# Cavitation-free, intrinsically safe pumping of condensates

## Special centrifugal pumps as an efficient solution for challenging tasks in power plant engineering systems

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## Kurzfassung

*Kondensate kavitationsfrei und eigensicher fördern – Spezial-Kreiselpumpen als effiziente Lösung für anspruchsvolle Aufgaben in kraftwerkstechnischen Anlagen*

*Die Förderung von Kondensaten stellt eine anspruchsvolle Aufgabe dar. In der Kraftwerkstechnik handelt es sich dabei meist um Wasser am Siedepunkt. Eine Schwierigkeit im Prozess besteht darin, das siedende Medium kavitationsfrei zu fördern. Kavitation, das explosionsartige Entstehen und Zerfallen von Gasblasen am Laufradeintritt einer Kreiselpumpe, beeinflusst je nach Grad die Verfügbarkeit, die Standzeit und die Sicherheit der Anwendung. Kavitation kann vom Strömungsabriss bis hin zur Zerstörung des Pumpenmaterials führen. Um die Gefahr von Kavitation zu verringern, wird auf Ersatzmaßnahmen zurückgegriffen. Diese erhöhen Investitions- und Betriebskosten (hoher Stromverbrauch). Kavitation wird dadurch nicht grundsätzlich verhindert; Langzeitstabilität oder Verfügbarkeit sind nicht gewährleistet.*

*Einen anderen Ansatz bieten Spezialkreiselpumpen vom Typ V-AN. Konstruktiv ist der Raum am Laufradeintritt der Pumpe mit dem Gasraum im Vorlagebehälter verbunden. Dadurch kann die Pumpe nicht mehr saugen. Da es keine Druckabsenkung am Laufradeintritt gibt, arbeiten diese Spezialkreiselpumpen generell kavitationsfrei. In jedem Betriebszustand selbstentlüftend, fördern sie nur die Menge an Flüssigkeit, die durch hydrostatischen Druck von selbst in Pumpe hineinfließt. Daher sind diese Spezialkreiselpumpen ideal geeignet, um kavitationsfrei Kondensate zu fördern, diskontinuierliche Zulaufströme selbstregelnd zu überwachen und direkt aus Vakuumbehältern Flüssigkeit wegzufördern.*



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## Introduction

Pumping boiling media is a challenging task in water/steam cycle-based power plant engineering. As a rule, standard end-suction centrifugal pumps are used. One disadvantage of these pumps is that they can cavitate in the pumping process. The term cavitation ("cavity formation") refers to the partial evaporation of liquids in a flow system [1]. The risk of cavitation increases the lower the difference between the suction pressure and vapour pressure of the medium (corresponds to NPSH of the system in m). An accompanying factor, the typical crackling noise, comes from the explosive formation and collapse of gas bubbles at the impeller inlet of a centrifugal pump. The process influences the availability, service life and reliability of the application, damages or destroys the pump material and may lead to stalling.

Avoiding cavitation is not the only problem to be solved when pumping condensates. Often the discontinuous exposure to liquids, which cannot be planned precisely, requires further constructive and control technology measures. Individual condensate processes are run under vacuum. On top of this, gas bubbles can form as early as in the feed inlet, which can lead to a critical pumping process with a 2-phase current.

To manage this complicated challenge, structural measures must be put in place in advance to ensure sufficient suction head (pits, scaffolding, storage tanks). To guarantee a minimum volume flow and for additional safety measures a large number of control and security elements, such as regulator valves, frequency converters, dry-running protection signals, filters or sealing systems are in use. These are intended to stabilise the function, and thus the availability of these pumps. At the same time, any additional components not only increase the costs, they are also potential fault sources. Taking into consideration the additional effort in planning, acquisition, programming, repair and documentation, this raises both technical questions (fault sources) and questions of efficiency.

