Photo: H.P. Merten

Self-regulating special centrifugal pumps master even the difficult, complex feed tasks that are often encountered in the chemical and petrochemical industries.

Use of centrifugal pumps in pumping processes with critical cavitation properties

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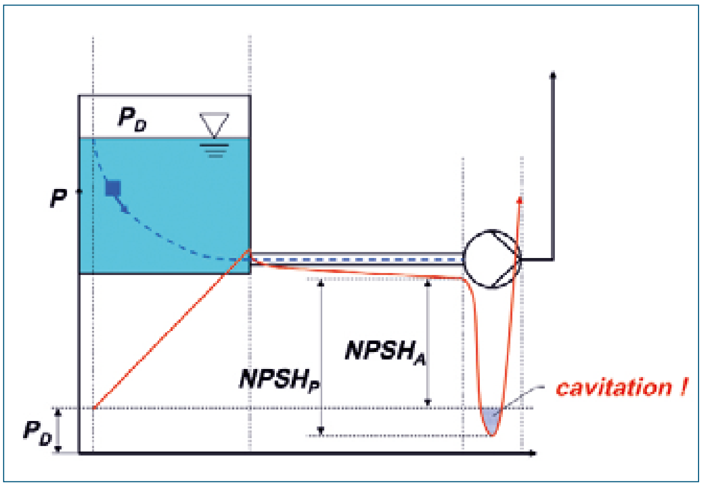
Centrifugal pumps are amongst the most commonly used pumps, accounting for around 80 to 90 %. They are used for pumping a very wide variety of liquids and LPG. Their functional principle is based on a hydraulic system, consisting of an impeller, a casing, and the seal and bearing unit. They have been in use for many years, pumping various media in many industries. Uninterrupted, safe and reliable operation should therefore be a matter of course. In practice, however, hydraulic faults such as dry running and cavitation regularly cause severe damage to pump systems. Particularly in the case of applications with critical cavitation properties, the selection of an appropriate pump allows permanently cavitation-free fluid pumping, and an economical and energy-efficient solution can be achieved.



Source: Bungartz

Fig. 1: Pressure curve for normal-priming centrifugal pump

The criteria by which pump systems are selected in practice are as varied as the requirements for pumps. When the procurement costs for a pump are given centre stage in a decision to buy, this means ignoring the life-cycle costs, which take into consideration all investment, operating and maintenance costs. It is more economical if pumps are optimally designed from the outset. Whether a new pump is being bought or a replacement, this requires a precise description of the pumped product, operating conditions and detailed information about the pumping task. Exact specifications regarding the composition, properties and effects of the product to be pumped are indispensable. Operators are often unable or unwilling to provide the necessary specifications. This makes operating faults inevitable. Various manufacturers have begun working with special pump selection software. Checklists provided by the manufacturers likewise record the parameters for the hydraulic selection. A lot is already possible, ranging from the operating conditions, e.g. application area, pumped product, flow rate and delivery height, to support with duty point selection and the standard processes for duty point adjustment and performance curve calculation (e.g. for a more viscous pumped product). This support generally only applies to standardised processes. Special design features and custom builds cannot generally be recorded in this way. Particularly in critical application areas, e.g. pumping boiling liquids occurring in power plants or in the chemical and petrochemical industries, solutions are required for which the pump technology has been mastered. In practice, damage to pump systems regularly occurs, together with production downtime, as a result of cavitation.

Source: Bungartz

Fig. 2: Special centrifugal pump using the V-AN process:
The pumping medium (hydrocarbon) is at its steam point.
Feed rate: 120 to max. 132 m³/h
Delivery height: 75 m
Pump is operated at n=3000 rpm.

Dreaded cavitation

The range of applications with critical cavitation properties is wide. Fluids particularly at risk include LPG, hydrocarbons and condensates, because these are generally at boiling point. Pumping condensates is a particularly challenging task in industrial processes, but especially in power plant engineering (figure 1).

