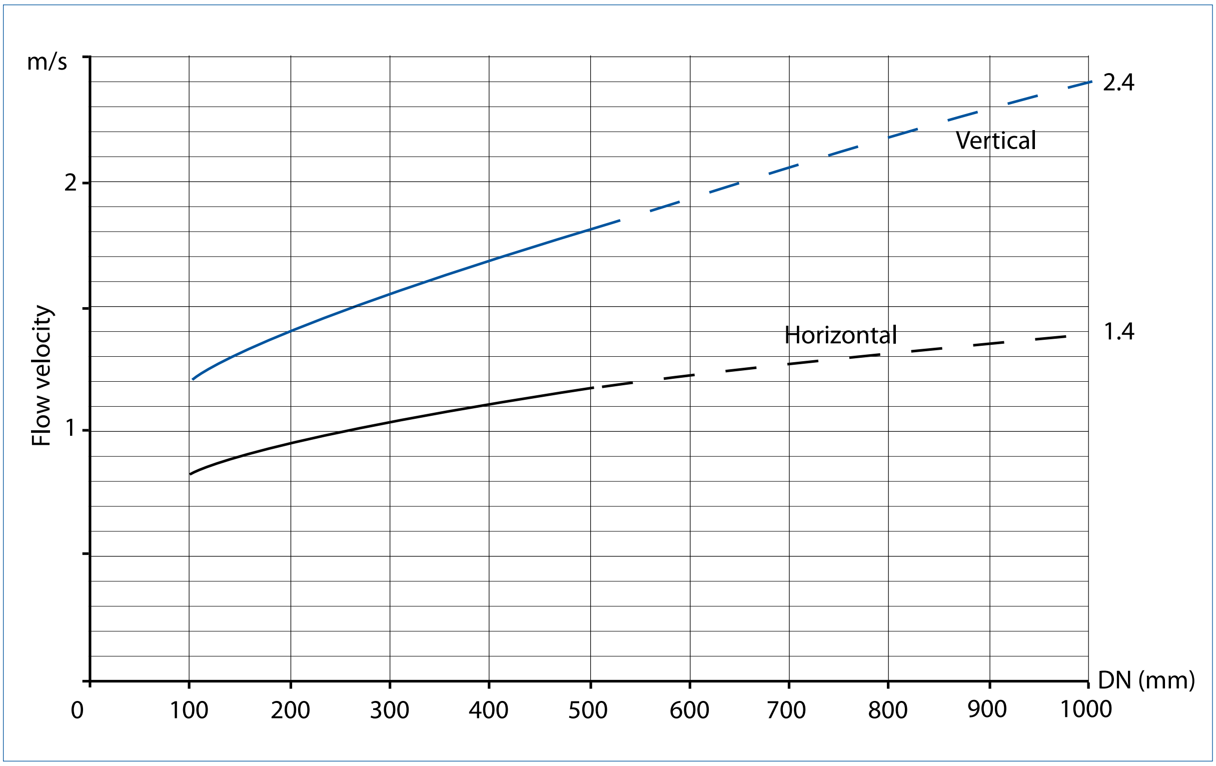


Fig. 4.1.1.1 b: Minimum flow velocities n

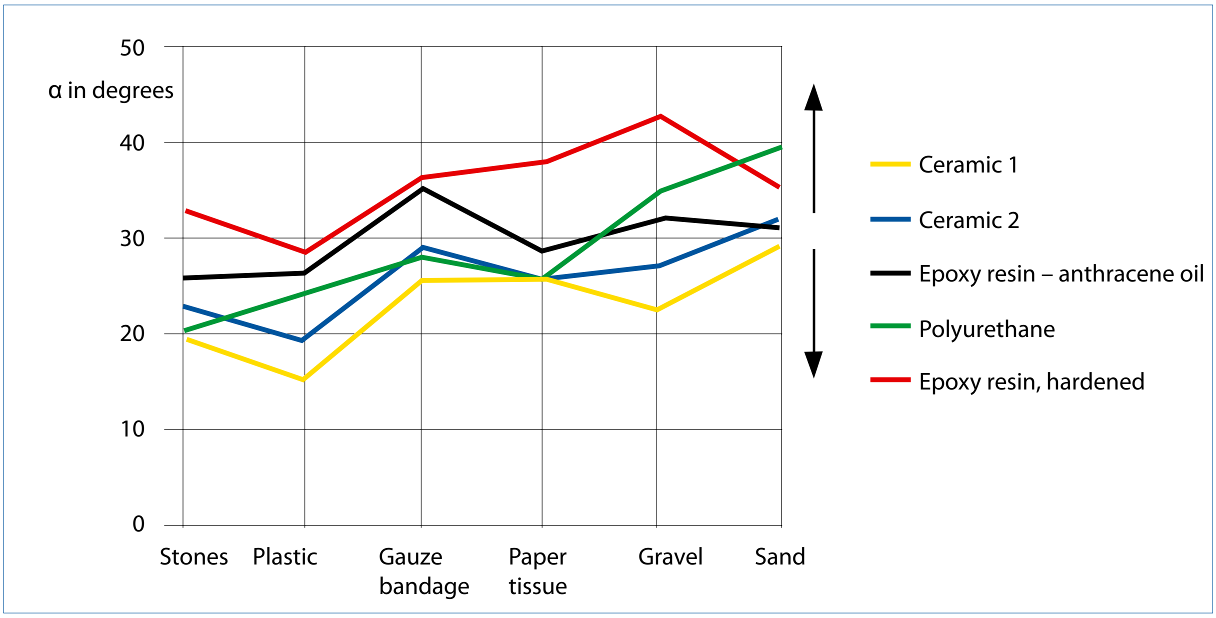


Fig. 5.4 b: Gliding angle of various solids contained in waste water combined with various coatings (without considering the flow)

