Rising raw material prices mean that ore and coalmines even in remote and little developed or exploited regions of the world have become profitable. The local infrastructure in those regions is usually not comparable with the infrastructure in Europe. Road and rail connections are usually absent across large parts of the areas in question, which is why pipelines are built alongside rivers, through deserts, mountains, and jungles. The line does not follow the geologically most favorable route but is instead the shortest route to the next harbor or the next processor. This is why it might be favorable to transport the accumulated ore and coal sludge by means of pump units.

Piston diaphragm pumps to remove and transport sludge and sediment

Dipl.-Ing. Friedrich Wiechmann
Hydraulic transport of sludge can be described as “two-phase flow.” It is a suspension consisting of solid particles mixed with a carrier liquid located in a sealed pipeline. Certain flow rates must be maintained in the pipe in order to pump sludge from A to B; different values apply depending on the consistency of the sludge. Sludge is classified as homogeneous, heterogeneous, and quasi-homogeneous sludge based on the composition, type, and flow behavior.

**Homogeneous sludge:** This type of sludge consists of different phases but flow rates and directions are nearly identical. The reason for this can be found in the properties of the solid particles, the concentration, and the flow rate. The flow profile is symmetrical; the solid particles are distributed evenly.

**Heterogeneous sludge:** This type of sludge consists of different phases, each with different flow rates and directions in the flow. For example, the flow rate must be above the “critical flow rate” to prevent the pipes from becoming blocked. Sediments in the pipes reduce the available cross-section of the pipeline so that flow rate as well as pressure losses increase. The flow profile of heterogeneous sludge is asymmetrical; the solid particles are not distributed evenly.

**Quasi-homogeneous sludge:** At a sufficiently high flow rate, this sludge exhibits the same behavior as heterogeneous sludge.

**Wear/abrasion due to sludge**

All solid materials have a specific hardness—from talcum powder to diamonds. The hardness of any given material contributes significantly to the wear and abrasion of pump components. Similarly, shape and size of the particles is another important factor.

Different types of wear and abrasion (e.g. corrosion, erosion, and/or combination of both) occur in pumps. Correspondingly, various methods are used to determine the type of wear and abrasion behavior. However, a method to predict the actually expected wear behavior accurately does not exist.

One of the most reliable tests is the Miller Number, standardized according to the ASTM Standard G 7582. The Miller Number makes it possible to draw a conclusion about the relative abrasiveness concerning a 27% chrome steel with a hardness of 62 HRC (hardness test according to Rockwell).

**Examination of wear behavior according to Miller**

<table>
<thead>
<tr>
<th>Sludge Type</th>
<th>Miller-Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bauxite sludge</td>
<td>9–400</td>
</tr>
<tr>
<td>Ash sludge</td>
<td>10–120</td>
</tr>
<tr>
<td>Copper sludge</td>
<td>20–120</td>
</tr>
<tr>
<td>Iron ore sludge</td>
<td>25–130</td>
</tr>
<tr>
<td>Coal sludge</td>
<td>6–57</td>
</tr>
<tr>
<td>Kaolin sludge</td>
<td>7–30</td>
</tr>
<tr>
<td>Tailings sludge</td>
<td>24–644</td>
</tr>
</tbody>
</table>
Parameters for the Miller Number are as follows:

- Hardness
- Size
- Form
- Particle distribution
- Brittleness
- Concentration
- Specific weight

The following also have an impact:

- Sludge temperature
- pH value
- Pressure
- Flow rate

**Structure of diaphragm pumps**

The structure of a piston pump for high-pressure sludge transportation follows a classical model. The product valves, pump casings, as well as the pipelines damping mechanisms on the suction and pressure side are primed with the sludge to be pumped. The pipelines must have very thick walls because they are exposed to the pressures as well as the abrasion of the sludge and sediment flowing through the pipe. Flow rates of 2.5 m/s are usually the limit. Such high speeds, coupled with the parameters of hardness, size, shape, particle distribution, brittleness, and the spec. weight of the sludge, generate high abrasion rates in the pipeline.

Diaphragm pumps with high pressures and high outputs are usually connected upstream of slower running booster pumps (e.g. rotary

### Selecting a suitable pump

<table>
<thead>
<tr>
<th>Pump type</th>
<th>Miller-Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotary pump</td>
<td>1–50</td>
</tr>
<tr>
<td>Piston pump</td>
<td>50–70</td>
</tr>
<tr>
<td>Piston diaphragm pump</td>
<td>70–higher</td>
</tr>
</tbody>
</table>
pumps). A suction flow stabilizer is integrated into the suction side as a dampening element (usually a gas dampener). This design prevents cavitation and increases the load degree of the pump.

Thick-walled pipes must also be used on the pressure side (pressure, abrasion). A gas dampener is installed in the pressure line as well, connected downstream of the pump. The diaphragms of the dampener must be adjusted to the sludge. The gas charge pressure is 0.6 x operating pressure because this setting achieves an optimal dampening. However, to do so, the dampener must be properly dimensioned.