Pumps that do not require suction head, minimum volume flow, any additional control technology or monitoring, a storage tank or filters offer advantages for these special applications. Special centrifugal pumps that are also designed to be suitable for solid material, dry-running and physically sealing can function without any additional measures and components. This reduces fault sources and the elimination of structures and components results in high savings potential.

## End-suction centrifugal pump

A "normal" horizontal centrifugal pump generates suction through a drop in pressure at the impeller inlet. Generally these pumps use the medium that is to be pumped to lubricate and cool the slide bearing and the necessary shaft gap seal (usually mechanical seal). This suction behaviour can lead to spout drag, impairing the necessary lubrication and cooling effect on bearings and seals. To avoid the resulting damage, a minimum cover, monitored by a dry-running protection signal, must be guaranteed for these pumps. In addition these pumps require a minimum volume flow, which is achieved by reducing the speed (frequency converter + volume flow measurement) or with a bypass and a regulator valve.

To monitor the process a large number of additional components are needed. Additional measuring points are set up, for example to monitor the bearing temperature or record vibration measurements; gas sensors and dry-running protection signals are introduced and filters are installed at the pump entrance to keep the solids away from the sensitive bearing and sealing parts. This variety of components that must supplement the end-suction pump adds up to a "centrifugal pump system". The likelihood of faults occurring in this "system" harbours the risk of a higher probability of failure.

### Additional components to limit cavitation

The fact that cavitation must be avoided is self-evident to any system planner or operator. Liquid evaporates due to the hydrodynamic drop in pressure in the pump. The lower the difference between the suction pressure and vapour pressure of the medium (corresponds to NPSH of the sys-