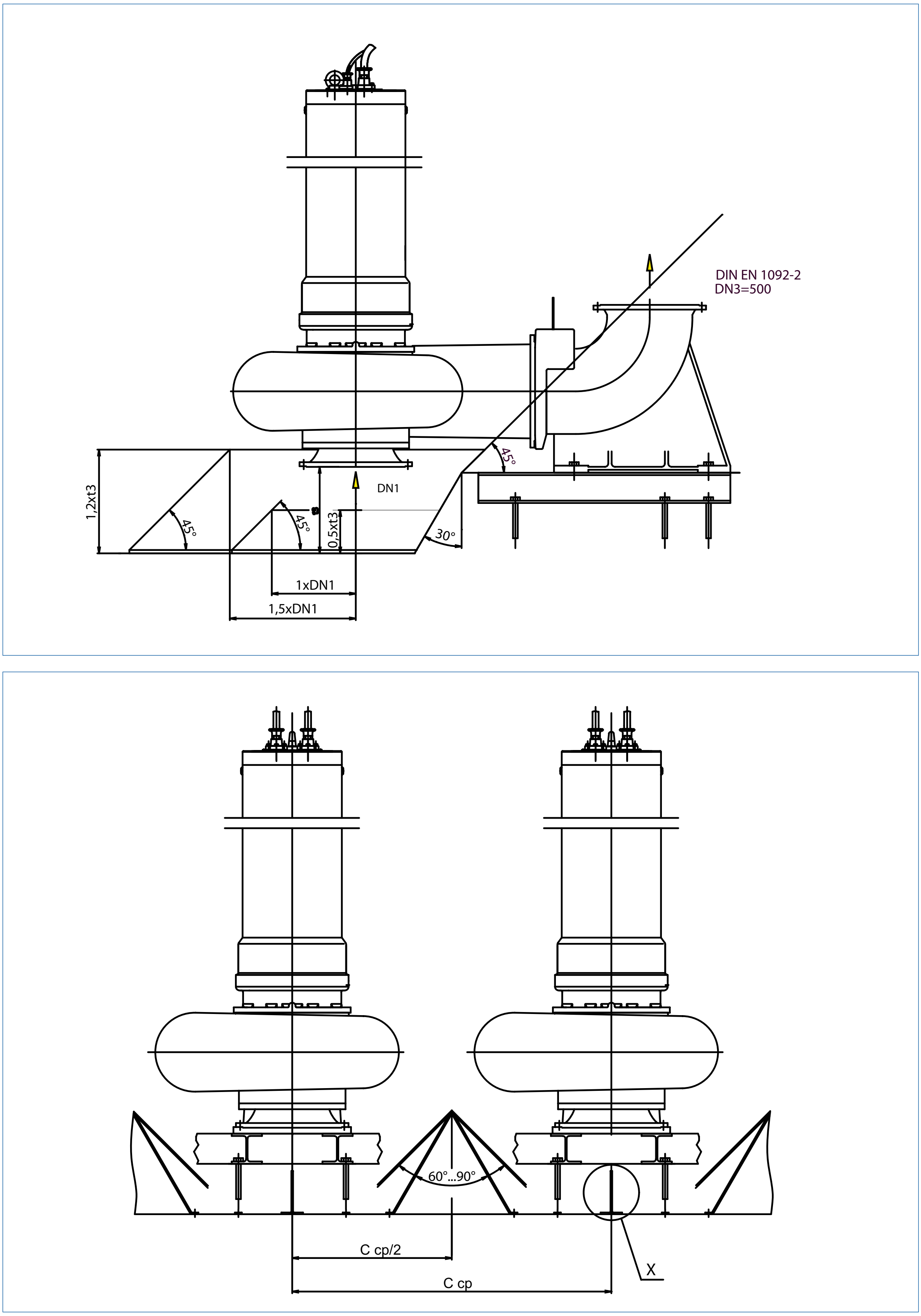


Fig. 5.5 a: Geometric design of (bottom) flow splitters

