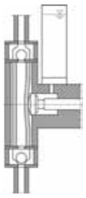

Hydrotransport – The cost-effective alternative solution to transportation by means of truck or train

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So far, truck or railway transportation has generally been applied for the delivery of a large variety of resources or waste products for processing, shipment or disposal to remote places. In view of global warming and the overall threat for our planet resulting thereof, a noticeable trend reversal is now observable in this regard. In terms of environmental protection, an innovative and cost-effective alternative solution is icreasingly applied: Hydrotransport

Using latest technology, solids carrying fluids (mostly non-Newtonian fluids) are pumped environmentally-friendly to their destination through pipelines, in many cases over several hundreds of kilometres. The fluid serves as carrier for the solids in the pressure line.

This ingenious solution is, inter alia, successfully applied in coal-fired power plants for the pumping of large amounts of accruing fly and bottom ash to remote waste dumps (see Fig. 1). Positive displacement pumps are typically applied for these tasks, such as piston pumps, hydraulically activated piston pumps or hydraulic diaphragm pumps.

Hydraulic transportation is an exceptionally challenging task for the mechanical and electrical equipment. Avoidance of sedimentations is an ultimate necessity. Whatever the operating conditions are, a constant flow is to be ensured, whereby the velocity must never fall below the critical value, which would result in the deposition of solids at the bottom of the piping and hence in a blocking of the pipeline.

For an optimum design of the pumps, it is therefore highly recommendable to carry out a rheological examination of the product in the first instance. This is usually done by means of a rotational viscometer. Amongst other things, this examination gives information on the boundary stress (yield strength) τ_o or τ_f respectively. In the event that the yield strength of a fluid is τ_f, a non-Newtonian fluid is generally concerned. The determined shear stress curve τ towards the shear rate provides information about the dynamic viscosity η. The Reynolds number is calculated on the basis of the dynamic and kinematic viscosity as well as the density of the product. On the other hand, the Reynolds number is the starting basis for the calculation of the loss of head in the piping, which is indispensible for the determination of the pressure range of the pump.

In order to avoid the deposition of the solids, the critical velocity v_{crit} is determined as next step, which depends on the chosen internal diameter of the piping, the density of the particles, the volume concentration C_v of the particles and on the grain size distribution. By means of the calculated sedimentation rate of the solids, the sedimentation risk can be analysed for the individual parts of the equipment.

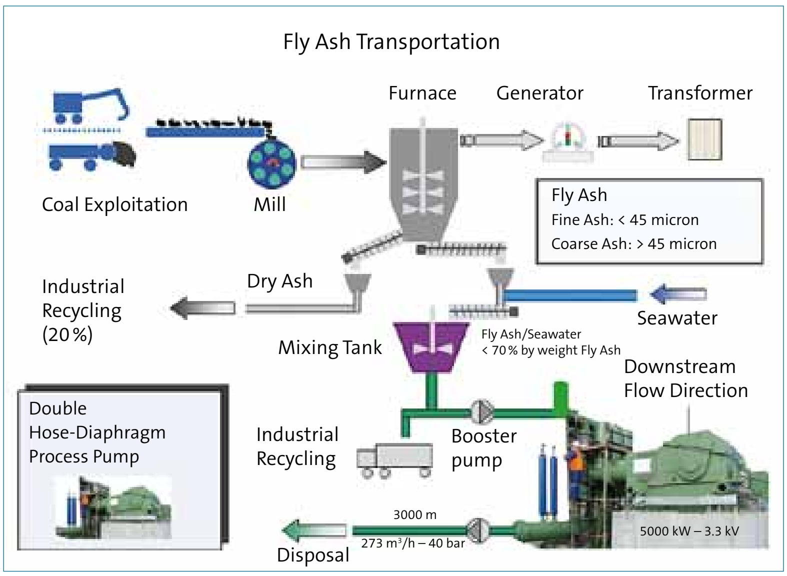

Fig. 1: Hydraulic transport system for the disposal of fly ash from coal-fired power plants

Hydraulically actuated double hose-diaphragm pumps provide the best conditions for such tasks at pressures up to 320 bar. Hose-diaphragm pumps ensure a considerably higher filling degree than piston pumps and prevent sedimentations of abrasive particles since the behaviour of the hose-diaphragm during the filling procedure is similar to that of the human intestine (see Fig. 2.2).