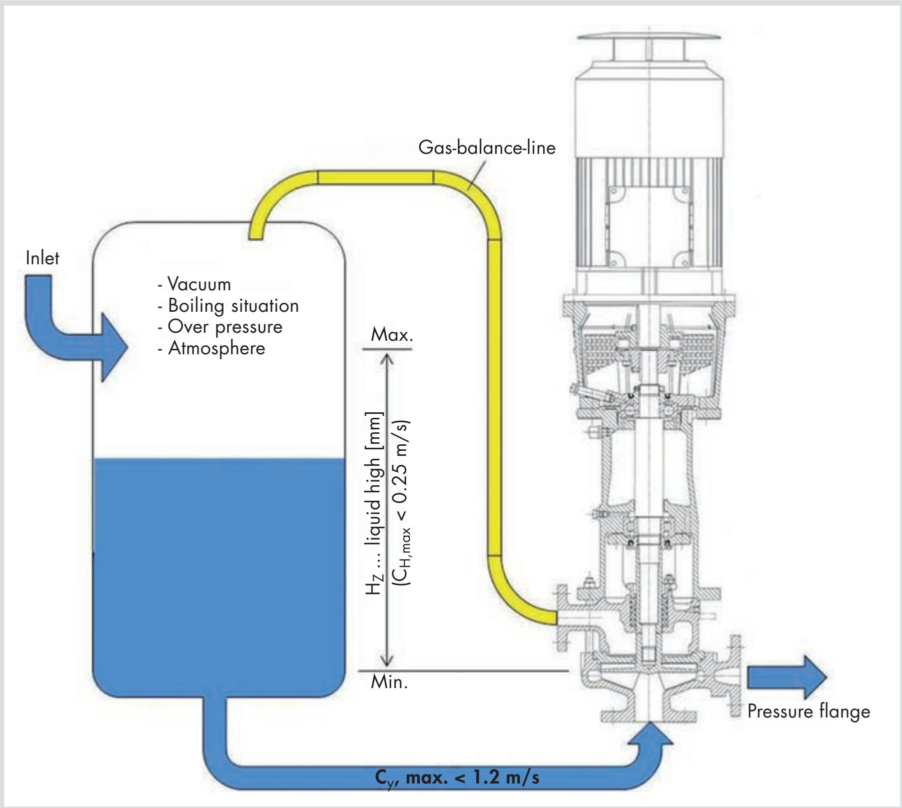


*Fig. 1. Process design of self-regulating pump.*

tem in m), the greater the risk of cavitation. The NPSH (net positive suction head) value refers to the energy differential between the total dynamic head at the inlet cross-section of the pump and the vapour pressure head of the medium. The gas bubbles which form and collapse explosively at the impeller inlet of a centrifugal pump during cavitation are carried away by the flow. They collapse implosively as soon as the pressure rises above vapour pressure again. This damages or destroys the pump material and may even cause stalling. If the most important indicators (NPSH (net positive suction head) value) are moving in the right direction (e.g. $NPSH_{pump}$ – $NPSH_{system}$ = 0.5 to 1 m) pumping is considered noncritical for cavitation.

To get these indicators into a range that is noncritical for cavitation for normal centrifugal pumps, a large number of measures are necessary. A significant factor for avoiding cavitation is sufficient system pressure. The hydrostatic pressure of the liquid is used to ensure this. It is produced using a filling level control in feed vessels or by building scaffolding so that the medium is fed in to the pump at an appropriate height. If these infrastructure measures cannot be implemented, this type of pump is installed in a basement or a pit. In practice a vacuum must also be taken into account in the feed vessel, and the geodesic suction head must be taken into consideration as well.

## Necessary adaptations for end-suction centrifugal pumps

Increasing the diameter of the impeller inlet, adapting the impeller blade entry angle, reducing the number of blades or using double-flow impellers (splitting the feed rates) "equalises" the flow through the pump so that as few cavitative conditions as possible can develop. However these measures always have a negative impact on investment costs, since the pump is as a result often designed to be larger than would actually be necessary for the flow rate it handles. The use of higher material quality that is often necessary also increases cost.

The way the pumps are operated can help to avoid cavitation as well. Since the risk of cavitation increases with the circumferential speed, pumps that rotate slowly are less prone to cavitation than pumps that rotate quickly. As a result, in practice condensate pumps are operated at lower speeds. However the efficiency of the pump declines with decreasing speed.

Another difficulty in the pumping process is the discontinuous exposure to liquid. Normally this is buffered in a large reservoir. The pumping medium is discharged cyclically through a min/max control.

## Cost-benefit analysis of the "standard centrifugal pump system"

With an end-suction centrifugal pump an NPSH-noncritical suction head is only feasible if costly infrastructure measures (scaffolding, pits, large feed vessels as a buffer) are integrated. In order to meet all the requirements for condensate pumping and avoid cavitation occurring in this type of pump, costly adaptations are necessary. All this significantly increases the amount of investment for the "standard centrifugal pump system".

The application's energy consumption also exceeds the requirements of a normal pumping task and has a considerable negative impact on the operating costs. The downstream maintenance costs of this kind of pumping task cannot be ignored either, since the system will generally be under higher stress. The area around the pump must be maintained and serviced (pit draining, tank inspection, etc.) and maintenance costs for the additional control technology must also be taken into account.

In general the use of standard centrifugal pumps for pumping condensates and cooling water is always accompanied by measures that involve higher investment, operating and maintenance costs. Summary: Efficient condensate pumping cannot be achieved with a standard pump and the illustrated "pump system" plus upstream and downstream costs.

## Self-regulating special centrifugal pumps offer a solution

The self-regulating special centrifugal pump (Figure 1), which has no suction capacity, works differently. The V-AN (AN stands for abnormal) type vertical pump is self-regulating, depending on the feed. This efficient method functions in accordance with *Torricelli's* law, better known as the formula of free outlet. If a medium flows into the container, the liquid level increases until the quantity of the medium flowing in is equal to the quantity flowing out. It balances out automatically. This principle works without any mechanical or electrical regulation equipment. In addition to the feed and discharge nozzle, this pump is equipped with a gas compensation nozzle. It is connected to the gas phase of the reservoir. If there is atmospheric pressure in the reservoir or a vacuum both are directed into the pump casing. Due to the nature of the process, through this design the pump loses its capacity to suck. The hydrostatic liquid column in the reservoir indicates the value by which the pressure below the impeller increases (ignoring losses in frictional pressure). As a result the pump only pumps the volumes that are pushed into the pump independently by the hydrostatic liquid column. The intelligent construction of the V-AN type non-suction special centrifugal pump is ideally designed, both technically and economically, for the condensate pumping sector.