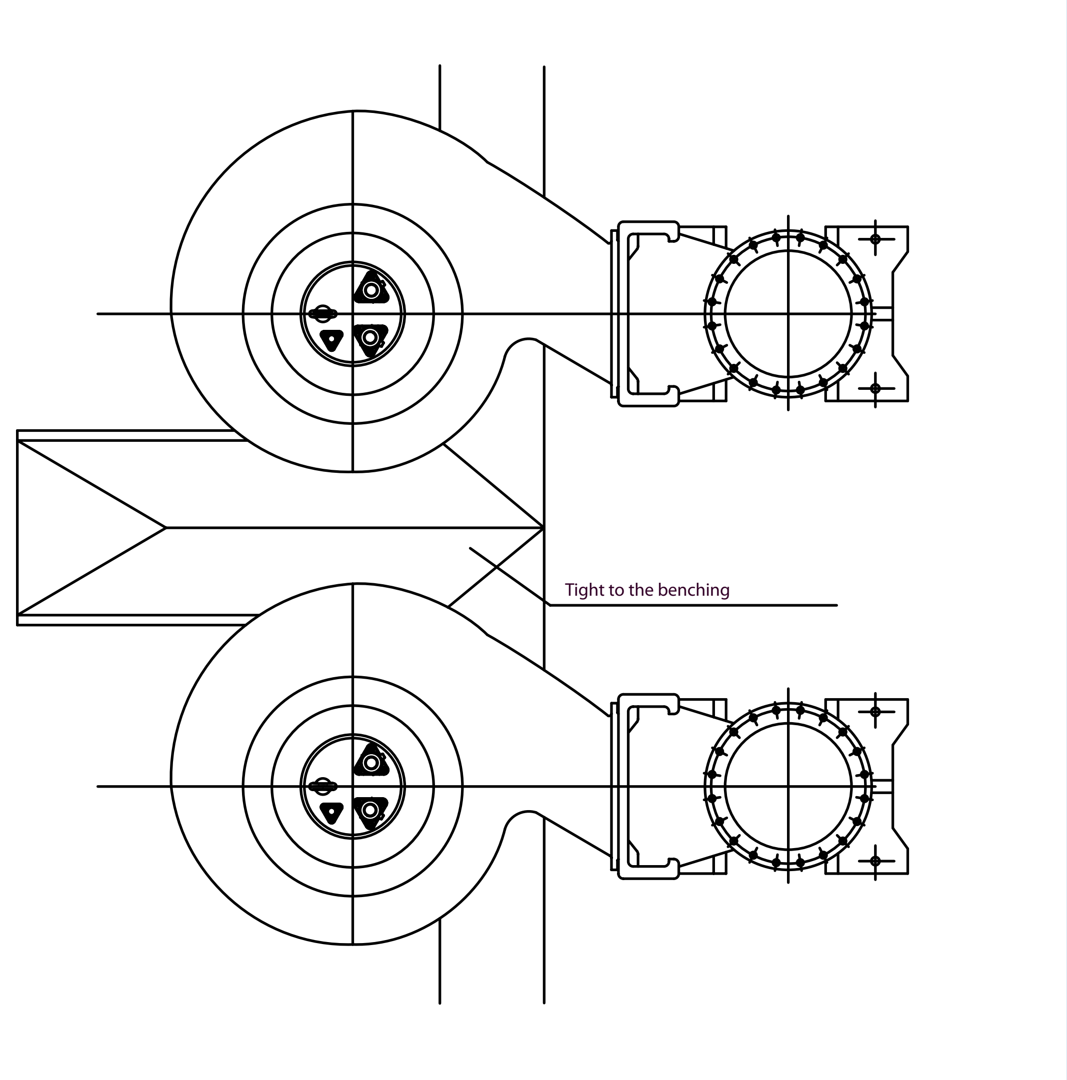


Fig. 5.5 b: Top view — flow splitter between two pumps

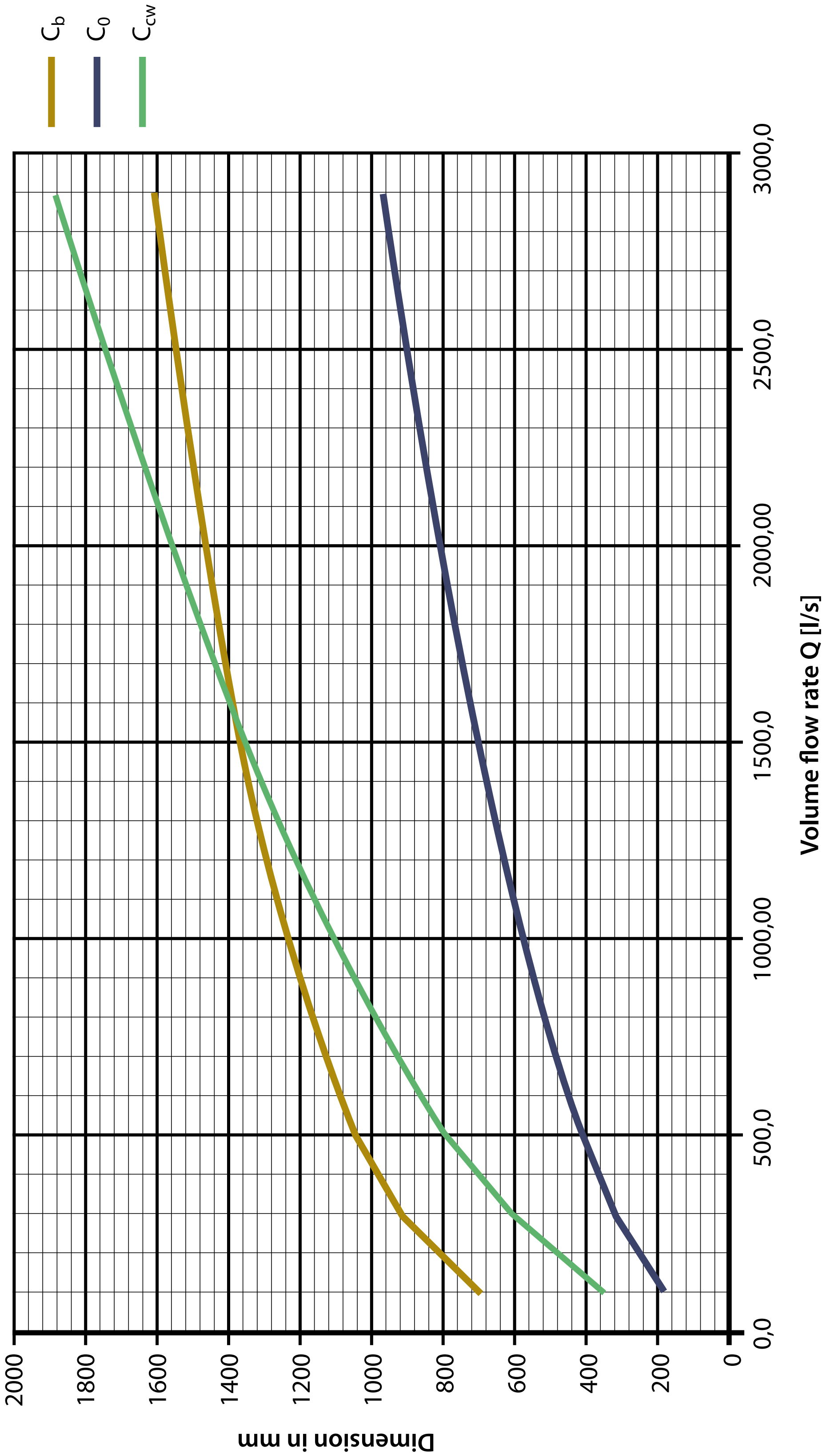


