Various pump systems are available for this unloading task. Their physical applicability must be checked using the parameters of specific gravity, temperature and vapour pressure of the pumping medium as well as the height of the tank.

These pump systems can be divided into two groups: firstly, suction systems that are installed on top of or next to the tank being unloaded, and secondly, submerged pump systems, such as immersed pumps or jet pumps, which are not discussed further in this contribution.

Equation 1 defines the limiting suction head (see Fig. 1) in dependence on all influencing factors. This physical limit is reached either when evaporation starts at the highest point of the loading arm or before then when the centrifugal pump cavitates, i.e. when a detrimental pressure reduction on the front edge of the impeller blades leads to local attainment of the vapour pressure and vapour bubbles arise. The contribution of this detrimental pressure reduction is designated as the NPSH value (Net Positive Suction Head) and is given in m liquid column by the pump manufacturer.

To give a feeling for the estimation of the suction capability of a system, the physical limiting suction head $h_{\text{ideal}}$ obtained for various pumping media where the vapour pressure has just been reached at the highest point of the loading arm are listed in Tab. 1. For this, an ideal suction process was assumed with an ideal centrifugal pump and the NPSH value of the pump set to zero. Furthermore, it is assumed that the priming process is slow so that the losses in the loading arm as well as the kinetic flow energy are negligible. This idealisation simplifies Equation 1 to Equation 2. If the suction head of

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Pump and suction pipe as complete system FSV to unload tanks from above!
the planned plant exceeds the limiting value calculated in this way, then either a pump system that is immersed in the liquid must be used or - if permissible - the tank liquid must be pressurized with inert gas. In most cases, the vapour pressure of the pumping medium with respect to ambient pressure can also be neglected. The maximum suction head is then a function of the density, as shown in Fig. 2.

$$h_{\text{max}} = \frac{(\rho - \rho_{\text{v}}) \cdot 10^5}{\rho_{\text{v}} \cdot 9,81} \cdot \text{NPSH} \cdot h \cdot \frac{c^2}{2 \cdot 9,81}$$

The maximum suction head (see Fig. 1) can be calculated from Equation 1.

$$h_{\text{ideal}} = \frac{(\rho - \rho_{\text{v}}) \cdot 10^5}{\rho_{\text{v}} \cdot 9,81}$$

Equation 2 expresses the maximum suction head under ideal conditions, where \(p_i\) is the system pressure in the tank wagon (bar), \(p_{\text{v}}\) is the vapour pressure, \(\rho_{\text{v}}\) the specific gravity of the pumping liquid (kg/m³), the acceleration due to gravity is 9.81 m/s², \(h\) is the pressure loss in the suction line (m liquid column), \(c\) is the speed of the pumping liquid in the suction line.

Two physical basic principles can be used to unload the vessel by lowering the pressure in the suction line. Firstly, evacuation, where the gas in the suction line is pumped off by the centrifugal pump, and secondly, by expanding the gas trapped in the suction line by lowering the level of the liquid in a prime chamber, i.e. by increasing the volume of enclosed gas.

**Overhead unloading by evacuation of the suction line**

Before the actual pumping process can begin, the gas contained in the suction line between the centrifugal pump and the surface of the liquid in the tank wagon must be sucked off by the centrifugal pump and then separated in the pressure line. During this priming process, the negative pressure thus produced decreases in proportion to the sucked liquid in agreement with Equation 3.

$$p_i = p_{\text{v}} \cdot h \cdot \rho_{\text{in}} \cdot 9,81 / 10^5$$

Equation 3 expresses the suction pressure \(p_i\) on the suction ports of the centrifugal pump during the evacuation process, where: \(p_i\) is the suction pressure (bar), \(p_{\text{v}}\) system pressure in the tank wagon (bar), \(h\) suction head (m), \(\rho_{\text{in}}\) is the specific gravity of the pumping liquid (kg/m³), acceleration due to gravity (9.81 m/s²).

Side-channel pumps, as self-priming centrifugal pumps, are available for this. Side-channel pumps have the disadvantage that, because of the relatively narrow gap between the impeller and the casing wall, they can only be used for mechanically clean or cloudy liquids.