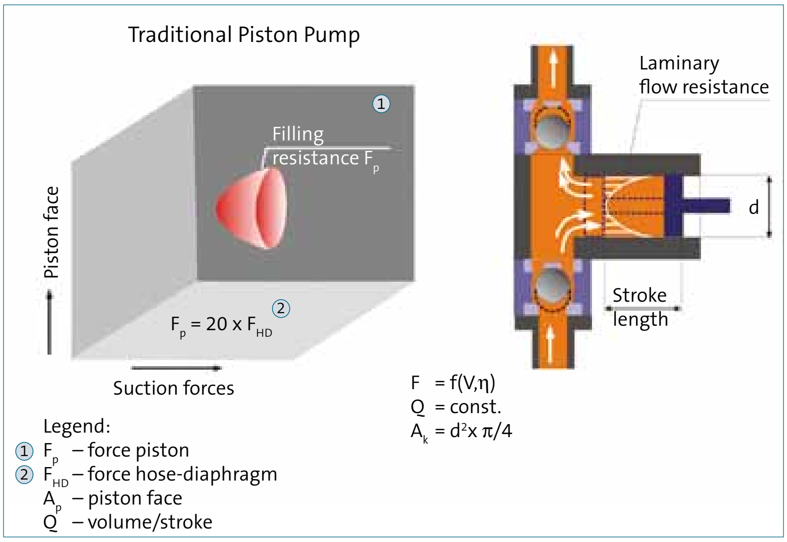

Fig. 2.1: Filling behaviour of traditional pumps

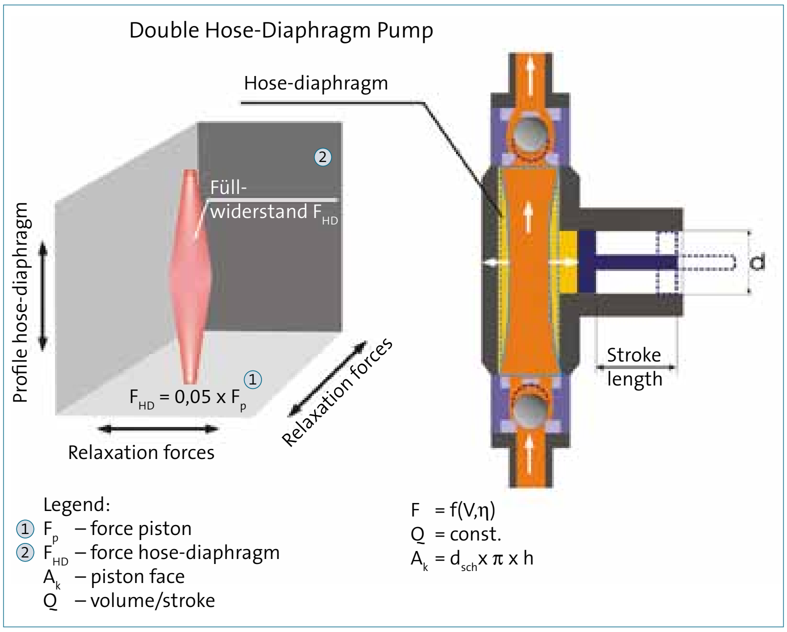

Fig. 2.2: Filling behaviour of double hose-diaphragm pumps

Working principle of hose-diaphragm pumps

At the heart of this pump are two hose-diaphragms which are arranged one inside the other and fully enclose the product in a linear flow path. Simultaneously, they ensure double hermetic sealing towards the hydraulic drive end of the unit. Both hose-diaphragms are actuated by the piston by means of hydraulic fluid and, in step with the piston stroke, they merely move in a way comparable to that of a human vein.