Fig. 5.6 a: Minimum dimensions for the pump sump

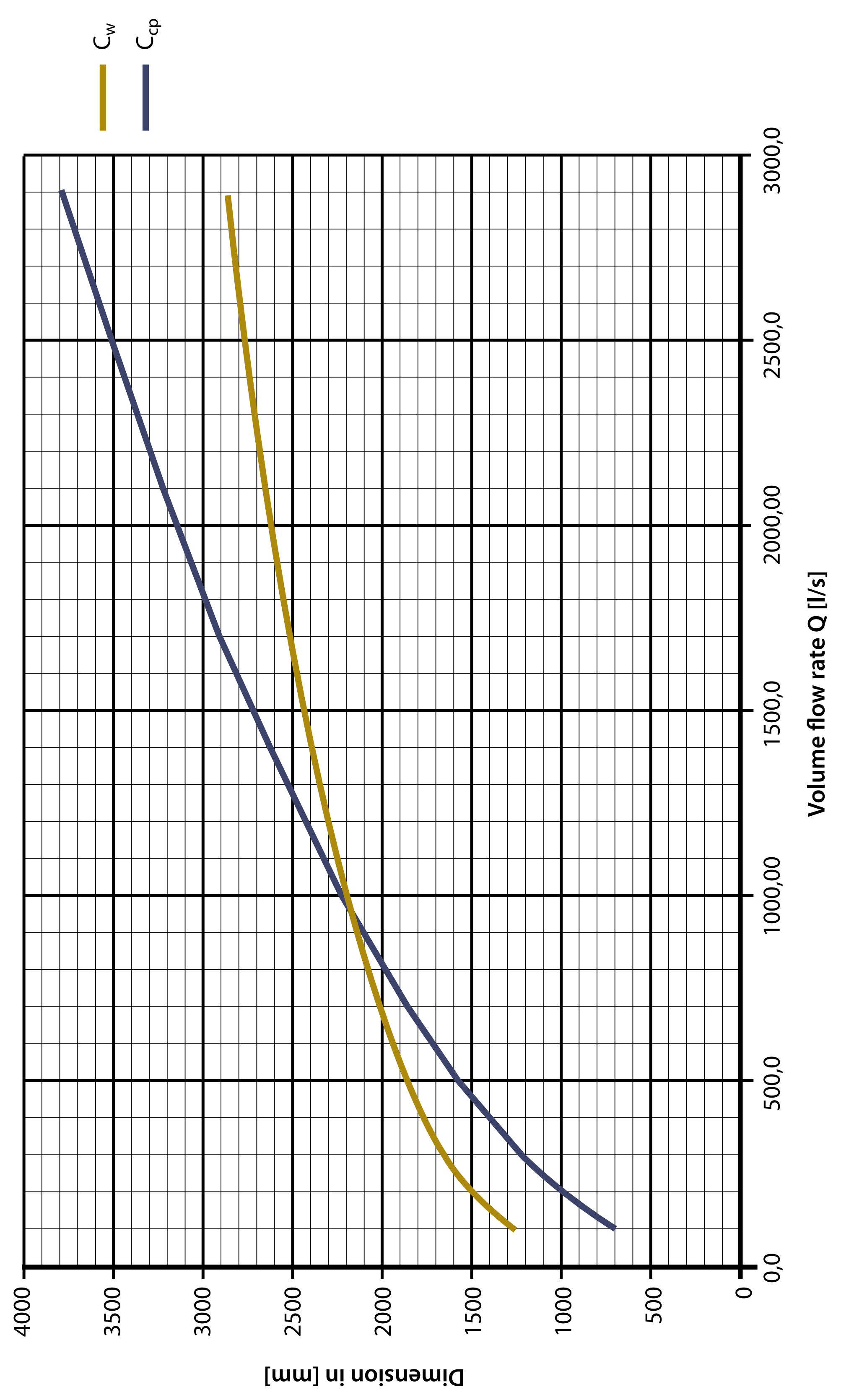