What does cavitation mean? Cavitation refers to "the partial evaporation of liquids in a flowing system"[1], accompanied by the impulsion of vapour bubbles in a higher pressure range. A systematic problem zone for suction centrifugal pumps is the typical pressure drop at the impeller inlet. A pressure drop to below the vapour pressure at the impeller inlet causes liquid to evaporate. This produces vapour bubbles, which can be drawn along by the flow. These collapse inside the pump. This is generally announced by drumming noises, and its effects are destructive: Interruption of the flow and component defects can result, and it may even become nec-

[1] J. F. Gülich: Kreiselpumpen – Ein Handbuch für Entwicklung, Anlagenplanung und Betrieb. Springer, Berlin, 1999, 2009

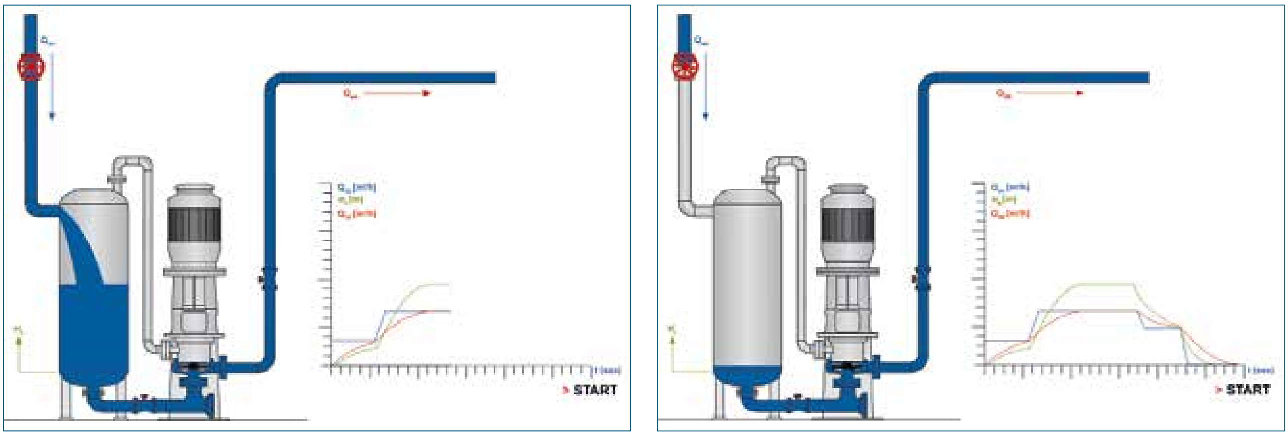
essary to replace the pump. The lower the difference between the suction pressure and vapour pressure of the pumped product (corresponds to NPSH of the system in m), the greater the risk of cavitation. The NPSH value (net positive suction head) refers to the energy differential between the total energy level at the inlet cross section of the pump and the vapour pressure head of the pumped product. Simply put, the NPSH value is the negative pressure or pressure drop that the pump generates in the suction nozzle. This pressure drop is typically expressed in metre liquid column. The NPSH value of the pump is principally determined by the impeller geometry and the pump speed. The NPSH value of the system is determined by the working temperature and boiling point of the fluid, the water level above pump intake (liquid level above pump intake), the atmospheric pressure, and the suction-side piping. This net positive suction head is pump-specific, and is connected in particular with the pump speed. A high speed produces a high NPSH, and a low speed produces a low NPSH in the pump. The temperature affects the NPSH of the system: high temperature = low NPSH value, as there is only a low pressure difference from the boiling point.

When pumping LPG, which is always at boiling point, the NPSH value tends to zero. The total unloading of a tanker truck can be used as an example. Alongside the delivery height, flow rate and output requirements, NPSH value is one of the most important operating parameters for a pump. The manufacturer specifies the value in the technical documentation. If the two key figures (NPSH value of the pump and the system) are within the correct range for a feed task (e.g. safety margin: NPSHsystem – NPSHpump = 0.5 to 1 m), the feed task can be viewed as non-critical for cavitation. This means cavitation can fundamentally be avoided if the total dynamic head is greater than the vapour pressure of the fluid. This is achieved by increasing the suction head – i.e. the hydrostatic pressure – to the pump suction side such that there is sufficient safety clearance between the NPSH system and the NPSH pump.

