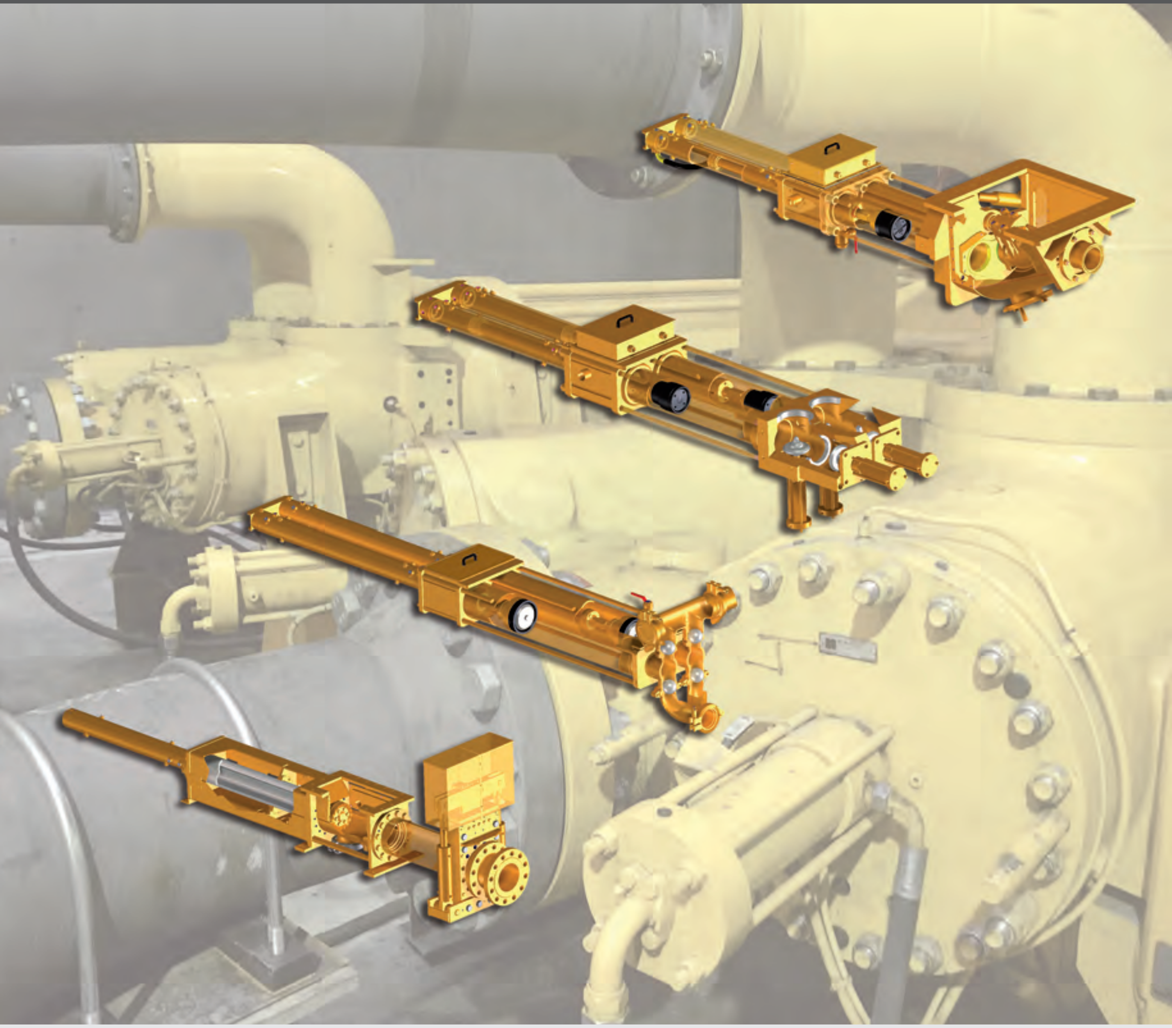
Industrial Pump Technology

Treatment, pipe transport and storage of high-density substances



Putzmeister

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Industrial Pump Technology

Treatment, pipe transport and
storage of high-density substances

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Summary

Range of applications

Biomass	Dredging	Chemical
		
Power plants	Mining	Co-incineration
		
Offshore	Waste treatment	Tunneling
		
Sewage plants	Cement industry	Paper Industry
		

Preface

Based on 60 years industrial experience with Putzmeister and concrete pumps, this book is intended to assist process engineers in the selection of high-density solids pumps as well as project planning for the adjacent conveying and storage systems of different high-density suspensions.

The main applications for high-density solids pumps for effective pipe conveying are:

- Wastewater treatment
- Coal-fired power plants
- Combustion and disposal of dewatered sludge
- Mining industry for dewatering, backfilling, tailing, transport
- Treatment of organic waste
- Offshore application

The design and the type of pumps utilized can be very different depending on the specific circumstances, the nature of the various fluids and substances to be handled.

This book provides an overview of the technical state-of-the-art-pipe conveying and pump systems. Basics and application limits are shown for the selection of our wide range of pump technologies and systems.

Therefore, this book presents practically proven technology and is a reference book at the same time.

According to the interest and success of the first edition of the book "Dickstoffpumpen Aufbau und Anwendung", it was the authors` obligation to update the topics and introduce technical innovations.

Special thanks go to Karl Schlecht, the founder of Putzmeister and his Foundation Karl Schlecht Stiftung (KSG), more information on http://www.karl-schlecht.de. He has inspired and supported this expanded second edition as a contribution for effective pipe conveying compared to other continuous conveying methods for most difficult masses beyond water and viscous pastes.

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Examples of pumping material

Coal sludge	Coal paste	Fly- and bottom-ash slurry
		
Food waste	Mineral cake	Mineral paste
		
Mineral slurry	Paper slurry	Tailings slurry
		
Titanium-dioxide paste	Washing residuals	Fly ash slurry
		

1. High-density substances

1.1. What are high-density substances?

High-density substances are mixtures of liquid and solid constituents.

Typical examples of high-density substances are sludges, which consist predominantly of liquid components and which have accordingly a solid content of up to 80% by weight, and slurries – these are suspensions in which solids range from the finest grades to 2 mm float in a liquid.

Suspensions in nature or in technical processes are called slurry. Suspensions are distinguished by particle size.

Suspension slurry

Fly ash with ground ash contain particle sizes in the range from 0.1 mm to 6 mm. In comparison the particle sizes in milk of lime range from 1 um to 100 um.

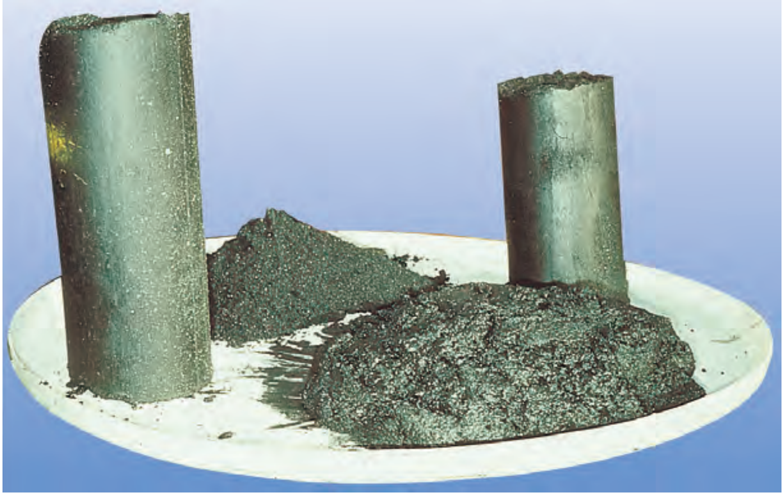
A suspension tends to have phase separation at rest. When transporting suspensions in a pipeline, sedimentation of the particles has to be considered.

High-density substances typically have unique characteristics such as specific gravity, solids content, maximum particle size as well as behavioural characteristics, for example, thixotropic, abrasive or adhesive.

Increasingly, engineers of industrial plants are faced with the problem that substances with a high proportion of solids – such as mechanically dewatered sewage sludges, filter cakes, bituminous coal sludges, waste and process sludges – have to be transported over relatively great distances to landfills, deposits or incineration plants.

In principle, long conveying distances can be bridged even with mechanical conveying equipment such as worm conveyors, scraper conveyors or through belt conveyors.

Fig. 1: A mixture of coal, limestone and water with 80% solids content as fed into pressurized fluidized bed furnaces



However, these do have the disadvantage of possibly considerable noise and odor pollution in their immediate environment. If a combination of horizontal and vertical conveying sections is required, this will necessarily involve multiple material transfer points. The bottom line here is that there are limits to mechanical conveying in systems planning and in implementation.

It is simpler to move sludges within an enclosed pipeline. This approach means very low noise emissions and no odors at all. The pipework can be installed in existing systems, thus saving on space. Pipe elbows make it a relatively simple matter to change the direction of the pipe or go round obstacles.

However, not every sludge or slurry is actually pumpable. The mixture of solid and liquid components in a sludge must be such that it results in a plastically deformable mass.

Every time there is a change in direction in the delivery line, for example in pipe constrictions or pipe elbows, this brings about a deformation of the sludge in the pipe which is always accompanied by an internal level of friction which tends to act as a brake on movement. The internal friction of the sludge is increased further by the friction between the medium and the walls of pipe. These two friction forces do not occur until the medium is actually moving and must be overcome by the pump before the sludge can be conveyed forward.

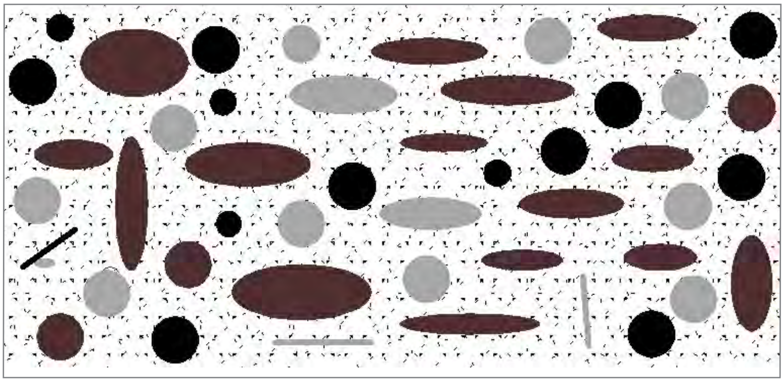


Fig. 2:
Image layer cut of sludge

A pumpable sludge must be saturated – in other words, the volume of pore space in the sludge must be filled with sufficient quantity of solid matter for a particle to be able to rest on another particle via a plastically viscous liquid and for interstices to be filled.

Sludges which do not naturally have a gas component can, by injection of about 2% air, be brought to a consistency which prevents knocking in the pipe as a consequence of pressure fluctuations.

Only a premixed and saturated sludge of this composition will have the plasticity which would allow it to be conveyed in pipes with the aid of pumps.

Fig. 3:
A high grade of dewatered sewage sludge with 47% solid content

This is a compact sludge with a friable structure

1.2. Properties of the high-density substances

As has already been mentioned, a medium must have certain properties before it can even be conveyed along pipelines. Of absolute central importance here is material consistency, viscosity and fluidity.

Consistency

The consistency of high-density substances is a measure of its plasticity. It depends on how the medium is composed of the solid component and the plastically viscous liquid component.

Efforts should be made to prevent "bleeding" – in other words, the high-density substances should be prepared such that highly liquid and watery components only escape gradually or not at all.

No bleeding

There is a very high risk of bleeding since the high pressure which conveying involves can force the liquid components outwards as if through a filter cake. This makes the medium thicker and more viscous and it may even block the pipe.

Screen analysis

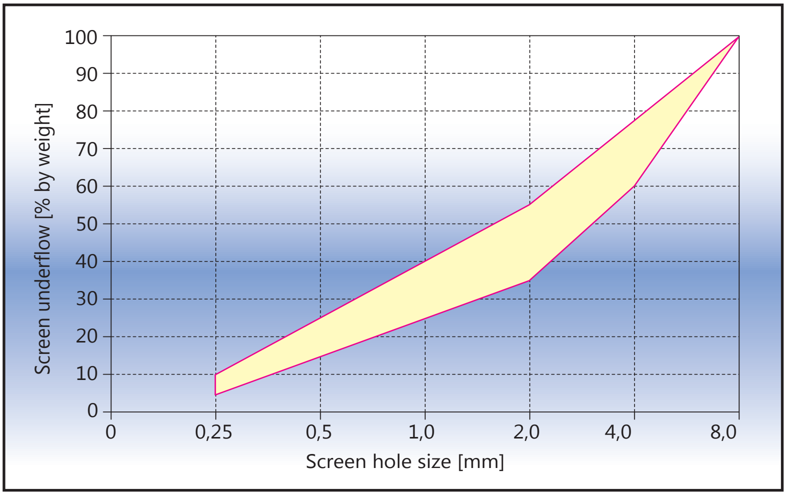
Pumpability according to the screen analysis

In deciding whether a water solids mixture can be pumped, the grading curve is of decisive importance.
The screen analysis of the individual size fractions is plotted in the grading curve diagram.

The granularity of a mixture with a good pumping capability would fall within the yellow region of fig. 4 or at least be very close to it.

Fig. 4: Grading curve diagram

Screen underflow as a function of screen hole size



Of great importance here is the proportion of fine grain less than 0.5 mm in size. If this grain size group is not present, it will not be possible to pump the mixture, as the relatively coarse particles will quickly settle as sediment or dewatering will occur during the pump intake phase. If mineral and coal solids are pumped as a mixture with differing grain distributions – in other words, with both a proportion of coarse particles and a proportion of fines – it will be possible to pump this mixture up to a solids content of 80% by weight.

Viscosity

In contrast to solid substances, the basic components of liquid substances can be pushed easily against each other. There is a weak force of attraction between the liquid molecules which is known as cohesion. However, this force is still strong enough for the liquid substances to retain its volume even when its shape changes.

A distinction is drawn between free running and cohesive media. Unlike cohesive media, free running media only hold together to a very limited extent. Free running media exhibit a considerably better flowability than cohesive media.

When a flat plate with surface A is to be moved at a constant speed v through a viscous liquid, a force will have to be applied.

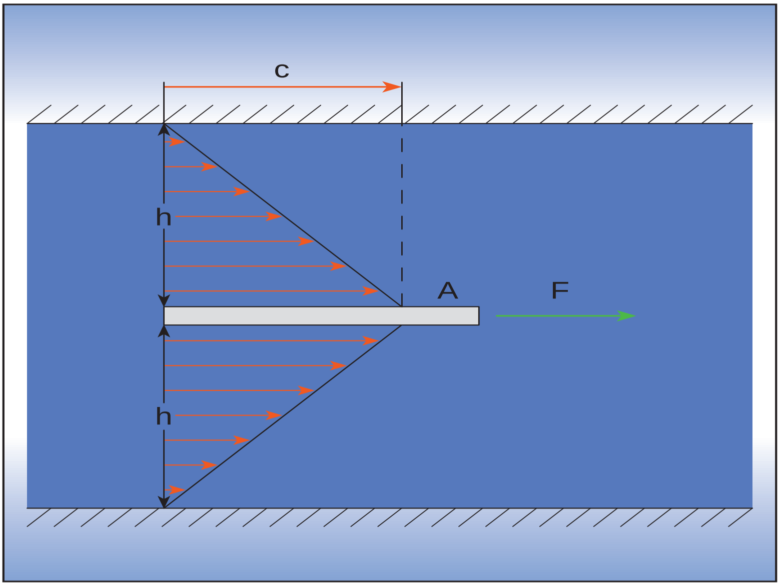


Fig. 5:
Liquid molecules adhere to the plate and to the edge of the wall

Between them, layers of liquid slip over each other and there is a drop in the speed at which the media moves

(1)
Shear stress

This yields the shear stress τ

$$\tau = \frac{F}{A}$$

with
F: Force
A: Area of the plate
τ: Shear stress

Between the shear stress (which is a function of the viscosity) and the drop in speed between the plate and the wall of the liquid the following relationship applies:

(2)
Dynamic viscosity

From then there results the viscosity:

$$\tau = \eta \times \frac{dv}{dh}$$

with
h: Distance between the two plates
dv/dh: Shear rate
η: Dynamic viscosity

The proportionality factor is termed the dynamic viscosity η and describes the ability of a substance to build up a tension as it is deformed. Accordingly, viscosity is a measure of the internal friction or of the stiffness of a liquid. Dynamic viscosity is a material constant which is dependent on temperature and pressure. The speed drop can often be approximated by the quotient of relative speed and plate distance (v/h).

Fluidity

The term fluidity means the ability of a medium to enter into a flowing state or to continue in the state. The method used to represent the fluidity of different substances is to plot their dynamic viscosity against the shear stress. (fig. 6). Media with ideal fluidity – such as water, for example – are called Newtonian fluids.

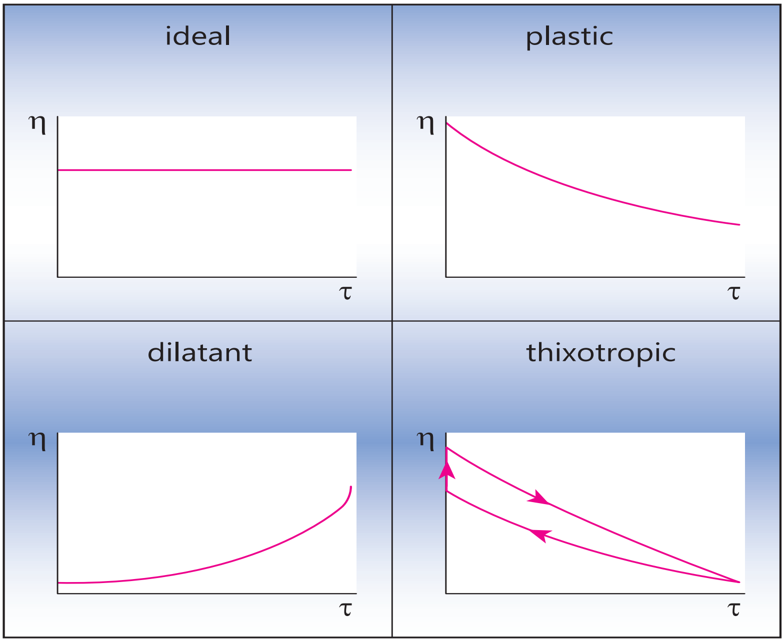


Fig. 6: Fluidity

With these fluids the dynamic viscosity is proportional to the shear stress, while non-Newtonian media do not flow until a certain minimum shear stress is exceeded.

Media with a plastic flow behavior include liquid chocolate, toothpaste and many lubricants. Here the viscosity falls as shear stress rises. Dilatant fluidity means that viscosity increases as shear stress rises and with very high shear stresses the viscosity can become “infinitely“ great. Examples of this are suspensions. When a suspension is stirred up the sediment rises and viscosity keeps increasing. This is a kind of behavior exhibited, for example, by old, sedimentated oil paints, starch in water and even sludges from lakes and rivers.

With thixotropic flow behavior on the other hand, viscosity drops as mechanical loading increases, for example, in the form of shaking. After removal of mechanical loading the original state of the medium is restored. Example of thixotropic media include sewage sludge and fly ash.

Fig. 7: Crude oil paste

2. High-density solid pumps, types

High-density solid pumps are hydrostatically operating machines which displace the medium being pumped and thus create a flow. The movement of a piston or a rotor causes the material to be sucked in and then pushed out into the delivery pipe. Depending on how the displacement principle is implemented, a distinction can be drawn.

Rotary and reciprocating pumps

The category of rotary circulation pumps includes eccentric screw pumps, centrifugal pumps, rotary lobe pumps, squeezed tube or peristaltic pumps. Reciprocating pumps can be subdivided into plunger, piston and diaphragm pumps.

The centrifugal pump is suitable for use with thin sludges or slurries with a low solids content and for relatively low pumping pressures of up to 40 bar. Their simple design means high output at comparatively low investment costs. However, rapid wear is the consequence of the high internal flow speed. Another disadvantage is their poor efficiency of less than 60%.

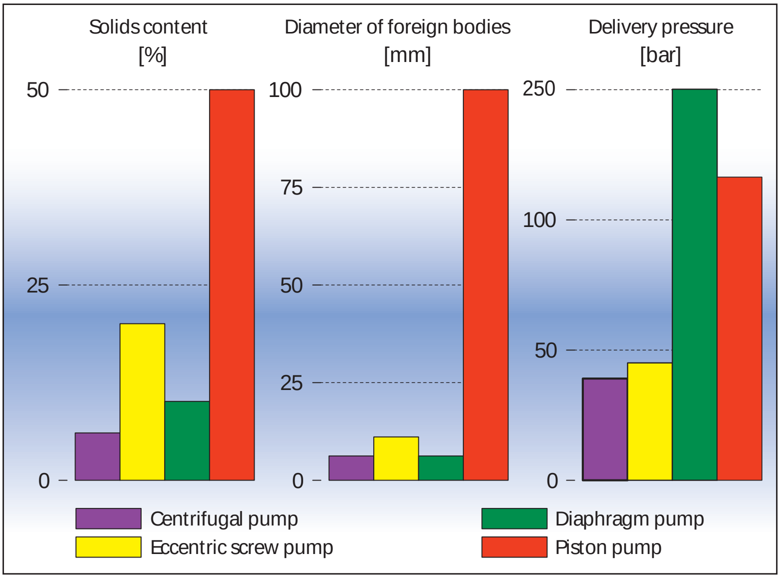
If sludges in the watery to viscous range with solids contents of 20% are to be pumped at pressures up to 48 bar, a suitable type is the eccentric screw pump. However even this pump has poor wearing characteristics and is not suitable for sludges which could contain relatively coarse foreign bodies.

In reciprocating diaphragm pumps the medium and the drive are separated by a diaphragm. The performance of this kind of pump is restricted by the suction and discharge valves. Operating pressures when pumping coal and mineral suspensions lie at around 100 bar. Max. operating pressures up to 250 bar are possible. Often booster pumps are necessary to ensure the required suction pressure.

The high-density solids pump which can be used in the widest range of situations is the hydraulically powered piston pump. This pump is capable of pumping even highly viscous media containing solids or extremely dry media (fig. 8). In the case of the two-cylinder piston pump, power is transferred to the material via delivery pistons working in a push-pull mode.

While one delivery piston sucks material from the feed hopper into the cylinder, the second piston simultaneously pushes the material in the other delivery cylinder into the delivery line.

Fig. 8: Pump types comparison



Two cylinder piston pumps come with or without valves. Control elements are necessary for the reversal phase from suction to pressure and vice versa. The particular form of these control elements will depend on the pump type used and the sludges which are to be pumped.

Different techniques will be found in the transfer tube pump, the seat valve pump and the ball valve pump. These will be dealt with in the sections which follow (chapter 2.2).

Other hydraulically powered piston solids pumps, such as the single cylinder piston pump, exploit their own design features to meet the various requirements which arise from particular sludge properties.

2.1. Rotary Pumps, Centrifugal, Eccentric screw, Lobe and Rotor pump

2.1.1. Centrifugal pump

Centrifugal pumps are used to transport fluids by the conversion of rotational kinetic energy to the hydrodynamic energy of the fluid flow. The rotational energy typically comes from an electric motor. The fluid enters the pump suction near to the rotating axis and is accelerated by the impeller. The fluids are flowing radially outward into a volute chamber (casing), from where it exits.

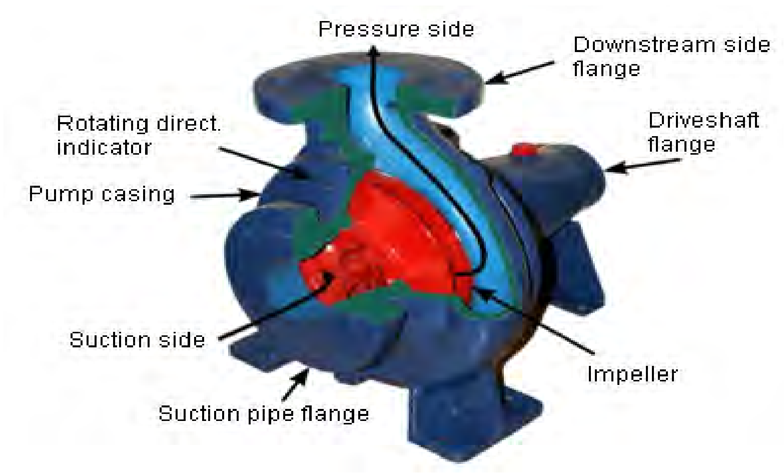


Fig. 9: Example of a centrifugal pump, radial type

Centrifugal pumps are used mainly for Newtonian fluids (water). Also liquids which contain small amounts of suspended solids are pumpable. The acceptable particle sizes are dependent on the "ball passage" between impeller and casing.

The typical features of the centrifugal pump are the output (m^3/h) and the discharge height. With centrifugal pumps arranged in series, the total pressure height can be raised. With the parallel installation the output of pumps are raised.

A speed change changes the output as well as the operating height. The output is a function of the engine speed, the pressure height is a function to the square of pump speed (see also chapter 2.3.1). For start up, the pump case must be filled with fluid, because the centrifugal pumps are not self priming.

2.1.2. Eccentric screw pump

The eccentric screw pumps (helical rotor pump) are suitable for conveyance of water and other free flowing media. The actual pumping elements of the pump are the rotor and the stator. The rotor rolls eccentrically in double threaded stator of the same minor diameter and twice the pitch length.

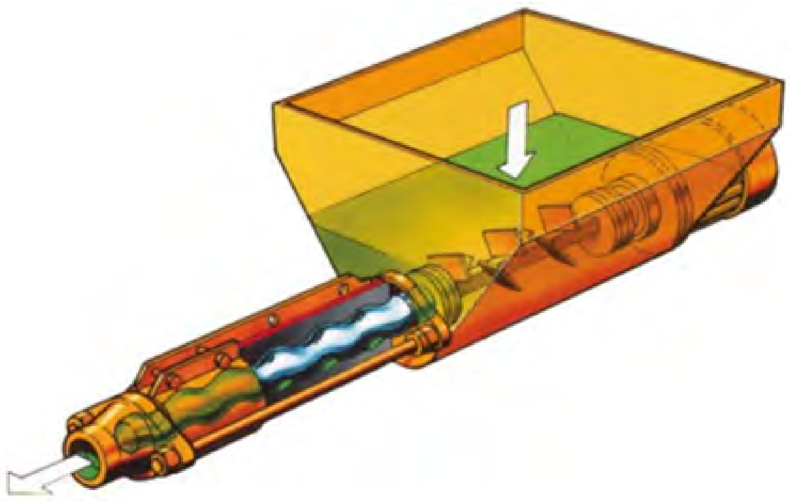


Fig. 10: Eccentric screw pump with mixing trough. Cross section of rotor-stator shows the cavity

The capacity of the pump is determined by the size of the cavity formed when the rotor is turned in the stator. Special designs involve the rotor of the pump being made of steel, with the body (stator) made of a molded elastomer and inside a metal tube body.

This leads to the volumetric flow rate being proportional to the rotation rate and to low shearing being applied to the pumping fluid. The cavities taper down toward their ends and overlap with their neighbours, so that, in general, no flow pulsing is caused by the arrival of cavities at the outlet.

Eccentric screw pumps are used primarily in wastewater treatment plants and in the food and pharmaceutic industry.

2.1.3. Rotary lobe pump

The rotary lobe pump belongs to the pump type of positive displacement pumps. Rotary lobe pumps are self-priming and valveless. The even rotation of the rotor pair creates a vacuum on the priming side of the pump. This vacuum draws the fluid into the pump chamber.

Fig. 11: Principle of rotary lobe pump with 3 rotor pairs

With further rotation, the pumped medium is conveyed past the pump wall into the pressure area.

When the rotor is at a standstill, the pump seals off almost completely. The maximum size of foreign bodies in the fluid depends on the geometry of the pump housing.

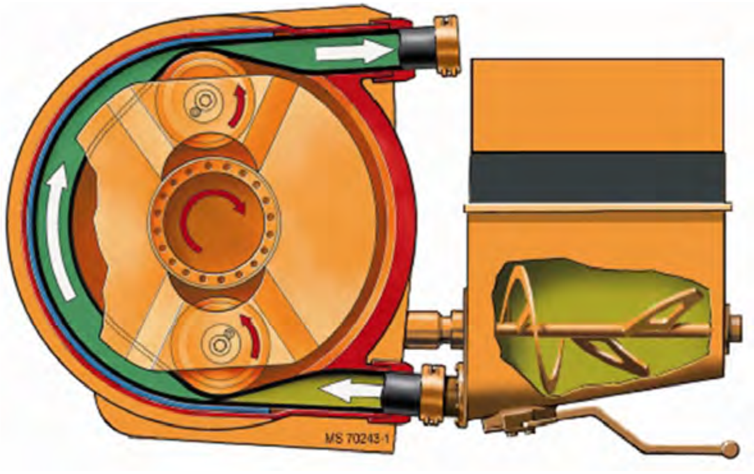
2.1.4. Peristaltic pump

The peristaltic or rotor pump consists of a pump casing, a rotor and a U-formed tube. The tube is supported by its outer contour in the pump casing.

Pump principle:

When a pair of rollers rotate, the squeezing force will force the transported medium flow in single direction and with no back flow. After the medium in the tube is transported, the squeezed tube will return to its normal shape by its elasticity and the pressing force of the rollers.