Fig. 5.6 b: Minimum dimensions for the pump sump

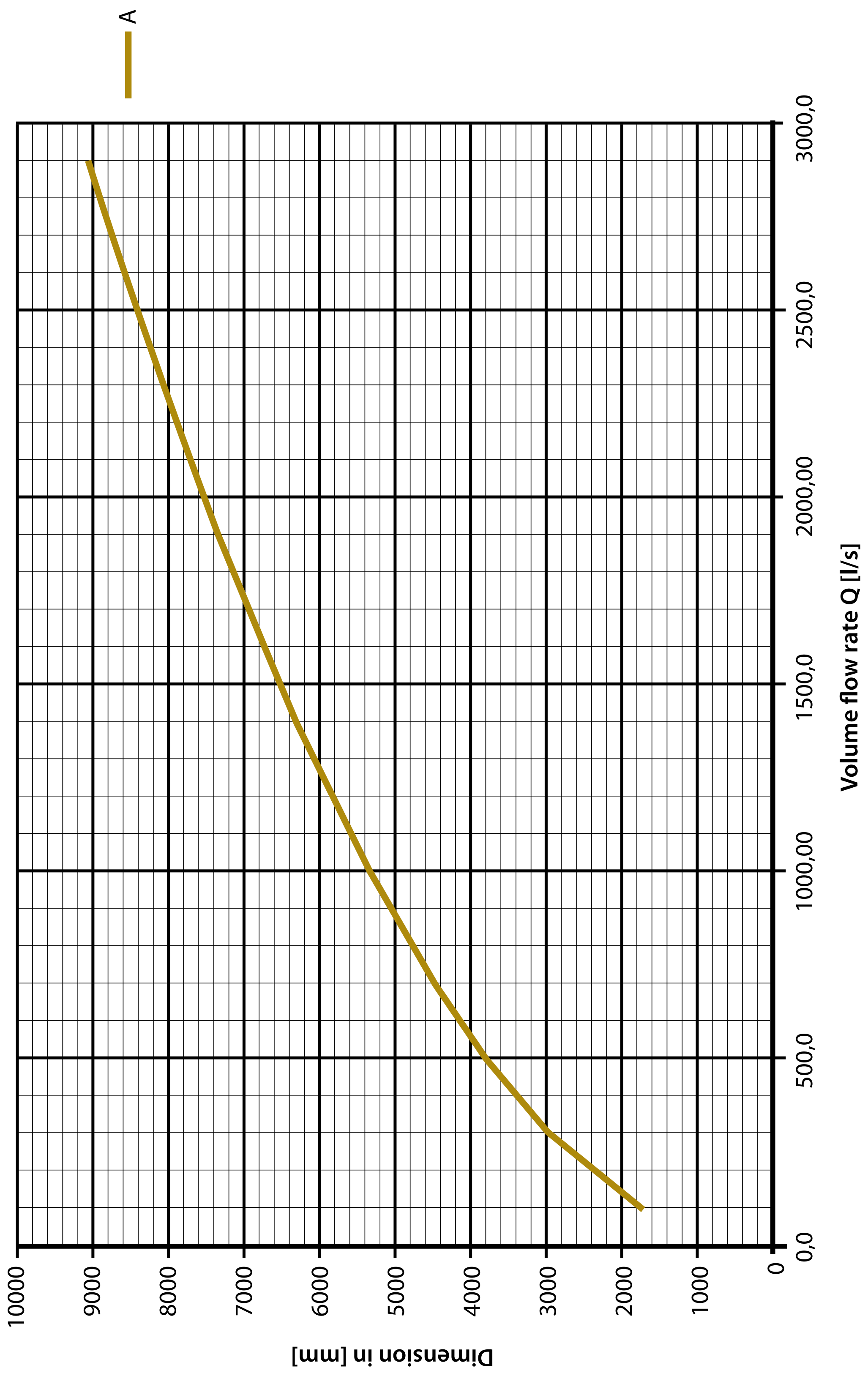
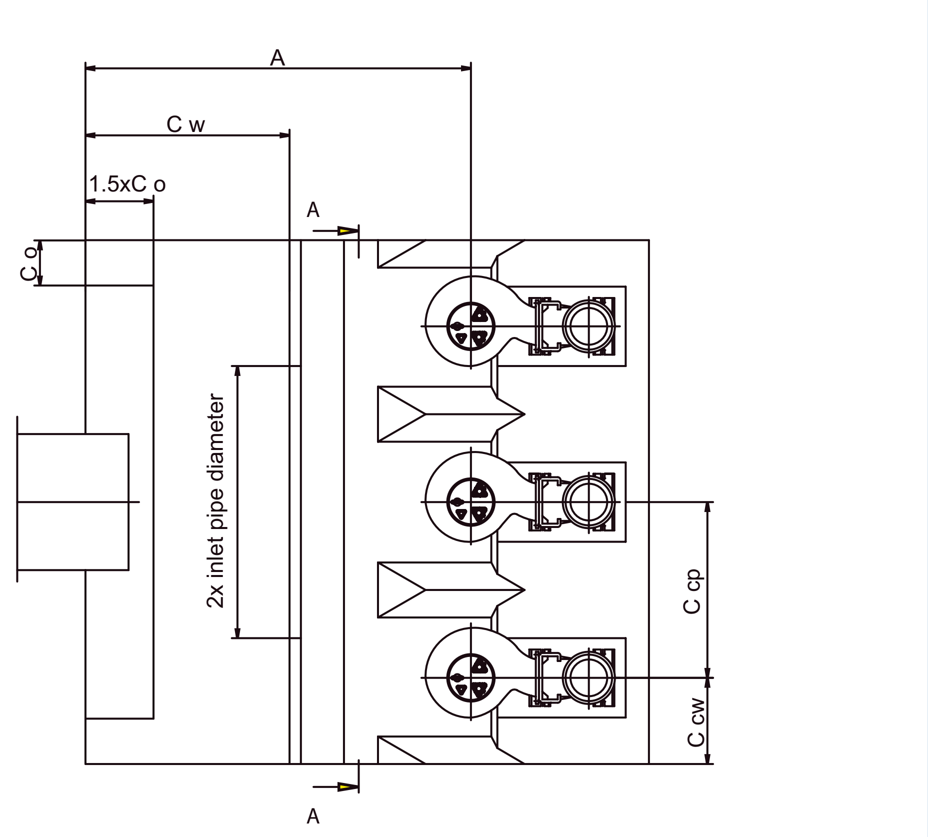