It is furthermore important to keep the flow speed in the suction line low in order to avoid large pressure drops (guideline value < 1.2 m/s).

General precautions to avoid cavitation

When using conventional pumps, the tendency to cavitation can be affected by various measures. In order to generate the necessary hydrostatic pressure, the pumped product must have a correspondingly high feed inlet towards the pump. In order to achieve this, a frame can be built and/or the filling level in the pump reservoir can be controlled correspondingly. If these approaches are not expedient or practicable, the normal-priming pump is installed in a basement, or a pump reservoir is installed at an



Source: Bungartz

Fig. 3: Pumps using the V-AN process continuously and automatically adapt to fluctuating feed rates.

appropriate height. In practice, design interventions are also possible, such as the enlargement of the vane diameter and a corresponding reduction of the speed, or optimisation of the impeller blade entry angle. This has a positive effect on the NPSH value, as does reducing the number of vanes, or using double-flow impellers (splitting the feed rate). The disadvantage of this is that the pump needs to be designed significantly larger than would ordinarily be required for the pumping parameters. Building a larger pump sometimes requires the use of higher quality and more durable materials. Both approaches generally increase the investment costs.

In most cases, the approach of reducing the rotation speed is used. Slow pumps are less prone to cavitation than fast pumps. The greater the circumferential speed at the impeller inlet, the greater the risk of cavitation. In practice, the problem is solved by running the pump at slower speeds (between 950 and 1,450 rpm). A disadvantage of this is that the performance efficiency of the pump falls at lower speeds. If the pump additionally has an overdimensioned design, i.e. it is not operating at optimum efficiency but rather in the partial load range, the efficiency of the application becomes even worse.

Summary: when using normal-priming pumps for applications with critical cavitation properties (e.g. pumping condensates), additional measures are always necessary to avoid cavitation. These are generally associated with higher costs (figure 2).

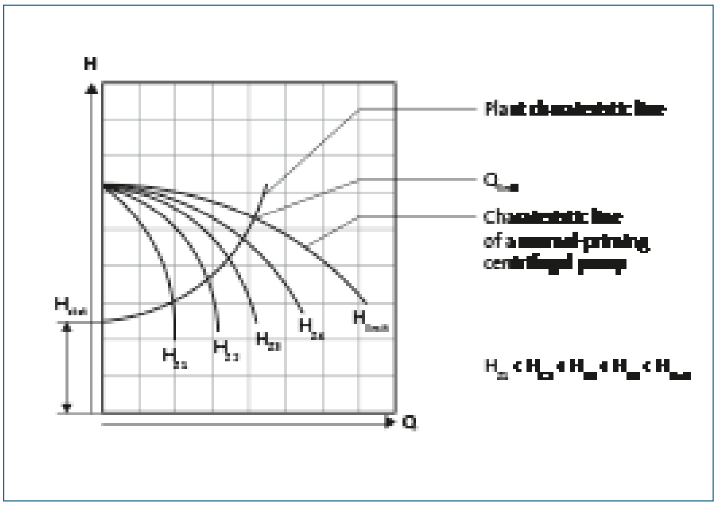
Innovative solutions thanks to special physical properties