The specific advantage of this design is the linear flow path, which has a favourable effect on the fluidic characteristics of aggressive, abrasive and solids-carrying fluids. Hence, double hose-diaphragm pumps are particularly suitable for the hydraulic transport of suspensions, which are not stable against sedimentation. The cylindrical shape of the diaphragm favours the flow behaviour and avoids the sedimentation of solids (see Fig. 3).

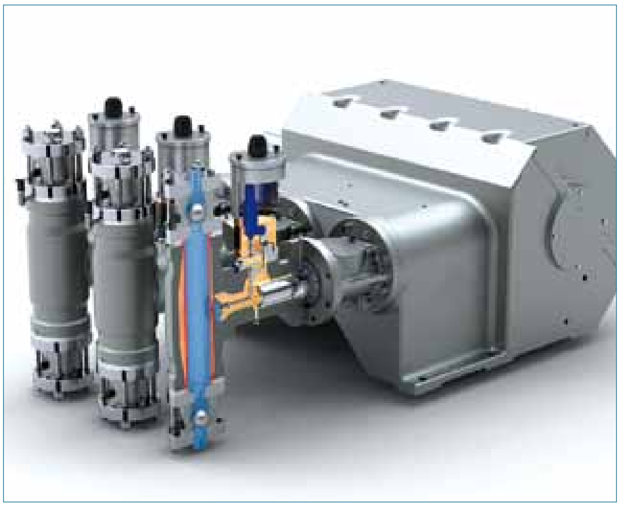

Fig. 3: Double hose-diaphragm pump in triplex design

Both hose-diaphragms are fully functional, even when individually operated. In the event that one of the hose-diaphragms leaks, it is ensured that the product will not come into contact with the pump casing. The redundant hose-diaphragm allows for the continued operation of the pump until the next scheduled operation downtime.

Since this unique pump design guarantees that the product to be pumped contacts the interior of the hose-diaphragm only and not the sliding seals, actually the check valves only are to be considered as wear parts. The wear of the check valves primarily depends on the working pressure and, above all, on the pressure pulsations. The working principle of hose-diaphragms is comparable with the human aorta. However, because of the high elasticity of its vascular wall, the aorta additionally takes over a so-called dampening function which enables a continuous blood stream due to pressure equalization of the blood intermittently ejected by the heart. Positive displacement pumps are not featured with this capability. Depending on the individual designs, displacement pumps exhibit most differential pulsations. For triplex pumps, usually provided with a piston offset of 120° or 2/3 π, flow and pulsation rates are calculated as follows:

For piston speed and pump flow, the equation holds:

$$v_k(t) = r \cdot \omega (\sin \psi + \frac{\lambda}{2} \cdot \sin 2\psi)$$

and

$$\dot{V}(t) = v_k(t) \cdot A_k$$

The examination of curve $v_k(t)$ shows that minimum pulsation occurs at 117° (approx. 2/3 π) and a maximum occurs, when

$$(\sin \psi + \frac{\lambda}{2} \sin 2\psi)$$

(at 82° or 38°). The residual pulsation corresponds to the differential amount of both points. Considering r x ω as a constant and analyzing these equations with regard to their extreme values, the result for r = 0.1 m and λ = 0.142 (gear applied) is a residual pulsation amplitude A of 22.2 %.

Legend:
A = Amplitude velocity pulsation
$\lambda = \frac{r}{L_P}$ = ratio to length of connecting rod = 0.142
r = Radius of crankshaft
Lp = Length of connecting rod = 0.7 m
ψ = Angle of rotation

Interesting comparative values in terms of the irregularity of different multiplex piston pumps result from this formula.

2 cylinders, double acting:	45.6 %
3 cylinders, single acting:	23.0 %
4 cylinders, single acting:	32.5 %
5 cylinders, single acting:	7.1 %
6 cylinders, single acting:	14.0 %

The by far best result is accordingly achieved by means of a single acting five cylinder pump (see Fig. 4), a fact that still applies over a wide pressure range.

However, the benefit of five cylinder pumps is not restricted to the favourable range of pulsations; it also has an equally minimizing effect on the wear of the check valves, since there is less pulsation dynamic acting on the valves, when pumping into a common manifold.