Fig. 12: Rotor pump with mixing trough



During this procedure, the vacuum generated will suck the medium into the tube cavity, and then, the sucked medium will be squeezed by the spinning rollers and discharged from the hose. With the continuous rotation of the rollers, the medium is sucked and discharged continuously. The flow rate and the lifetime of the tube is an important parameter for the pump. For a given speed of the pump, a tube with larger inside diameter will give a higher flow rate. Increasing the number of rollers does not increase the flow rate.

The advantages of the peristaltic pumps are:

No contamination, because the only part of the pump in contact with the medium being pumped is the interior of the tube. The pump is able to handle slurries, viscous, shear-sensitive, aggressive fluids and high-density solids like dewatered sewage sludge and coal paste. The disadvantage of the pump are the flexing tubing, which has to be replaced periodically.

2.2. Dual cylinder piston pumps

2.2.1. The transfer tube pump

Pumps without valves

The defining characteristic element of the transfer tube pump is the "S transfer tube" installed inside the feed hopper (fig 13). The job of the transfer tube is to control the flow of high-density solids, in other words, the pump cylinder, which is currently pushing the material, is connected to the delivery line by the S transfer tube.
At the end of each piston stroke this S-shaped tube (S-tube) which is connected to the delivery line is swung over to the other delivery cylinder with the aid of two hydraulic switching cylinders (plunger cylinders).

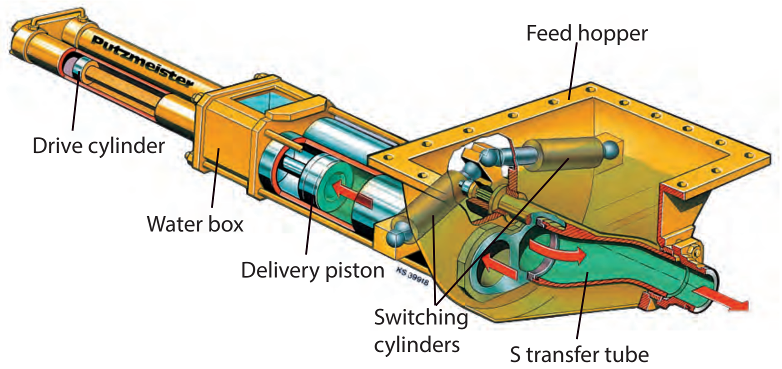


Fig. 13: Transfer tube pump

A hydraulic circuit is used for synchronizing the position of the transfer tube and the movements of the two delivery pistons. What is of high importance in regards to the reliability and the correct functioning of the transfer tube pump is that the S-tube should swing over rapidly and not suffer undue wear. This is effected with the aid of the generously sized plunger cylinder. Of great importance here is the design of the seal ring on the transfer tube and of the spectacle plate upstream of the two cylinders.

Faultless operation of a transfer tube pump cannot be assured unless the seal ring guarantees an absolute seal between the spectacle plate and the S-tube during the pumping phase.

Automatic sealing

The centering diameter (A) of the S-tube is larger than the effective hydraulic diameter (B) of the seal ring. For this reason the seal ring, which moves axially on the transfer tube, is pressed automatically by the delivery pressure onto the spectacle plate – in other words, as the delivery pressure rises so does the sealing force which presses the seal ring onto the spectacle plate (fig. 14).

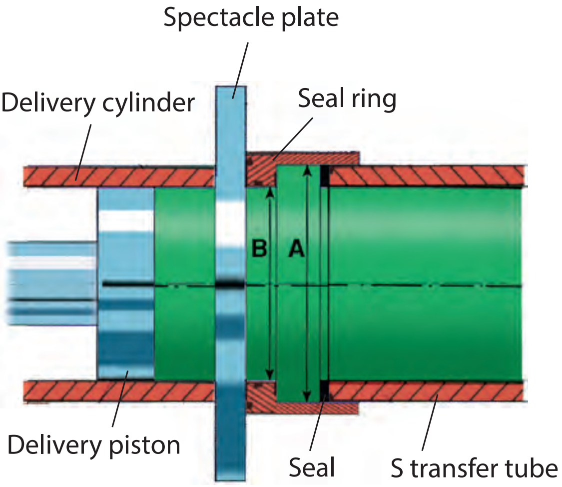


Fig. 14: The seal ring ensures that the transfer tube cannot leak

The large cross-section of the holes in the spectacle plate means that with a delivery cylinder diameter of 200 mm it is possible to pump high-density solids with a mean grain size of as much as 80 mm.

The maximum diameter of individual foreign bodies may be as high as 60% of the diameter of the delivery line – in this example, this would be 120 mm.

Transfer tube pumps are suitable not only for sludges with a solids content of up to 80% by weight and a fluctuating particle size distribution, but also for conveying fly ash, coal or minerals in suspension.

The right mix matters

If the mineral or coal solids component of the suspension is a mixture of coarse and fine particles, then with a maximum grain size of 50 mm the pumped medium can have a solids content of as much as 80% by weight and be pumped for a low energy consumption of 0.05 kilo-watt-hours per ton and kilometer.

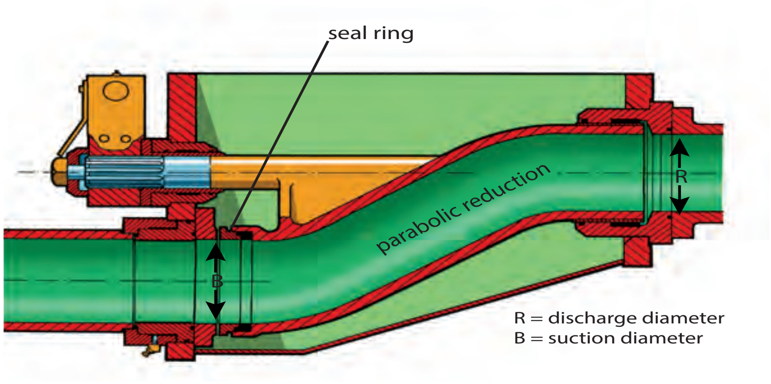


Fig. 15: S-Tube with parabolic reduction

In cross-section the S-Tube is circular with a diameter which tapers in the direction of flow (fig. 15). This, coupled with the S-shaped design of the tube, keeps the risk of clogging down to a minimum. The sealing faces of the spectacle plate and of the seal ring lie parallel with the swiveling movement of the S-Tube. This means that they cannot be damaged when foreign bodies are cut through or get stuck.

The housing of the transfer tube pump has a large square feed opening. This allows stiffly plastic solids to be fed into the delivery cylinder openings without obstruction, risk of hammering or pressure drops.

2.2.2. The seat valve pump

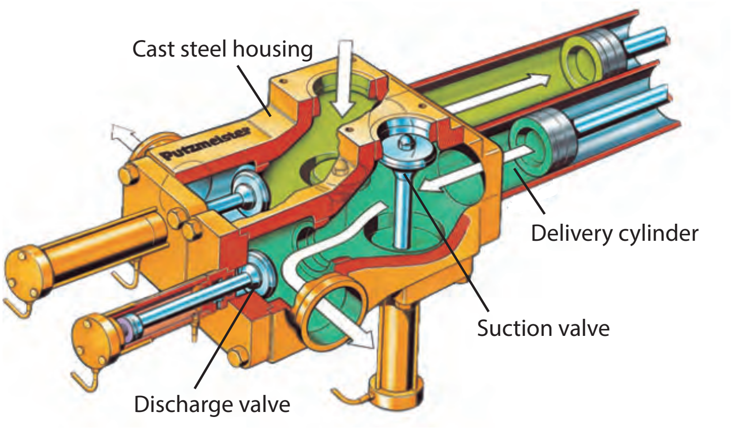
The hydraulically controlled seat valve pump is also a good choice for the pumping of a media with a solids content of up to 50% - 70% and for the high-pressure pumping of paste like industrial media such as sludges. This pump does not need check valves. Since valves are used in this two-cylinder pump it is only suitable for grain sizes up to eight millimeters at most.

With this valve pump the medium being pumped should not contain too many hard inclusions. Should the grains be coarser and make up a higher proportion of the medium the transfer tube pump will be found to be a better choice. The sturdy steel housing of the seat valve pump contains four hydraulically controlled seat valves, two suction and two delivery valves for the two hydraulic cylinders (fig. 16). This means that there are four cylinder rods which have to be sealed. The suction and discharge valves of the pump head are synchronized with the hydraulics of the delivery piston.

Hydraulic synchronisation

This ensures that the contents of the delivery cylinder is equal at all times to the volume being pumped. Once the "sucking" piston reaches its end position, the corresponding suction or delivery valve is simultaneously closed or opened. If there is overpressure in the delivery line, the suction valve will close first. This prevents the pumped medium from being pushed out of the pressure line and back into the hopper.

Fig. 16: Seat valve pump



The valves and valve seatings can be replaced rapidly and easily without the need to remove any other components on the suction or delivery sides. Which type of valve is selected will depend on the high-density solids to be conveyed. For materials containing grains with solid content up to 50% a sharp-edged metal valve seal can be a choice. With low viscosity and rather fine sludges the choice would be a large area elastomeric valve seal.

In one hydraulic control variant the valve is opened passively by the thrust of the medium. In this case the discharge valve has a dependable non-return function which prevents flow back from the pressure line.

At the same time, the high-density solids are precompacted to close to line pressure, before the discharge valve opens noiselessly. This means that pipe knocking resulting from pressure pulsations can be avoided.

2.2.3. The ball valve pump

The two-cylinder high-density solids pump with ball valves is suitable in the low to middle pressure range for pumping highly liquid to paste-like media, for example, mortars, mineral and sewage sludges, provided these can be sucked in through the valve openings. In other words, it is suitable for media with a less dense consistency and when no solid inclusions worth mentioning are expected.

The ball valve pump is to all intents and purposes insensitive to corrosive and abrasive media since the ball valves do not have to be opened or closed from the outside.

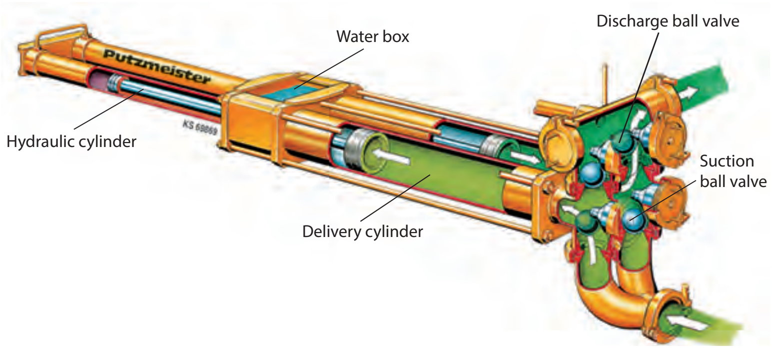


Fig. 17:
Ball valve pump

Suitable for abrasive solids

At the same time, the ball valve on the delivery end is sucked into the valve seating by the vacuum pressure resulting from the suction (automatic valves).

Parallel to this, the second delivery cylinder piston is making its pressure stroke and forces the medium through the discharge ball valve into the delivery line.

The suction ball valve is pushed into its seating by the delivery pressure and thereby closes off the connection to the pump intake.

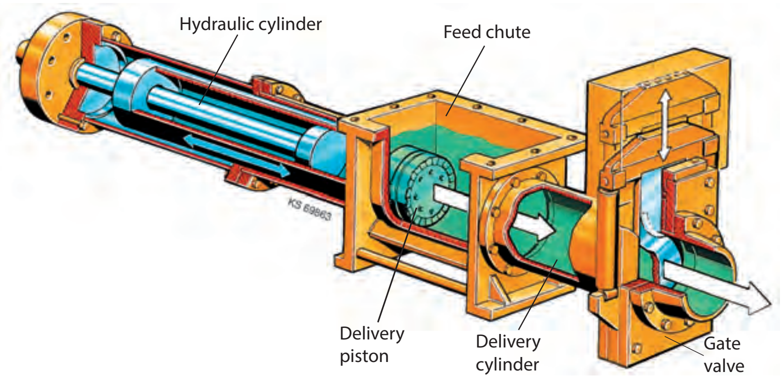
2.2.4. The single-cylinder piston pump

In contrast to the two-cylinder piston pump described above, where a returning piston sucks in the medium which is to be conveyed with the single-cylinder piston pump, the medium is "stuffed" into the delivery cylinder. This approach means that even bulk materials with an awkward coarse composition – for example, wood chips, organic waste, hazardous waste or even shredded paper – can be transported as a mixture in enclosed pipes.

The single-cylinder piston pump also has an oil-hydraulic drive. The delivery piston pushes the medium directly out of a feed chute into the delivery cylinder (fig. 18). Depending on the level of the delivery pressure in the pipe and on the flow properties of the medium, the delivery flange of the pump will be fitted with a flat slide valve or a lamellar non-return valve in order to prevent flow back of the material on the return stroke. Which delivery piston is actually selected will also depend on the material which is to be pumped: free-flowing media for BUNA-N sealing elements while bulky materials which have to be chopped up during pumping mean that hardened cutting edges are required.

If unsaturated material is to be conveyed over large distances, one possible approach is the hybrid feed system. Here compressed air is injected into the delivery line. The compressed air presses the plug of material into the pipe. As the compressed air expands the material being conveyed is loosened and separated. With increasing distance from the air injection point, the initial plug of material conveying turns into a continuous airborne stream.

Fig. 18: A single cylinder pump with gate valve



The one-cylinder-piston pump has proven its capabilities in wastewater treatment plants for the transport of screenings, as well as for the feeding of biogas plants with refeed medium. Larger one-cylinder piston pumps are used in the hazardous waste incineration plants and in tunnel construction for overburden conveying (see also chapter 3 Applications).

2.2.5. The diaphragm pump

In the case of diaphragm pump, the conveying medium is sucked in and ejected by means of a diaphragm instead of by a cylinder. There are two types of diaphragm pumps: Mechanically controlled diaphragm pumps and oil hydraulically driven diaphragm pumps.

Diaphragm pumps with mechanical drives, consisting of a connecting rod, eccentric and electric gear motor are only suitable for lower pressure range up to 100 bar. In the design of the hydraulically driven piston diaphragm pump, the drive cylinder transmits the oscillating movement to the diaphragm. Hereby, pressures up to 250 bar are possible.

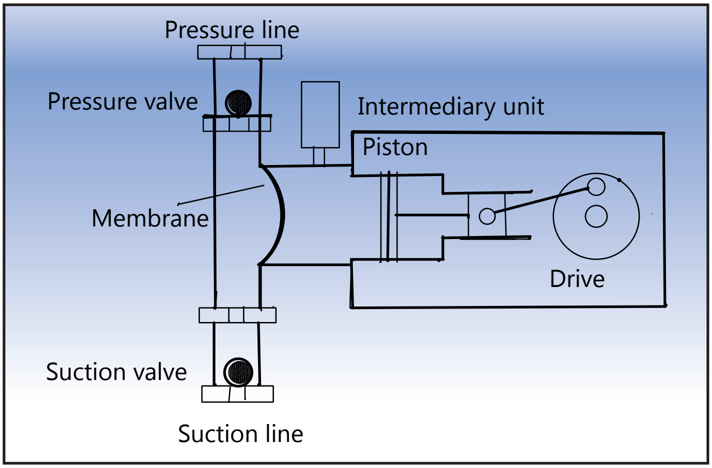
The hydraulic drive is separated from the conveying medium via a barrier fluid. The barrier fluid acts on the diaphragm all over the surface, which means, that the diaphragm is not overstressed in the suction and pressure position.

The suction and pressure valve, comparable to the balls of the ball valve pumps, reduce the application spectrum of the diaphragm pump in the particle sizes to be conveyed.

Piston diaphragm pumps are used for slurry, paste and tailing applications. These pumps can handle a range of applications including mine dewatering and backfill and long distance slurry pipelines of ores and minerals.

Often booster pumps are necessary to supply the required suction pressure. This means additional investment and energy costs.

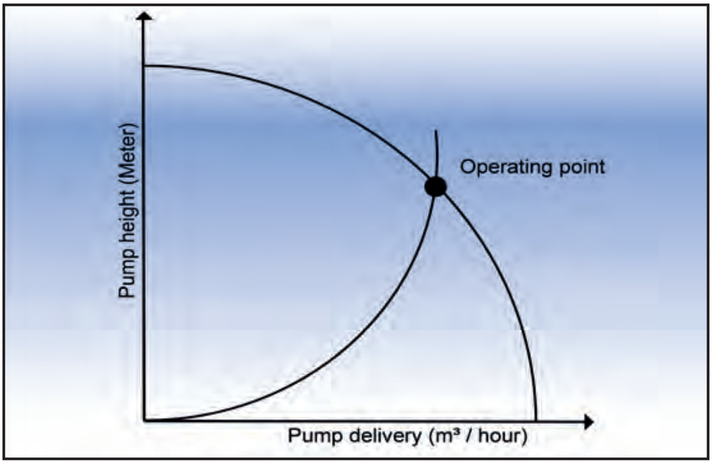
Fig. 19: Diaphragm pump with mechanical drive



2.3. Pump criteria

2.3.1 Centrifugal pump

Fig. 20: Operating point centrifugal pump



The maximum working pressure of a pump is reached when pumping against a closed valve. The operating point of the centrifugal pump results from the pipeline characteristic curve.

2.3.2. Eccentric screw -,rotor -, lobe pump

The pump volume characteristic curve is proportional to the pump speed. The effective volume curve (red line) is parallel to the theoretical curve.

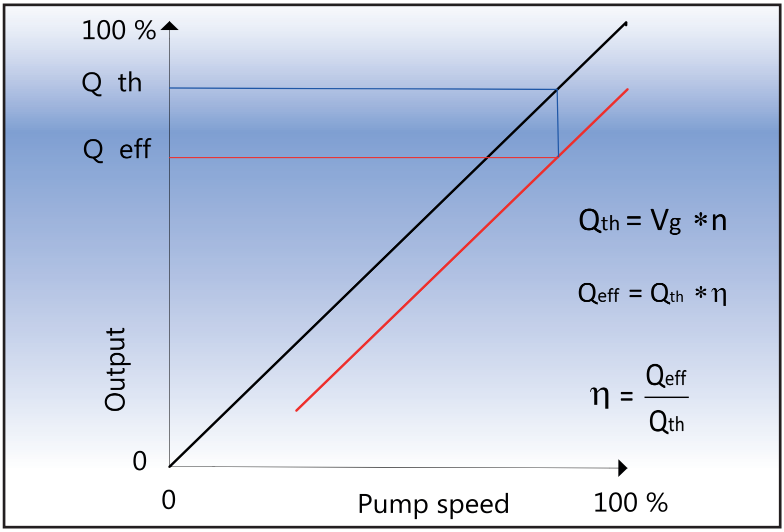


Fig. 21: Performance diagram lobe pump

(3) Theoretic flow rate

(4) Effective flow rate

(5) Pump efficiency

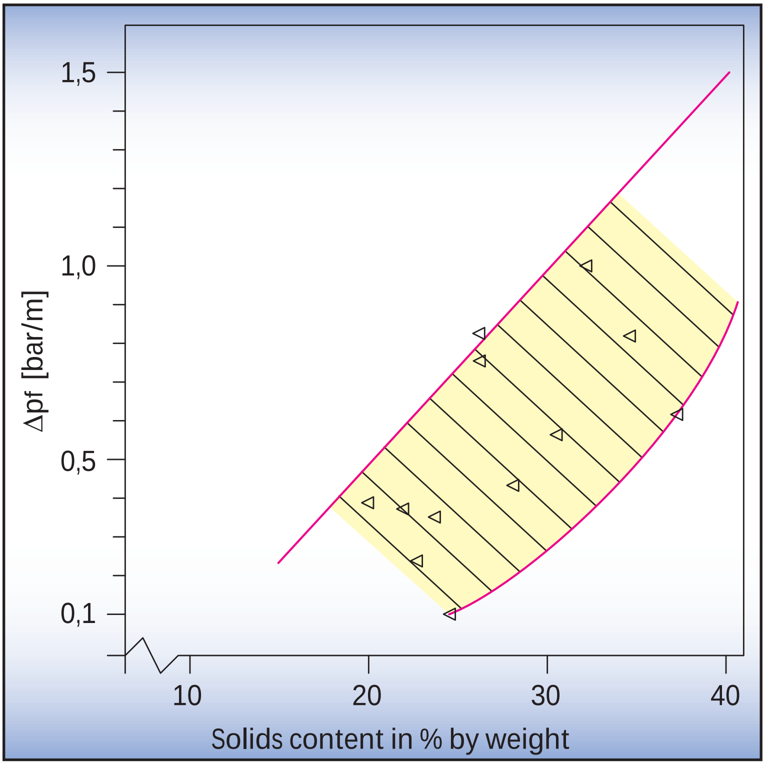
Qth: Theoretic flow rate
Vg: Volumentric flow rate per rpm
η: Pump efficiency
n: Speed

2.3.3. Piston pump

Pressure requirements

There are other aspects that contribute to the pumpability of a sludge, it is not determined soley by the dry-matter content (solids content), but also by other factors such as the sludge type, its consistency, type of treatment, grain size distribution and organic components. This variety of influences is the reason for the wide scatter of measured values in fig. 22. Starting with the required pumping volume per time period and the conveying distance and then estimating the pressure drop in the pipeline and taking into consideration the effect of the sludge characteristic, it is possible to obtain a rough figure for the expected pumping pressure.

Fig. 22: Specific pressure drop as a function of solids content



Until now no regular pattern has been detected which could be used for calculating in advance the precise pressure required for pumping high-density solids.

For this reason, high-density solids pumps are designed empirically. In the case of large-scale installations pump trials are often conducted as an aid to designing the pumps.

(6) Delivery pressure

As a result delivery pressure:

$$p_f = \Delta\, p_f * l$$

with
pf : Delivery pressure (bar)
Δ pf: Pressure drop per meter conveyed (bar/m)
l: Pipe length (m)

Pipeline pressure drops depend only a little on conveying speed since a highly liquid lubricating layer forms in the marginal zone, for example, in the case of media with thixotropic flow behavior.
The conveying speeds in the pipe should fall within the range of 0.1 to 0.4 meters per second for sewage sludge. Fig. 23 shows that an increase in conveying speed brings about only a small increase in the pressure drop. In case of risk of sedimentation (tailing, ash, ore slurry transport), conveying speeds up to 2.5 meter per second are necessary to avoid clogging.

Various ways of reducing pipeline pressure are dealt with in the "additional components", see also chapter 6.6.

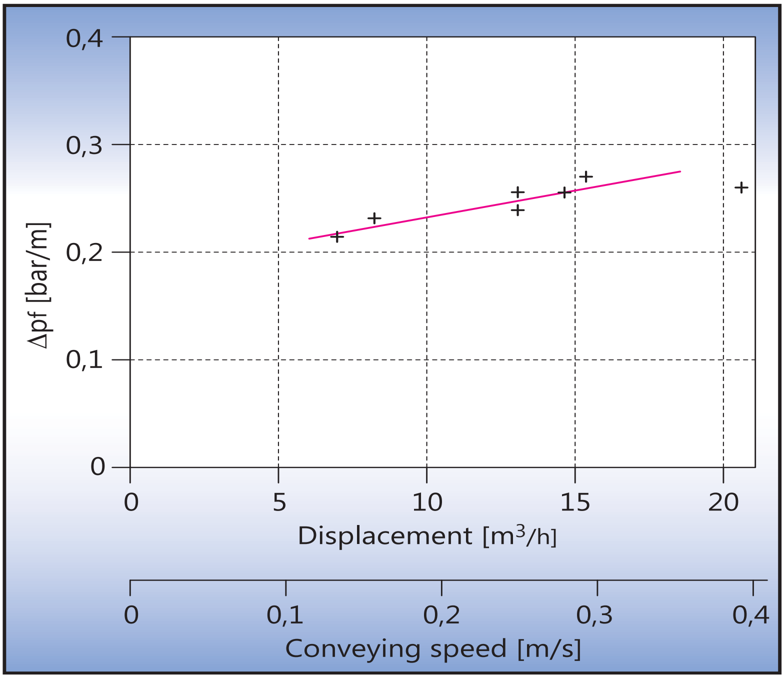


Fig. 23: Delivery pressure loss as a function of conveying speed exemplified by sewage sludge with 30% solids content

2.3.4. Pump dimensioning

The drive pistons and delivery pistons of a high-density solids pump are usually of different sizes. In each case one drive piston and one delivery piston are permanently linked together by a piston rod. The so-called pump transmission ratio „**i**" is calculated from the ratio between the cross-sectional areas of the delivery cylinder and the drive cylinder.

(7) Pump transmission ratio

As a result – pump transmission ratio:

$$i = \frac{A_f}{A_a}$$

with

A_f:	cross section of the delivery piston
A_a:	cross section of the drive piston
i:	pump transmission ratio

Assuming pressure pa at the drive piston, then the force effective there is Fa which is transferred via the piston rod to the delivery cylinder. This force Fa must be applied by the hydraulic system. On the assumption that no friction losses occur (Fr=Fa).

(8) Delivery pressure

Maximum delivery pressure and pump transmission ratio:

$$p_f * A_f = p_a * A_a$$

or

(9) Pump transmission ratio

$$i = \frac{p_a}{p_f} = \frac{A_f}{A_a}$$

p_a: hydraulic pressure
p_f: delivery pressure

With the aid of the formulas the pump transmission ratio and the maximum delivery pressure can be calculated for different applications.

2 examples: In our first example the hydraulic pressure is at the base of the drive piston.

Hydraulic pressure:	p_a = 200 bar
Diameter of hydr. cylinder:	d_a = 14 cm
Cross section of the drive piston:	A_a = 153 cm^2
Diameter of delivery cylinder:	d_f = 20 cm
Cross section of delivery piston:	A_f = 314 cm^2

With these values, the transmission rate will be i = 2 and the maximum delivery pressure **p_f = 100 bar**.

In the second example the hydraulic pressure is at the rod end of the drive piston. When the same pump is actuated in this second way the effective cross-sectional area of the drive piston is reduced by the cross section area of the piston rod and once more the pump transmission ratio can be calculated by using equation (7).

Hydraulic pressure:	p_a = 200 bar
Diameter of hydraulic cylinder:	d_a = 14 cm
Diameter of piston rod:	d_{st} = 8 cm
Effective cross section drive piston:	A_a = 103 cm^2
Cross section delivery piston:	A_f = 314 cm^2

In the case of actuation from the rod end the transmission ratio i = 3. The maximum possible delivery pressure **p_f is now 66 bar** (see fig. 24).

The theoretical output is related via the fill level of the pump to the effective output.

(10)
Output

$$Q_{theo} = \frac{Q_{eff}}{f}$$

with
Qtheo: theoretical output (m^3/h)
Qeff: effective output (m^3/h)
f: fill level of the pump ($0 < f < 1$)

From the theoretical output, the stroke volume of the high-density solids pump can be determined via the number of strokes per time unit (n)

(11)
Stroke volume

$$V_{Hub} = \frac{Q_{theo}}{n}$$

with
V_{Hub}: minimum stroke volume of the pump (l)
n: number of strokes per time unit

The delivery cylinder diameter and pump stroke can be selected for a given stroke volume from table 1.

Table 1: Stroke volume (liter) as a function of delivery cylinder diameter and pump stroke

Delivery-cylinder	**Pump stroke (mm)**			
(mm)	**1000**	**1400**	**2100**	**2500**
120	11,3	15,8	23,7	
150	17,6	24,7	37,1	
180	25,4	35,6	53,4	
200	31,4	44,0	65,4	
230	41,5	58,1	87,2	
280	61,5	86,2	129,3	
360				254
450				397
560				615

The oil flow rate for the pump drive can also be determined from the theoretical output and the transmission ratio i.

(12)
Oil flow rate

Oil output:

$$Q_{\ddot{o}l} = \frac{Q_{theo}}{i}$$

with
Qtheo: oil flow rate of the hydraulic pump

Finally the power requirements of the high-density pump can be calculated from:

(13)
Drive power

Drive power:

$$P_{el} = \frac{Q_{oil}}{\nu} \; x \; p_a$$

with
Pel: drive power (kW)
pa: hydraulic pressure (bar)
ν : efficiency (mechanical, hydraulic %)

The energy required to pump the high-density solids is as a rule higher than for transport with mechanical conveyors. Once you have selected the appropriate flow rate and delivery pressure you can use the diagram below to determine the pump output and also the necessary oil quantities and hydraulic pressures.