An alternative to the operating mode of conventional centrifugal pumps is offered by pumps using the V-AN process (AN stands for abnormal). These special centrifugal pumps are self-regulating. They operate without suction capacity, i.e. they themselves generate no negative pressure at the impeller inlet. Specially designed for each application case, they are manufactured individually or in small series. One important design detail consists in the hydrodynamic sealing of the pump. The starting basis was and still is the problem of how the transition between the pump casing and the rotating shaft can be designed so as to remain tightly sealed. The design approach, which continues to be developed further, utilises a primary and a secondary seal. The primary seal consists of concentric vanes on the rear of a conventional centrifugal pump impeller. As the speed of the pump increases, the pumped product is driven outwards by the centrifugal forces. When operating the pump, this prevents the fluid from coming into contact with the shaft. As a secondary seal, a downstream sealing system is selected depending on the application, consisting of a stuffing box, a mechanical seal, a lip seal or a magnetic drive. The downstream seal only serves for idle state sealing, and during pump operation, it only comes into contact with the gas phase of the pumped product. At a minimum speed determined by the design, the seal during operation can be guaranteed. This hydrodynamic shaft seal works with any type of fluid, irrespective of whether it contains solids, is viscous or boiling. This is a component of the V-AN process (figure 3)

The self-regulating performance of the pumps is based on the fact that they have “broken the suction habit”. Between the inlet at the impeller and the gas phase of the pumped product in the pump reservoir upstream of the pump, a pressure compensation system is created. This is dependent on three factors: the first basic requirement is a vertical pump design; the second is the hydrodynamic shaft seal downstream of the impeller, as described above; and the third is that, in addition to the normal connections, such as the suction line and the pressure port, this process additionally requires the installation of a gas compensation line downstream of the pump’s impeller. This line is connected directly to the gas phase of the pump reservoir (because it is a non-suction pump, the normal word “suction line” is replaced by the term “feed line”). If the pump reservoir is at atmospheric pressure, this leads directly into the pump casing. As soon as the pump is running, the zone downstream of the impeller is empty. There is no further pumped product present. The pressure in the gas phase of the pump reservoir is equal to the pressure downstream of the dry impeller. Equilibrium is achieved between the pressure at the impeller inlet and in the gas compensating line.

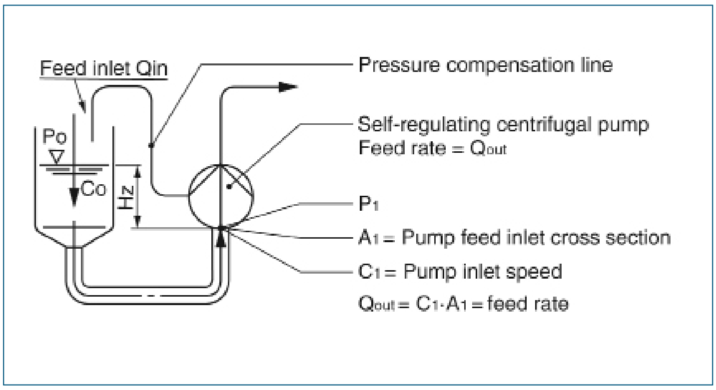
Centrifugal pumps are used to convey a wide range of liquids and liquid gases.

The process engineering advantage is that the special centrifugal pump using the V-AN process only requires as much volume as is forced into it. The necessary pressure is supplied by the hydrostatic liquid column. The pump is designed for the maximum anticipated volume flow (Qlimit) (figure 4). When this volume is present, the



Source: Bungartz

Fig. 4: Characteristic curve for centrifugal pump of type V-AN. Here, the following applies: $Q_{aus} = k A_1 \sqrt{2 g H_z}$



Source: Bungartz

Fig. 5: The speed (C1) at which a medium emerges from an open vessel is determined using the Bernoulli equation:
Qab = K · √2gHz · A1 = Qzu
K < 1
K = f (pump and speed)

liquid level (HZ) in the pump reservoir rises. The resultant increase in pressure means that more liquid is forced into the pump. The pump reacts directly to this volume. If less liquid follows, the filling level falls, and the pump draws less from the reservoir. The minimum filling level that can be achieved is derived from the horizontal centre line of the pump impeller.

In a manner similar to a siphon, no further liquid follows (figure 5). The pump impeller rotates freely in the liquid. The principle follows the formula for free outlet (see figure 4). Here, the feed factor K considers impact losses at the impeller inlet as well as other negative influences and is thus smaller than 1. A1 is the cross-sectional surface of the pipeline.