As shown in Fig. 5, the cylindrical shape of the hose-diaphragms contributes much to the considerably reduced dimensions compared to traditional diaphragm pumps.

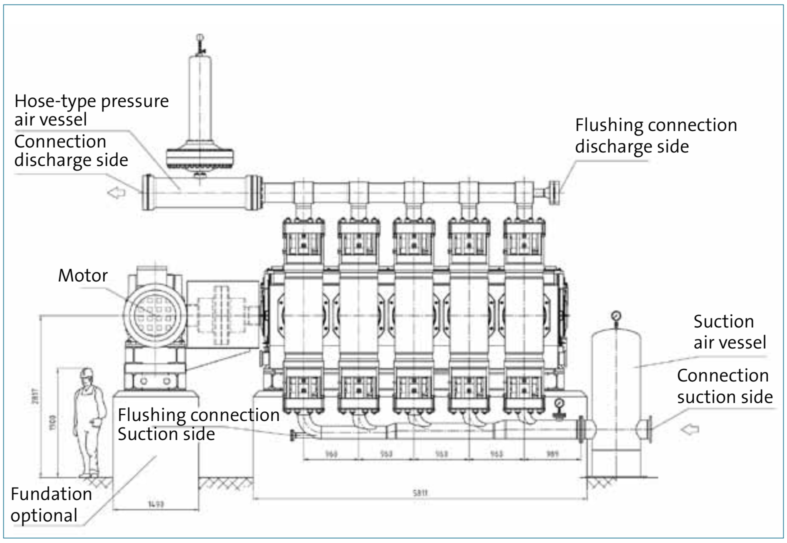

Fig. 5 : Double hose-diaphragm pumps in quintuplex design · flowrate 525 m³/h at 38 strokes/min. · driving power 2,200 kW

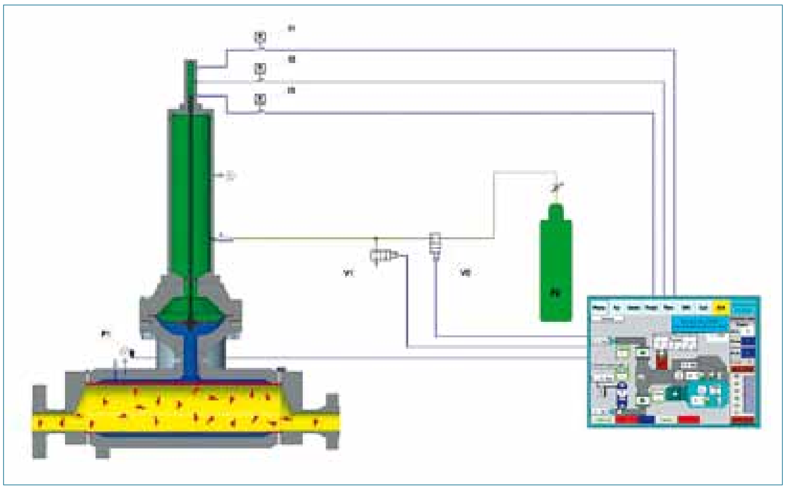

Fig. 6: Hose-diaphragm pulsation dampener with automatic adaptation to the working pressure

Pulsation dampening

In order to provide for an optimum dampening of pulsations inside the valves and the discharge pipes of piston pumps, pulsation dampeners are directly installed into the collecting pipe over the check valve of the pump. To achieve maximum uniformity regarding both pump pressure and flow rate in case of an even number of pump heads, each pump head needs to be provided with an individual damper. Due to the offset arrangement of the crankshaft, however, a single pulsation dampener on the discharge manifold is usually sufficient in case of an odd head number (at least three). In order not to interfere with the linear flow path by deviations in the area of

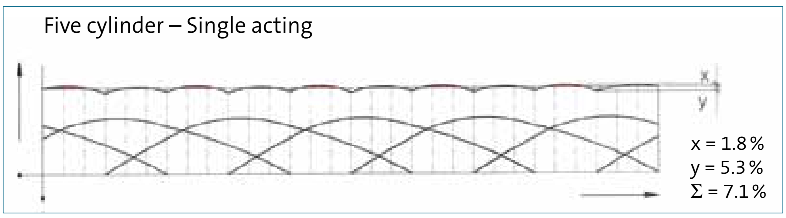

Fig. 4: Irregularity of single acting five cylinder pumps related to the medium flow rate

the pulsation dampener, double hose-diaphragm pumps for high-pressure applications are provided with horizontally arranged hose-diaphragm pulsation dampeners, which have proven most efficient in a great variety of branches of industry (see Fig. 6).