Fig. 5.6 c: Minimum dimensions for the pump sump



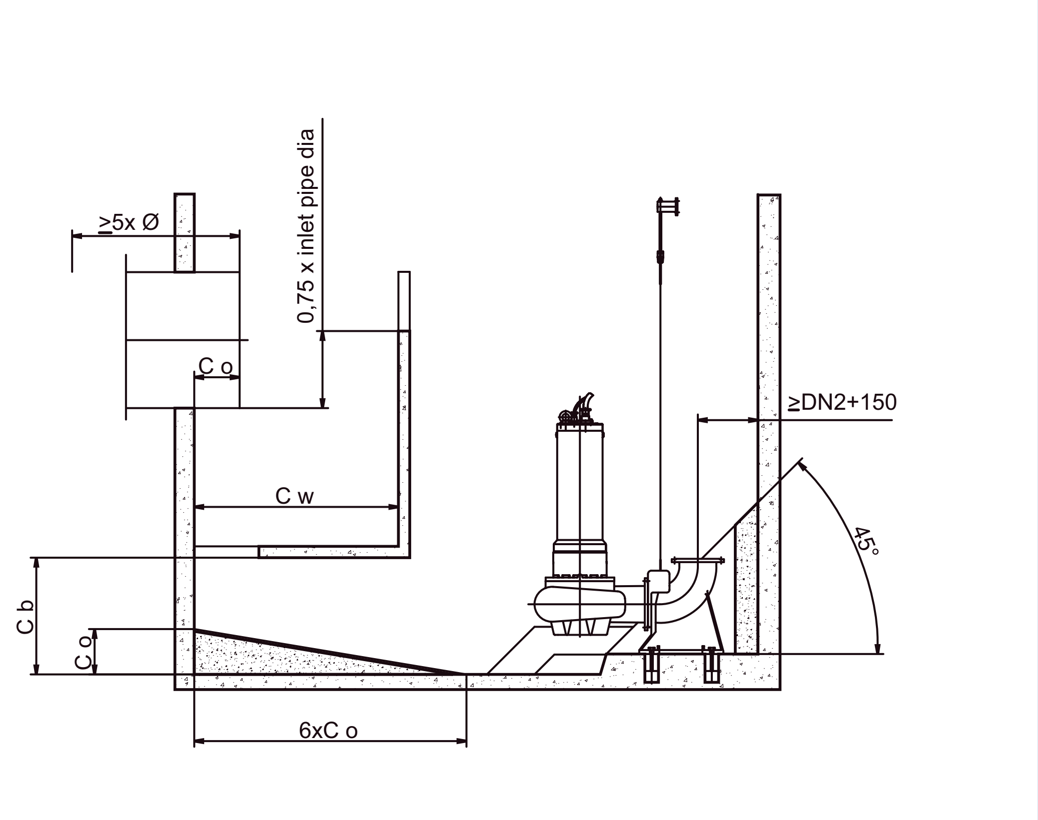
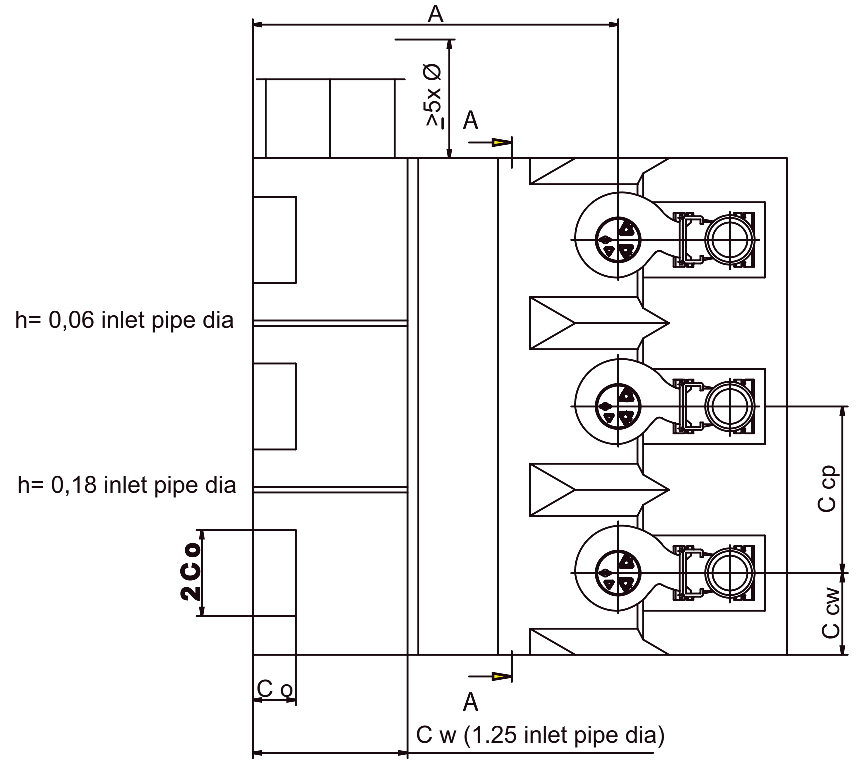