## Cavitation-free pumping

The pressure drop at the impeller inlet is greater for boiling media than for normal

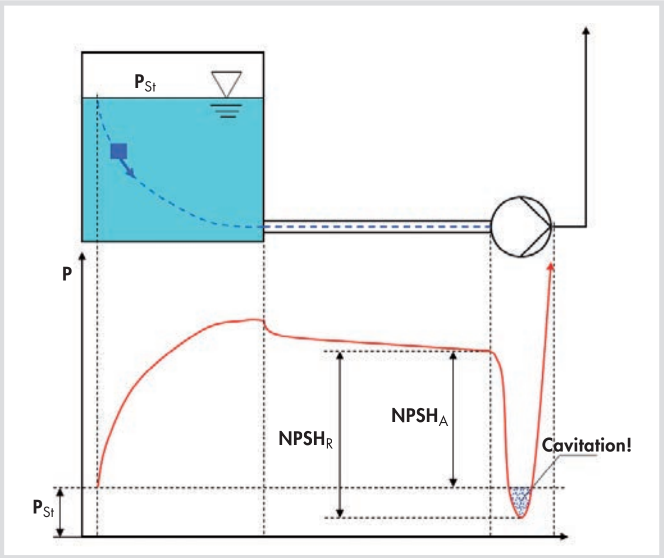


Fig. 2. Pressure flow of normal priming pump.

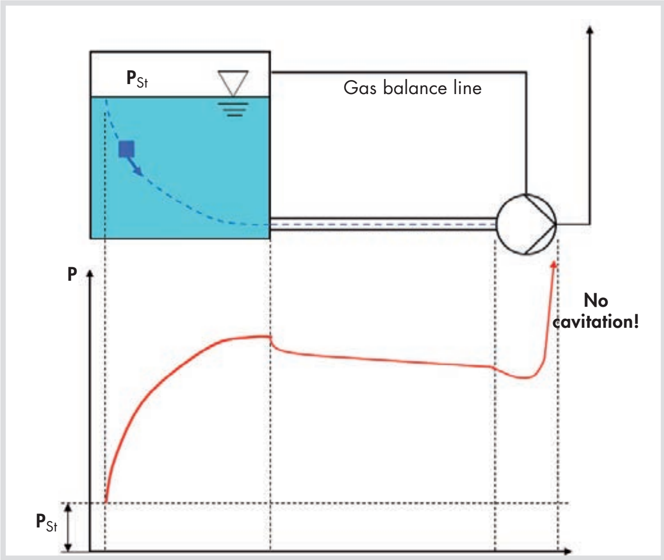


Fig. 3. Pressure flow of self-regulating pump.

pumping tasks. Consequently, the risk that the NPSH of the system will exceed the NPSH of the pump is particularly high for condensates. Unlike normal end-suction centrifugal pumps, where the typical drop in pressure always occurs systemically at the impeller inlet, pumps without suction capacity show a linear pressure gradient over the entire pumping process up to the start of pressure build-up. These pumps have an NPSH of zero and pump all media in all operating conditions without cavitation (Figure 2 and 3).

## System-inherent self-regulation

A design feature of special centrifugal pumps is their unique regulating characteristic: their control system automatically adapts to changing feed rates. The principle can be compared with a siphon. When a medium flows into a container, the liquid level rises until the inflow and outflow balance out – without any type of mechanical or electrical regulation equipment. The necessary pressure is indirectly supplied by the hydrostatic liquid column. The pump is designed for the maximum anticipated volume flow limit.