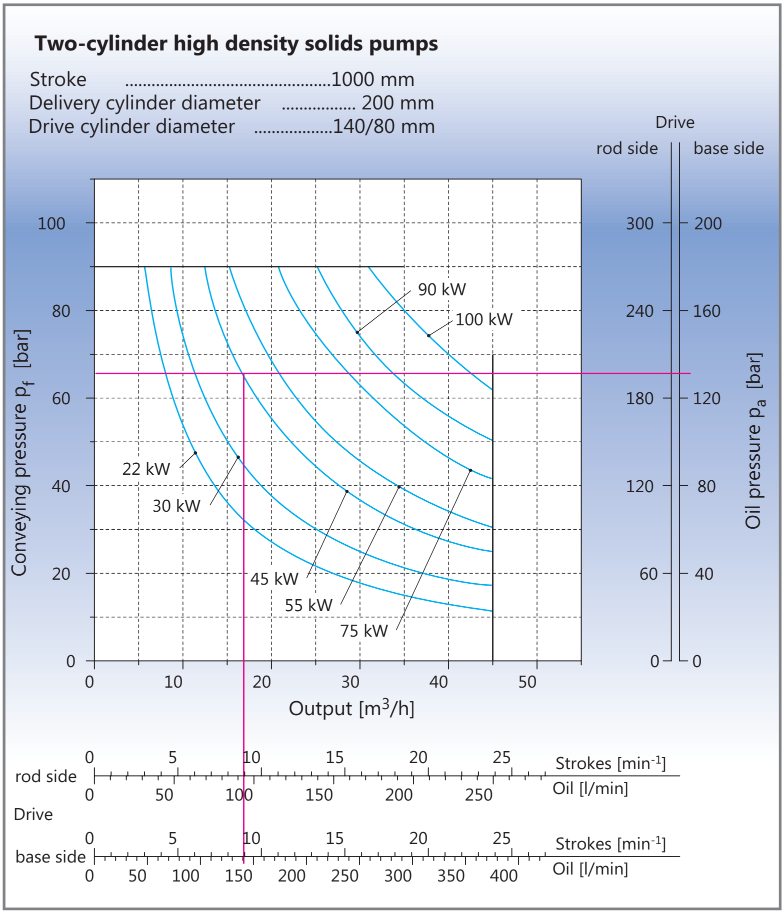


Fig. 24: Performance curves of a two-cylinder piston pump

In addition to the general operating costs it is also necessary to take into account the outlay on energy and the costs for wearing parts, maintenance and repair. These must be weighed against the advantages of the availability achieved and the general system advantages arising from conveying within a closed system.

2.3.5. Selection table - Which pump is suitable for which conveying medium?

Table 2: Selection table

Type / Medium	Rotary pump	Lobe Pump	Screw pump	Hose pump	S-Pipe type	Poppet valve type	Ball-type	Single Piston pump	Diaphragm pump
Water	xxx	xx	xx	xx	x	xxx	xxx	0	xxx
Water with mud particle	xx	xx	xx	xx	x	xxx	xxx	0	xxx
Suspension	x	x	x	xx	xx	xxx	xxx	0	xx
Suspension with foreign body 5 mm	0	x	x	xx	xx	xx	xx	0	xx
Suspension with foreign body > 10 mm	0	0	0	xx	xx	x	x	0	x
Stiff paste	0	0	0	xx	xxx	xx	x	xxx	0
Screening biomass	0	0	0	0	x	0	0	xxx	0
Bulk medium	0	0	0	0	0	0	0	xxx	0

Legend
xxx: most suitable
xx: suitable
x: less suitable
0: not suitable

Fig. 25:
Titanium paste


GEFA
SYSTEM DOMINO
GEFA
SYSTEM DOMINO

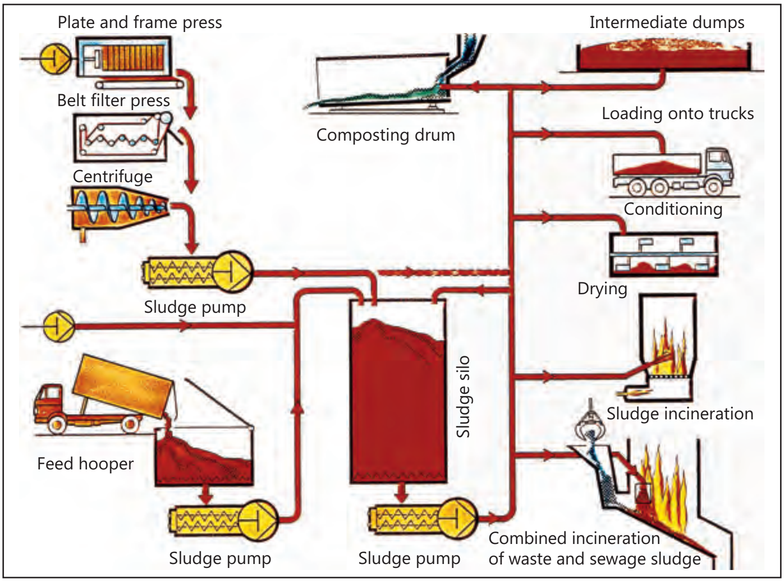
Fig. 26:
Sewage treatment plant
in Ulm/Germany

3. Applications

The hydraulic pumping of solids with high solids contents is a process engineering method which offers a wide range of possibilities. Oil-hydraulically powered two-cylinder piston pumps with an S-transfer tube have become the standard technology since many years in civil engineering projects for transporting concrete.

Expertise with this type of pumping has been successfully transferred to further areas of application in various sectors of industry. Four typical areas of application have been selected as examples of the versatility of these high-density solids pumps.

Fig. 27: Flow chart showing sewage treatment plant



At the head of the line here is their use for pumping mechanically dewatered sewage sludges. In contrast to other conveying systems, environmentally safe pumping within enclosed pipes has been proving its worth for years in this sector.

In power station construction one new process is pressurized bed combustion which enables a particularly high boiler efficiency and environmentally friendly operation. Here, two-cylinder high-density solid pumps inject the coal and lime mixture directly into the pressurized combustion chamber.

Increased environmental awareness results in a constantly growing list of special wastes requiring proper disposal. These substances, some of which are hazardous or easily flammable, have to be prepared physically, chemically and even biologically in order to achieve a volume reduction in quantities occurring. For transporting these substances within hazardous waste treatment plants, high-density solids pumps are increasingly being used in order to benefit from the advantages of piped conveyance.

The fourth area of application is the overburden transportation in tunnel construction, using as an example the EUROTUNNEL between England and France where this type of pumping was utilized.

Finally, this book would also like to introduce the interested reader to several other applications (mining, offshore, landfills and desludging of lakes and rivers) to demonstrate the versatility of high-density solids pumps such as the mineral production of sand and gravel sedimentation from the deep sea, handling of cuttings from drilling rigs, dewatering , backfilling, the handling of tailings from ore extraction mining and the transport of solids from land reclamation.

3.1. Sewage treatment plants

One way of avoiding direct contact with sewage sludges and preventing the contamination and odor emission is pipe transportation of the dewatered sewage sludges and screenings. The sewage sludges can be dewatered by centrifuges, belt filter presses or plate and frame presses after which they are conveyed by high-density solids pumps to silos or to further treatment facilities. These last may include composting drums, lime conditioning units or sewage sludge incineration plants (fig. 27).

Integration of the high-density solids pumps in the sewage sludge incineration plant has proved advantageous. Combining the silo, discharge system (sliding frame, discharge screws) and pump means that conveying distances can be kept short.

The discharge screws carry out three functions simultaneously:

1. Silo discharge
2. Pump feeding
3. Pre compaction

3.1.1. Screening

The first step in a typical municipal waste water treatment plant is to remove foreign bodies (large solids like rags, paper, plastics and metals). A sieve or screen, also sometimes called a Grizzly retains the solids and other waste and allows the water phase to pass through. The retained screenings have to be transported in a closed system which requires the use of a piston pump without valves, like the EKO type pump (single piston pump).

Fig. 28: Screening

With the single piston pump, the screenings are dropped down into the conveying cylinder directly, because the cylinder cannot suck in the screening. The single piston pump is equipped with a plunger cylinder, that has the same inner contour of the conveying cylinder. With the pressure stroke of the plunger cylinder, the screenings are conveyed into the pipe network.

At the return stroke of the cylinder, a gate valve or lamella device prevent the backflow of the screening. This pump system represents a plug conveying system and this version has been utilized in America, Asia and Europe.

3.1.2. Sewage sludge incineration

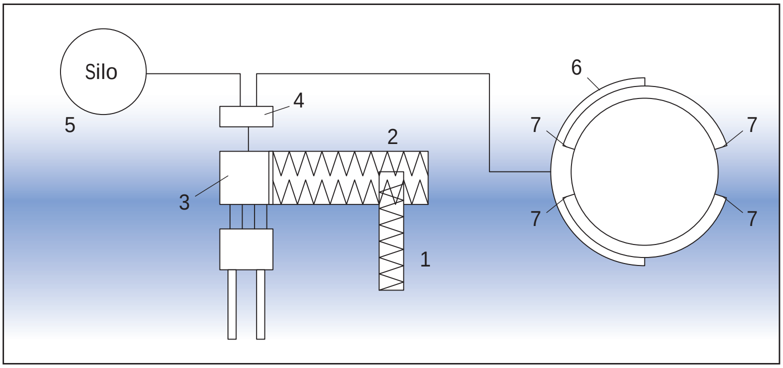
Mechanically dewatered sewage sludge can be pumped by a high-density solids pump via a pipe network directly into a furnace.

Ideally, the sewage sludge should be distributed via the delivery line ring pipe which passes around the furnace and feeds it at several charging points.

Fig. 29: Single piston pump, type EKO, used in the sewage sludge treatment plant Coney Island New York

The system shown in fig. 30 consists of a screw (1), a mixing and pre compaction screw (2) and a high-density solids pump (3) which, via a transfer tube (4), either pumps the sewage sludge into the furnace for immediate incineration or pumps excess sewage sludge into a storage silo (5). The sewage sludge passes through a delivery line ring pipe (6) and then into the incineration furnace through seat valves (7) built into the ring pipe.

Fig. 30: Flow chart for sewage sludge incineration silo



The seat valves permit a defined quantity of sewage sludge to be fed in at each charging point (feed lance). The operational reliability of the system is increased by the fact that multiple charging points are fed with sludge and the seat valves are opened and closed one after the other. In the event of incrustation or blockages, the high-density solids pump can be used for pumping clear.

The heart of this system is the programmable logic controller (PLC). In the control room the quantity of sludge per unit of time is specified. The controller then calculates the number of pump strokes required and divides the sludge quantity amongst the furnace charging points (fig. 31). If the quantity of incoming sludge rises, the number of pump strokes is increased. In this way, the pump gets more quickly through the preset quantity of sludge which is required for controlled combustion in the furnace.

Intelligent plant control

In the time still left over from the preset time period the excess sludge is pumped into the silo via the pipe distribution network. The pump runs with a controlled volume flow, without idle periods and without the need for interruptions in the dewatering process.

Fig. 31: Sewage sludge distribution with four charging points at the furnace

The above sewage sludge Mono-Incineration is gaining importance in the future, if as a result of climate protection laws and regulations, the coal power plants received no further operation permits for co-incineration of sewage sludge in the coal fueled power station.

3.1.3. Lime conditioning of sewage sludge

Fig. 32: Sewage sludge

Dewatered sewage sludge which is used in agriculture as a fertilizer, should preferably be conditioned with lime or Fe III chloride. Sewage sludge treated with lime has a loose porous consistency with a dry content of up to 40%. This treated sewage sludge can be used as an agricultural fertilizer. It contains valuable substances such as phosphates for nutrients which saves the use of industrially manufactured phosphate fertilizers.

In the wastewater treatment plant in BONNEUIL, France centrifuges are used to dewater the sewage sludge to 27% dry content.

In the following procedure, the mechanically dewatered sewage sludge will be mixed with lime. A special mixer and double screw conveyor, called a "MIXOPRESS" conditioned the sludge up to a 37% dry content. The conditioned sludge is then conveyed outside via pipe network into the storage silo for truck loading.

The silo has a capacity of 250 m^3, the diameter is 5 m and the silo floor is arranged as a square, 5 by 5 meter. The silo floor is equipped with two redundant running sliding frames and one centrally arranged discharge screw.

The discharge capacity is effective 90 m^3 per hour, so that the trucks can be loaded in a very short time. The truck loading is performed with an emergency stop function.

If a problem occurs, for example, electric power failure during truck loading, the silo outlet gate closes automatically, to prevent overflowing the truck.

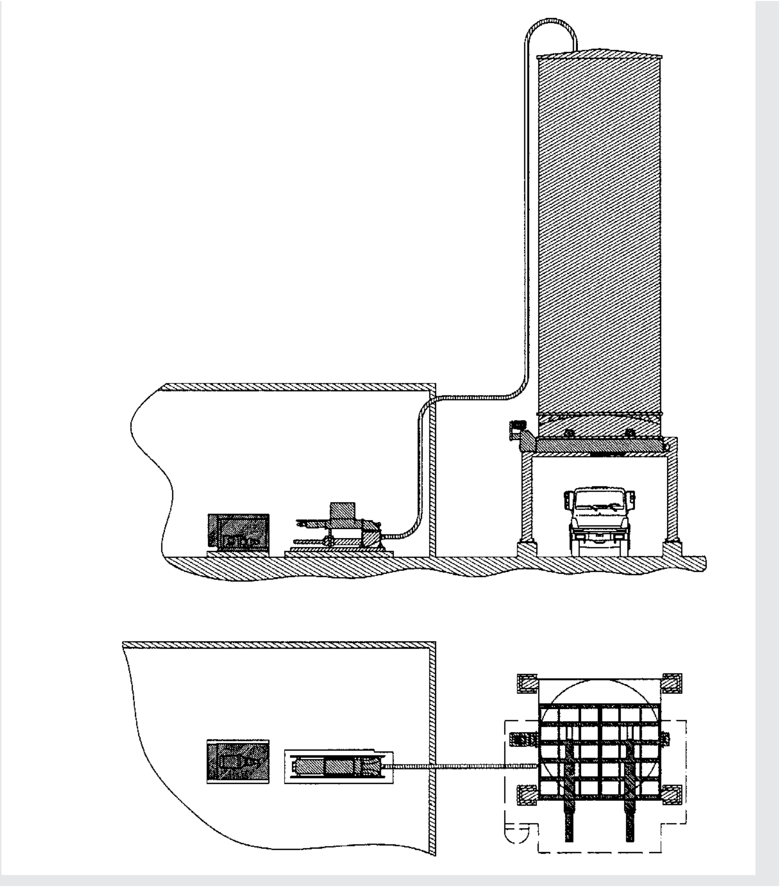


Fig. 33: Illustration Bonneuil

3.2. Power station

3.2.1. Fluidised-bed combustion

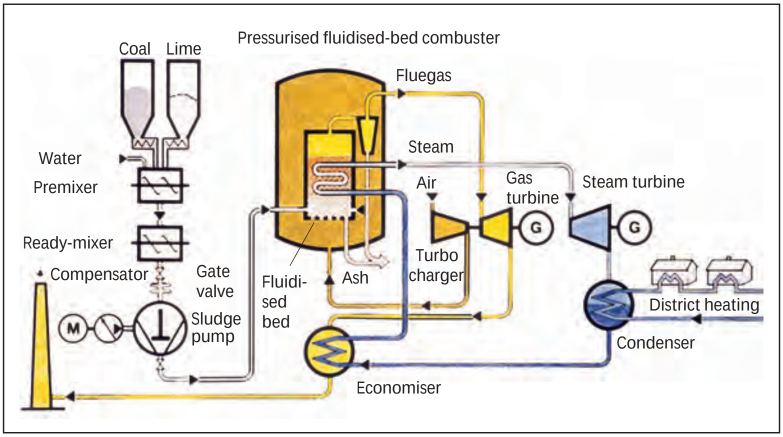
Modern energy production

Burning coal in fluidised bed furnaces has a particularly low environmental impact since adding limestone to the combustion medium causes the sulphur to bond and the low combustion temperature means that relatively little nitrogen oxide is produced. In fluidised bed combustion a layer consisting of ash, limestone and coal is kept moving by combustion air blown in from below. This causes the solid particles to float and tumble as if held in a boiling liquid (fig. 34). This very intense mixing results in a high speed of chemical reactions and a high efficiency of combustion. This means that fluidised bed combusters allow energy to be extracted from virtually all qualities of coal and

Principle fluidised bed furnace

even from lower grade fuels such as sewage sludges or wood waste. So called pressurised fluidised bed combustion offers even more advantages. The combustion gases in the boiler are at pressures of up to 20 bar. Since a turbine can be run from these gases the power yielded can be increased by 25%.

Fig. 34: Flow chart for coaling pressurised fluidised bed combusters



Advantages of the pumping principle

The most economically efficient way of feeding the combuster with this mixture of coal and limestone is to use transfer tube pumps.

Another approach, that of pneumatic conveying, is considerably more expensive not only with regard to preparing the coal itself along with the mixture but also to the energy required for transporting it.

Also the air lock systems are very large and unfortunately do not appear to be as operationally reliable or have the flexibility that the process requires.

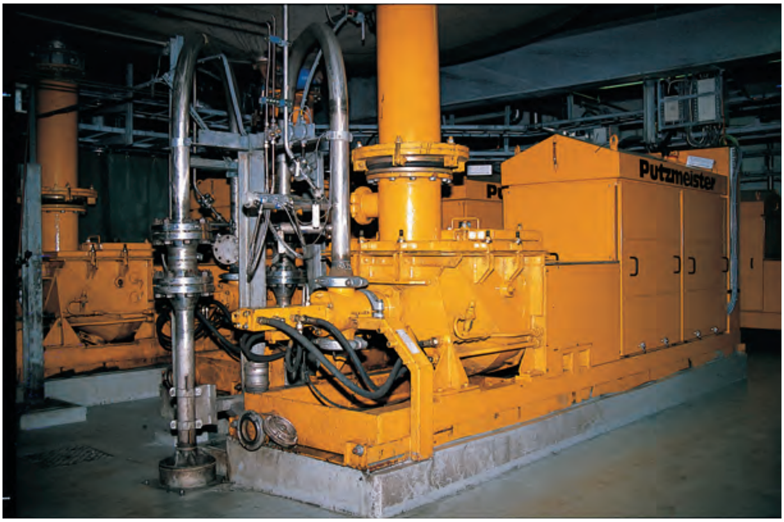


Fig. 35: Pump feed hopper with coal-limestone mixture in feed and hydraulically check valve at the pump outlet

High-density solids pumps permit a precise and operationally reliable metering of the fuel mixture (fig. 35). However the gross calorific value is reduced by the unavoidable addition of about 20% of water by volume. On the other hand this disadvantage is offset by the fact that the energy of the steam also contained in the flue gas can be exploited in a gas turbine. The high-density solids pumps used were designed by keeping in mind the specific requirements pertaining to combustion in power station engineering. For example, they are equipped with downstream shut-off elements. This prevents backflow of hot material from the fluidized bed, which is under pressure.

Gas turbine installations use water content

The shut-off element also allows bumpless conveying of material. To achieve this, the material is first precompacted in the delivery cylinder with the shut-off valve closed, continuing until the pressure in the cylinder is the same as that in the delivery line. The valve then opens and the fuel mixture is thrust into the delivery line. It closes again before the S-transfer tube switches over, thus preventing backflow.

The consistency of the mixture of coal, limestone and water can be assessed with the slump test. The slump is calculated as being the difference between the height of the mold and the height of the tested medium cone after removal of the mold.

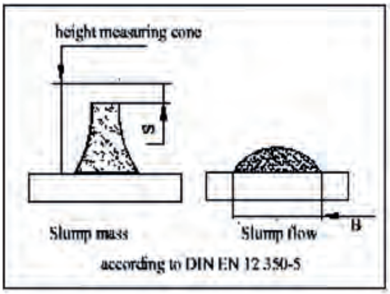


Fig. 36: Slump and slump flow test according to DIN EN 12350

3.2.2. Co-Incineration in coal fired power plant Lippendorf in Germany

A lignite fired power plant, called Lippendorf, in sight of the city of Leipzig was completed in the year 1996. As a way of increasing the economic efficiency of the power station, the plant was extended with a co-incineration using sewage sludge and further equipped with a heat extraction system that provides district heating for the city. The double power block-unit has a net output of approx. 1.800 MW and is operated jointly by Vattenfall Europa Generation AG.

Fig. 37: Sewage sludge receiving hall; In the back-ground the two storage silos, each 850 m³ capacity

The coal throughput based on the net output of 1.800 MW is 10 Million tons per year.

The co-incineration of sewage sludge in the coal fueled power plant was designed, planned and delivered as a turnkey contract with an annual throughput performance of 350.000 tons.

Fig. 38: Receiving bunker for unloading of two trucks

Fig. 39: Screw and piston pump underneath the receiving bunker

To prevent damage, a foreign body separator was installed in the pipe network. The contract for the co-incineration plant consists of:
Three receiving bunkers, two storage silos, silo discharge devices, piston pumps, pipework, pipe nozzles for injection, hydraulic power packs and the complete electrical control system.

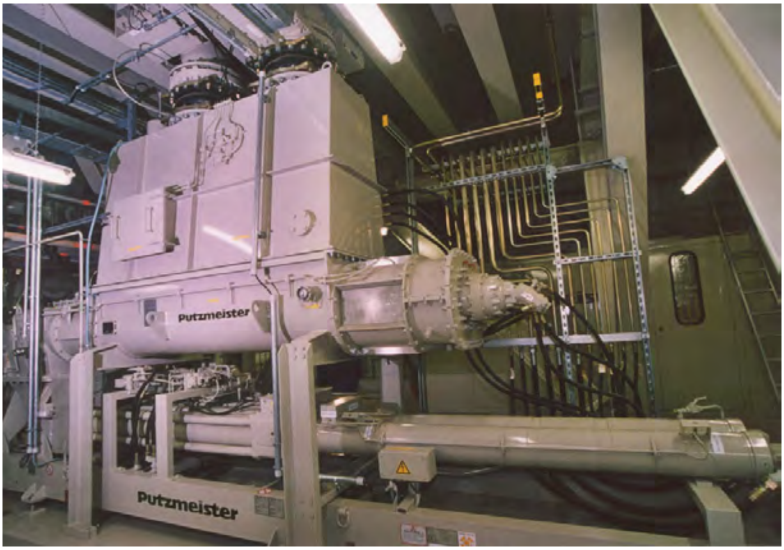


Fig. 40: Piston pump with hopper and prepressing screw underneath the storage silo

The capacity of the two storage silos is 1.700 m^3. A heavy duty version of the piston pump is conveying the sewage sludge over a distance of 385 meter into the boiler hall.

3.2.3. Co-Incineration for coal fired power plant Zolling in Germany

As mentioned before, the existing infrastructure in a power plant can be utilized with regards to the disposal of sewage sludge. The combustion of sewage sludge increases efficiency and gives the energy company additional revenue for the disposal of sludge.

For co-incineration the following equipment needs to be installed: Receiving bunker, high-density solids pumps, pipe network, intermediate sludge container, hydraulic power pack and electrical panel. The sewage sludge will be introduced from the intermediate container by means of screw in the coal mill.

The sewage sludge to the coal ratio is 1 to 9 by weight.

Fig. 41: Flow chart: Co-incineration of sewage sludge in a coal fired power plant

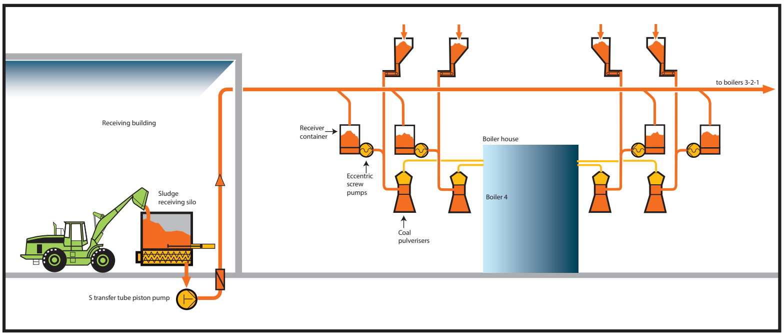


Fig. 42: Receiving bunker with S-tube pump and hydraulic power unit

3.2.4. Conveying fly ash

Dust removal of flue gases with electrostatic filters creates extremely fine particles known as fly ash (fig. 43) which due to the high content of abrasive SIO2 and AL2O3 quickly produces measurable levels of wear in conventional screw conveyors and in pneumatic conveying systems also.

High wear in conveyors

Fig. 43:
A suspension of fly ash and water is especially abrasive and extremely thixotropic. Solids content 65%

If the fly ash is strongly diluted with water – for example, down to a solids content of just 7% – and transported at high speeds with centrifugal pumps, other serious disadvantages emerge in addition to the high levels of wear on the pumps and pipes:
First, there is the high energy input required, some even for the return transportation of the water, and second, the large quantities of contaminated water entering the ground beneath the landfill.

Dry matter content must be high

For this reason there is pressure from power station operators and industrial installation planners for the fly ash slurry to be pumped with the maximum solids content possible which would at the same time allow dust free deposition. The ash deposited in this way hardens within a day or two without it being necessary to extract water and without there being any contamination of ground water. Extra-powerful and wear-resistant high-density solids pumps with seat valves or in special cases also with S transfer tube are capable of pumping the fly ash separated by the electrostatic filters with solids content of 60 - 70%.

In this case they would run at extremely low piston speeds. This suspension consisting of fly ash and water is thixotropic to a high degree. A piston pump can cope with pumping ranges of several kilometers.

Fig. 44: Large capacity pump for low wear when conveying abrasive fly ash

Cleaning without disassembly

The mean solids content of the medium handled by the pump system shown in fig. 44 is 65%. With a pipe length of 230 meters and a nominal diameter of 150 millimeters and with 40 cubic meters being pumped an hour, the system has a delivery pressure of 15 to 20 bar.

As the landfill site expands, the pipeline can be extended to 800 meters without having to change the piston pump already installed in the system.

When it becomes necessary to clean the delivery pipe, a pig can be injected via a pig trap into the pipe, pushed along through the pipe by the high-density solids pump and then retrieved at the other end.

3.2.5. Reconstruction of a coal fired power plant for biomass combustion in Copenhagen, Denmark

As part of the efforts to reduce CO^2 emissions, the AVEDORE POWER PLANT, Copenhagen, will be converted from burning coal to burning biomass (wood pellets). Adding fly ash to the biomass helps to optimize the combustion process, the emission CO^2 can be reduced and this also extends the service life of the boilers used.

Fig. 45: Avedore power plant Copenhagen

This is where the services offered by Putzmeister as a system provider will come into play, for the planning, supply, installation and commissioning of the wet ash supply system.

The processing medium: Wet fly ash

Dry content:	35%
Density:	0.9 – 1.4 t/m^3
pH value:	6.5 -9.5
Flow rate:	9.5 m^3/h

Scope of supply:

- Receiving hopper 10 m^3 with box feeder
- Belt conveyor with magnetic separator
- Double belt conveyor including belt scale
- 3 (three) day bunkers with a capacity of 75 m^3 each
- Fly ash slurry conditioning system
- Fly ash slurry pumps including hydraulic power pack
- Pipe network – in total 1200 meters
- Fly ash slurry feed control system consisting of 6 (six) dosing pumps (hose squeeze rotary pump type)
- Connection between dosing pumps and coal mill inlet shut via lances by rubber hoses

Method description:

Wetted fly ash will be fed by a front loader into the hopper of the box feeder. On top of the box feeder is a grid which is installed in order to protect the system from oversize material.

Wetted fly ash is fed to the belt conveyor and to the disc screen where coarse grain particles > 10 mm are separated out. Steel particle will be sorted out by a permanent magnet. Fine material with grain size 0 - 4 mm will be transported by double belt conveyor to the top of the 3 (three) day bunkers. On top of the day bunkers is a distribution belt conveyor to feed one after another of the day bunkers depending on the material level in each day bunker.

One of the box feeders conveys the fly ash to the double belt conveyor which feeds the continuous mixer. The capacity is measured by a weighing belt and the incoming moisture is measured by a moisture control sensor. The condition of the fly ash is controlled by a moisture control sensor and the feeding pressure in the main ring pipeline. The required amount of additional water fed into the continuous mixer is calculated at the central control room based on the incoming fly ash amount (tons/h) and measured moisture content. If necessary the water input may be adjusted if the feeding pressure in the main ring pipeline is higher or lower than designed. 2 (two) discharge pipe lines feed the fly ash slurry from each piston pump. The piston pumps are operated by a hydraulic power pack. The piston pumps and hydraulic power packs are controlled by a local Putzmeister control panel and PLC. At the start-up phase, the material will be recirculated by piston pump until the jumbo trough is filled and the fly ash condition is in accordance with requirements.

Then the piston pump will feed the fly ash slurry into the ring main pipeline and circulate the material back to the mixer. When the fly ash condition is ready for use the feed control system (hose squeeze rotary pump) can be started.

The dosing pumps feed the fly ash slurry into the chute to the coal mills. At the end of each feeding hose an injection lance is installed.

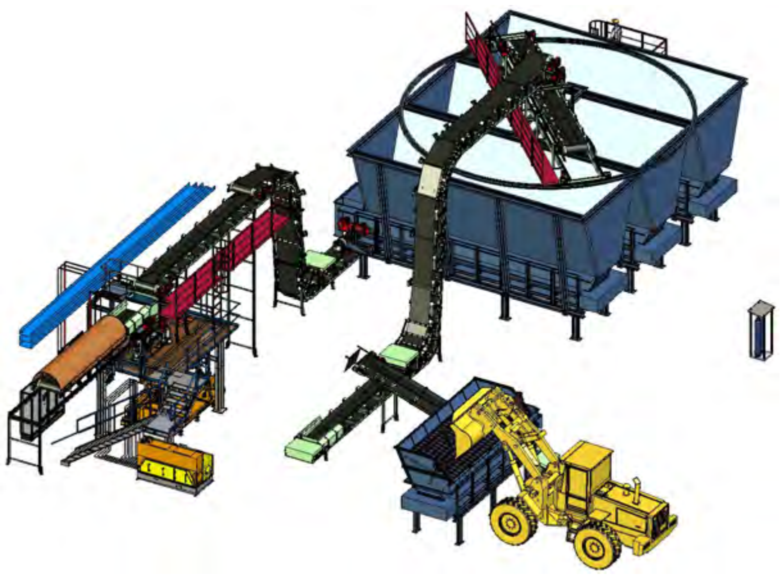


Fig. 46: Wet fly ash system in 3-D animation

3.2.6. Fly ash conveying in the Lignite coal-fired power plant Belchatow in Poland

The fly ash from lignite coal combustion is mainly land deposited. Using this as backfill material is possible under some conditions. In comparison, the fly ash from "stone" coal combustion is more valuable than a secondary raw material needed by the cement and concrete industry.