Fig. 5.6.1 a: Example of a KRT (wet installation) with direct approach flow and height difference between pipe invert and pump sump



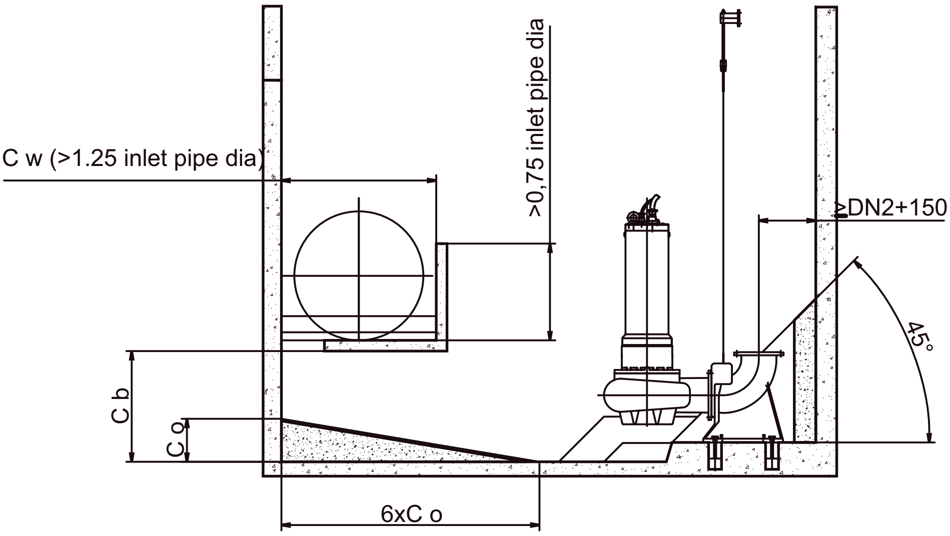


Fig. 5.6.1 b: Example of a KRT (wet installation) with longitudinal approach flow and height difference between pipe invert and pump sump