In case of volume as shown in Figure 4, the liquid level (HZ) in the pump reservoir rises. The resultant increase in pressure means that more liquid is forced into the pump. This type of pump reacts directly, but harmoniously, 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. No more liquid will follow (Figure 5). The pump impeller rotates freely in the liquid. The principle follows the formula for free outlet (k…feed factor < 1). V-AN type self-regulating pumps have the advantage that they react completely self-sufficiently to a discontinous feed rate with maximum availability, without the use of control technology (no frequency converter, no volume flow measurement).

## Minimal suction head/total emptying

Since this type of pump always operates without cavitation, the NPSH value can be ignored when planning the system. All that is necessary is that enough liquid is fed to the pump. In order to obtain the maximum desired pumping rate, the pump must be designed with a suction head Hz, to push the required volume into the pump. This suction head Hz is substantially smaller than an NPSH value and only needs to act initially. To discharge 50 $m^3$/h, for example, a 500 mm suction head is needed depending on pump size. If this 500 mm is not achieved the pump will continue to pump volume, but at a decreasing rate. This advantageous process is particularly suitable for total emptying of containers. For this purpose the impeller is positioned below the minimum desired liquid level. Unlike with a normal end-suction pump, with V-AN type self-regulating pumps the pumping process is protected against the typical spout drag and the associated damage and re-venting/restarting.

## Minimal reservoir volumes

The V-AN process not only reduces the necessary overall height, it also enables the reservoir to be significantly smaller than usual. A maximum speed of $c_{H,max}$ < 0.25 m/s is intended for the suction head adjustment design criterion. This ensures, amongst other things, that the pump reacts

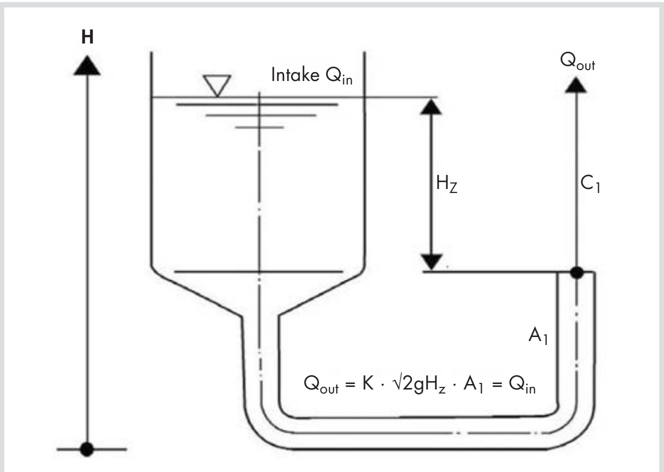


Fig. 4. Physically background of self-regulating.

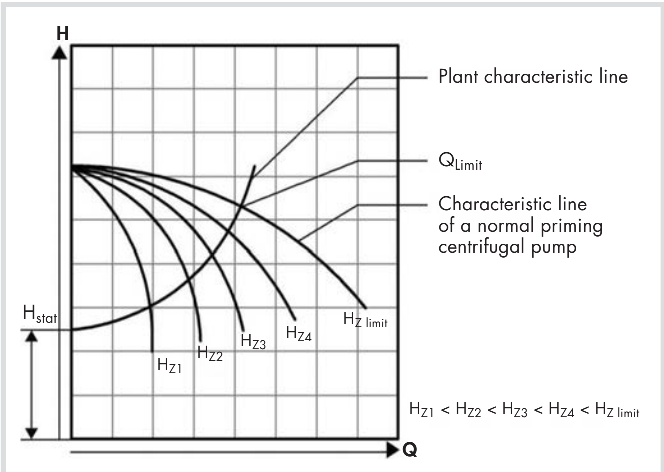


Fig. 5. Characteristic line V-AN.