Large volume pumps are used to convey the fly ash from the power plant area to the landfill site deposited. In 2013, 6 (six) double piston pumps with seat valve technology were ordered for transportation of fly ash.

Performance Data:

Diameter-delivery cylinder:	450 mm
Stroke delivery cylinder:	2500 mm
Flow rate per pump:	200 m^3/h
Delivery pressure:	up to 90 / 100 bar
Installed electric power each pump:	800 kW
3 pumps in process total output:	600 m^3/h
3 pumps stand-by	

The conveying distance was originally 5000 meters and will have to be extended to 8000 meters, due to the increasing landfill capacity.

Fig. 47: Large volume piston pump HSP 25150 HP

Fig. 48: Pipe network land fill DIA 200 mm

3.3. Treatment of waste

The sheer quantities of industrial and domestic waste are constantly increasing. In order to reduce this waste as much as possible, it can be subjected to treatment involving physical and chemical processes. However, residues remain which have to be incinerated at high temperatures in special installations. Since this residual waste usually ignites readily and can be toxic, it is appropriate to transport it within an enclosed pipe system. Waste which contains solvents and other types of waste which have a low spontaneous ignition temperature due to their ingredients will result in the additional requirement that the waste treatment installation must be rendered inert. It is particularly easy to set up the necessary nitrogen atmosphere with pipe conveying systems.

3.3.1. Hazardous waste incineration plant

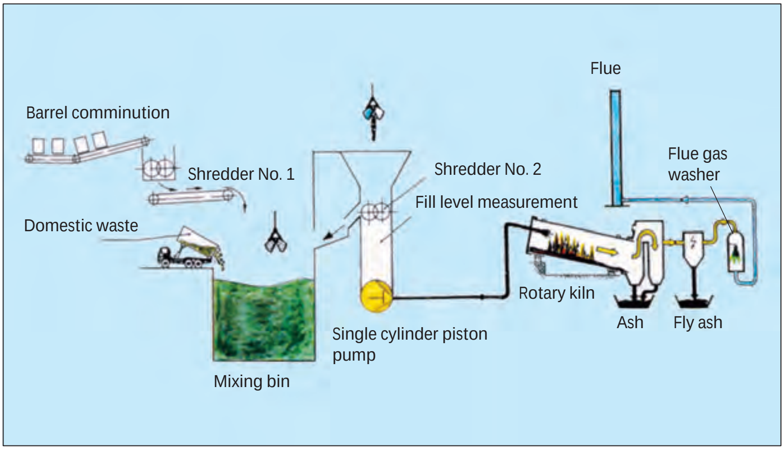
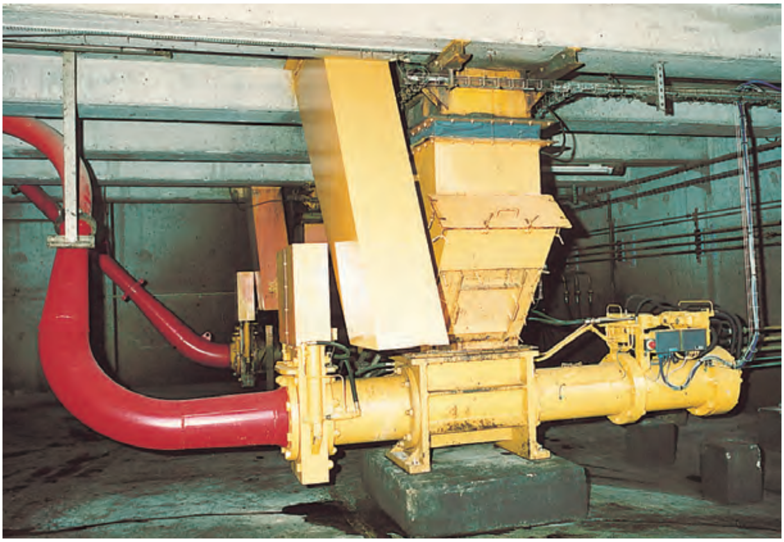


Fig. 49: Flow chart for hazardous waste incineration

Hazardous waste usually arrives in 200 liter (55 gallon) steel barrels which are comminuted in a shredder together with their contents and then stored temporarily in a mixing bin (fig. 49). City waste which cannot be recycled is also fed into the mixing bin where it is mixed in from a bucket grab until the mixture is homogeneous. In addition to paste-like ingredients, this waste mixture also contains foreign bodies, such as foils, fibres and strips of sheet steel from barrel shredding. In a second comminution phase, the waste is reduced to a particle size of less than 80 millimeters in diameter and a length of 200 millimeters.

A single cylinder piston pump feeds the comminuted hazardous waste into a rotary kiln. As is born out in practice, the comminution process along with a metered feeding into the furnace achieves a more complete and more even combustion. The conventional way of charging the furnace using a bucket grab always results in a shock loading of the furnace. In other words, temperature peaks accompanied by uncontrollable levels of gas emissions.

Fig. 50: Single piston pump with gate valve



Plant safety

In the case of installations planned for the future, the open mixing bins are to be replaced by enclosed positive mixers. In this way homogenization of the waste can be further improved, which also means an increase in the furnace throughput.

The single cylinder piston pump (fig. 50) which was developed especially for this application not only does the actual pumping but also, thanks to the special shape and design of the pump piston, can if necessary cut up the material fed in, particularly the strips of sheet steel. This means that downtimes due to blockages are eliminated and a reliable and dependable process is assured.

3.3.2. Treatment of organic waste

A French manufacturer has come up with a new way of disposing of domestic waste: the Valorga process which takes its name from the company (fig. 51). Here the incoming waste is first comminuted and recyclable inorganic substances such as glass and metals removed. The remaining organic material is fed into tanks where it undergoes anaerobic clarification – in other words, the waste is fermented at around 37° C under exclusion of air. This produces a biogas, whose most important component is methane.

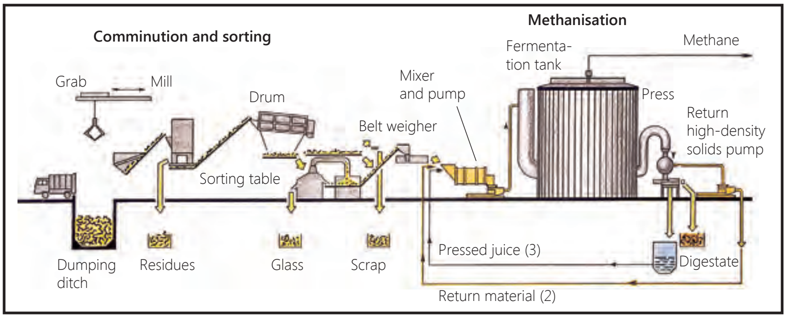


Fig. 51: Flow chart for the treatment of organic waste

The waste remains in the fermentation tank for between 15 and 20 days. A mixture of prepared domestic waste, return material and process water which is as homogeneous and airfree as possible and which has been preheated to the fermentation temperature is fed into the fermentation tanks by means of a high-density solids pump (fig. 52). The return material is excess material created during mechanical dewatering.

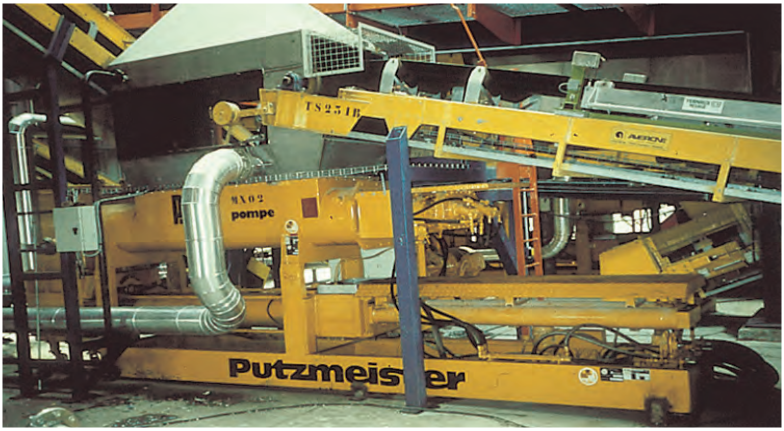
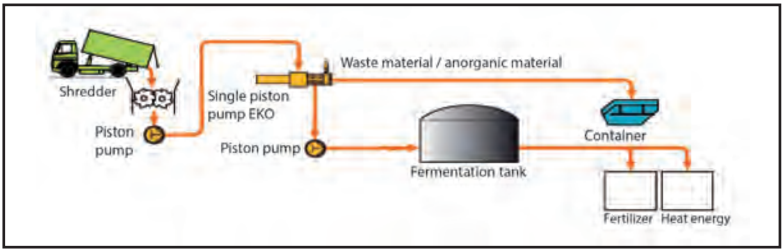


Fig. 52: Mixing and pumping prepared domestic waste

3.3.3. Biomass from food remains and packaged food

A unique design of a single piston pump makes it possible to convey various types of biomass material, including those that are contaminated with foreign objects like knifes, spoons, bottle caps or glass, which can dramatically disturb the fermentation process. To meet these requirements a single piston pump has to be modified to develop a process to separate out foreign particles during the pumping process.

Fig. 53: Biomass from food remains and wrapped food



The wrapped food including foreign objects will be conveyed into the pump hopper. When the gate valve is closed, the delivery piston presses the biomass material into the delivery cylinder. The front area of the delivery cylinder is provided with holes, through which the liquid portion of the biomass is pressed. If the hydraulic pressure of the delivery piston exceeds a defined value, the shut-off valve opens and allows for ejection of the foreign particles.

Fig. 54: Single piston pump

***Function**: Separation of biomass, foreign particles discharge*

Fig. 55: Wrapped food

Fig. 56: Biomass

Fig. 57: Green household

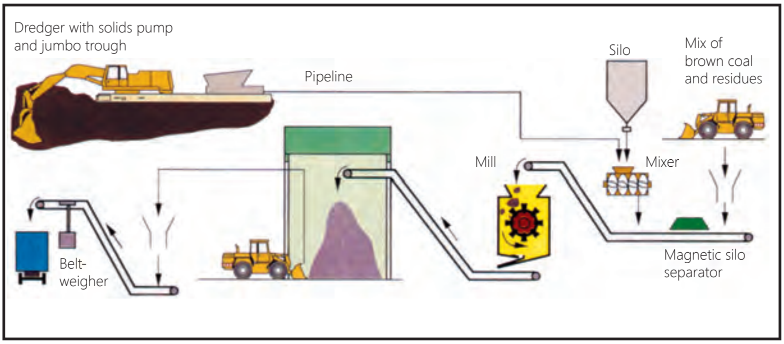
3.4. Treatment of water bodies and remediation of legacy contamination

For the removal of sludge from river courses, harbours and other bodies of water, floating operating platforms mounted on pontoons can be used.

On these platforms are mounted a dredger, a separating unit, a mixing trough and a high-density solids pump including hydraulic power pack and electrical control device.

The bucket dredger removes the sludge and dumps it onto a vibrating screen which is used for separating out the various foreign particles (fig. 58).

Fig. 58: Cleaning up a tar lake using a floating dredger and high-density solids pump



The sludge is then fed into a mixing trough. An S-transfer tube high-density pump pumps the material to a mixing station on land via floating flexible hoses.

In the mixing station, additives are added to the sludge. Depending on its ultimate destination, additives ensure that the sludge is suitable for land fills or for incineration.

Fig. 59: Remotely controlled operating platform

In the background the Power station called „Schwarze Pumpe“

A preparation plant for mixing fuel of high calorific value was manufactured, supplied and is being used in the process for disposing of the Zerre dump.

Mixing in brown coal with the residual substances from the dump creates a fuel suitable for the Schwarze Pumpe Power Station. These residual substances are basically a solids mixture containing tars and left over from brown coal refinement.

What is special about the Zerre floating platform?

The special feature of the floating platform is that all of the equipment on it must be remotely controlled, because toxic phenol fumes escape during dredging and pumping.

This kind of desludging of bodies of water is becoming increasingly important in remediation of legacy contamination – for example, in returning temporary dumps to landfills or to incineration.

3.5. Mining Technology

3.5.1. Conveying mine water with high sand content

Valve controlled high-density solids pumps have proved very successful in conveying mine water with a solids content of up to 70% and a delivery pressure of up to 100 bar.

Originally, centrifugal pumps were also used for this application but due to the low operating pressure, a group of centrifugal pumps have to be connected in line before they could cope with the vertical heights ranging up to 800 metres.

An example is the installation of 2 (two) seat valve piston pumps in a zinc lead mine in Southeast Asia. The task is to convey sludge and water from the deepest bottom of the mine to the surface. The specific performance date are listed below:

Table 3: Performance data HSP 25100 HP

Drive	**Performance data**
Flow rate	200 m^3/h
Delivery pressure	80 bar
Oil volume flow	1500 l/min
Hydraulic pressure	220 bar
Electr. power	630 KW
Delivery height	550 m
Medium	**Mining water**
Specific weight	1,25 t/m^3
Grain size	< 8 mm
Dry matter content	50% (sand)
pH-value	7-8
Temperature	Max. 35 ° C
Rel. humidity	Max. 95%

When the task is to convey sand-laden water out of the mine to the surface, it is essential to keep the flow rate in the conveying pipe high enough at all times to rule out sedimentation. The usual consequence is a blockage. The hydraulically controlled outlet valves of the seat valve pump prevent backflow of the sand-laden mine water during the switchover phase. This also rules out the knocking in the delivery line which results from decompression.

Fig. 60: Seat valve pump with mounted damping vessel

Since piston pumps always pump with periodic interruptions due to the stroke changeover, pressure peaks can occur in the delivery line since the material being conveyed usually contains no air and is thus very hard. To reduce or even remove this risk entirely a damping vessel has been installed in the form of a vertical pipe.

If medium is to be conveyed over large vertical differences, an air vessel or control elements will be required to keep the column of medium moving during the pump switchover phase (see also chapter 6.7 - pulsation dampers).

3.5.2. Backfilling and surface transport with high-density solids pumps

Underground mining requires dewatering, overburden, ore and coal conveying, backfilling and tailing slurry transport to the landfill. Underground modes of access include drift-, slope- and shaftmining. Shaft mines are the deepest mines, a vertical shaft with an elevator is made from the surface down to the coal or the ore. Slope mines usally begin in a valleys bottom and a tunnel slopes down to the ores to be mined.

Mineral processing flotation

The excavated material will be loaded onto a shuttle or ram car, where it will eventually be placed on a conveyor belt, that will move it to the surface and treatment plant.

The treatment plant is usually located on the mine site itself in order to reduce the transport costs of smelting. In the first step, the ore stones (zinc, lead, silber, gold) are fed to crushers, mixers and mills and sorted into sieves and wet classifiers.

The flotation separation is the most widely used method for the concentration of fine grained minerals. It takes advantage of the different physicochemical surface properties of minerals in particular, their wettability , which can be a natural property or one artificially changed by chemical reagents. By altering the hydrophobic (water-repelling) or hydrophilic (water-attracting) conditions of their surfaces, mineral particles suspended in water can be induced to adhere to the air bubbles passing through a flotation cell or to remain in the pulp. The air bubbles pass to the upper surface of the pulp and form a froth, which, together with the attached hydrophobic minerals, can be removed. The tailings containing the hydrophilic minerals, can be removed from the bottom of the cell. A significant advantage of the flotation is the possibility of separating several different minerals from each other and collecting them in separate concentrations. By means of this selective flotation with subsequent dewatering, it is possible to obtain a concentrated (ZnS) with more than 70% Zn.

The remaining components (tailing slurry) during processing are fed to a thickener by means of centrifugal pumps. Together with a binder suspension, the thickened tailing slurry is mixed to form a tailing paste. Hydraulic driven piston pumps (seat valve type) are used for further transport. The tailing paste has a solids content of approx. DS 75% (by weight). The binder portion is 5 to 7 volume percent and the grain size of the tailing paste is in a range of 10 to 1000 um.

Fig. 61: Tailing paste (landfill)

With this consistency, the tailing paste hardens within 14 days, so that refilled areas can be walked on and used with working machines. If the backfilling is interrupted the pipe network must be changed, the pipe is to be emptied and cleaned with a pig to prevent hardening of the tailing paste in the pipeline.

Seat valve piston pump with reduced pressure pulsation

The seat valve piston pumps are to be selected accordingly with regards to the flow rate and pressure requirements. For the tailing paste handling the selected piston speed should not be greater than 0.3 m/sec. The transport of tailing paste requires a low pressure pulsation in the pipe network, since in underground mines the pipes are merely suspended on chains.

The high-density solids pumps are equipped with an electronic control system, named PCF (Putzmeister Constant Flow), for nearly constant product flow rate and for reduction of water hammer.

For the pipeline, the low pressure pulsation results in an increased fatigue strength. As a consequence, a lower wall thickness can be used with reduced investment costs.

Example of dimensions of delivery pipeline:

Increased durability of the piping system

A pipe with a diameter of 200 mm and a discharge pressure of 80 bar with a pressure pulsation of 30 bar during pump switch over, with 10 mm wall thickness the pipe is calculated fatigue-resistant.

A lower pressure pulsation of less than 10 bar (PCF controlled) allows a pipe selection of 7 mm wall thickness.

Landfill

In the classic mining regions, such as the Andes in South America, the deserts of Africa, Tanzania and Australia, high-density solids pumps are preferred.

If centrifugal pumps are used, the tailing paste must be mixed up to 70% - 80% water content to form an aqueous slurry since such pumps types only allow discharge pressures of up to 15 bar.

High-density solids pumps are able to convey tailing pastes up to 150 bar with less water content which is essential due to the availability of water in these regions.

Example: Barrick Gold Corp's Bulyanhulu Mine in Tanzania

The tailing paste is pumped over a distance of 2100 metres with a pipe diameter of 200 mm.

The end of the delivery pipe is mounted in a 12 meters high tower which is shown on the picture 61.

Drive	Performance	Material	Tailing
Output	80 m^3 /h	spec. weight	1970 kg/m^3
Delivery pressure	80 bar	Dry matter content	76%
Electrical power	315 kW	pH	11

Table 4: Technical data tailing paste

Fig. 62: Bulyanhulu mine, mineral processing, which is located about 2 km away from the treatment station

3.6. Tunnel construction

3.6.1. Overburden conveying

Due to the consolidation and constant expansion of the transportation network, real tunneling (in other words, not cut and cover) has increased noticeably in recent years and will become even more important in the future.

However, until now, it has not always been possible to exploit the full cutting power of the tunneling shield. Since the soil has to be taken back to the tunnel entrance in bucket lines or using railborne vehicles, bottlenecks can occur in conveying overburden. With high-density solids pumps this overburden can be transported back to the surface economically and without these restrictions.

During the construction of the Eurotunnel, the overburden created by the tunneling machine was brought back by rail directly to a preparation unit with a pumping unit connected to it (fig. 63).

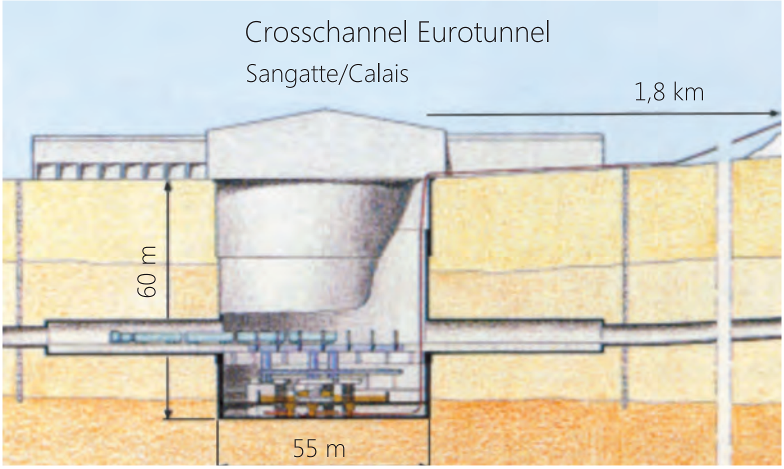


Fig. 63: Overburden conveying in the Eurotunnel; preparation and pumping unit

No problem with large distances

This unit then conveyed the overburden out of the tunnel. Originally overburden conveying was to take the form of flushing – slurry pumping – using centrifugal pumps. On account of fears regarding sedimentation of fine calcareous components in the micrometer range, piston sludge pumps were used instead (fig. 64).

With centrifugal pumps the quantity of flushing water would also have been considerably higher due to an allowable content of only 10%.

With the piston high-density solids pumps the proportion of solids depends on the grain size, but is ranged between 50% and 60%. The overburden was comminuted in the start shaft and simultaneously mixed with water to form a slurry. It was then fed into the high-density solids pumps situated beneath the preparation equipment. A total of eight solids pumps transported the overburden to a dump located at a distance of 1.8 kilometers. This involved dealing with a difference in elevation of 140 meters (see page 76).

Fig. 64: One of eight muck pumps during the construction of the Euro Tunnel between France and England

3.6.2. Ring space injection for tubbing Tunnel Ring space injection arrangement (TRIA)

Continuous ring space drilling for tubbing are mostly used in tunneling operations in which closed tunneling machines line the tunnel with concrete or steel segments. The ring space between the tunnel wall and the tunnel machine must therefore be filled at the same rate as the tunnel is cut. Double piston pumps with ball or seat valves for the efficient conveying of fine-grained mortars and low-consistency slurries up to 70% dry matter content are used. The pumping process requires an output capacity of up to 40 m^3/h and delivery pressure of 80 bar per pump.

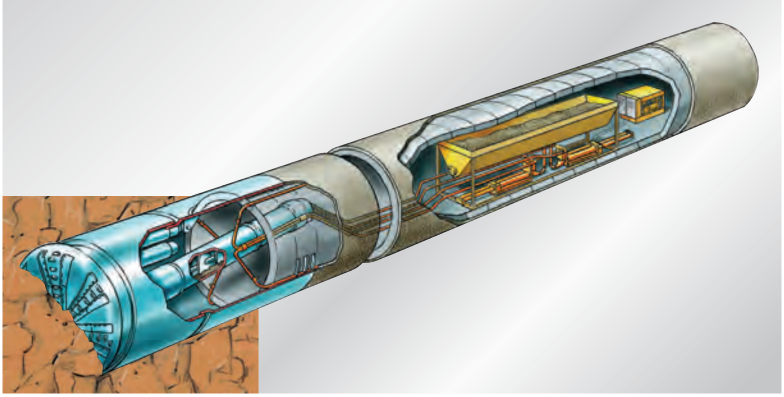


Fig. 65: Application for the ring space injection for tubbing fitting in tunnel drilling machines

3.6.3. Muck pumping

Tunneling produces excavated muck which has to be transported from the tunneling machines discharge system through the tunnel to the surface. Delivery by pipeline with hydraulic piston pumps is possible dependent on the pumpability of the material.

Double piston pumps have a performance of up to 400 m^3/h per pump unit. This means that by using double pumps, tunnel machines can be equipped with diameters of up to 14 meters or more.

For the tunnel project – London Heathrow – two single piston, decompression pumps, were developed. The two single piston pumps are connected by a pressure seal directly behind the outlet of the screw conveyor of the tunnel machine.

The pumps are able to remove 200 m^3/h of untreated loamy soil from the shield area supported by compressed air.

Fig. 66: High-density solids pump in twin version with pressure resistant hopper

The technical data of the twin single pump are:

Table 5: EKO 25300 Twin

	Performance
Piston diameter	750 mm
Piston stroke	2500 mm
Piston speed	0,5 m /sec
Output loosened	400 m^3/h
Output compacted	200^3/h
Total weight	41 ton

This prevented the ground from subsiding and the loamy soil was not contaminated by bentonite or polymers. The pumps compress the excavated muck and form a material plug in its cylinder. The two single pumps thus have an airlock function, so that the overpressure of 3 bar in the drill shield area is maintained.

Fig. 67: Excavated muck; the material plug is easy to recognize

The material plug formation was tested before delivery of the pump in the factory test field.

Fig. 68: View through the pump housing

3.7. Offshore application

3.7.1. Subsea pump HSP 570

Due to the increasing global demand for minerals, the search and development of new sources of minerals is becoming increasingly important for the high-tech industry.

At depths of over 500 meters, large deposits of ores, precious and high-tech metals, such as manganese, cobalt, nickel, copper and gold, can be found. Mineral resources from the near-coastal occurrences of phosphorenes, sand and heavy mineral enrichments, which are already actively mined to day.

In close cooperation with the Indian Government, the University of Siegen (Germany) and Putzmeister Solid Pumps, a tracked vehicle was developed and built for exploration on the east coast of India.

The aim of the exploration was to evaluate the deep-sea conditions, the movement of the tracked vehicle and the process of sucking, crushing and conveying of minerals in sedimentation, up to the surface.

The deep sea is generally defined as water below 200 meters. Enrichment of minerals in sediments, called soaps, were discovered here.

The subsea double piston pump selected was developed on the base of the seat-valve piston pump type. For lowering of the tracked vehicle with the pump unit from the supply vessel to minus 500 meters, a piston accumulator had to be installed for the pressure compensation from sea surface zero bar (0 bar) to sea button (plus 50 bar).

The electrical control elements were installed in pressure-resistant housings. The drive motor for the power supply of the whole unit is designed as a submersible engine in a deep sea-version with 132 kW at 6000 Volts.

Function of the subsea pump:

The sediment mixture is sucked in by the pump via an articulated suction mast. The suction mast is equipped with a crusher at the head, which crushed up the sucked grains to a small 5 mm grain size. The crushing is necessary in order to avoid sedimentation and thus blockages in the delivery line to the supply vessel. The tracked vehicle with the pump is connected via a 700 meter long cable line to the control room on the supply vessel.

For a further dive, the function of the crusher was omitted and the double piston pump with seat valve control was modified to a double piston pump with S-tube type. The S-Tube type piston pump allows larger grain sizes to pass through.

Technical data of the installed sub sea pump:

Table 6: HSP 570

Delivery output	max. 45 m^3/h
Delivery pressure	50 bar
Electrical drive	132 KW /6000 V

Fig. 69: Subsea pump is left to water

For further explorations of mineral resources, the Federal Republic of Germany has concluded a licensing agreement with the State of India in 2015 which expires in 2030.

3.7.2. Reclamation of land in Japan

With around 33 million inhabitants, the heavily populated Tokyo Bay is the largest center in the world. For many years now the demand for useable land area has led to artificial islands being built in the bay. In addition to Narita International Airport in northeast Tokyo, the Japanese capital also has a second airport, Tokyo Haneda Airport.

At the end of March, 2007, a consortium began work on a fourth runway (runway D) at Haneda. The project is emerging as an artificial island, actually in the water. A 2500 meter long runway and taxiway are being built here as an addition to the existing airport site.

Fig. 70: Scheme Treatment

The runway, which is surrounded by water, consists of "super geo material" (SGM). The SGM base material is predominantly excavated earth taken from Tokyo Bay (for instance, in the area of harbours and river estuaries) and the mainland. Barges transport this basic material to several special ships that are anchored around the area of the future runway. The ships are fitted with a processing plant and other equipment that mixes the excavated earth with cement and a special foam to form a stable and relatively light building material. The processing ships also have a large power shovel for unloading the barges, a screen and classification system, a silo for cement, a tank for the special foam, a mixer, a pump installation and a large boom for placing the material.

Fig. 71: Floating processing plant with placing boom, excavator and various structures

The two high-density solid pumps are below deck

Each pump installation consists of two high-density solids pumps which are designed for delivery rates of up to 550 m^3/h. Material is transported through a pipeline with an initial internal diameter of 350 mm. This line is connected to the large placing boom. The boom is specially adapted to have an additional 30 meters of horizontal reach for their use here. The boom's end hoses reach to the ground, in a similar manner to underwater concreting and create layers of material in an upward fashion.

Technical data of KOS 25200:

Table 7: KOS 25200

Delivery output:	550 m^3/h
Delivery pressure:	40 bar
Electrical power:	2 x 315 kW
Piston diameter:	560 mm
Piston stroke:	2500 mm
Foreign body max.:	80 mm
Weight:	22,5 tons

Fig.72: Piston pump-installed below deck

3.7.3. Multiphase flow pump KOV 1075

Key features of Putzmeister Closed Drains Multiphase Flow pump:

- Pumping multiphase media – gas, liquid and solids
- 90% reduction in maintenance costs
- High reliability and availability
- High pressure capability with no pulsations
- Low noise and vibration
- Variable flows

Introduction Statoil

Statoil ASA is a Norwegian multinational oil and gas company headquartered in Stavanger, Norway. It is a fully integrated petroleum company with operations in 36 countries. It is one of the largest oil and gas companies in the world with a true global footprint. The company has about 23,000 employees.

Åsgard

The Åsgard field is located on the Halten Bank in the Norwegian Sea, around 200 kilometres off mid-Norway. Åsgard supplies about 11 billion cubic metres of gas annually. Åsgard B is a semi-submersible gas and condensate processing platform. The gas is transported by pipeline from the field to the Kårstø processing plant and then by the Euro pipe II gas trunkline from Kårstø to Dornum on the German coastline. The electrical control elements were installed in pressure-resistant housings. The drive motor for the power supply of the whole unit is designed as a submersible engine in a deep sea-version with 132 kW at 6000 Volts.