This is advantageous because further cost blocks can be saved: mechanical or electrical regulation equipment is unnecessary, and neither frequency converters nor volume flow monitors are required. The self-regulating behaviour of pumps that operate using the V-AN process is completely autonomous.

A further special feature of the process is the continuous self-ventilating effect. If gas gets into the pumping process, this is also discharged. The pump does not need to be ventilated, and the pumping process is not interrupted by gas in the feed line. The continuous dry-running protection facilitates long pump operating periods without liquid. Even during difficult commissioning phases, intermittent feed rates and the total unloading of containers, the highest levels of availability are guaranteed.

Cavitation-free pumping

One fundamental property of the process is the cavitation-free pumping of a wide range of media in any operating mode. In normal-priming centrifugal pumps, a systematic pressure drop occurs at the impeller inlet. Because of the corresponding spaces above and below the impeller, the V-AN process has an almost straight-line pressure curve throughout the entire pumping process until the pressure begins to build up (figure 6). The pressure drop available at the impeller inlet is lower for boiling fluids than in normal pumping tasks, as only the suction head is generally available as a differential. When pumping condensates, there is therefore a significant risk of the NPSH of the pump exceeding the available NPSH value of the system. The non-suction special centrifugal pump using the V-AN process has an NPSH value of < 0.1 m.

Typical applications

Under the V-AN process, the special centrifugal pumps always work cavitation-free. The NPSH value can therefore be ignored during the system planning stage. The design adaptations of the pump and the associated advantages allow the development of numerous properties and application possibilities. Special centrifugal pumps using the V-AN process are used for pumping mixtures of boiling, solids-laden and toxic liquids. It is no problem for them to be installed in pits and in closed, non-pressurised vessels such as refinery waste containers or vacuum filters, centrifuges, distillation columns, evaporation plants or septic tanks. The total unloading of tanks is also a special feature.

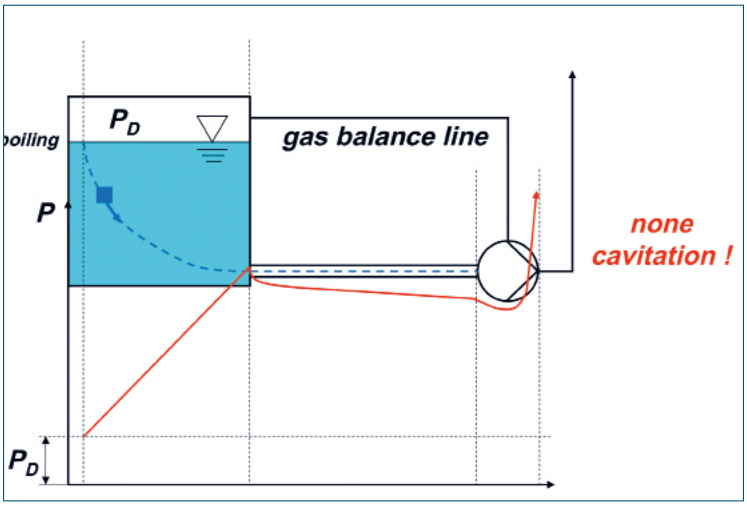
Pumping condensate

The positive characteristics of non-suction pumps stack up in the pumping and collection of condensates. In contrast to conventional condensate recycling systems, no large reservoir is required here. The pump draws directly from the flash tank. With normal-priming standard pumps with a horizontal design, condensate flows are collected in collector pipelines and delivered into a flash tank. This facilitates the stabilisation and evaporation of the condensates and operates using a min/max control system. High infrastructure costs are required to get into ranges that do not have critical cavitation properties. These include costs of cooling the condensate or frameworks, pits etc. Condensate pumps are frequently operated at lower speeds and overdimensioned at the design stage in order to avoid cavitation as much as possible. Amongst other things, this generates high energy consumption. If the physical properties of pumps mean that they no longer cause cavitation, they can be dimensioned smaller. (Pump casing and impeller are designed for the volume of condensate actually being pumped.) Operating at an optimum speed (2,900 rpm), it can achieve large energy-saving effects despite the open impeller structure.