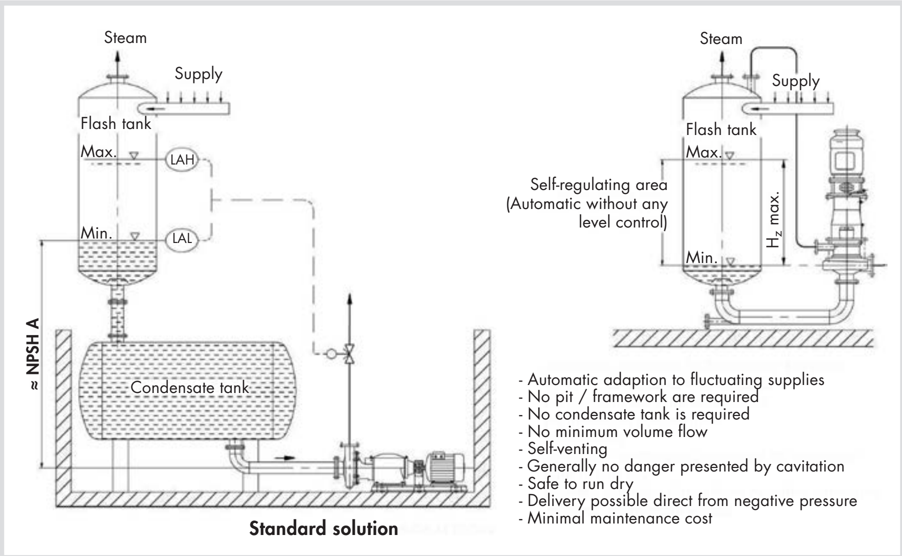


*Fig. 6. Comparison of standard solution vs. solution with self-regulating pumps.*

harmoniously, without pressure surges, to the changing feed and the associated suction head adjustment. If, for example, this criterion is designed for an expected maximum feed flow of 150 $m^3$/h, a receiver pipe of 500 mm diameter is sufficient.

## Pumping from vacuum

For some condensate applications there is a vacuum in the receiver. Due to the V-AN process integrated system, in which the pressure in the pump casing and the pressure in the receiver remain equal, the pump functions completely independently from the pressure in the reservoir. The physical fact that only the liquid that runs into the pump independently is pumped remains unchanged under vacuum. The advantage is that the pump can be installed directly next to the vacuum applications. Pumping of the medium is cavitation-free without additional suction head and, if necessary, self-regulating.

## Optimal energy efficiency

If condensate pumps run at low speed and are oversized to avoid cavitation, this increases the energy consumption. The special centrifugal pump described, which does not cavitate for physical reasons, can consequently have smaller dimensions. (Pump casing and impeller are designed for the volume of condensate actually being pumped.) This type of pump can be run at optimum speed (2,900 rpm). Although an open impeller structure is used, it produces energy-saving effects, which can be high in individual cases. This is because, for example, no minimum volume flow has to be circulated in the bypass. The bigger the volume of condensate to be pumped, the higher the savings.

## Permanent self-venting/two-phase current

Another useful advantage of the process is the permanent self-venting effect. During the commissioning phases or during total emptying of containers in particular, the use of a V-AN pump ensures maximum availability. The pump no longer has to be vented. Even an inflow of gas into the feed line does not interrupt the pumping. Permanent dry-running protection also enables the pump to be operated long-term without liquid.

## Practical applications in power plant engineering

There is a wide array of applications with critical cavitation properties in a power plant. It ranges from tank car emptying to cooling water, drainage and condensate pumping tasks.

When pumping condensates with horizontal standard centrifugal pumps, additional installations and other measures are necessary (Figure 6). Various condensate feeds are gathered in collecting mains and fed to a flash tank. This facilitates the stabilisation and evaporation of the condensates, and operates using a min/max control system.