Fig. 73: Åsgard field

Fig.74: Example of different Putzmeister solid pumps

Process
The closed drain system shall collect hydrocarbon liquid drains from platform equipment and piping, and safely dispose and degas the liquid.

The process is defined by system 57 in the NORSOK process coding's.

The NORSOK standard defines the minimum functional requirements for process systems on an offshore installation.
This includes mechanical and electrical design and compliance to health and safety requirements.
On Åsgard B pumps were used to transfer the collected closed drains media produced during natural gas processing. The requirement was to feed the 1st stage separator via a network of pipes and valves.
The substances are hereby separated by disposition and separation devices and the hydrocarbons processed with the water being forwarded for disposal. The media is a mixture of salt water, sand, petroleum residues, gas, chemicals, NOxx and tars. The pump is to be capable of handling multiphase media including gas, hydrocarbon and sand. The most critical NORSOK requirement was to ensure the pump had a double barrier philosophy.

Previous system
The existing Triplex Plunger pumps with 35 mm diameter pistons suffered from high erosion and had also noise and vibration issues. This was a result of various types of foreign objects, for example, silicate-containing sand.

The wear caused by foreign bodies lead to frequent failure of the pumps, which provided reduced availability of the system. There was a high amount of workovers averaging two per month for the 2 units.

This led to a high life cycle costs, in addition service technicians were exposed to levels of benzene fumes in working on the pump repair.

Fig. 75: Plunger pump

Present system

The KOV double piston pump, with suction and discharge ball valves was installed. It was designed for a required output of 24 m^3 per hour at a pump pressure of up to 87 bar. Customer specifications, specifically NORSOK standards were fully complied to regarding the design, fabrication and material. The pump is fed by a booster pump with a discharge pressure of approximately 2 bar.

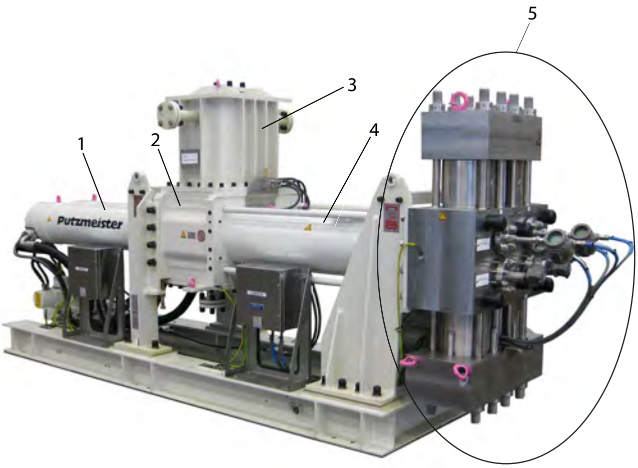


Fig.76: KOV 1075

Pos.	Designation
1	Drive cylinder
2	Water box
3	Water box attachment
4	Delivery cylinder with internal delivery piston
5	Pump head

The challenge was in the specific pumping process and the media to be pumped. Consideration was taken on the space and weight availability, therefore a compact design was realised. To optimize the resistance to abrasive/corrosive wear and thermal / mechanical stress the pump head was constructed in Duplex stainless steel, piston seals in Viton and a hard chromed coated conveying cylinder. Low noise and vibration was achieved using the PCF method (pressure constant flow®) developed by Putzmeister. This is offered on most of its valve pumps. It has been developed to provide a reduction of pressure differences during switchover of piston valves. Two independently driven hydraulic cylinders are synchronised so that pressure drops and peaks optimally adjust themselves and guarantees low pulsation conveyance. This will provide control of flow requirements. The package also included sound absorbing elements for lower noise emission. A centralised automatic lubrication system was included to ensure the correct amount of greasing is provided this will prolong the life of the wear parts. To meet the double barrier philosophy ensuring zero emission to atmosphere, the pump included a closed water tank with over pressure handling capability.

The system was driven by hydraulic power pack HA 90S which had the following key features:

- small footprint
- with noise protection hood
- stainless steel design
- well proven hydraulic pumps
- pressure-, temperature-, oil level-sensors for full control

Fig. 77: Hydraulic Power Pack HA 90S

Following the above pump supply we provided a pump head modification improving the sand handling capabilities and to provide minimal erosion and ease of maintenance. The areas focused on the velocity of material through the system and ensuring valve closure.

The work included changing the suction / discharge orientation and supplying spring loaded valves.

The system was tested with the modified pump at our facility in Germany. This test included for sand to be injected to the liquid this proving the sand handling capability of the pump to operate with a high percentage of sand content.

Current situation

In nearly one year continuous operating on an on/off basis the new installation has required ½ day work while the previous pump required 26 days work per year - a considerable saving on the availability and maintenance costs.

Increased service life of all plant components and pipes. This is done by significantly reducing the pressure surges and therefore reducing the thermal and mechanical stress.

In summary the solution now provides the following:

1. Low noise
2. Low vibration
3. High reliability
4. Low Maintenance
5. Limiting technicians exposure to chemical and hydrocarbons

Enclosed snapshot detailing the vibration in mm/sec. following the switchover from Triplex Plunger pump to Double piston pump with ball valves.

The time frame was from 28.10.15 to 17.02.16. The vibration reduction is clear at switchover to piston pump.

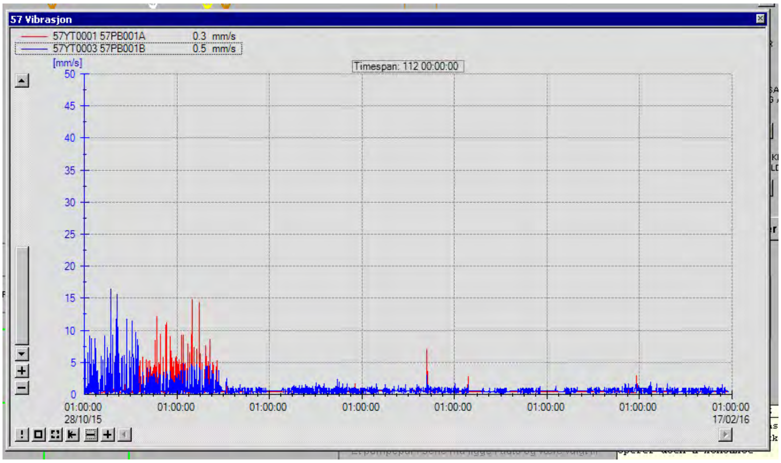


Fig.78: Vibration in mm/sec. when switching over from Triplex plunger pump to double piston pump

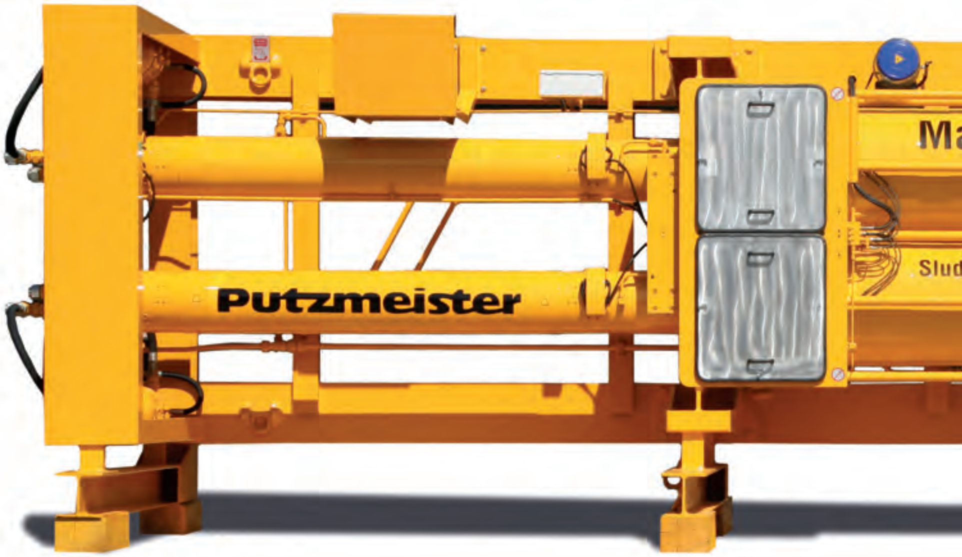

Putzmeister
Ma
Slud

Fig. 79:
Mammoth pump KOS 25200 was built for landfilling project in Tokyo bay area in Japan

Fig. 80: Heidelberg, Germany Cement Guangzhou

Fig. 81: Zonguldak, Turkey Co-Incineration

Fig. 82: Waste water treatment plant Prague, Czech Republic

4. Pump Drive and Control

Figure 83 shows the pump unit of a two-cylinder high-density solids pump. The two drive pistons are put into motion oil-hydraulically. Depending on the application for which the high-density solids pump is used, the hydraulic pressure can be applied at the rod end of the drive piston (1) or at piston base (2).

When pressure is applied to the piston base, higher delivery pressure can be obtained (see also chapter 2.3.4 pump dimensioning), but for the preset output a greater oil flow rate will be necessary. The two delivery cylinders are hydraulically synchronized. This means that both cylinders run completely and smoothly in push-pull mode.

Hydraulic synchronisation of the piston

While one piston sucks the high-density solids into the delivery cylinder from the feed hopper, the other piston pushes the material in the second delivery cylinder into the delivery line via a control system.

Depending on the pump type, the control system consists of an S transfer tube, seat valve or a gate valve (see also chapter 2.3.5 selection table, which pump is suitable for what conveying medium). The delivery cylinders and the drive cylinders are separated by a tank filled with water thus ensuring an absolute decoupling of the components which come into contact with the medium and the drive cylinders filled with oil. In this way not only are malfunctions resulting from foreign bodies in the drive prevented but leakage of the hydraulic oil into the conveyed medium is avoided.

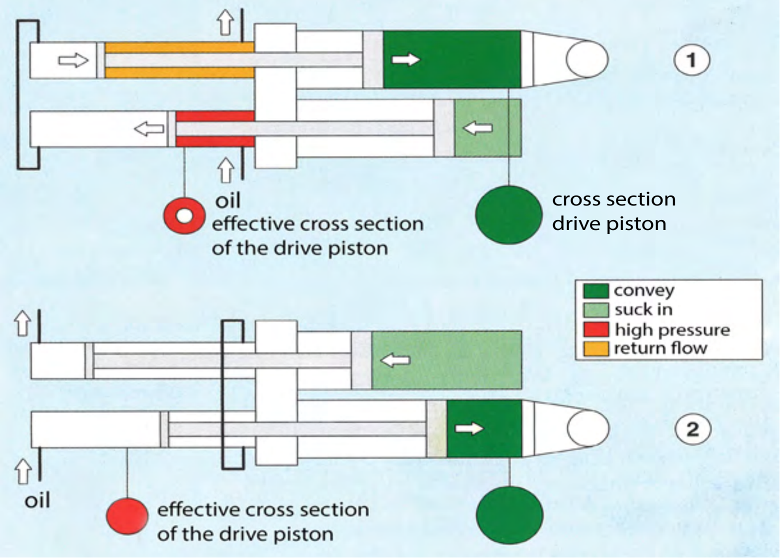


Fig. 83: Pump unit of a two cylinder high-density solids pump with hydraulic drive

4.1. Drive concepts

Two drive concepts have proved themselves in practice:

1. the open hydraulic circuit and
2. the closed hydraulic circuit.

With the open hydraulic circuit (fig. 84) a pump sucks hydraulic oil out of a tank and pumps it to a control block. By means of a directional valve in the control block the two drive cylinders of the high-density solids pump are alternately pressurized with oil and in this way the delivery and intake strokes are implemented. An additional cooling pump conducts cooled and filtered hydraulic oil directly to the main pump. The oil flowing back into the tank from the pressurized drive cylinder of the high-density solids pump then divides itself on the intake side of the hydraulic pump: one part is sucked in by the cooling pump while the rest of the oil flows back into the tank. The practical advantages of the drive variant are that only filtered oil is admitted into the hydraulic circuit of the high-density solids pump and that the tank volume of the hydraulic unit (which depends on the intake volume of the pump) can be kept small.

Closed hydraulic circuit for big pumps

The open hydraulic circuit is suitable for oil flow rates up to 250 litres per minute. With the closed hydraulic circuit, the hydraulic oil flows directly – and with no interposed control block – to the drive cylinders of the high-density solid pump. Once the pushing cylinder in the solids pump reaches its end position, the hydraulic pump changes its pumping direction and pressurizes the second drive cylinder. The closed circuit is used with upwards of 150 litres of hydraulic oil per minute. Pumps with up to 3000 liter per minute are in service.

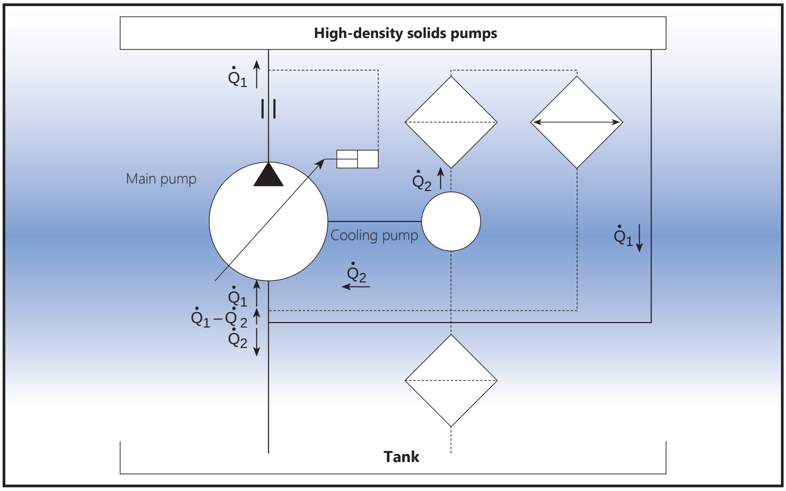


Fig. 84: Load sensing closed loop control for the open hydraulic circuit

4.2. The Single cylinder piston pump with the drive concept

A typical hydraulic cylinder has a larger extending force than retracting force because of the area difference between full bore and annulus sides of the piston. To equalize the force and speed of the hydraulic cylinder, the selected cylinder must have a 2 to 1 rod ratio.

Function of regeneration circuit:

When the hydraulic solenoid valve A must be energized, the oil pump flow is connected to the cap end of the cylinder to make it extend. Oil leaving the rod end of the cylinder mixes with the pump flow and regenerates to the cap end of the cylinder (see also fig 85).

If the hydraulic solenoid valve B is energized, the oil pump flow goes directly to the rod end and the cylinder retracts. The hydraulic oil from the cap end returns to the tank. In the case of the one single piston high-density solids pump the described hydraulic circuit is suitable in the event that a foreign body obstructs the entry of the delivery piston into the delivery cylinder. If the piston force is insufficient to cut or shear the foreign bodies, the control detects the blockage and initiates the return stroke. With repeated forward movement of the delivery piston, the hydraulic solenoid valve is reversed and the entire amount of oil is directed from the oil pump into the cap end of the hydraulic cylinder. Thus, the acting force on the delivery piston is doubled. By the ratio cap end to rod end = two (2) to one (1), and the advancing speed is halved. With this piston force increased by 100% the occurring blockages can be remedied without interrupting the whole pump process.

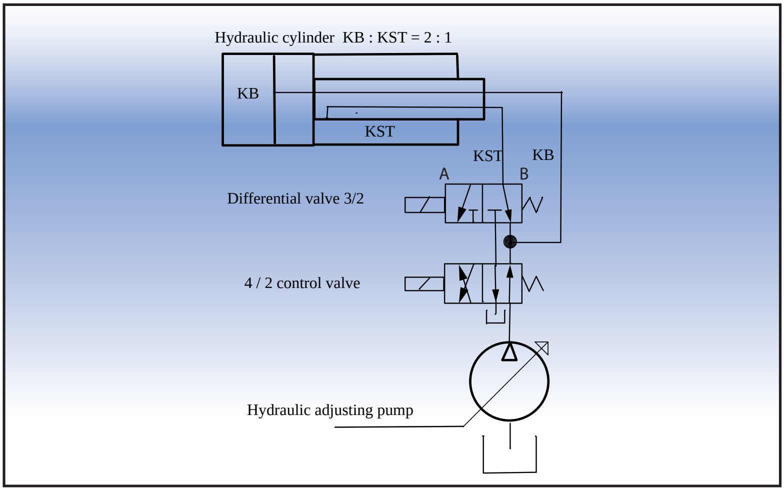


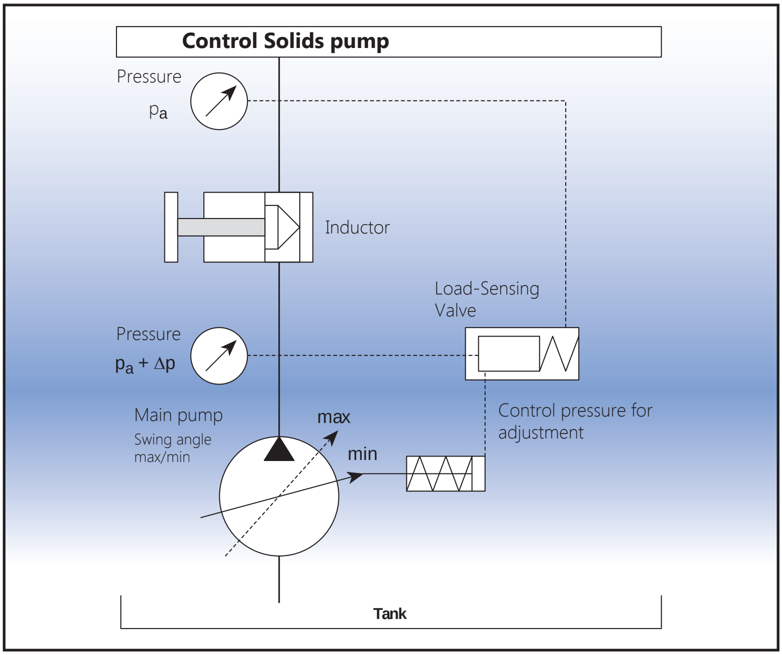
Fig. 85: Regeneration circuit

4.3. Open-loop drive control on the load sensing principle

The main pump for the open hydraulic circuit is a flowrate-controlled axial piston pump which works on the load-sensing principle (fig. 86).

The hydraulic oil flow rate is set in an axial piston pump by a change in the angle of a swash plate.

Fig. 86: Load-sensing regulation for the open circuit



The load-sensing valve regulates the oil flow-rate via a control connection through the hydraulic system to that required by the "consumer" (the high-density solids pump) and this rate is proportional to the delivery rate desired for the high-density solids pump.

Located between the hydraulic pump and the drive side of the high-density solids pump there is a restrictor, known as a control element which brings about a pressure drop Δ p in the hydraulic circuit.

The pressure differential makes it

The load-sensing valve is subjected to the pressure differential across the restrictor and then applies to the axial piston pump a corresponding control pressure.

Should there be a differential pressure Δ p rise, the hydraulic pump is swiveled back to a smaller angle and thus to a lower oil flow rate.

If the differential pressure Δ p falls, the hydraulic pump is moved to allow a greater flow rate.

Fully hydraulic control and free-flow hydraulics

If the restrictor is closed completely, the differential pressure Δ p will rise strongly and the hydraulic pump swings to its minimum slewing angle - in other words, to the minimum flow rate. It will then be in stand-by-mode, producing little heat and requiring little energy.

This type of closed loop hydraulic control is particularly advantageous with two-cylinder pumps, since in the changeover phase of the delivery pistons from output stroke to intake stroke the quantity of oil pumped by the oil pump does not have to be discharged by a pressure relief valve.

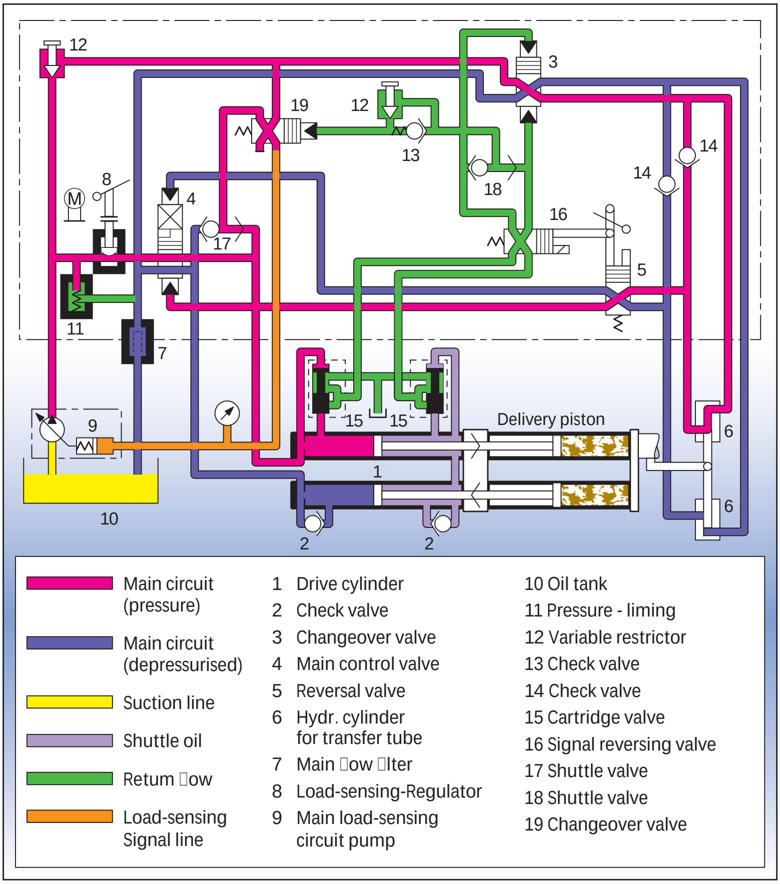
4.4. Control concepts

These two kinds of drives lead to two completely different concepts for controlling the flow rates of two-cylinder high-density solids pumps. The so-called fully hydraulic control is based on the open hydraulic circuit while the development of so-called free-flow hydraulics was based on a closed hydraulic circuit. The main differences between these two concepts will be described in the following sections.

4.4.1. Fully hydraulic control

Figure 87 on the next page shows the valves and signals arrangement for conveying high-density solids as exemplified with a transfer tube pump driven at the piston base side.

Fig. 87: The fully hydraulic control of a transfer tube pump



Hydraulic pressure is applied at both the drive piston and the S-transfer tube switch cylinder. Hydraulic pressure at the switch cylinder is removed by a signal point. Pressure is present at the check valve (14), at the reversal valve (5) and at the pilot valve of the main control valve (4).

Load-Sensing Signal

Once the drive piston reaches the hydraulic signal point in the rod-side connection of the drive cylinder, the cartridge valve (15) switches and sends a hydraulic end position pulse via the reversal valve (16) to the changeover valve (3) in order to effect changeover of the S transfer tube.

The load sensing signal is set from the complete control pressure and is used for regulating the slewing angle of the hydraulic pump. The drive piston is here in its end position. In parallel with this the hydraulic end-position signal is tapped off via shuttle valve (17) for the changeover valve (19) which ensures that the load-sensing signal is passed on to the axial piston pump. In this way the axial piston pump is adjusted to the maximum slewing angle. The S-transfer tube is switched over by the switch cylinder. Just before the mechanical end position is reached the hydraulic signal is tapped off at the switch cylinder and passed to the pilot valve of the main control valve (4) which then switches it through. Not until then do the drive pistons reverse their direction. With the two-cylinder high-density solids pumps, the fully hydraulic control concept guarantees 100% stroke correction after every second stroke. No shortening of the piston stroke occurs, irrespective of the pump outlet.

100% stroke compensation

The purpose of the changeover valve (19) is to ensure that the speed at the S tube switch over remains independent of the preselected slewing angle of the hydraulic pump. In this way it is possible to satisfy a major requirement of the application, namely that the speed of changing over from one delivery cylinder to the other should remain constant. The signal line of the cartridge valves and the connections to the changeover valve are depressurized. The control valve for the S transfer tube latches into the activated position.

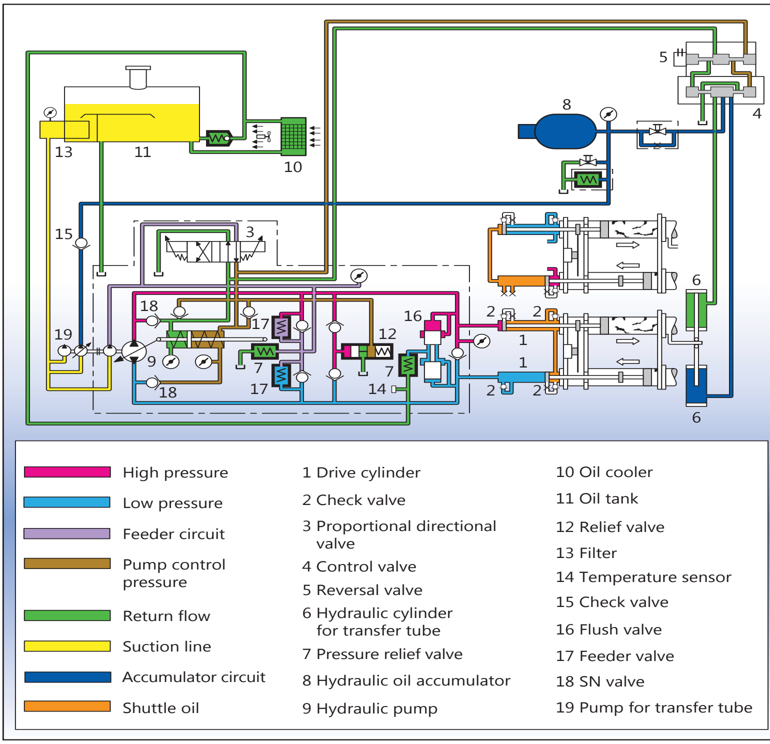
4.4.2. Free flow hydraulics

Attempts to make a decisive improvement in the efficiency of hydraulic drives resulted in the development of an oil supply for two-cylinder piston pumps which does not employ a control block.

Free flow hydraulics was developed on the basis of the closed hydraulic circuit for traction drives: a free flow of oil without the use of valves. The circuit diagram for a high-density solids pump with free-flow hydraulics is shown in fig. 88. The two main connections of the hydraulic pump are directly connected by hoses and pipes to the two drive cylinders of the core pump unit, either at the base or rod sides. In contrast to fully hydraulic control, whereby the one hydraulic pump can only be varied from minimum to maximum output, free-flow hydraulics can effect a change of direction in the flow of hydraulic oil in the axial piston pump. This means that there is no need for a control block with a directional valve for pressurizing the drive cylinders alternately.

A control and feed pump integrated into the main pump (9) supplies both the proportional directional valve (3) and the feeder block, consisting of the two feeder valves (17). The main circuit of the free-flow hydraulics is protected by the relief valve (12) while the incoming or outgoing hydraulic oil is protected by the pressure relief valve (7).

Fig. 88: Free flow hydraulics (FFH)



The proportional directional valve (3) specifies the control pressure for the main pump and the direction of pumping of the main pump.

Analogous to a control voltage, a control pressure is present at the proportional valve which is applied to the slewing cylinder of the main pump and which switches the pump from minimum to maximum output.

SN valves

The directional capability of the proportional valve allows the main pump to be swung through the zero position into the opposite direction, which in turn results in a change in the pumping direction. One special feature of free-flow hydraulics for two-cylinder high-density solids pumps is the SN valves (18). These valves connect the low-pressure side of the main pump to the control pressure of the adjustment cylinders of the main pump.

Under normal circumstances the valves are closed – in other words, the low pressure is equal to or greater than the control pressure. In this case the main pump is in equilibrium and the outgoing flow rate corresponds to the incoming flow rate.

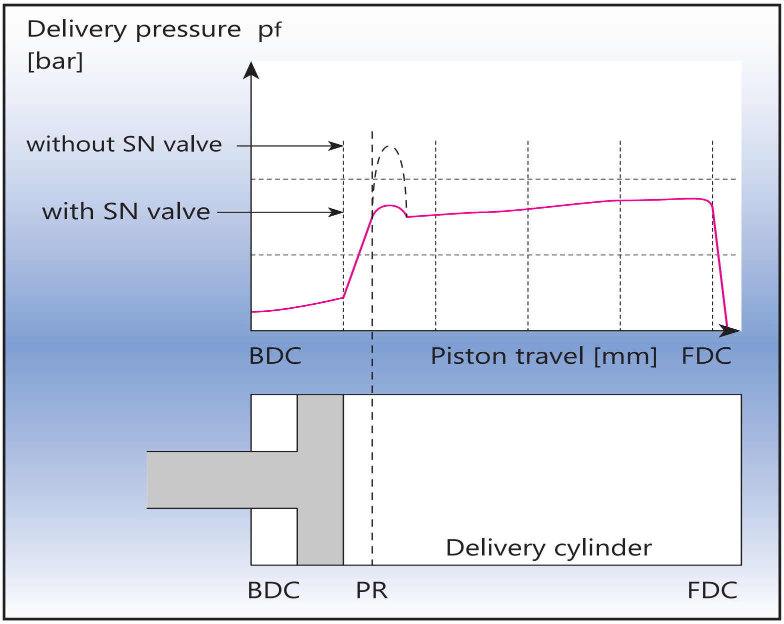


Fig. 89: Effect of the SN valves in the free-flow hydraulic system

BDC = back dead centre of the delivery piston

FDC = front dead centre of the delivery piston

PR = position of the piston at which pressure rises sharply due to the force required to start the medium column moving

During the changeover phase of the high-density solids pump an increase in pressure occurs which causes the relief valve (12) to deliver hydraulic oil out of the high-pressure circuit and into the tank. The quantity of hydraulic oil missing on the low-pressure side of the closed circuit would cause cavitation of the main pump, something which has to be prevented. Cavitation of the main pump is counteracted with the aid of the SN valves – in other words, on the low-pressure side of the main pump, more oil is drawn into the closed hydraulic circuit.