Application example: Highly efficient gas/steam cogeneration plant

- **The task:** Pumping condensate from a water/steam cycle
- **The situation:** High levels of turbulence in the tank and a boiling hot medium

In a power plant process, boiling hot condensates are drained from the water/steam cycle. These are first delivered into a separator vessel (a flash tank with high turbulence), and after appropriate cooling, the condensate then continues to the next process stage and is pumped



Source: Bungartz

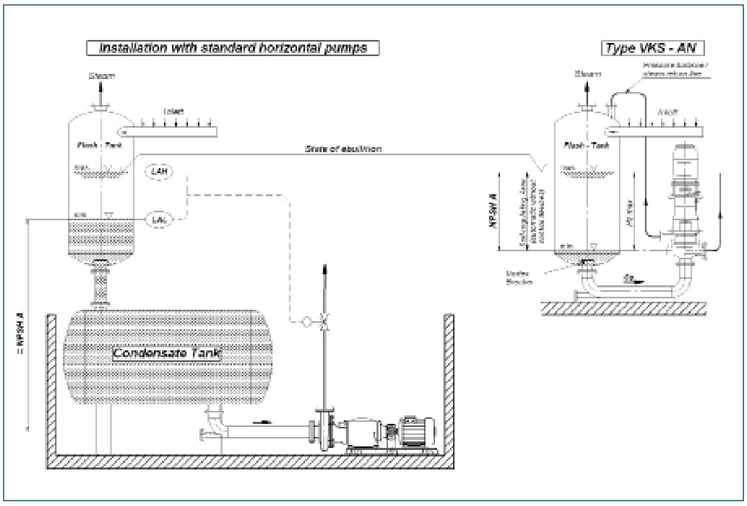
Fig. 6: Pressure curve of the special centrifugal pump using the V-AN process

into a neutralisation vessel. Conventional pumps require an additional condensate collection tank in order to store condensate virtually vapour-free. These pumps require an additional level control system to ensure that the level is higher than the NPSH value of the pump (NPSHA > NPSHR +0.5 m). The required headroom could only be achieved by constructing a pit. The use of a self-regulating special centrifugal pump using the V-AN process allows headroom to be saved. The features of the impeller geometry and the pressure compensation system at the impeller improves stability. The pressure compensation system at the impeller inlet avoids cavitation. Any steam reaching the pump does not cause any damage. Even where gas and vapour bubbles are drawn through, no stalling occurs. Fault-free pumping requires neither a control system nor a dry-running protection system (figure 7).

In many condensate applications, liquids are pumped directly out of a vacuum. The procedure described can also be applied in these cases, irrespective of whether the vacuum being pumped from is in the condensate collector, hotwell or flash tank.

Tank unloading from below

For unloading LPG or heavy media (e.g. sulphuric acid) from tanks or boilers, pumps are used in the petrochemical, chemical and fertiliser industries (figure 8). LPG, e.g. propane or butane, is stored in vessels with volumes of a few hundred to several thousand litres. These gases are fluids at boiling point. They are highly combustible and form explosive mixtures with air, and containers are therefore emptied from below. The barrel-type pumps that are used as standard, i.e. suction centrifugal pumps, are vented by means of an empty pressure line. In order to achieve sufficient suction head, they are expensively installed in recesses in the floor. When the pump is switched on, the liquid immediately starts being pumped. As the process progresses, the liquid level falls and gas is drawn in by the pump. These gas bubbles reduce the performance and cause irregular running, and even stalling. This does not occur with special centrifugal pumps using the V-AN process which are used for the total unloading of containers.