Other disadvantages that incur costs in advance:

- Construction of a pit which then requires pit drainage or steelwork for access to and security of the pit.
- General poor accessibility and limited maintainability within the pit
- Often additional applications (condensate tank) for cooling the medium are necessary in order to reach an area that is noncritical for cavitation.
- High cost of system isolation, container inspections

When planning operation of the self-regulating special centrifugal pump in the planning phase of a power plant or a process engineering system basic advantages can be utilised: Construction of a pit can be completely avoided. The flash tank is often the lowest point. Since this type of pump reacts directly to the condensate feed, the volume of the flash tank can be minimised. The self-regulating effect reduces the control technology required and the lack of cavitation means cooling measures are unnecessary. The constructive dry-running safety of the special pump and the permanent self-venting effect increase operating reliability.

Typically this type of pump is used at the hotwell or condensate collector. (Figure 7) In both cases no pit is necessary. The pump is installed directly next to the condensate collector pipe or the hotwell. If the collector pipe is wide enough (Figure 8) it can serve as feed vessel. The nec-

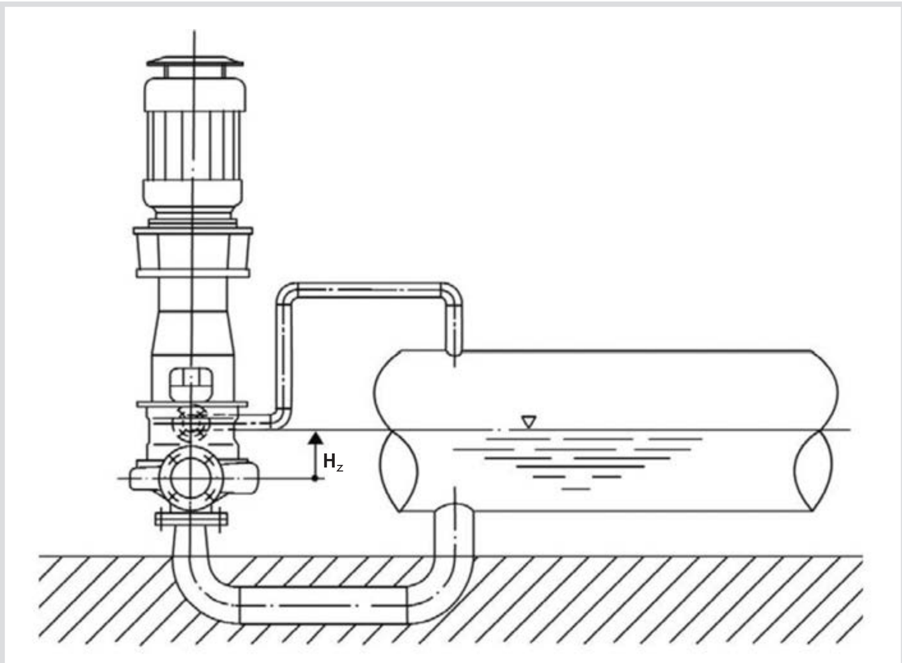


*Fig. 7. Self-regulating pump under hotwell.*

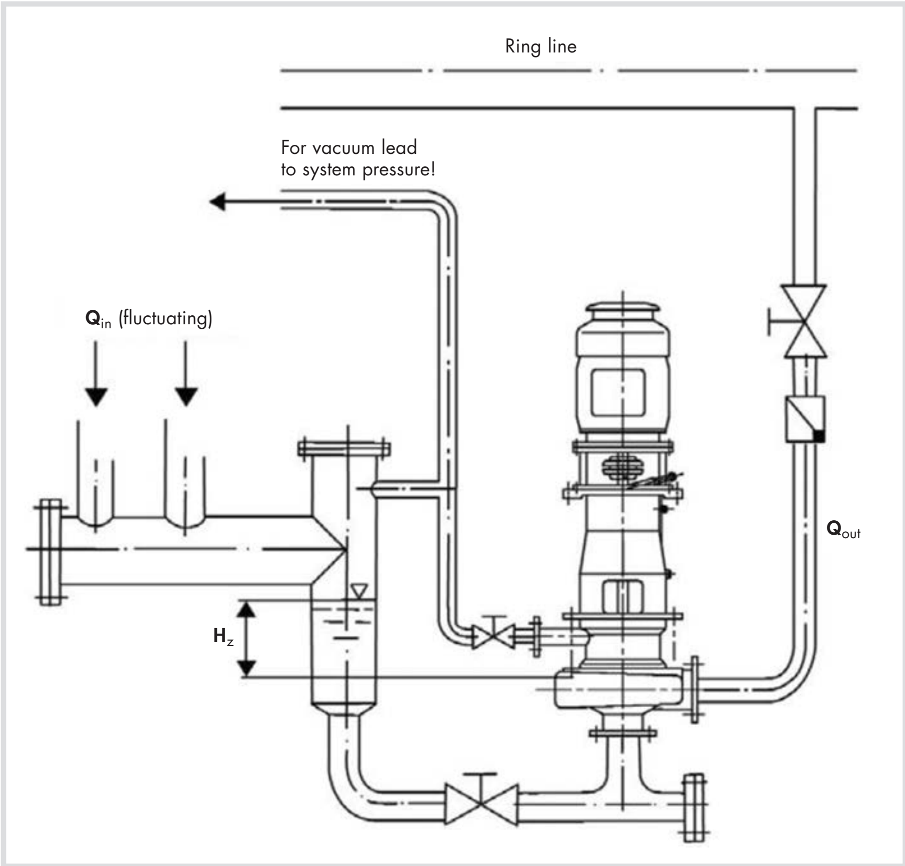


*Fig. 8. V-AN collector condensate.*

essary suction head (hydrostatic pressure) can self-regulate. If the pipe is too narrow, a T-piece is inserted, in which a hydrostatic liquid column can form.

There are many reasons for conversion. Primarily, frequent pump failures and high repair costs mean a new approach is necessary. Important reasons for using the self-regulating versions are continuous operating reliability, increased need for space or re-evaluation of operating costs (optimisation). By comparison, the reduction of electronic components alone (no frequency converter, no volume flow monitoring or min/max control) results in optimum availability, since there are fewer components and thus fewer fault sources in the system as a whole. The process feature of pumping liquid directly from vacuum must not be ignored, but equally important are the operating cost savings due to low maintenance costs and high availability (no cavitation, dry-running, self-venting).