Taking in more hydraulic oil from the control circuit causes a reduction in the slewing angle of the main pump accompanied by a reduction in the oil flow. This damping of the gradient minimizes loading peaks in the drive system of the hydraulic pump and permits a soft starting push of the delivery pistons in the high-density solids pump (Fig. 88). In addition, the hydraulic diagram shows an additional pump (19) for operating the S transfer tube and also the cooling circuit from the feed-out (16) to the oil cooler (10). The oil cooler is activated by the temperature sensor (14). Since there are no hydraulic directional valves or control blocks in the main oil flow, a hydraulic pressure of up to 30 bar lower is possible. The lower pressure drop with free-flow hydraulics also results in less heating up of the oil. The fact that the hydraulic oil can flow free and unimpeded from the main pump to the drive cylinders improves the overall efficiency of the high-density solids pump and increases the output.

5. Components

5.1. Silo - General

In applications where storage of material is required, the construction of “SILOS” can be found. This creates a buffer between production and further processing. The intermediate medium in the silo can prevent discontinuous transport with the medium flow. Originally used as feed and grain storage in agriculture, silos are also used in other industrial sections.

Today`s silo plants and bunker systems are not simple storage containers. The characteristic of the medium to be stored and it`s flow behavior require detailed planning. In the case of silo design and planning, the question must always be asked about the intermediate storage of the conveying medium first. The safe and trouble-free operation of the silos, the following listed characteristics of the medium have to be taken into account:

- Fluidity
- Interim storage time
- Method of the outlet
- Silo discharge equipment
- Inclusion of silo design in the entire medium handling
- First in - first out

The following list describes the various functions and tasks of silos:

- Receiving silos can be filled by a truck and emptied by means of high-density solids pumps and screws
- Stockpile silos are used for longer storage of medium
- Intermediate silos are used in production plants at the beginning and at the end of a process to decouple the treatment steps.

In principle, silo cross sections can be constructed as square, rectangular or round. Almost all media to be stored can be filled into round or rectangular silo cells. The advantage of the round design with a flat bottom is the low production costs, high stability and low dead zones. Round design silos with a cone shaped bottom develop medium dead zones. The square silo design is preferred for receiving silos with a large opening area for truck loading and a low filling height. Subsequently, some silos are designed, having a flat floor, which is not self emptying and therefore requires a discharge system. Silos with inclined bottoms are to be investigated with regards to the grain size and moisture content of the media and the risk of bridge formation.

5.1.1. The behavior of media in silos

The classification of bulk medium or high-density solids, their grain texture, density and cohesion are described in the DIN-ISO 3435. The medium characteristics are important for the reference of the flow behavior in the silo. The medium characteristic - cohesion - classifies the medium to be stored in two groups.

Free-flowing (cohesive less) media and cohesive media

For free flowing media, the angle of incline is a measure of internal friction. In practice, it has significance in the design of the silo volume. The angle of inclination as the medium characteristic represents the maximum inclination angle of a medium surface opposite the horizontal at which the medium is not yet about to move. For the flow of the medium, the slope angle is a represented parameter. The particle size of the substances is important for the flow behavior. If the substances contain foreign bodies or particles, this leads to contact forces between the individual particles, the cohesion. Cohesion substances cause greater angle of inclination.

Whether a stored medium flows in the silo, can be determined with the help of shear tests. If a pressing force N is applied to a medium, a thrust force S is required for movement along the surface A. There is a linear correlation between S and N in the form of the coefficient friction $\mu = \tan \varphi$.
φ is the friction angle.

Shear stress = $$\tau = \frac{S}{A}$$

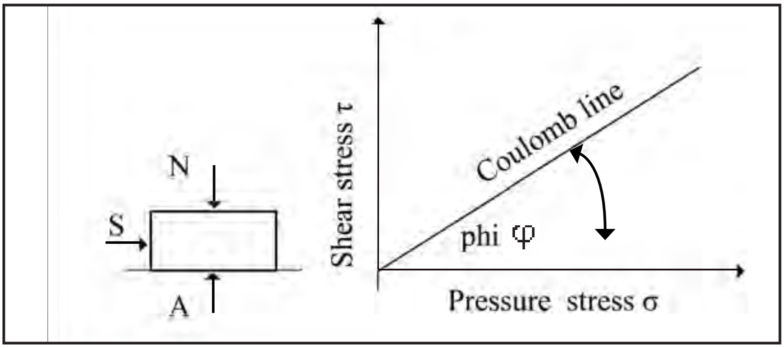
Pressure stress = $$\sigma = \frac{N}{A}$$

The characteristic line in the diagram (fig. 90) is called the Coulomb Line and represents the physical correlation between shear stress and pressure stress with the friction angle φ.

Shear stress $\tau = \sigma \cdot \tan \varphi$ **(14) Friction coefficient**

μ : friction coefficient
φ: friction angle
τ: shear stress
σ: pressure stress

Fig. 90: Flow criterion according to MOHR - COULOMB



Under the influence of cohesion, the **Coulomb – line** does not pass through the coordinate center.

The point of intersection with the τ – axis is called cohesion c.

From the flow criterion, it can be deduced that no flow occurs when τ is less than c.

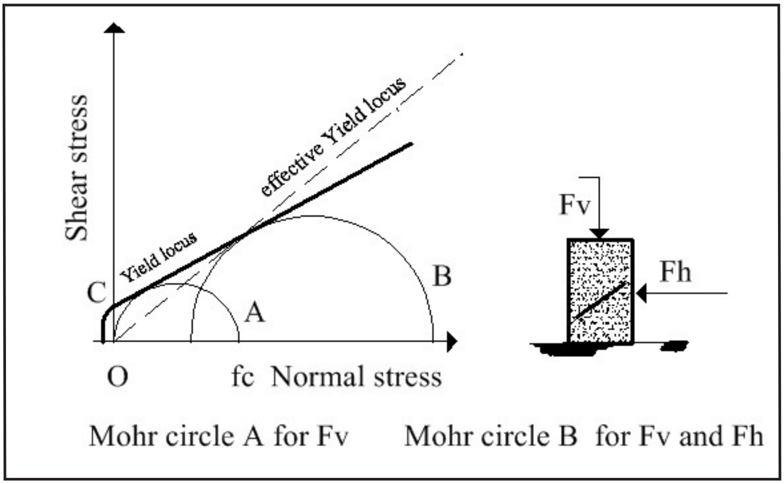
(15) Shear stress

Shear stress: $\tau = \sigma \times \tan\varphi$

(16) No flow

$\tau < C$

Fig. 91: Jenike: Shear cells to analyze the flow of solids in bins and silos and to develop a model of flow and non flow



Each yield locus has an end point which a stationary flow state is established. The small circuit passing through the coordinate center indicates the pressure strength of the solid substance fc which indicates the maximum possible situation, for example, in the case of an auger feeder opening in the silo floor. When the medium in the silo tends to consolidate with time, the strength fc increases, that means, the flow decreases.

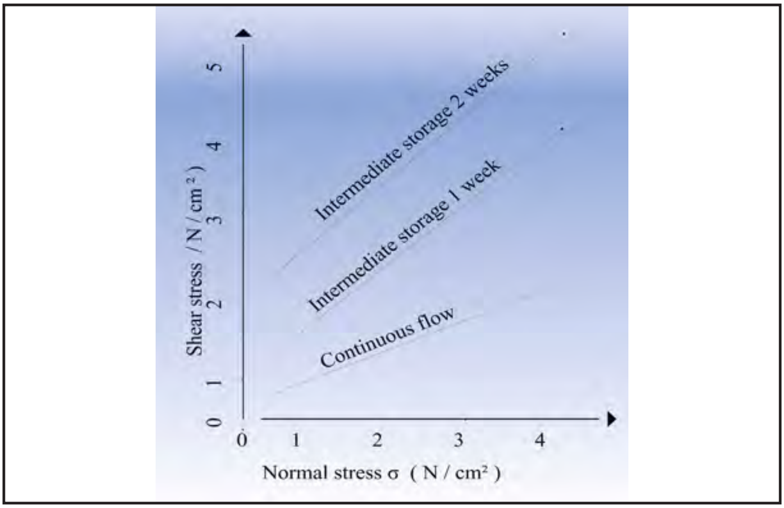


Fig. 92: Consolidate with time

Example: Sludge with lime conditioned Dry matter content 30%

Fig. 93: Sewage sludge DC 38%

5.1.2. Flow profiles in silos

Table 8: Flow profile in silo

Tunnel flow	In the case of the core flow, it is observed that the medium, which is located directly above the outlet opening, first runs out. After the center core has flowed out, a sliding surface is formed on which the medium layers slide. Dead zones which the medium does not flow out, are created. With suitable discharge elements, the formation of dead zones can be minimized and the usable volume of the silo can be better utilized.
Mass flow	In contrast to the core flow, the mass flow is characterized by a regular flow, comparable to the flow of liquids.
Segregation	Solid substances are in themselves not equal. Particle size and particle shape or density may differ. As a result, inhomogenous microstructures are produced during emptying.
Bridging	Stored solids can be compacted under their own mass and interlocked. As a result, vaults can form above the silo discharge opening. Both the trough width of the auger feeder and the silo discharge equipment can prevent bridging.

5.1.3. Pressure conditions in silo

In silos, high-density solids are fundamentally different from liquids. *Jansen** has shown that a part of the storage mass is absorbed by the silo wall friction, so that the pressure stress on the silo floor increases according to a logarithmic curve. This means, that there is no pressure increase from the silo level from a certain filling height.

In a vertical pipe, the static pressure of a liquid rises linearly from the top to the bottom with the fill height h, even with changes in the cross section, for example, through a cone. With high-density solids, the pressure increases only degressively. The static pressure of liquids is a scalar size and is the same in all directions.
Each layer presses with its mass

A x Density x g x dh

on the underlying one.

(17)
Static pressure

This is not the case with high-density solids and bulk material. This results in a pressure difference of

dph = Density x g x dh

(18)
Pressure difference

vertical to the height h and normal to the silo wall a pressure pn also results, but not by molecular movement of the liquid, but by mechanical shock forces.

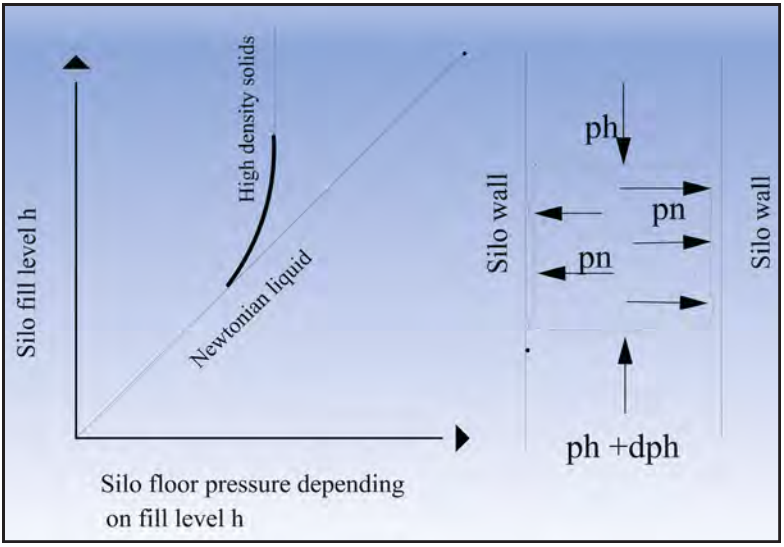


Fig. 94:
Silo floor pressure depending on fill level

When filling with a high-density medium mixture the silo bottom pressure increases according to a logarithmic curve

Thus, normally, the pressure vertical to the effect of the force caused is smaller.

(19) Lateral pressure

$$pn = K \times ph$$

(with coefficient K = 0,5 to 0,8)

The gravitational force acts in the direction from the height h.
In other cases, there is a mechanical pressing force, as in the case of an auger feeder.

5.2. Silo discharge systems

Silo discharge systems are equipment, which support the emptying silos. Silo discharge systems have the task of regulating the required outflow without hindering the flow behavior.

With this equipment, an approximate mass flow can be established in the silo if the medium has the required flow behavior.

The discharge systems can be divided into three categories:

- Bunker slider
- Discharge device
- Special construction

A bunker closure can be: flat gates, shell gates, swivel flaps among other things.

A discharge device can be: a screw conveyor, trough chain conveyor or vibrating trough, among others.

Examples of special constructions are: screw live bottom, shaped discharge arm, spring arm and rotary discharge, sliding frame.

5.2.1. Screw live bottom

In this case the silo bottom is provided with adjacent screws. With this, complete emptying of the silo is possible by the use of screws with a progressive pitch of the screw blades. This guarantees a uniform discharge over the entire cross section of the silo. For this, screw speeds up to 10 rpm are selected.

5.2.2. Shaped discharge arm

This type of the discharge system – revolving shaped arm – rotates above the horizontal silo floor and moves the medium to the central discharge opening. The discharge arm is logarithmically shaped, so that the medium cannot be compressed. The outlet opening is covered upward by a fixed cone. Due to the medium movement from the silo inner wall to the middle axis, the silo diameter is limited to a maximum of 6.5 metres. Discharge arms are used for coal, gypsum, brick dust etc.

5.2.3. Flexible towing arm discharge

The rotor unit consists of a drum-shaped rotor connected to two (2) towing arms. The towing arms are installed on the rotor drum at different heights which feed the medium to the discharge screws. Depending on the resistance on the medium, they can deform elastically downwards or rearwards. As a result, medium bridges are avoided.
The silo flexible towing arm system is suitable for non free flowing, low density medium that tend to solidify and compact when stored in the silo. This applies in particular to moist media which tend to stick and which tend to interlock as a result of their structure.

5.2.4. Rotary discharge

The rotary discharge device is a flat rotor equipped with two arms slipping over the silo floor. The silo geometry is limited to 6.5 meter.

Rotor discharge creates mass flow for non-free flowing and difficult medium to handle. Rotary discharge arms are used for wood span, paper sludge, oil sludge etc.

Fig. 95:
Screw live bottom

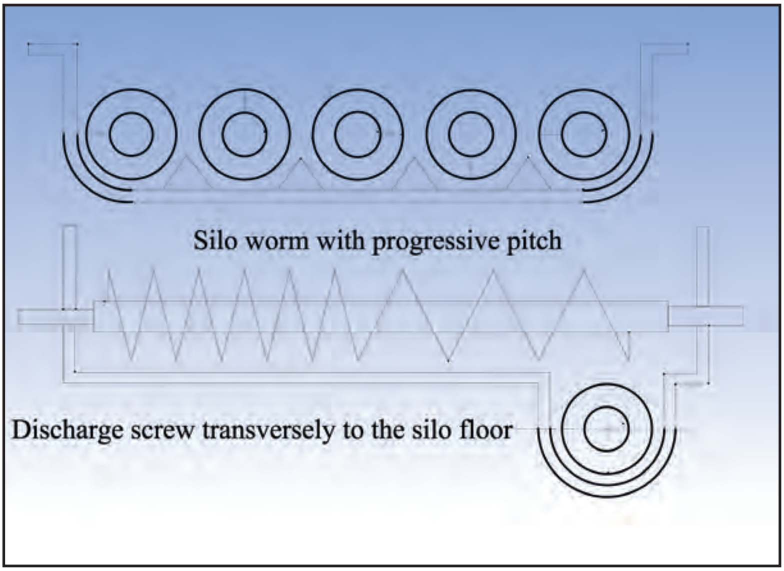
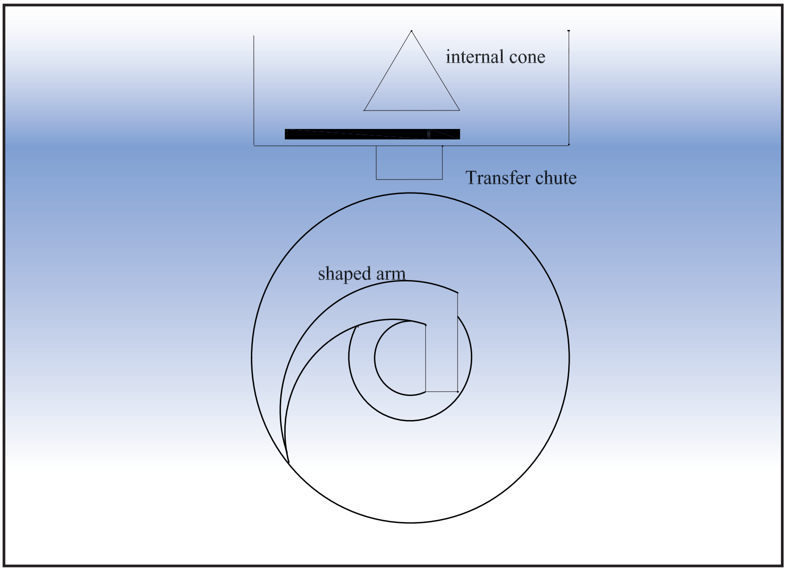


Fig. 96:
Shaped arm



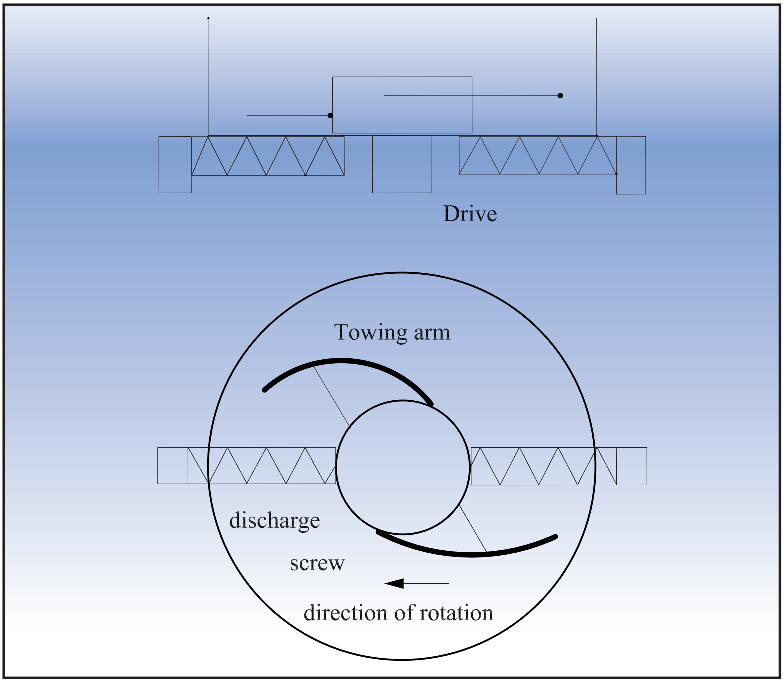


Fig. 97: Towing arm

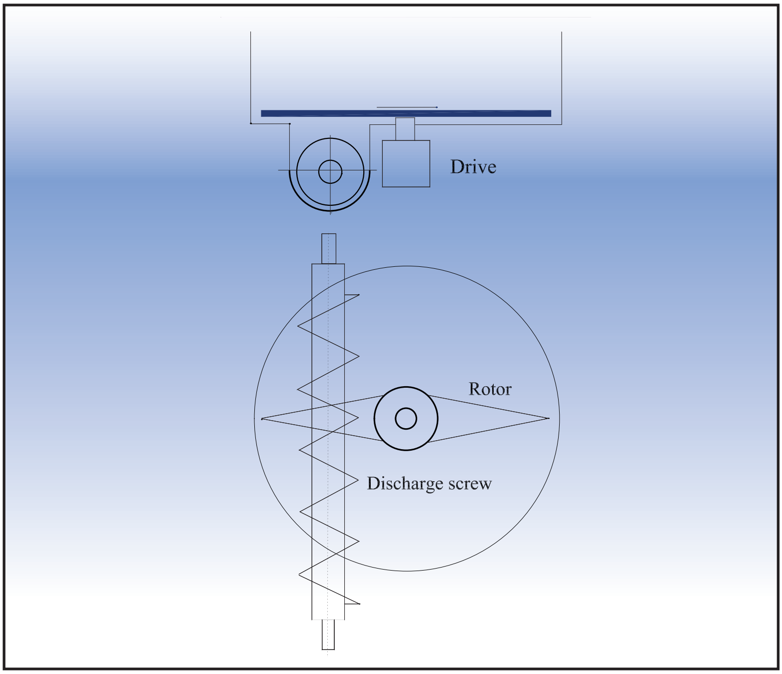


Fig. 98: Rotary arm

5.2.5. Silo sliding frame

In the case of silo sliding frame, a welded frame is moved back and forth across the entire silo floor. Due to the special sliding profile, the medium stored in the silo is undercut and moved into forward movement of the frame. This movement is effected by the beveled edges of the frame and is maintained by the opposite vertical edge of the frame. This results in a uniform discharge of the medium.

Fig. 99: Sliding frame

Medium pushed into the trog

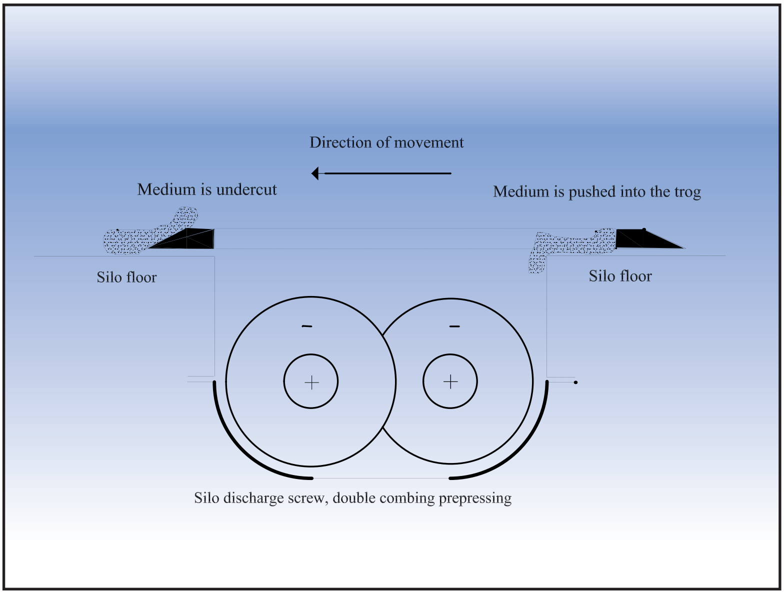


Fig. 100: Sliding frame for rectangle bin

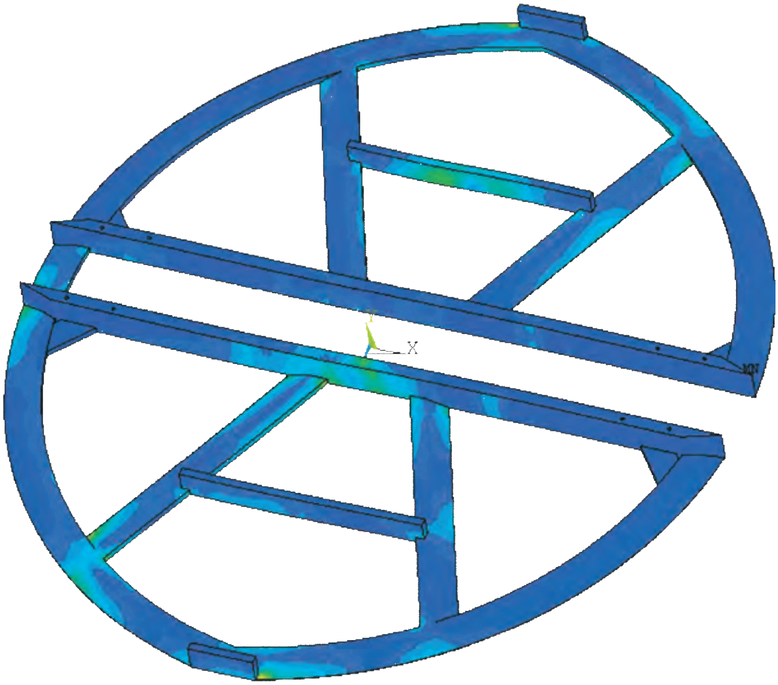


Fig. 101: Sliding frame diameter 8 meters

Designed with finite elements according to method FEM

Fig. 102: The construction height can be minimized with the double combing pre-pressing screw

5.2.6. Table valuation criteria discharge systems

Table 9: Discharge systems

Valuations criteria discharge systems						
Selection criterion	**Form and size**	**Screw live bottom**	**Shaped arm**	**Towing arm**	**Rotor**	**Sliding frame**
silo form	round angular	conditionally yes	yes no	yes no	yes no	yes yes
silo size	meters	up to 6 m	up to 6 m	up to 6 m	up to 6 m	up to 12 m
silo discharge transfer	--	only outside the silo, via a tranverse screw	only in silo center output on conveyor	from the silo center displaced screw troughs	medium transfer inside and outside the silo wall-possible	medium transfer inside and outside the silo casing
regular silo emptying	mass flow	only with progressive screw	mass flow	mass flow	mass flow	mass flow
silo medium	bulk material up to 0,3 m particle size abrasive sticky, moist	no	yes	yes	partially	yes
bio waste	--	yes	yes	yes	yes	yes
wood chips	--	yes	yes	yes	yes	yes
oil sludge	--	no	no	no	yes	yes
paste	--	yes	no	partially	yes	yes
particle size	meter	critical	0,3 m	0,3 m	critical	not critical
drive	redundancy	possible	not possible	not possible	not possible	possible
drive	power required	up to 1 kW per qm	up to 1 kW per qm	up to 1 kW per qm	0,5 kW per qm	0,3 kW per qm
availability	percent	90%	95%	95%	95%	95%
main-tenance	wear characte-ristics	many moving parts	only broa-ching tool	only towing arm	only rotor	low ,since v=small

Fig. 103:
Silo Hangzhou Qige plant

5.3. Silo plants

The combination of equipment – sliding frame – together with discharge screw and high-density solids pump has proved to be a good choice for the non self flowing media. For

- Coal sludge
- Sewage sludge
- Oil sludge
- Poly sludge
- Bio waste
- House waste
- Wet and dry wood chips
- Paste media

the sliding frame has less wear than other discharge elements with its small movement of 0.02 meters per second. The criterion for the application limits of the sliding frame is the ratio of the consolidation stress to the medium stress. The medium strength increases with increasing consolidation stress. A larger consolidation stress can be the result of the static pressure in the silo.

Trouble-free discharge:

Medium strength to consolidation stress < 0,25
This means, the medium is very much cohesive.

Medium strength to consolidation stress < 0,50
This requires special design measures for the silo.
The ratio of the silo height to the silo diameter should be selected to be less than two (2). The storage time of the medium must be limited or the stored medium has to be circulated using solid pumps.

Medium strength to consolidation stress > 1
Scraper arms or towing arms are preferable to the sliding frames.

Silo or bunker manufactured in steel or concrete:
The steel or concrete decision is made according to local and commercial considerations. A symmetrical silo larger than 400 square meter capacity can be the most cost-effective solution in concrete construction.

5.3.1. External sewage sludge receiving

The sewage sludge receiving plant consists of a bunker for truck loading with a silo extraction system and a high-density solids pump. Furthermore, the plant includes a storage silo for conveying the sludge into one of six installed dryers. The dried sewage sludge is combusted directly in one of two fluidized bed furnaces.

Fig. 104: View plant Stuttgart

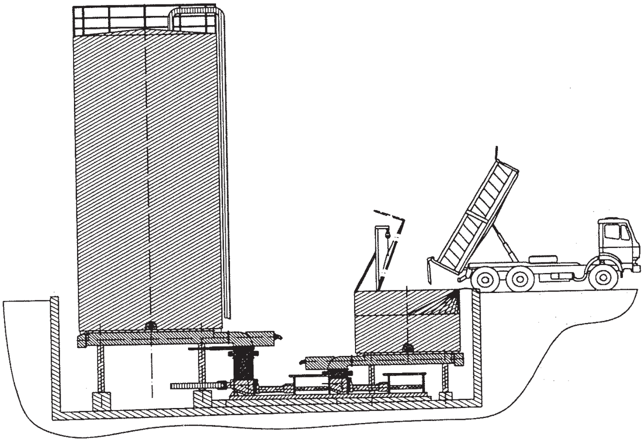


Fig. 105 Schematic silo installation

Fig. 106: Transport of the complete manufactured silo with 5.5 m diameter and 13 m total length to the installation side

Advantage: Complete welding assembly and painting in the factory

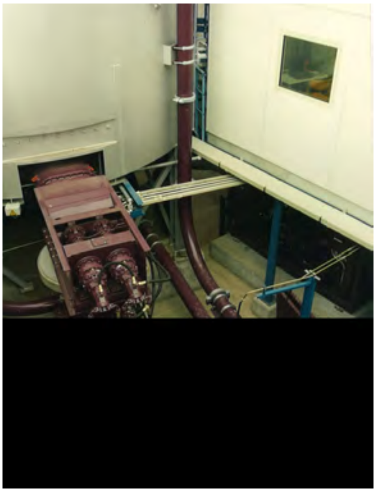


Fig. 107 + 108:

Left picture: Truck receiving bunker with open cover

Right picture: Equipment underneath of the silo

High-density solids pump with auger feeder filling the storage silo or via 3/2 way flat gate and pipeline direct feed into the dryer

5.3.2. Bunker extraction system for special waste and wood chips

Two bunkers are installed according to the sliding principle for a loading station for special waste and wood chips. The wood chips are added to the special waste in the mixer.