Source: Bungartz

Fig. 7: Condensate pumps in power plants

Application example: Container discharge

- **Condition for pump selection:** Total unloading
- **Pumped product:** LPG (n-butane)

For an international company that manufactures plasticisers containing oxygen, fine chemicals and polymer dispersions, a special centrifugal pump is used for pumping LPG (n-butane). The vertical pump is designed for the following operating conditions: flow rate 100 m^3/h; delivery height 100.0 m C.L.. If the impeller is positioned at the lowest desired liquid level in the feed vessel, the pump can also pump down to this level. This self-regulating pump operates without independent suction capacity. The volume flow rate falls continuously in proportion to the suction head. It reaches 0 when the liquid level has reached the centre line of the pump casing. As soon as a stable liquid level is reached, the pump flow rate equals the feed flow rate. Pressure compensation is achieved via the gas compensation line. After starting, the pump ventilates automatically; the gas is mixed into the pumping medium. This method ensures that no further construction measures are required for the pumping of LPG. The special centrifugal pump can be installed at ground level, next to the tanker truck. The vapour pressure in the tanker truck means that the NPSH value for the total unloading is almost zero. The only condition is that the hose connections must be located lower than the tanker outlet nozzles. The operational task for the pump was the total unloading of a container. At the same time, it was possible to cut the unloading time in half.

Tank unloading from above

In combination with a suction vessel, the V-AN process is suitable for the total unloading of heavy substances such as oleum, sulphuric acid, tin tetrachloride. With densities of between 1,800 and 2,300 kg/m^3, these liquids are difficult to unload. Once pumping begins, the falling liquid level in the filled suction vessel acts like a piston that is slowly being pulled out. This generates negative pressure. During unloading from above, the pressure at the highest point of the loading arm drops almost to the boiling point. This pressure is the only limiting variable for pumps operating under the V-AN process. The physics of the pump means that dry-running safety is guaranteed at all times, such that the pumps using the V-AN process can continue pumping until the container is completely empty, even after the formation of the first vortices in the container being unloaded. Self-priming magnetic drive or canned motor pumps are normally not safe to run dry. They need to be switched off before gas starts getting drawn in. This requires continuous monitoring. With these pumps, it nevertheless cannot be avoided that residual quantities are left in the tanker truck.

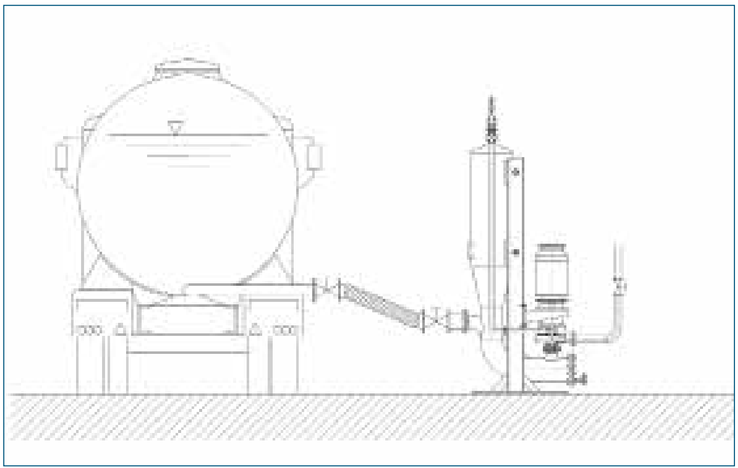


Fig. 8: Tank unloading from below

Extreme media from pits

The typical fields of activity for pumps using the V-AN process include pumping boiling, solids-laden or toxic liquids. These media are pumped out of pits or closed, unpressurised vessels such as refinery waste tanks. The magnet-coupled, self-regulating vertical submerged pump using the V-AN process is ideally prepared for these problem situations. It also works with a hydrodynamic sealing and an impeller with back vanes.