Centrifugal pumps with cell rinsing have the same hydraulic system as pumps with conventional suction. The difference is a web in the spiral casing, which together with the impeller forms a jet pump which sucks the gas in the impeller and discharges it to the pressure port. However, its priming capability is less than that of a side-channel pump.

An estimation of the NPSH value of self-priming pumps cannot be based on the value given by the pump manufacturer in the pump characteristic data for the transportation of liquids as this is not valid for the evacuation process, which will be evaluated first. For example, if the self-priming side-channel pump with a front impeller (stage with conventional suction) is considered, then it must be taken into account that the front impeller is not filled with liquid during the evacuation process. Therefore, the much lower value of the side-channel stage is decisive. For the pumping capacities relevant here, 20 to 30 m³/h, and a rotation speed of 1450 min⁻¹, this value is approximately 2.5 m.

In the following, a pump system is considered that expands the gas in the suction line. This system has a NPSH 0.1 m and thus almost attains the ideal pump head given in Tab. 1.

**Expansion of the gas volume in the suction line**

The system described here, part of Fig. 1, consists of a priming tank and a special centrifugal pump type V-AN. Because of its pressure equalisation with the priming tank, the pump does not have an intrinsic ability of suction and has an NPSH value of maximum 0.1 m liquid column. The actual suction is carried out by the priming chamber, which is filled with liquid before the unloading process is started; this is achieved with the return volume of liquid in the discharge line.
When the pumping process starts, then the decreasing level of liquid in the priming tank acts like a piston that is slowly withdrawn to produce a negative pressure. According to Equation 4, which is valid for the isothermal state change of ideal gases, the product of the initial pressure \( p_1 \) in the suction line and the gas volume \( V_g \) equals the product of the corresponding values after completion of the priming process. Thus, the gas volume after the priming process, for which the pumping medium is at the highest point of the loading arm, can be easily determined.

The difference in volumes then gives the required volume of the priming chamber (Equation 5).

\[
   p_1 \cdot V_{si} = p_2 \cdot V_{sl}
\]

Equation 4 gives the isothermal state change of the gas volume in the suction line during the expansion process.

\[
   V_{sl} = V_{si} \cdot \left( \frac{p_1 \cdot 10^5}{p_1 \cdot 10^5 - p_{si} \cdot h_s \cdot 9.81} - 1 \right) S
\]

Equation 5 is used to determine the volume of the priming tank \( V_{pp} \), where

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\]

After the liquid has reached the highest point of the suction line, the descending pipeline acts as a siphon. The pressure in the priming tank correspondingly increases. The pump now increases its output until the intersection with the characteristic curve of the pump is reached, i.e. the pumped flow rate for which the flow losses plus the height difference equals the delivery head of the pump.

As the level of liquid in the tank wagon sinks, the pumping process reverses since the suction head \( h_s \) correspondingly increases. This state is much more critical since the high flow losses further reduce the pressure at the highest point of the loading arm until the vapour pressure is reached and the flow is interrupted. If a self-priming pump is used, this status is reached a short time after every new priming process.

If a self-regulating pump type V-AN is used, the system always conveys the flow volume which almost induces the vapour pressure at the highest point. However, the flow is not interrupted since the vacuum is retained in the priming chamber. Thus, the maximum flow rate is always achieved in correspondence with the prevailing suction head. During the pumping process, the entrained gases are sucked off via a separate pressure compensation line. Even media containing a lot of gas, such as zinc tetrachloride, can be easily pumped.

Fig. 3 shows this ideal pumping process using the example of pumping mixed acid. Here the current suction pressure at the highest point of the suction lance is plotted against the current output flow rate. The segment between 1 and 2 represents the priming process with a partially filled tank wagon. Between point 2 and 3, the liquid has reached the highest point and is siphoned to the pump.

The pump increases its output until the characteristic curve of the pump intersects with the characteristic curve of the system. The critical state is reached at point 4. Now the level of liquid has fallen so that the sum of the geodesic suction head as well as the pressure loss reduces the pressure at the highest point down to the vapour pressure.

For further unloading, between points 4 and 5, the pressure at the highest point of the suction lance equals the vapour pressure. As the level of liquid sinks in the tank, the flow rate decreases correspondingly.
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