The material to be mixed is fed into the bunker by means of a conveyor belt system and a tripper car. The forward and backward driving tripper car creates the bulk material stockpile on top of the sliding frame over a length of 15 metres.

Bunker dimensions (fig. 110): 15 meter x 8 meter (length by width). Dimensions of each sliding element (sliding ladder) is 15 m x 1 meter (length by width). The ladders are controlled independently of each other.

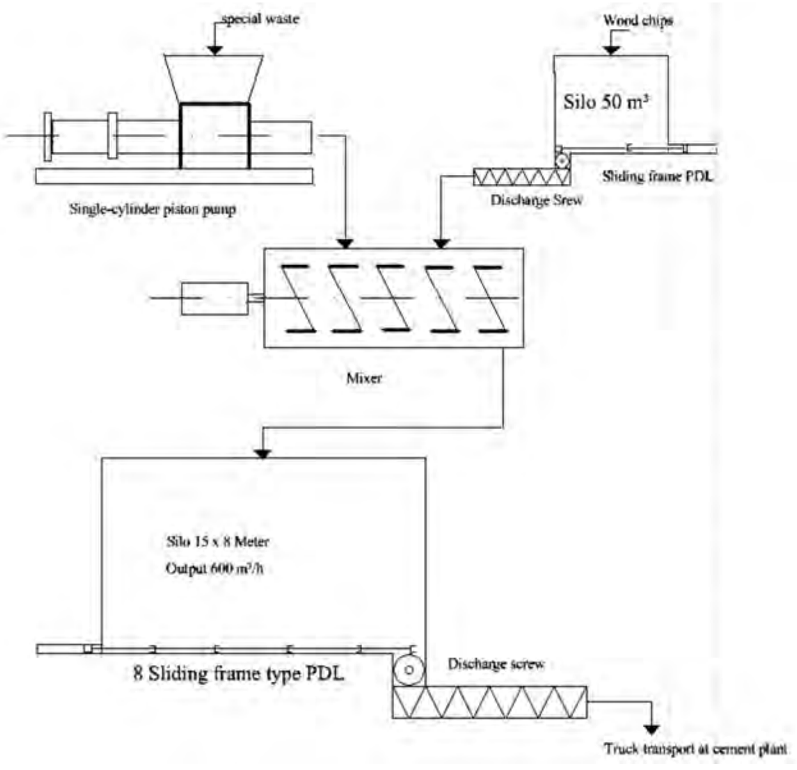


Fig. 109: Interim storage for mixed wood chips and special waste for truck transport for combustion at a cement plant

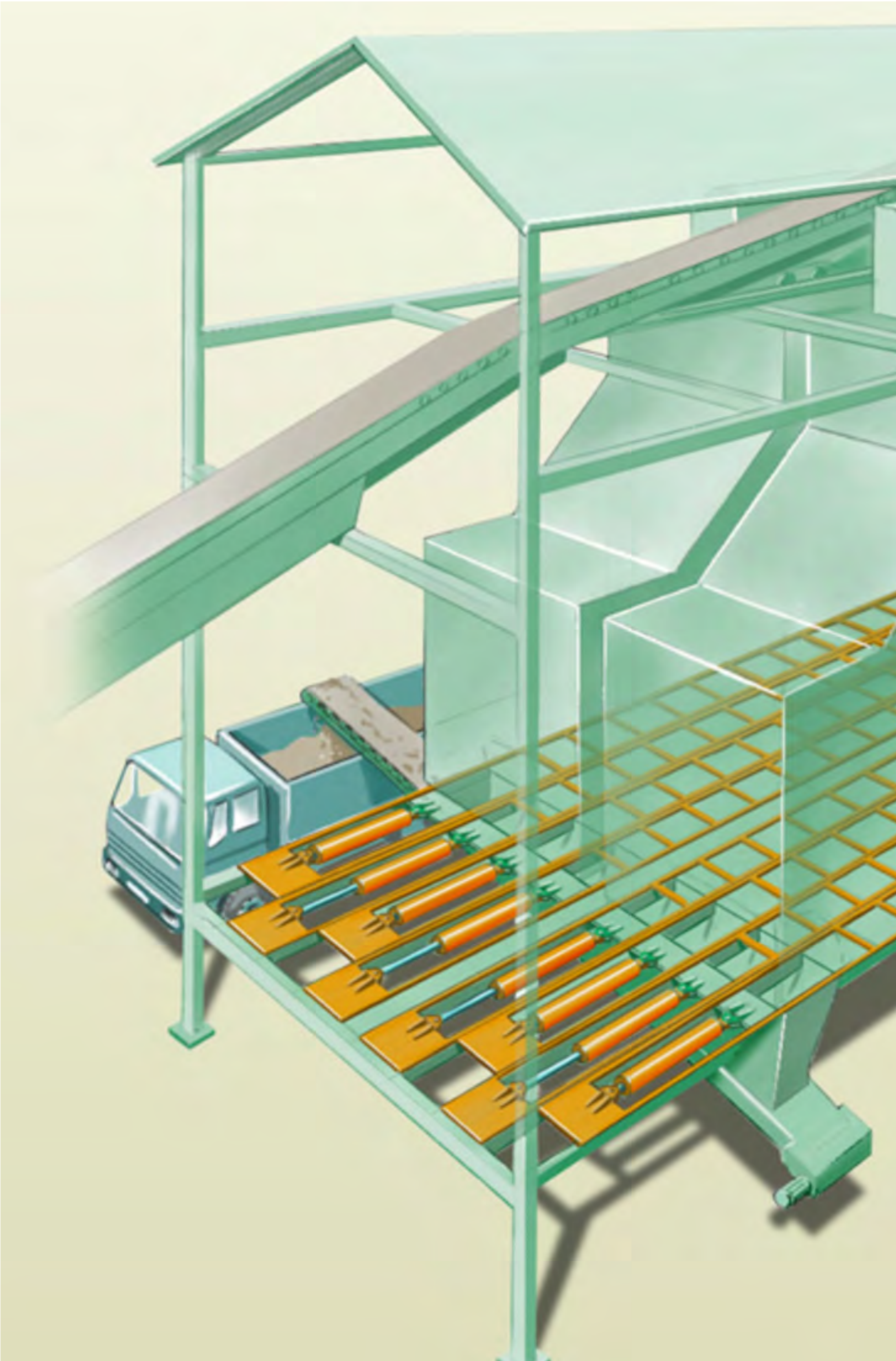


Fig. 110:
Bunker 15 x 8 m for interim storage of waste and wood chips

5.3.3. Co-incineration of sewage sludge in a coal power plant

Fig. 111: Sewage sludge receiving station; in the background the storage silo is shown

Power plant with a capacity of 510 Megawatts per year, sewage sludge addition 60,000 tons per year.

Fig. 112: Look in the bunker with rectangle sliding frame 3.5 x 3.5 m (LxW) and auger feeder (yellow) 2 x 400 mm diameter with 3.5 m length

Fig. 113: Discharge of receiving bunker on level minus 6.5 m auger feeder, flat gate, piston pump with oil pan

Fig. 114: Foreign body separator on level zero

Sludge conveying into the storage silo

5.4. Auger feeder

5.4.1. General

Silo discharge screws, placed underneath the silo floor, can convey stiffer-flow or non-flow media for transport as well as truck loading. In the case of the receiving bin, the discharge screw together with the sliding frame or sliding ladder forms the silo extraction system. The following variants can be distinguished for medium transport:

A - One single screw for truck loading with a center outlet
B - Auger feeder (double screw) for truck loading with an external outlet
C - One single screw for conveying of the medium for further treatment
D - Auger feeder as a pre-press device for direct feeding of the solid pumps. When stiffer media are being pumped, the auger feeder will charge the delivery cylinder.

The A or B variants are available for loading directly onto a truck or a container.

Both variant C and variant D are possible for media fed into a pump hopper. The variant C can be more cost-effective for silo sizes greater than 8 meters. For this application, a progressive screw (different pitch) is recommended, giving uniform output over the entire length of the screw. The large, one single screw is fed into a short pre-compression screw, which is designed as a twin screw.

Double-auger, pre-compression feeders with combing augers automatically clean themselves of adhering medium.

A feeder of this type can also perform the duties of a mixer if mixing blades are fitted: by making the appropriate adjustment of the distance between the two augers not only do they continue to pre-compact the medium but now they also mix it more intensively, with back flowing material (fig. 115).

Normally, feeder devices will be located above the pump. However the fact that they can also be mounted on the sides of the pump hopper, or beneath it, offers a high degree of flexibility to installation planners.

Single shaft or shaft-less pre-compression feeders work well with stiff high-density solids but are less suitable for predominantly mineral or grainy medium which tends to stick.

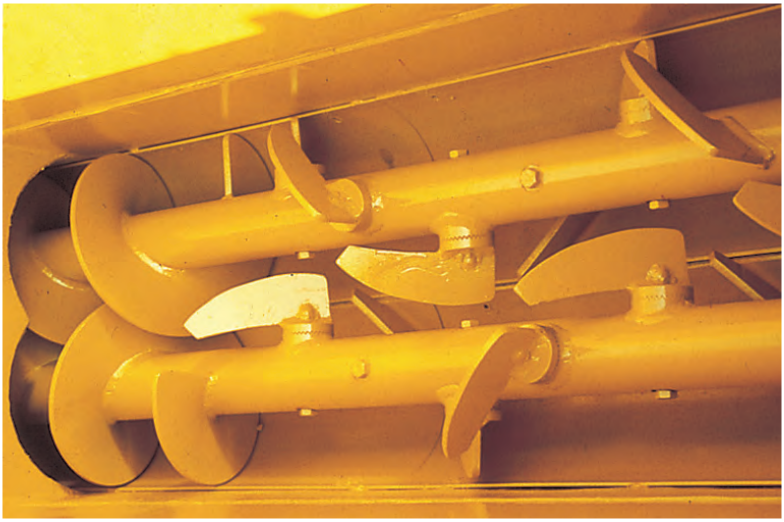


Fig. 115: Double pre-compression screw with mix blades

5.4.2. Conveyor worm principle

An auger feeder consists of helical curved screw blades which are attached to the rotatable shaft and a trough.
The rotation of the medium with the screw blades is prevented by the friction of the medium at the screw trough wall (roll formation). This causes the medium to move in the axial direction in the screw trough.

The helical line is shown as a straight line. The rotating screw blade acts on the contacted medium particles with the radius rx and the force Fr.

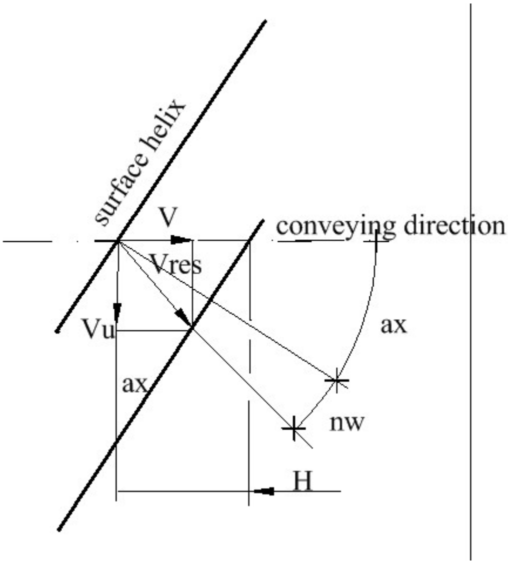


Fig. 116: Speed components Vu and V at the screw blade

The medium particles move with the speed Vres. The speed has a component Vu in the direction of rotation and a component v in the axial direction – the conveying speed.
Since during one revolution the screw displaces the medium about the pitch H, the volume throughput is

(20) Delivery velocity

Formula: $v = H * n / 60$ (in meter/sec.)
$Q_V = d^2 * \pi / 4 * v * 3600 * \eta$ (in m^3/h)

with
d = screw diameter in meter
v = speed in m/sec.
η = total efficiency

In a double combing screw, the volume throughput is calculated:

(21) Volume output

$Q_V = A * v * 3600 * \eta$ mit $A = 2x (A - A1)$

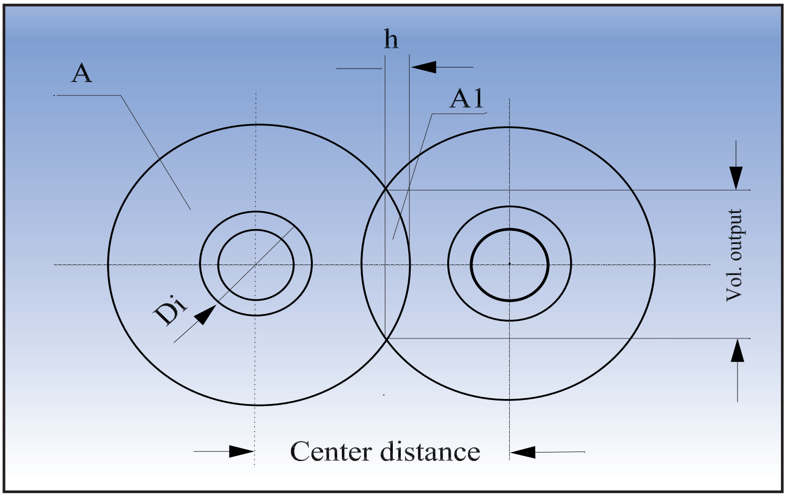


Fig. 117: Double screw auger, covered surface A1

5.4.3. Auger feeder drive power

For the drive power the following equation is applicable:

$$P = M_d * \omega * \eta$$

with $\varpi = 2 * \pi * n$

$$P = M_d * n / 9554 * \eta$$

(22)
Drive power

M_d = Drive moment in N_m
n = Revolution Screw
P = Drive power in KW
η = Efficiency

The movement of the auger feeder and the medium counteract a number of resistances. The sum of the resistance determines the required drive torque:

- ⇨ Friction of the medium at the trough
- ⇨ Friction of the medium at the screw blades
- ⇨ Friction in the shaft bearings and sealings
- ⇨ Internal friction of the medium
- ⇨ Increased torque required for pre-compression

The movement resistors which are derived from the resistance coefficients (lambda) according to DIN 15262 are decisive for the worm torque.

The following table 10 shows the drive torque requirements per running meter for various applications.

Table 10: Screw torque

Worm DIA (m)	Solids content (%)	Torque Nm per meter
0,315	20-40	600-800
0,400	20-40	600-1000
0,500	20-40	800-1200
0,630	20-40	1000-1400

Fig. 118: Feeding screw mounted on S-tube pump

Fig. 119: Double feeding screw

Dimensions: 2 x 0.4 x 6 meters

5.4.4. Table Auger feeder torque requirement

The operational safety on the screws are influenced by the type of sealing selected.

On an auger feeder, which also produced a pre-pressure, transverse forces act on the bearing and seals. This requires sealing systems which must be flexible and not rigid (see also fig. 118).

Fig. 120: Silo discharge screw feed the solid pump

6. Piping

6.1. General

The terms delivery pipe or –line – generally includes both the pipes themselves and their connections, as well as fittings, couplings and insulation and control devices such as transfer tubes. Delivery pipes are used for conveying the most varied types of material. When designing the piping systems, engineers must take into account the stresses arising from high and fluctuating delivery pressures and also possible wear. Conveying by pipe has many advantages including the following:

Advantages of pipe conveying

- ⇨ Ideal adaptation of the piping route to local conditions
- ⇨ The material conveyed is hermetically sealed
- ⇨ The environment is protected from contamination

In calculating the size of the pipe internal diameter the following variables need to be taken into account:

- ⇨ The consistency of the flow
- ⇨ The speed at which the medium is moving
- ⇨ The pressure drop which is to be expected

With stiff sludges and sewage sludges with dry solid content DS = 30% the flow speed should not exceed 0.4 meter per second. Suspensions which have a tendency to settle – such as fly ash, for example – call for flow speeds of up to 2.5 meter per second. Increasing pipe lengths and the use of pipe elbows raises the friction and leads to pressure losses which might mean that a greater cross section is required. The following are decisive factors influencing selection of pipe wall thickness:

Flow speed

- ⇨ The delivery pressures
- ⇨ The strength of the pipe material
- ⇨ Factors influencing internal and external corrosion wear
- ⇨ The requisite safety values
- ⇨ The standard dimensions

The piping system design has to comply with the applicable or mandatory regional standards or guidelines.

In addition to this, the mandatory guidelines of the industrial accident insurance associations also will apply - for example, the Accident Prevention Regulations of the Central Industrial Employers Liability Insurance Association in Bonn, Germany (UVV-VBG).

The connection of the conveyor line to the building substructure requires the consideration of the delivery pipe weights and the masses of the medium to be conveyed per running meter. This leads to the determination of the tie down distances by means of fixed points and flexible bearings.

Standards in pipe construction

Since the double piston pumps convey more or less in a pulsating manner as a result of the switching phase from the pressure to the suction stroke, pressure fluctuations and pressure peaks can occur in the pipeline. These pressure fluctuations and pressure shock have to be absorbed as a force impulse from the pipe support.

The Joukoswky formula can be used for the consideration of pressure fluctuations and pressure shocks on the pipe fastening.

Prerequisite for the ***Joukoswky*** formula:
No change in medium density and the changes of the flow velocity compared to the sound wave spread speed are small. From the pressure difference, the external force acting on the pipeline systems:

(23) Pressure fluctuation and water hammer

This results in the following pressure shock:

$$\Delta p_{Jouk} = \delta \times a \times \Delta v$$

with

Δp = pressure difference (N/m^2)

δ = density of medium (kg/m^2)

a = velocity of wave propagation (m/sec.)

Δv = change of flow velocity (m/sec.)

(15)
External force

This results in the external force:

with $$F = A \times \Delta p$$

A = area cross-section pipe (m^2)
F = force (N)
Δp = pressure difference (N/m^2)

The nature of the inner surface of the pipe roughness, a parameter for the pressure losses per running meter, which is obtained during operation for conveyance of media to landfills, mining backfill, power plant pipeline networks.

Possibilities to minimize the pressure loss are, among other things, the choice of stainless steel pipe, steel pipes with glass liners or ceramic liners. The choice of pipeline type is primarily based on procurement, logistics and availability.

6.1.1. Pipe fittings

Using couplings to assemble the pipeline is preferred to welding pipe sections together. Various coupling systems are available for connecting up easy-to-handle pipe sections. In addition to the familiar DIN flanges, snug-fitting center ring Zentrifix (or ZX), couplings have proved their worth as a coupling system for sludge conveying lines which can be easily assembled.

The Zentrifix coupling uses flanges with a spigot (ZXV) or recess (ZXM), see also fig. 122.

The pipe connection cannot be rotated axially. In the case of high pressure and regular pump shocks this rigid connection prevents the flange and seal from knocking out and is particularly suitable for use as a riser coupling when conveying material vertically.

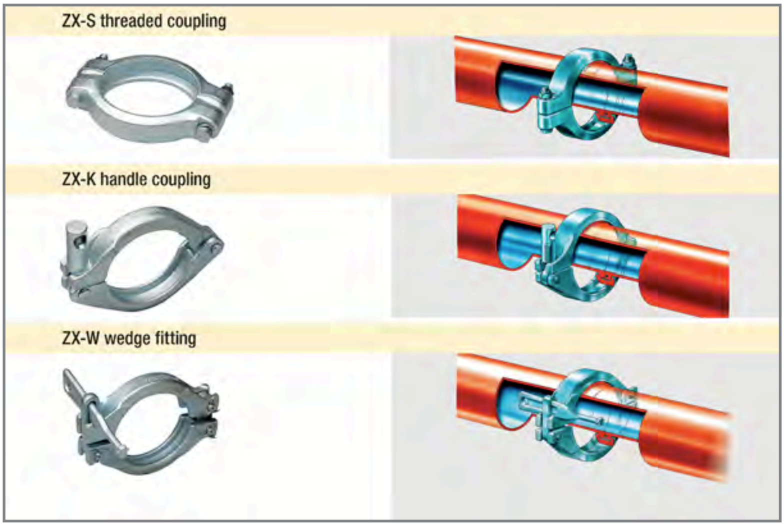


*Fig. 121:
Pipe connection
using Zentrifix
coupling*

Like the DIN flanges, the Zentrifix coupling meets the pressure directive according to 2014/68/EU.

Media vapours may form an explosive mixture with the oxygen, which can ignite under certain conditions.

Conveying pipes which should be installed in potentially explosive atmospheres should be inspected by safety authorities (TÜV) and recommendations and protective measures must be followed.

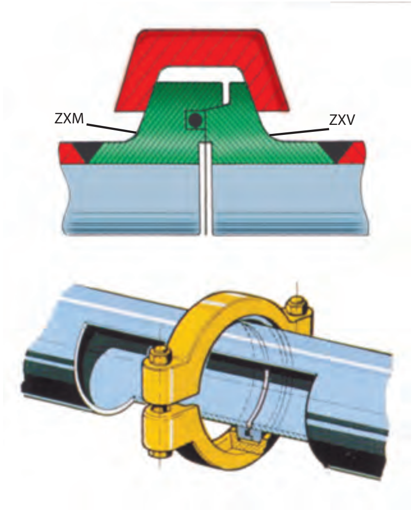


*Fig. 122:
Pipe connection
using Zentrifix
coupling*

6.2.2. Foreign bodies separator in a pipeline network

In case of the acceptance and further processing of foreign sludges from sewage treatment plants, sludge with foreign bodies cannot be ruled out. For the protection and prevention of blockages and damage to the plant equipment, for example co-incineration in coal power station, there is the requirement to remove foreign objects.

A foreign object separator consists of a pressure-proof-housing with an internal collecting basket. The housing is equipped with pressure sensors at the input and output. If a pressure difference at the sensors is exceeded, the separator signals "Separator basket filled". Opening the foreign body separator, pulling out the filled basket and cleaning is simple and represents an additional safety for the whole installation.

Fig. left 123: Two separators installed directly after the foreign sludge acceptance

Fig. right 124: Foreign body separator with demountable trolley; the trolley makes the extraction of the basket easier

Fig. 125: Foreign objects

6.3. Metal detector

Beyond the foreign bodies separator, metal parts can affect plant equipment. In particular, metal parts, which have a small volume but a substantially larger surface area, such as wires.
In order to remove such foreign bodies an installed metal detector protects plant equipment.

The solution to remove metal parts from the pipework is accomplished with a by pass-line. In the design and construction of the pipeline, it must be taken into consideration that the flow rate in the delivery line can vary from 10% to 100% and the detected metal part continues to move in the delivery line after signaling.

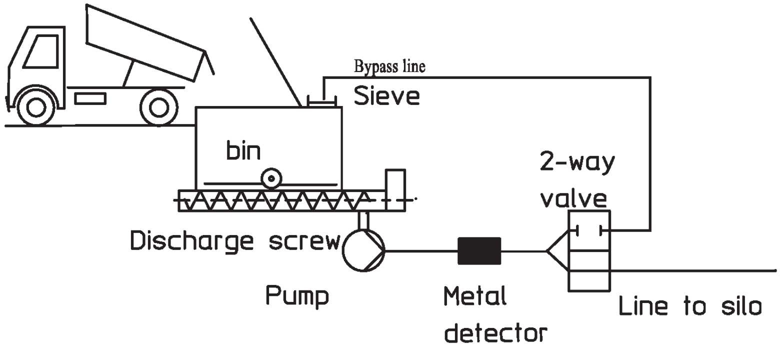


Fig. 126: Separation of metal parts

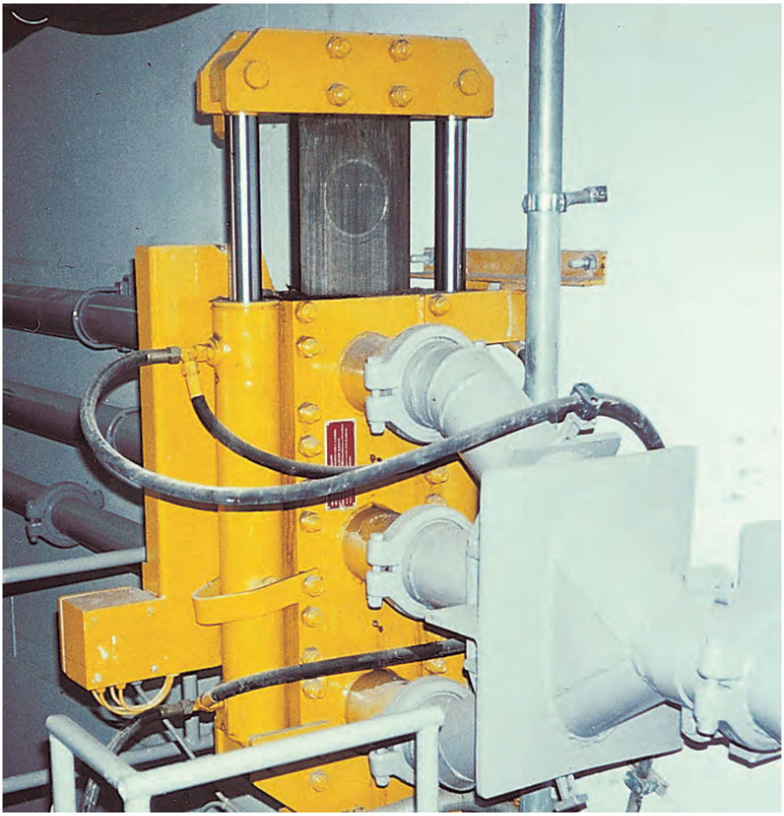
The installed metal detector senses the foreign metal part and sends a signal to the two-way valve, which opens the way to the bypass line. Without switching off the pumping process, the medium with the foreign part is pumped back to the receiving bin via a sieve.

6.4. Pipe gate valve and transfer tube systems

Pipe gate valves and transfer tubes are indispensable for conveying high-density solids by pipe when the process calls for several alternative conveying routes.

In this way it is possible to route the high-density solids in the piping downstream of the pump to different destinations by means of a gate valve. The material may thus be pumped to a dryer or to a holding facility. Pipe gate valves (see also fig. 127) are operated hydraulically.

Fig. 127: Pipe gate valve for three different delivery lines



For fast switching-over, the hydraulic unit used is recommended to have an output of at least 7.5 kilowatts. The gate valve housing is sealed with hardened sealing rings which are pressed against the moveable tongue of the gate valve.

6.5. Cleaning pig

Until now - and particularly in installations of the chemical and mining industries - it has been a problem that pigs cannot be put into the pipes to clean them without sections having to be removed first. This tedious procedure is time consuming and involves a lot of work, which is exacerbated if the pipes need frequent cleaning. In the case of continuous conveying, cleaning during pumping was virtually impossible. The consequence was sedimentation of the high-density solids accompanied by a risk of blockages. Fitting pig traps allows the pipe to be cleaned even during use of the pipeline during brief interruptions to pumping. To do so, the pig trap is installed in the line directly following the high-density solids pump. The trap puts the pig into the pipeline with the aid of a hydraulic gate valve. If necessary , the pig can be retrieved at the end of the delivery line by means of a pig exit trap. This is particularly necessary with closed conveying systems.

Fig. 128: Automatic pig entry lock for delivery line cleaning (left, red)

Pulsation dampener (center, yellow)

Two-way valve (right, red)

Fig. 129: Wash-out pig

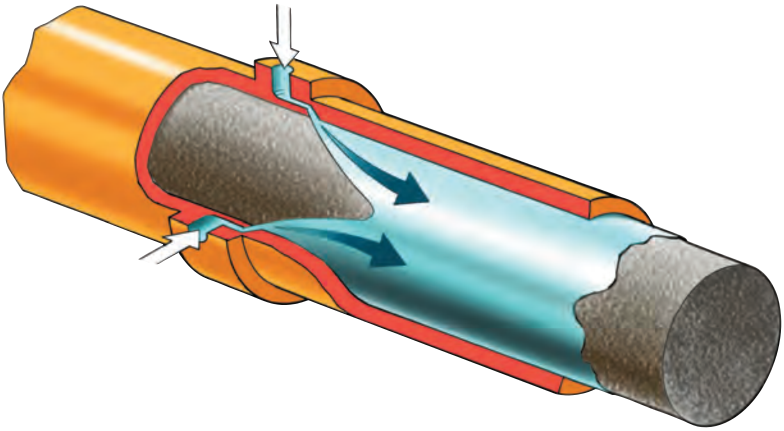
6.6. Injection stations

In the case of viscous media or under certain background conditions – such as unfavourable material consistencies, high erection locations or long-distance conveying – delivery pressures may be required which are beyond the capabilities of high-density solids pumps. Another problem is caused by the further development in solid-liquid separation (higher proportion of dry substance).

Injection is a way of reducing high delivery pressures - and thus makes pumping certain media economically viable.

Fig. 130: Section through an injection nozzle

The lubricant is distributed over four outer entry points over the entire area of the inner tube area by means of an annular gap



The benefit of injection is that the addition of water, oil or a lubricant to the pipe creates a capillary film of lubricant which reduces the shear stress. Here a small quantity of a liquid or lubricant is sprayed from the ring nozzle evenly over the inside of the pipe.