Gas barriers are installed to protect the bearing unit against the penetration of product vapour. On the product side, these are designed as single mechanical seals or with depressurised lip seals. This special pump is hermetically sealed against the atmosphere by means of a dry-running magnetic drive. The use of a ceramic containment cup means that the vortex losses occurring with a metallic containment cup are avoided. The vertical arrangement prevents product contact with the seal, even if the sealing gas supply were to fail. Any monitoring systems required can be installed outside the pit, and are therefore not located in the potentially aggressive or explosive atmosphere of the container.

Application example:
Refinery waste pump in a sump tank

- **The medium:** Crude oil with water and sand

Solid particles and the explosiveness of the crude oil due to its volatile components make this a challenge. The atmosphere in the pit is ATEX zone 0. It is only permitted to use pumps that have been approved for this zone, e.g. the dry-running submerged pump described above. Due to its vertical design and the essential monitoring systems, which can all be installed outside the pit, contact between the seal and the product is prevented, even in the event of a sealing gas failure. The design takes into account the extremely corrosive and abrasive fluid. This requires a durable material with high strength. The pump, which has been in operation since 2010 without any faults, has proven itself with a super duplex material (figure 9).

Application example:
Oil separator in a refinery plant

- **Pumped product:** Surface water hydrocarbon phase
- **Pump:** Dry-running special submersible pump using the V-AN process, with an NPSH value of < 0.1

The pump has a submersion depth of 5.5 m, and was installed in a coalescence separator (pit) in 2009. The feed inlet is positioned very low down. It must not impede the oil separator. Further conditions: the area is classified as ATEX zone 1. The medium, surface water (hydrocarbon phase), is at boiling point. At a delivery height of 45 m and a flow rate (Q) of 15 m³/h, the self-regulating pump operates with a half-open impeller. The pressure compensation system at the impeller inlet does not permit the formation of vapour. Because there is no suction at the pump,

Fig. 9: Refinery waste pump / sump pump for use in zone 0

Infobox: pumps using the V-AN process

Advantages:

- high operational reliability
- self-regulating
- self-ventilating
- unaffected by gas bubbles
- protected against dry-running and reliable
- no pressure shocks due to discontinuous operation
- savings because low structure height and pit not required
- savings because control technology not required
- generous maintenance intervals
- bearing life of up to 32,000 operating hours
- no control system problems at low feed rates or during discontinuous feed
- robust construction with an extremely long service life
- reduced feed vessels
- sealing technology is simple to implement
- suction pressure in reservoir can be lowered to boiling condition
- low maintenance costs
- long service lives and many years of fault-free operation

Application areas:

- pumping and collection of condensates at vacuum filters, centrifuges, distillation columns, evaporation plants or refinery waste containers
- unloading "heavy" media (density > 1.0 kg/dm³)
- pumping gas-laden media or boiling and solids-laden pumping liquids
- fluctuating feed rates
- total unloading of containers, e.g. tanker trucks

Source: Bungartz

the feed rate falls at the same time as the suction head. An NPSH value = 0 would be possible here. The shaft bearing uses permanently grease-lubricated rolling bearings, and is located inside the sealing gas atmosphere of the secondary seal, and is hence not in contact with the solids-laden pumped product. Safety systems, which would kick in upon failure of the pump, are dispensed with entirely. There have been no faults of any kind to date.

Effect on investment, operating and maintenance costs

Systems for preventing cavitation are generally associated with high investment costs. Greater equipment construction heights and the construction of pits also lead to increased material requirements. If criteria for optimal pump selection are defined at the planning stage already, the use of appropriate pumps can generate significant investment savings during the plant engineering phase. The design and technical features of the vertical self-regulating centrifugal pumps using the V-AN process make it possible to dispense with expensive construction measures such as pits, or allow a significant reduction in overall height. Lower operating costs (e.g. due to lower monitoring costs) and low maintenance costs are economical, as are the many years of service life. Whether for the total unloading of containers, and particularly of tanker trucks, or for pumping and collecting condensates, pumps using the V-AN process have for many years been successfully and economically deployed both in newly built plants and when retrofitting existing facilities throughout the world.

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