Downflow configuration

Especially when handling non-Newtonian fluids there is a risk of product sedimentation within the pump that must not be underestimated, since it affects the movement of the diaphragm to such an extent that it finally fails. With traditional diaphragm and piston diaphragm pumps with upflow, there is the risk of the solids dropping back into the lower area of the pump chamber during the suction stroke, in case the sedimentation velocity of the solids contained in the medium exceeds the pumping velocity.

For hydrotransport, the traditional working principle of the pumps was literally turned upside down so that the flow is directed from the top to the bottom of the unit. For this purpose, double hose-diaphragm pumps are provided with downflow valves, which have especially been developed for the handling of heterogeneous mixtures (see Fig. 7). The flow path from the top to the bottom prevents the sedimentation of solids and moreover ensures a considerably improved filling behaviour and thus an accordingly improved overall efficiency of the pump. Double hose-diaphragm pumps (Fig. 8) are modular design units and available for flow rates of up to 750 m³/h and a maximum driving power of 2,500 kW. The pump design with linear flow path provides best conditions for the hydrotransport of problematic products, such as the disposal of fly and bottom ash from coal-fired power plants or the transportation of coal, copper, ore or similar slurries over long distances.

In cases of critical process conditions in which the continuous flow must by no means be interrupted, it is moreover recommended to use double valves. Leaks resulting from jammed solids are thus reliably avoided. Since the wear rate increases proportionally to the differential pressure, the utilisation of double valves helps reduce the wear rate whilst maintenance intervals are increased. All available check valve options are of cassette design and can easily be removed and refitted without prior dismantling of the piping.

Driving, control, and diagnostic systems

State-of-the-art hydrotransport systems of course require adequate driving, control and diagnostic systems. Based on actual site conditions, double hose-diaphragm pumps are either provided with low or medium voltage

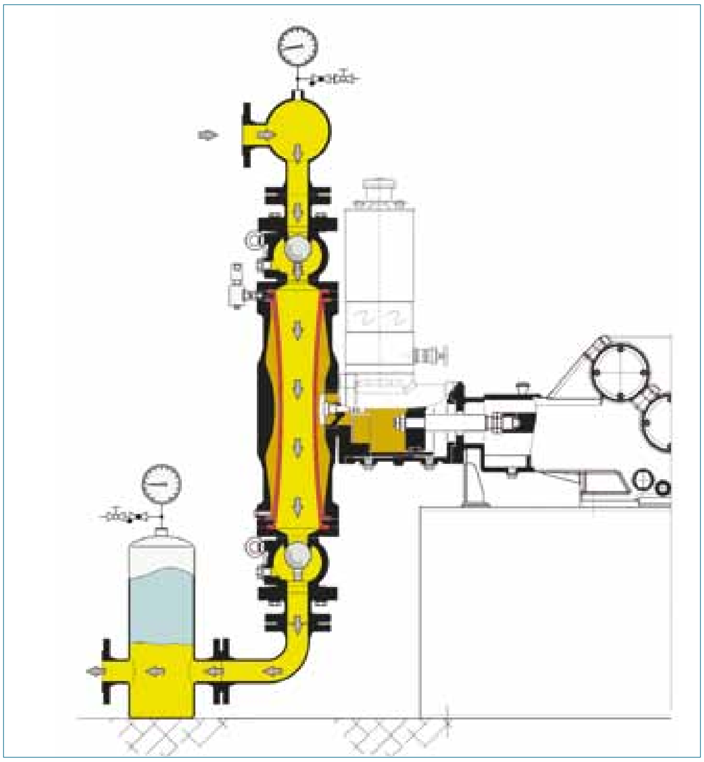

Fig. 7: Downflow configuration

Fig. 8: Double hose-diaphragm pumps in triplex design

motors with the speed being controlled by means of variable frequency drives. In the event that several pumps discharge into a common main, variable frequency converters are additionally provided with special incremental encoders in order to avoid vibration of the pipework.