If lubricants are to be injected continuously and automatically, a conditioning unit with a metering pump will be required. The lubricant metering pump sucks the mixture of high molecular weight polymers and water out of the tank and injects the lubricant into the pipe at a rate which depends on the delivery pressure of the high-density solids pump.

As the pump delivery pressure increases or falls, so too is the quantity of injected lubricant increased or reduced, thus optimizing the delivery pressure of the pump.

If the metering pump does not convey any lubricant, the inner ring is pressed against the outer ring by the medium, thus preventing a medium backflow and the injection nozzle remains free of blockages.

With certain special lubricants, it is possible to reduce the pressure drop in the pipe to as low as 20% of the original value.

Lubricants are injected in quantities from 0.1 to 1% of the pump output and it should be remembered that the lubricant must be diluted with water in the ratio 1 : 50.

Fig. 131: Injection nozzle directly installed behind the high-density-solids pump

Fig. 132: Preassembled injection unit with polymer tank and triple mixing device, as well as three dosing pumps for three separate conveying lines

Lubricant dosing stations in pipelines serve to optimize the plant and the operating conditions.
The achievable reduced conveying pressures are decisive arguments for the use of the injection. Furthermore, the injection reduces the energy requirement and the cost of wear parts and service.

Fig. 133: The injection with water or lubricant

The delivery pressure can be reduced

For example: Sewage sludge with 37% up to 47% dry-contents

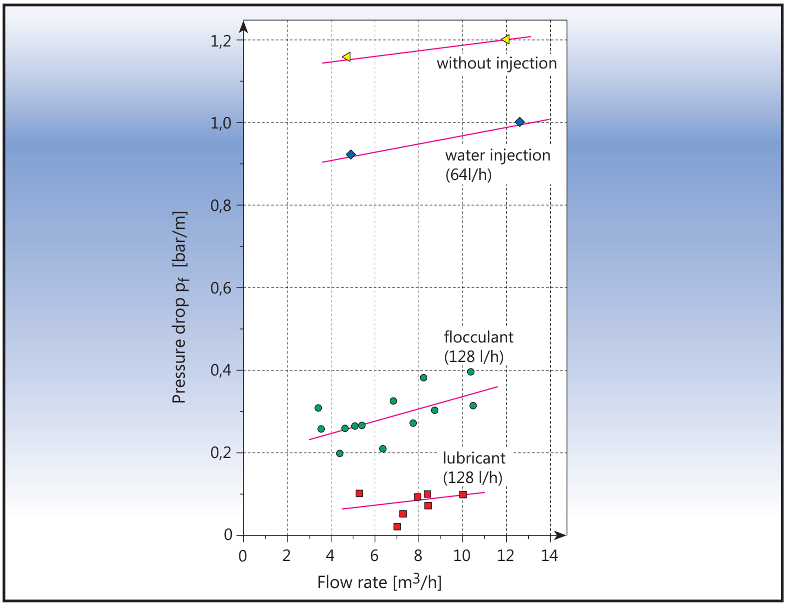


Table 11: Lubricants

Advantages and Disadvantages of different lubricants		
Product	**Arguments + for / - against**	**Reduction of pressure**
Water	+ reasonable - Mixing with sludge	20 - 50%
Oil	+ Cost advantage when used as combustion support - only co- incineration	25 - 50%
Poly-electrolyte	+ high efficiency - eventually dosing station required	50 - 75%
PLC	+ high efficiency + no mixing with media - dosing station required	70 - 90%

6.7. Pulsation damping

Piston pumps – disregarding the most special versions – pump in pulses. With every pump stroke the pumped medium in the pipe must first be accelerated to maximum speed and then decelerated back down to a standstill. This results on one hand in pressure fluctuations and on the other hand in pressure losses – which can vary through time – due to the friction between the high-density solid and the pipe. Pulsation damping may be necessary for the following reasons:

- ⇨ To remove impermissibly high pressure fluctuations (maximum pipeline pressure)
- ⇨ To create an approximately "continuous" flow
- ⇨ To prevent pressure peaks (so called water hammer) resulting from water-based high-density solids with low air content being pumped at great speed against a high pressure

The simplest and most economic way of meeting these requirements is to fit a hydraulic check valve in the pump output line of a transfer pump. The check valve prevents material from flowing back under high pressure as the S-Tube connects.

In this way the pressure in the delivery line is kept at least to the level of the static pressure even during the pump changeover phase in order to prevent decompression knocking in the piping system.

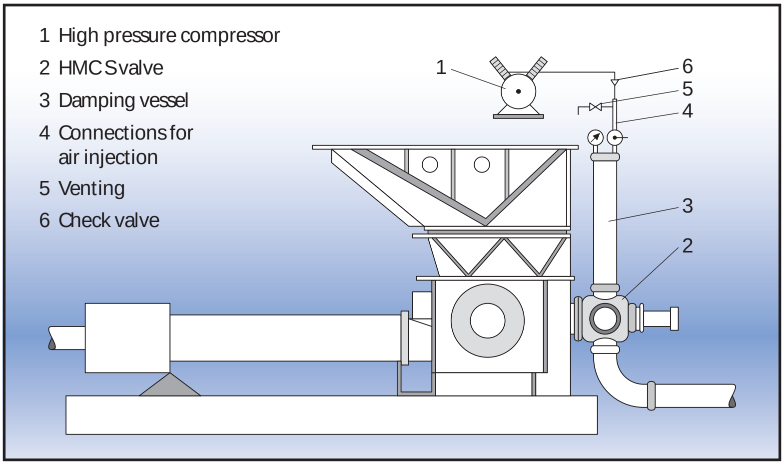


Fig. 134: High-density solid pump with damping device

Another very welcome damping effect can be obtained by injecting air into the system, particularly with media containing water but which do not naturally contain gas. The air can be fed into the pipe by means of a small piston compressor via an air chamber, which itself provides additional damping (fig. 134).

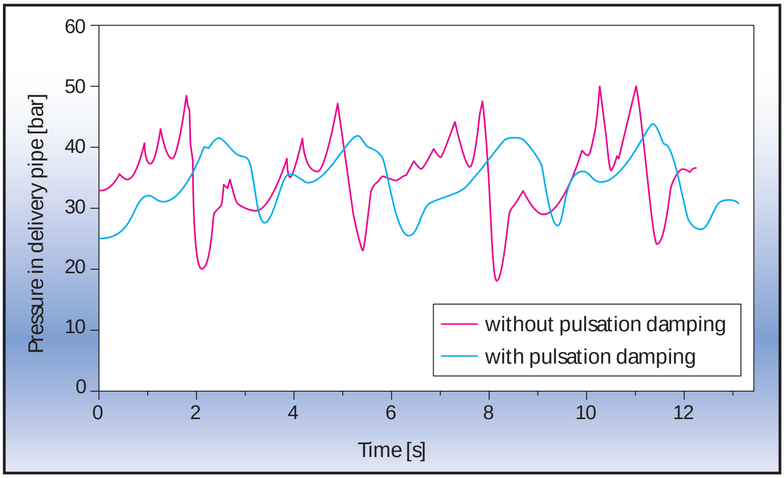


Fig. 135: The pressure curve in a pipe can be smoothed considerably by an active damping cylinder and air injection

Should air injection not be possible for technical reasons, one solution might be an active damping cylinder. The damping cylinder is mounted near the pump outlet. It fills with material during the pump stroke. At the end of the pump stroke, in the changeover phase, the damper is activated hydraulically and puts its buffered material into the pipe during the break in conveying.

6.7.1. Putzmeister Hydraulic dampening System (HPD)

The Putzmeister Hydraulic Pulsation Dampening System is a special dampening system for any kind of Piston Pump application and is used when slurry or paste is containing sand or coarse material. The HPD literally acts as a third delivery cylinder, which is connected with the delivery pipeline by a T-flange immediately behind the pump flange. If the System is used with a KOS Piston Pump, the KOS has to be equipped with an hydraulic actuating check valve (HMC-S) to prevent any backflow of the material into the pump during the changeover.

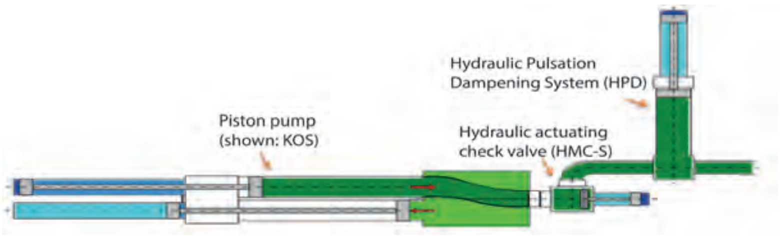


Fig. 136: Principal Layout of a piston pump with HPD dampening system

The HPD is charged during each delivery stroke of the pump. The content of this third cylinder is actively pushed into the delivery pipeline during the changeover of the Piston pump.
This closes the delivery gaps created by the change-over process and creates an almost even flow of material and consequently a way smoother pressure reading within the pipeline.

Fig. 137: KOS with HPD pulsation dampening system on the Putzmeister test field

The HPD is designed as a stand-alone unit and usually driven by a dedicated power pack. Hence it could be used for new installations or as a retrofit for existing pump lines.

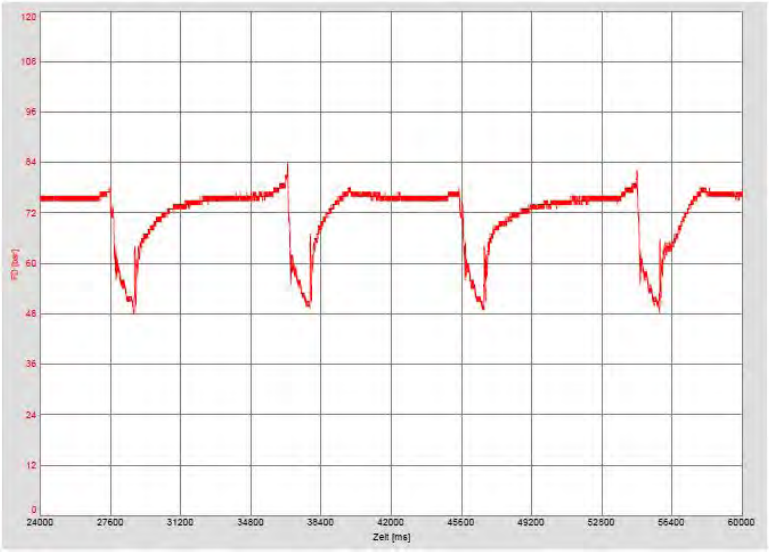


Fig. 138: Pressure reading of a KOS with HPD in operation

Advantages of the Pulsation Dampening System (HPD)

- Hydraulically driven system
- Best and reliable pressure dampening solution for hardening material (like cemented paste or slurry) with coarse material size
- Insensitive towards foreign bodies like stones
- Elimination of water hammers in the pipeline
- Working in different pressure levels without any manual adjustment
- Designed as a stand-alone unit and usually driven by a dedicated power pack
- Application for new installations as well as retrofit for all kind of existing pumps

6.7.2. Passive damper System (VPD)

The Ventilated Pulsation Damper (VPD) has been developed to reduce pressure drops in the pipeline.

This leads to a reduction / avoidance of pressure shocks in the pipe and consequently to a constant flow of material inside the pipeline.

Therefore, the piping, the couplings and the bearings of the pipeline are significantly less stressed. This leads to a smoother operation of the pump system, longer lifetime and less wear.

If the System is used with a KOS Piston Pump, the KOS has to be equipped with an hydraulic actuating check valve (HMC-S) to prevent any backflow of the material into the pump during the changeover.

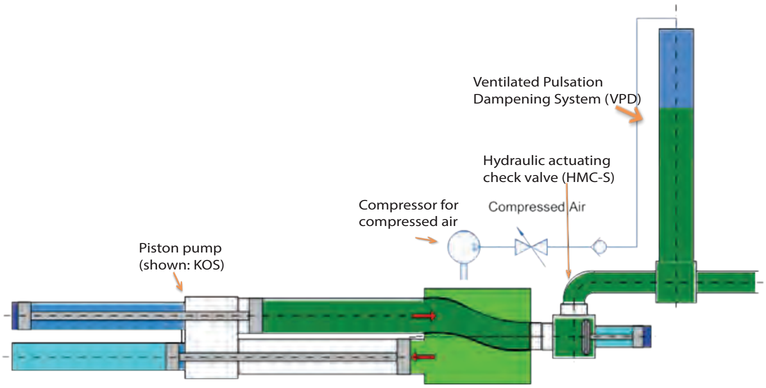


Fig. 139: Principal layout of a piston pump with VPD dampening system

Important note: Due to the design of the VPD it can be only used for non-hardening slurries and pastes. Cemented paste must not be pumped through this system.

The VPD is designed as a stand-alone unit. Therefore it can be used for new installations or as a retrofit for existing pump lines as shown in the following picture.

Fig. 140: Installed VPD dampening system for tailings handling

During the pump stroke of the pump, the pre-compressed air in the dampers gets further compressed by the medium through which the medium rises in the dampers. During the changeover of the seat valves or the S-tube, the compressed air presses the medium downwards into the conveying pipe, whereby the pressure collapse is reduced. The amount of air needed is detected by a pressure sensor in the damping unit, calculated by the controller, generated from the compressor and provided from the storage unit.

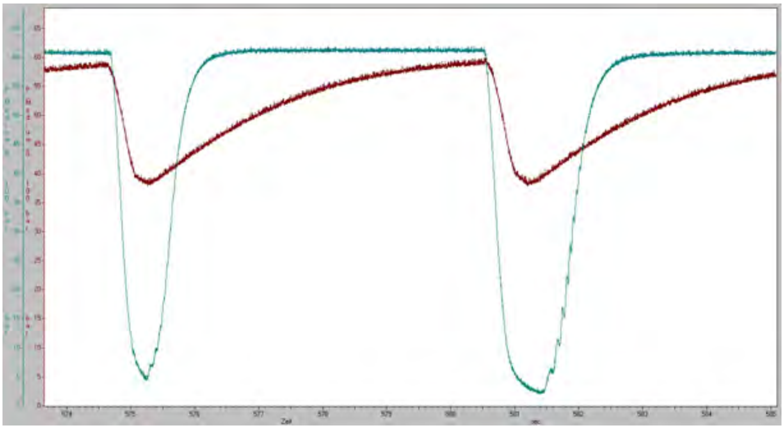


Fig. 141: Pressure reading of a piston pump with and without VPD operation

Advantages of the Ventilated Pipe Damper (VPD)

- Economic system driven by compressed air used as a spring
- No wear parts (membrane) necessary
- No permanent loss of energy (the compressor is only needed if the output or the pressure are changing)
- Easy cleaning and maintenance
- Elimination of water hammers in the pipeline
- Working in different pressure levels without any manual adjustment
- Designed as a stand-alone unit and usually driven by a dedicated compressor
- Application for new installations as well as easy retrofit for all kind of existing pumps

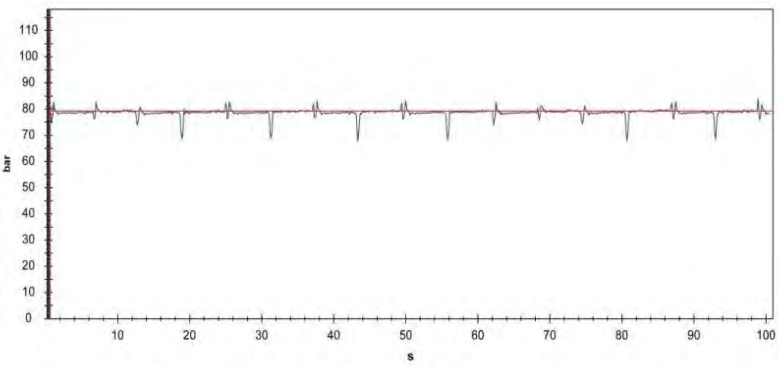
6.7.3. Putzmeister Constant Flow PCF

The Putzmeister Constant Flow PCF System is the best pulsation dampening system for seat valve – or ball valve pumps as no additional mechanical components have to be installed within the delivery pipeline. The only required Equipment is a Putzmeister Seat Valve (HSP) or Ball Valve (KOV) Piston Pump equipped with a PCF Hydraulic Power Pack.

Fig. 142: Installed PCF system with a HSP 25.150 piston pump

With this system the material flow is kept at an almost even level which consequently reduces the pressure peaks significantly.

Fig. 143: PCF Pressure reading of a HSP 25.100 HPS



For a pump every cylinder of the piston pump needs to be equipped with an independent Hydraulic Oil Pump, mounted in the Hydraulic Power Pack. This gives the possibility that the suction stroke can be done way faster than the pressure stroke in order to pre compress the material in the cylinder before the pressure valve is opened.

This Control Philosophy leads to an almost even Flow and Pressure Curve of the pump, directly after the pressure outlet as shown in Picture 143.

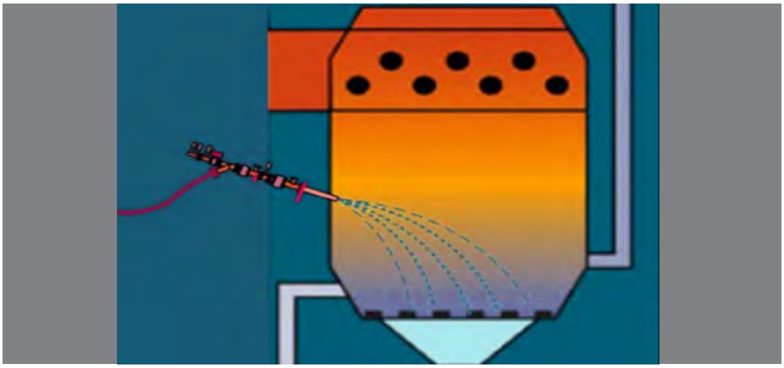
Advantages of Putzmeister Constant Flow (PCF)

- Best Possible Dampening Device for Seat valve Pumps
- PCF is working in different pressure levels without any adjustment
- PCF has no membrane or other additional mechanical parts with a limited life time
- PCF can be used for different pumping material at the same installation, even for paste containing cement or other additives
- Easy cleaning and maintenance of the entire system as no additional mechanical parts have to be installed within the pipeline
- Can be used for hardening material (cemented paste)
- Reliable operation at 150 bar (2.175 psi) continuous pumping pressure can be realized with Putzmeister Seat Valve (HSP) Piston Pumps.

6.8. Coal sludge entry with atomizing lances in power station

In coal preparation at the transfer stations of the mechanical conveyors, spillages are formed which are collected together with wash water and stored in landfills. The task is to determine, how the energetically valuable coal sludge can be fed into a power station without negatively influencing the fluidized-bed combustion and the boiler temperature.

Fig. 144: System lance for fluidised bed combustion



The coal sludge is specified with:
Dry content: 65 - 70%
Density: 1,55 t/m^3

The atomization lance consists of an inner tube through which the coal sludge is forced into the pressurized boiler. An intermediate tube which forms with the inner tube an annular cross section through which compressed air or process steam is fed. Cooling air is fed into a second annular surface between the intermediate tube and the outer tube.

In the head of the lance, the compressed air causes a tearing and crushing of the coal sludge. The effect of the lance leads to a substantial enlargement of the coal sludge surface, so that the sludge particles are distributed finely grained and uniformly over the fluidized bed in the boiler.

A further advantage of the lance effect is that temperature zones in the boiler remain stable by the feed of sludge.

The proportion of the coal sludge that can be co-incinerated is about 8% of the coal requirement of the power plant based on 100% rated power.

Depending on the amount of coal sludge entering; between 2 and 14 m^3/h, a compressed air quantity of approx. 400 Nm^3/h at 6 bar has been confirmed in practice.

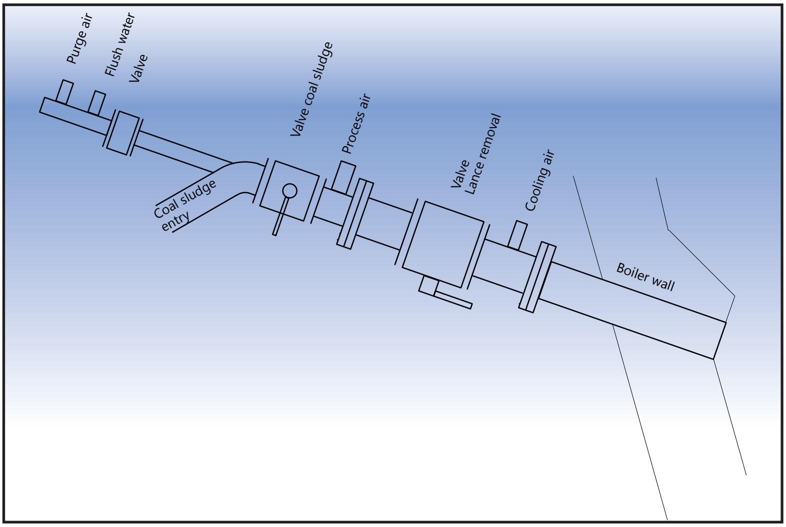


Fig. 145: Lance

As a result of the temperature influences in the boiler blockages due to the clogging may occur in the lance head. During the development of the lance type, this fault was taken into account, in which the lance inner tube was designed to be dismantled during operation. If the coal sludge entry is put out of operation, the inner tube of the lance has to be cleaned with wash water.

The co-incineration functional group disposal of energetically valuable coal sludge consisting of:

- receiving bunker
- solid pump
- pipe network
- atomization lance

has proved itself in practice and is a good investment due to a short amortization period.

7. Future Prospects

Developments in the design of high-density solids pumps are characterized by a particular "problem situation" and the corresponding technical possibilities. In addition to the existing development goals, such as improving operational reliability and economic efficiency, the starting points for improvements and innovations are a wide variety of new forward-looking applications.

7.1. Sewage sludge as raw material (Phosphorous recovery)

In the preceding chapters, the disposal of sewage sludge by incineration or by material recycling in agriculture was presented. Disposal in agriculture is strictly regulated. Sewage sludge contains substances that are considered finite resources.

Phosphorous is an essential component for further utilization. The phosphate molecule, in which the phosphate atom is surrounded by the oxygen atom, represents a vital nutrient for humans, animals and plants.

Around 90% of phosphorous reserves are controlled by only five nations , and nearly half of the world's proven continental phosphorous reserves are located in Africa (see also fig. 146).

Global distribution of explored raw phosphate reserves as of 2013 (U.S. geological survey).

Fig. 146: Five nations own about 90% of all global phosphorous reserves

Germany imports all of its rock phosphate and the mineral fertilizers obtained therefrom. Hence phosphorous particularly in its capacity as a crop nutrient, is a strategic resource, 138.000 tons of which were used as phosphate fertilizer in fiscal year 2007/2008 (IWMI). The recovery of raw materials from sewage sludge is synonymous with environmental protection, such as the recycling of metal, glass and plastic.

In order for phosphorous recovery from sewage sludge and sewage sludge ash to be efficient, sewage sludge needs to be incinerated separately. If all of Germany's sewage sludges were incinerated separately (around 2 million tons) of dry mass annually, around 66.000 tons of phosphorous could potentially be recovered from the residual ash. According to a recent study, the phosphorous peak is likely to be reached in 2033. Phosphorous peak is the date from which the phosphate offered can no longer meet the increased demand.

The forward-looking processes of phosphate recovery are an extension of the product range for the system supplier with the core competence of sewage sludge handling.

7.2. Large volume piston pumps

For the mud removal of seabeds and riverbeds and for land reclamation hydraulically driven piston pumps with S-tube technology have now been used. For silt and mud removal for lake and river beds piston pump sizes with about 100 m^3/h were suitable. For the land fill of new land plots piston pumps with a delivery capacity of 440 m^3/h are used. Also high delivery output is required in the mining industry.

Fig. 147: Sludge supply with barge preparation plant on the vessel stacker conveyor for the prepared medium

With these pump sizes the requirements can be met in the future. For large volume piston pumps the damping components (see also chapter 6.) have to be further developed with regards to pulsation reduction. The experience with piston pumps for land reclamation is helpful for further applications, like flood protection measures in coastal regions.

7.3. Backfilling

Land fill sites can only be intermediate solutions.

The final deposits must be biospherically safe. A safe disposal of medium to be disposed has already been carried out in disused salt mines.

Fig. 148: Salt mine

Handling facilities above ground level are collecting and preparing waste to be stored in empty chambers in underground depths from 500 to 800 meter below the groundwater zone.

Suitable minerals are pumped to the final storage areas, where the chambers are filled and the waste hermetically sealed for the environment.

In Germany, there are several possible sites for conventional arsenic, cyanide, mercury containing waste as well as filter dusts from the flue gas purification to be concluded for a long time from the biosphere.

The annual capacity of these deposits is estimated at around 300.000 tons by the operators. The same value applies to the backfilling of tailings in coal mines. The tailing mixture is treated in a thickener and mixed with a cement slurry in a mixer plant, pumped down by means of piston pump to fill empty chambers.

Fig. 149: Backfilling in Lisheen Mine (Ireland)

There is still an enormous potential for industrial, environmental, recycling and disposal industries. The competence of a single manufacturer is not sufficient for the complex engineering process. The system supplier, who is able to bring process engineering know how beyond the technological know how, is also in demand. In order to implement such projects, personnel resources, IT and logistics are required.

7.4. Offshore Application

In the search of existing resources, the focus will be on the seabed in the future.

Research projects, as presented in chapter 3.7.1. have shown that the technical possibilities and prerequisites for deep sea mining are given. The next step will be to obtain polymetallic sulphides in depths of 500 to 1000 meter. In addition to high proportions of metals, such as zinc and copper, the massive sulphides also contain gold and silver.

Polymetalic Sulphide

Both the piston pump with S-tube technology as well as the piston pump with seat-valve device and the maritime compatible execution of the hydraulic and electrical control have shown their functionality in the Indian ocean.
The Federal Republic of Germany has become active and has applied for licenses for the degradation of raw materials in the deep sea in the Indian Ocean at the International Ocean Soil Authority (ISA).

The license secures the exclusive access to the raw materials for the next 15 years (published by Bundesanstalt (BGR 29.12.2013).

7.5. Oil exploration – Drill cuttings

In view of the increasing energy demand world wide, the production of oil is absolutely necessary. Sea deposits are explored by drilling platforms. During the exploration, hollow drills are used to convey the drill cuttings to the surface. Piston pumps with S-tube technology, which are able to pump drilling fluids with foreign bodies, have proven themselves in practice.

New international regulations have determined that drill cuttings may not be deposed of in the deep of the sea. For the transport of drill cuttings on land, piston pumps are indispensable.

7.6. Methane hydrate

With this oil exploration, marine researchers have come across the phenomenon of methane hydrate. Since the author Franz Schätzling published the novel "The swarm", the existence of methane hydrate on the seabed from a depth of 500 meters has become known.
At atmospheric pressure and 20° celcius, carbon dioxide is gaseous.

If the pressure is increased, the gas CO^2 becomes liquid. The methane hydrate can thus be split into methane and carbon dioxide. The gas CO^2 combines to form a solid hydrate cement, while the methane becomes free. Methane can be used in gas power plants to generate energy. It remains to be seen how, in particular, nations such as Japan and China are using this process for practical purposes.

7.7. Digital services / Teleservice

Data exchange for the purpose of: Error detection, diagnosis, maintenance, optimization.

Machines and plant components which are operated far from the manufacturer's location, can be diagnosed and maintained with teleservice. This helps to reduce service costs. Thus, in the warranty phase travel and personnel costs, in particular, can be eliminated.

Teleservice can be utilized in the passive or active mode. In passive transmission, the service engineer can give suggestions and recommendations through the screen view. Direct intervention in the control part cannot be carried out. In the active teleservice, the service engineer directly accesses the plant computer, which means, that optimizations and errors can be remedied by a parameter change.

Tele service requires a trust relationship between the plant manufacturer and operator (Customer).
A secure connection with security functionality is important to the customers.
For system suppliers, who offer Teleservice, that means, remote maintenance, security features are indispensable, for example:

- Agreement prior to connection
- Identifications checks as access control for the system
- Logging of the Tele service meeting.

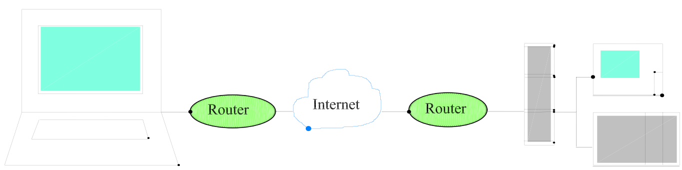


Fig. 150: Programs, data or even parameters can be changed via internet connection

7.8. Conclusion

Hydraulic piston pumps for the transport of solids are an alternative to mechanical delivery systems. They can pump high-density substances with a high content of solids and large particles or foreign bodies.

The advantages are lower water and energy requirements for the delivery job. In recent years, the limits of machine performance have been pushed higher and higher, larger machines have been developed, and new fields of application have been opened up. The service lives of wear parts have been increased significantly, which has improved the cost-effectiveness of machines.

Putzmeister has developed from a manufacturer of pumps to a system supplier of complete pump systems. As well as the actual conveyance of high-density substances, this includes their treatment and storage as well as engineering, product management and service.

7.9. Outlook

Pushing the limits of pumping – that`s what Americans say about Putzmeister`s activities. With regard to service lives, machine size and machine performance, new possibilities which were previously unheard of in this form are now available.

There is no other technology which can rival this method with regard to meeting this combination of requirements (maximum particle size, output, solids content and service life).

8. Annex

8.1. References

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8.2. Picture credits

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