**Pulsation dampers**

Pulsation dampers are available as
- non-regulated gas dampers
- regulated diaphragm pulsation dampers

Non-regulated gas dampers are set to a specific operating pressure. This type of damper cannot be regulated and does not work under the preload of the gas charge. To separate product and gas charge, a diaphragm is installed that prevents the gas charge from dissolving, which would require constant refilling. The diaphragm’s pressure is balanced above the preload pressure; below it, the diaphragm moves to the wall of the damper and uses it as a support. The position of the gas damper’s diaphragm (receptacle at the top or bottom) affects the service life of the diaphragm. If the diaphragm receptacle is at the top, the product can become lodged between the diaphragm and the damper wall. The diaphragm constantly rolls over the built-up layer and becomes worn when the spot is so damaged that gas starts to leak. With corrosive fluids, the damper case must also be selected carefully.

Dampens with diaphragm receptacle on the bottom do not have problems with a built-up layer and adjustment to the pumped material to the same extent. The bottom flange and the dia-
Phragms must be selected carefully to match the product.

Regulated gas dampers adjust to the respective pressure conditions automatically, i.e., non-damped pulsation does not occur. This type of damper is a combination of open pulsation damper and the gas damper.

**Pump valves**

Product valves are dimensioned in such a way that the specific valve load and the valve speeds are as low as possible. This way, the service life of the product valves is extended as much as possible. All valve components can be installed or removed through inspection openings, i.e., the valve boxes do not have to be disassembled to replace wear parts.

The valve seat has a conical receptacle, the valve box a hydraulic connection to press out the valve seat, which is made from through-hardened steel the same as the closing element. Elastomers are used for the seals incorporated into the closing element.

Types of valves:
- Ball valve
- Conical valve
- Mushroom valve

Mushroom valves are a combination of the positive properties of ball and conical valves and offer the following, for example:
- Dynamic behavior
- Easy installation through valve cap opening
- Additional degree of freedom compared with the ball valve

**Characteristics of the pumps**

The product side of the pump must be dimensioned in such a way that the shaped diaphragm, the operating pressure, and the expected wear are considered. The pump case cover must be removable for maintenance without the necessity to disassemble the suction and pressure side tubes. A so-called diaphragm clamping ring is installed behind the pump case cover; this ring or spring presses the diaphragm against the pump case and thus maintains the sealing force so that hydraulic fluid cannot flow into the product, or product into the hydraulic fluid.

The diaphragm is designed in such a way that it will not stretch and/or fold under normal operating conditions. NBR (Acrylonitrile Butadiene Rubber), HNBR (Hydrogenated Nitrile Butadiene rubber), EPDM (Ethylene Propylene Diene Monomer), FKM (Fluororubber) etc. have been proven excellent materials for diaphragms. The outer seal is created with an annular O-ring. Moreover, a metal disk is vulcanized into the center of the diaphragm, which centers and stabilizes the diaphragm. The disk also serves as a holder for the diaphragm rod and protects the hydraulic area from sludge penetration. The metal disk withstands system pressures up to 250 bar so that the diaphragm cannot be destroyed by a defective or improperly closed pressure valve.

The diaphragm is controlled with the diaphragm rod, with the front and rear diaphragm position being monitored. The control is not activated during normal operation so that the diaphragm is able to pulsate freely. The service life of the diaphragm is not reduced by a stress situation. The described measures have yielded a service life of more than 8,000 hours for the diaphragm.

The diaphragm keeps the sludge away from critical and moveable components, which is necessary since these are not coordinated to match...
the product (as those parts are that are in contact with the product) but instead originate from a modular system (e.g., cylinder liners, pistons, piston rods, plungers, gland seals).

The hydraulic system contains components to monitor the diaphragm, to discharge the gas, and effect the overpressure protection. Hydraulic oil or emulsion is used as the hydraulic fluid. The reservoir above the control mechanism is a substitute option for any missing hydraulic fluid in case of a leak.

Piston and cylinder lining are designed for heavy duty; the cylinder liner is hard-chrome plated and honed. The piston is equipped with heavy lip seals and piston guide rings. Due to the great positioning forces of the lip seals on the cylinder lining, the piston lubrication must be extensive. The lip seal strips off all deposits on the cylinder wall (including the oil), which leads to the piston (lip seal) running dry. Lubricating the piston spreads the required oil to the rear side of the lip seals and abducts the friction heat as well. This also creates a “water barrier” that prevents air from entering the hydraulic area.

Triplex pumps have an identical displacement volume per piston. Double duplex pumps have different piston front and piston rear side volumes. This is due to the piston rod's dimensions that must be deducted from the displacement volume of the piston rear side. This unevenness leads to worse residual pulsation values compared to the triplex pump. The additional sealing between piston rod and cylinder is another disadvantage. Since this area is subject to the high operating pressure and must be sealed against air penetrating, packing, lip seals, or combinations of both must be used. The sealed area must also be cooled and lubricated.