Condition monitoring

The Internet is gradually evolving into a comprehensive medium for the transport of all kinds of data. By 2015, the number of Internet users is expected to increase to approx. five billion. The industry is also increasingly focussing on wireless data communication and appreciates the new perspectives resulting thereof.

By means of comprehensive diagnostic systems and touch panels, the process pumps presented here now offer an HMI (Human Machine Interface) with full integration of pump diagnostics into industrial control systems with web service option. The touch panel integrated in the control cabinet give the operator information about current operating data and readings, such as stroke rate, suction pressure, pressure fluctuations, temperatures of hydraulic oil and gearbox oil or the condition of hose-diaphragms and check valves. Not only do they indicate possible loss of volume and efficiency resulting thereof, but at the same time they contribute noticeably to the reduction of energy costs.

When integrated into industrial control systems, touch panels additionally provide the possibility of webservice, which in many cases renders on-site service superfluous.

A decisive criterion of condition monitoring is the early recognition of the first signs of wear or any other deviations from set-points that enables the operator to pursue the further development and include the required maintenance into the process in order to avoid an unscheduled shutdown of the system. Since the leak-free sealing of the check valves not only plays a decisive role in hydrotransport, an innovative system for the early detection of wear in check valves has been developed for these double hose-diaphragm pumps in cooperation with a well-known electronics company. The measuring principle of these tailor-made sensors is based on the analysis of solid-borne sound and capable of detecting leaks between valve seat and ball or cone respectively at a time already when the loss of flow is still less than 1.5 %. Multiple options are available for the transmission of the measuring results by means of dry contacts (such as Internet or Intranet) and provide the operator the opportunity of a well-directed advance planning of maintenance or repair work as well as the precise determination of the MTBR values. By means of the 4 in 1 diagnostic system, operational safety and availability of the pumps are significantly increased. This system involves the permanent condition monitoring of all check valves (Valve Performance Monitoring System – FVPMS), primary and secondary hose-diaphragms, suction/inlet pressure as well as the temperature of hydraulic and gearbox oil.

Thus, maintenance costs can be considerably reduced. The FVPMS determines precisely which suction or discharge valves are leaking and must possibly be replaced. Preventive maintenance is thus becoming a phased-out model.

Operating expenses

Apart from the aspects of environmental protection, hydrotransport not only represents a substantially more convenient system solution, but moreover contributes to considerable cost saving, as it is evident from the following example.

Example of operating cots (excluding piping and conditioning)
Pipe length: 72,000 m
Geodetic delivery head: 108 m
Product: Coal slurry
Density: 1,180 kg/m³
Dynamic viscosity: 104 mPas
Flow rate: 3 pumps of 440 m³/h each = 1,320 m³/h
Discharge pressure: 120 bar
Electrical power consumption:
1,795 kW each = 5,385 kW (total consumption)
Stroke rate: 43 strokes/min.
Energy costs: 5,385 kWh/1,320 m³/h = 4.07 kW/m³, at 0.07 €/kWh, this results in 0.285 €/m³
Overall cost (CAPEX & OPEX) for the transport per m³ : 0.323 €/m³
(acquisition costs based on a service life of 30 years + wearing parts for the first two years + energy costs)

Conclusion

Particularly in view of the linear flow without unnecessary deviation, the double sealing between wet end and drive end as well as the optional downflow configuration, the application of double hose-diaphragm pumps is highly recommendable for the hydraulic transport of abrasive and/or aggressive fluids, slurries and pastes.

With a maximum flow rate of 750 m³/h and a maximum pressure of 320 bar, the patented, multi-award winning pump design represents a profitable alternative solution to the traditional disposal by means of truck or railway for the benefit of both the operator and the environment.

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