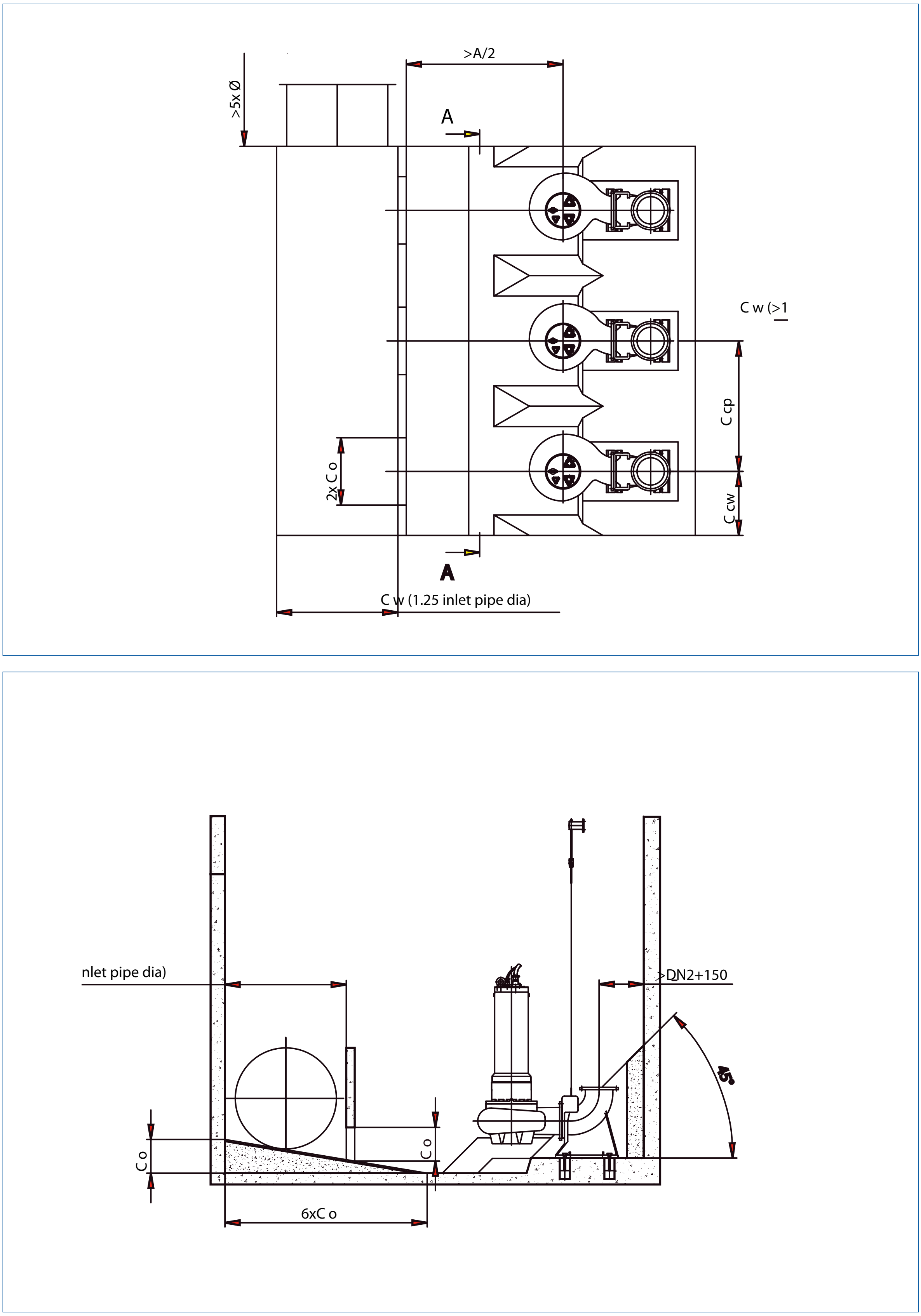


Fig. 5.6.1 c: Example of a KRT (wet installation) with longitudinal approach flow and no height difference between pipe invert and pump sump

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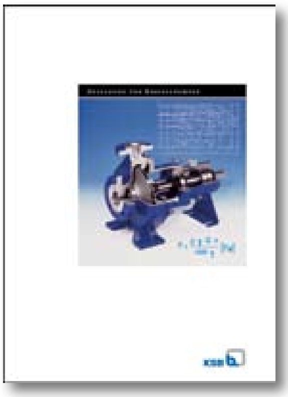

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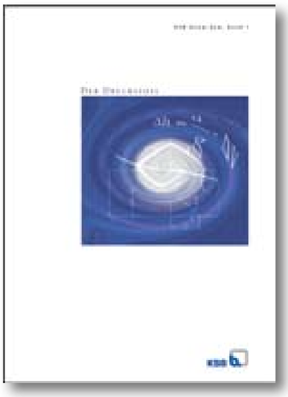

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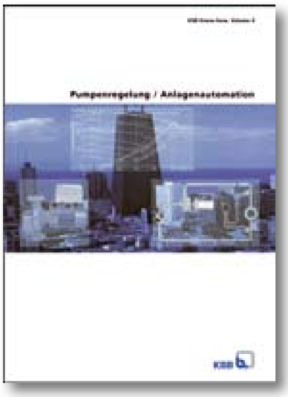

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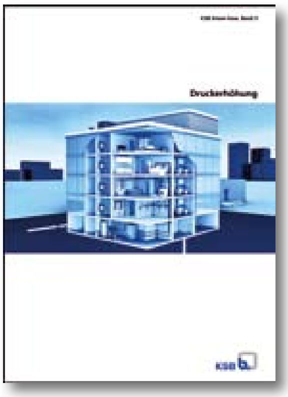

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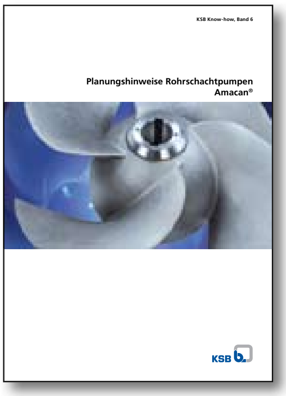

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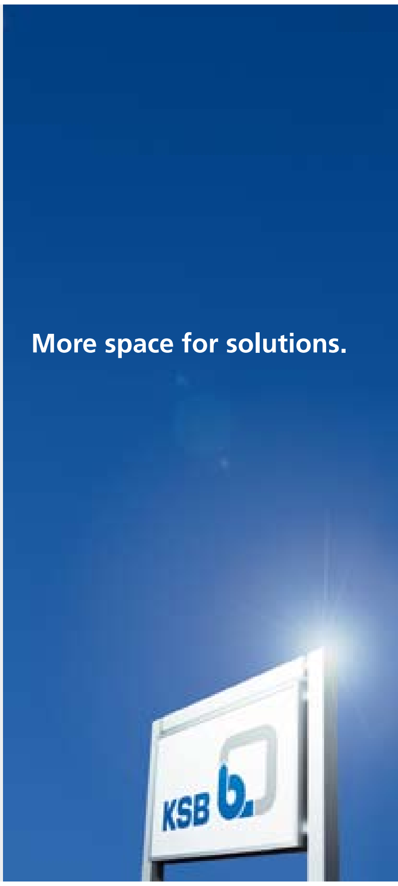

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