The piston rod seal to the pump gears uses bellows or lip seals or packing. The latter two seals must also be cooled and lubricated. This is usually done with gear oil. The bellows is thus the easiest seal.

The demand for pumps with high capacities, great reliability, and long service life has led to the development of hydraulic diaphragm pumps for the transport of abrasive and highly abrasive sludge. These are horizontal piston diaphragm pumps that run slowly due to their long strokes and large pistons. Stroke rates are max. 60/min; some smaller pumps and in special cases with max. 120 strokes per minute are possible as well (2). The max. piston or plunger speed and unbalanced masses (eccentric, eccentric rods), as well as the valve speeds are the decisive factors.

The pumps are either triplex (single-action) or double duplex (double-action) pumps. The two models have different gear designs. Due to the machined allover crankshaft, the triplex gear is able to run at higher rpms; the crankshaft has a crank offset of 120° and because of that a more balanced volume flow. The rigid crankshaft guided by two swivel-joint roller bearings is driven by an external reducing gear. The pistons are pressurized on one side.

Due to the large eccentric, the double duplex gear is unable to run at rpms above 60 strokes per minute; the eccentric offset amounts to 90°;
The piston is pressurized on both sides and exhibits a worse volume flow and higher residual pulsation. The double duplex gear is equipped with an internal gear reduction (herringbone gearing). The herringbone gearing does not generate any forces that have an effect in axial direction and normally must be absorbed by the gearbox. Contrary to a crankshaft, the use of the eccentric shaft makes it possible to install encased main bearings into the eccentric rod. A V-belt intermediate gear is used for capacities up to approx. 200 kW. Higher capacities require reducing gears designed to match the capacity. The electric motor is used primarily as a drive motor followed by diesel motors.

Pumps can no longer be started directly because the masses in the pump and the gear are too great. The liquid column in the pipeline must be accelerated slowly if the pump is started when it is connected to a filled pipeline. Bypasses were used for this process in the past. During the start phase, the pump's pressure and suction sides are short-circuited so the pump does not actually pump any liquid or sludge from the pipeline. The bypass is slowly closed once the pump has reached the working rpm; the flushing fluid starts to move slowly until the bypass is closed completely and the required flow rate has been reached. Today, the following devices are used to start the pump:

- Fluid turbo couplings
- Soft starters
- Frequency converters

The pumps available are models HMT (triplex, single-action) and HMQ (double, duplex, double-action). The two models have different gear designs. Piston speeds are below 1 m/s; valve speeds range from 0.8 to 1.8 m/s. This results in very low pump rpms, which significantly reduce wear of the components in contact with the product.

The die line of the gears leads through the main bearings. This type of division makes it possible to fit the large and unwieldy components into
the gear. With at least 1.5 x the stroke length, the lantern is dimensioned generously. It is protected from dust, dirt, and water by an inspection panel.

Splash or centrifugal lubrication can no longer be used with these gears since the pumps reach the necessary operating speeds slowly and are then set back. The pressure circulating lubrication supplies the pump gear with the necessary lubricant. The treated oil flow is adjusted for the individual consumers; oil pressure, oil temperature, and oil pollution are monitored continuously.

These large pump systems can be equipped with a smart monitoring system that indicates the real condition and status of the pump at any time. Regardless of the application location of the pump, the parameters of the pump can be logged on site or at the control station and analyzed by means of remote diagnosis using a modem and/or the Internet.

**Application example**

At the KCM copper processing facility in Chingola, Zambia, graded copper tailings must be transported from a thickener and cyclone station to a subterranean mine across a distance of 3.5 kilometers where they are used as backfill. Approx. 70 tons of dry solid material must be transported per hour.

A triplex piston diaphragm pump like the one described above was installed for transporting these tailings. The solid concentration in the sludge amounts to 59 %, the sludge volume is 90 m³/h, and the required pressure for the distance of 3.5 km is 50 bar.

The operating costs have been extremely low since the pump has been commissioned: Due to the high efficiency of the new unit, the power consumption amounts to 90 m³/h and 50 bar as well as 160 kW.

The parts replacement is limited to replacing the valves every 5,000 to 7,000 operating hours.

The diaphragms are replaced every 12,000 to 16,000 hours as part of the preventative maintenance.

The piston diaphragm pump used in this case also incurs low operating costs due to the physical separation of the abrasive sludge from the most important moveable parts of the pump using preformed caoutchouc (rubber) diaphragms.

Only the product valves at the suction and pump side as well as the diaphragms are in direct contact with the sludge. The reciprocating principle of the piston diaphragm pump ensures a very high efficiency of at least 93 %. The pump costs of this type of pump are thus minimal and more economic than compared with other methods of sludge removal and transport.

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**Literature:**