## Summary and conclusion

In power plant engineering, pumping boiling media in condensate systems is one of the most common tasks. The biggest difficulty lies in processing the condensate or cooling water without cavitation. Cavitation, i.e. the formation and collapse of gas bubbles at the impeller inlet of a centrifugal pump affects the availability, service life and reliability of the application, destroys the pump material and may lead to stalling. In addition to the cavitation problem, further situations that make the delivery process more difficult often arise in condensate plants. In the condensate container gas bubbles can develop and the volume flow can vary heavily. In normal end-suction pumps the risk of cavitation can only be reduced by means of costly additional measures, e.g.

- Implement suction head (plant is constructed upwards, pump installed in pit),
- Adapt pump (reduce speed, ensure minimum volume flow),
- Optimise feed flow (preferably laminar, flow correction through inserts, if required).

These measures increase investment costs and operating costs (high energy consumption) and can reduce availability (large number of fault sources).

Using V-AN type special centrifugal pumps, the space at the impeller inlet is structurally connected with the gas space in the reservoir. This removes the suction capability of the pump, but creates the following useful properties:

- No pressure reduction at the impeller inlet > generally cavitation-free (NPSH <0.01 m),
- Only the liquid which flows into the pump independently due to hydrostatic pressure is carried away > self regulation without use of control technology,
- Minimum required suction head height > no pit or frame necessary,
- Pumping directly from vacuum without suction head,
- Self-venting in all operating conditions.

The V-AN type special centrifugal pumps are therefore ideally suited for pumping condensates that are guaranteed cavitation-free, monitoring self-regulating discontinuous feed flows and carrying away boiling liquid. Delivery heights up to 120 m are possible. Depending on the intake head and pump size the pumps deliver between 0 and a maximum of 2,000 m$^3$/h.

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