TECHNICAL REPORT

CO_2 and Ammonia in Industrial Refrigeration Plants

Challenges, as well as tips and solutions for selecting pumps

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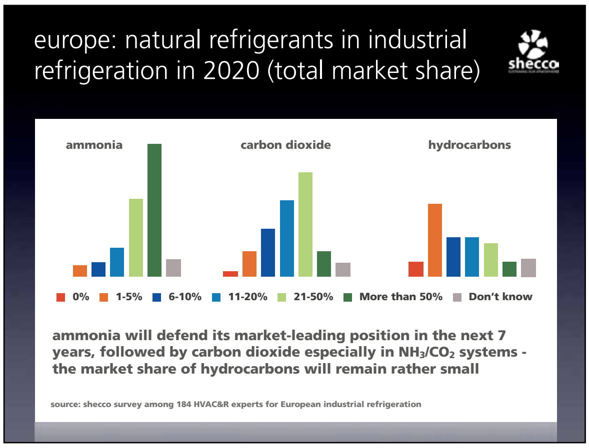

Fig. 1: Europe: Percentage of natural refrigerants in industrial refrigeration plants by the year 2020 – survey results in 2014, source: Market trend update on Industrial and light-commercial refrigeration (Presentation of Shecco Japan, Tokyo, 04/02/2014)

The pump manufacturer HERMETIC in Gundelfingen considers that the trend towards use of ammonia and CO_2 in large refrigeration plants is confirmed. This trend was predicted in the context of the new F-Gas Regulation (see Fig. 1). These refrigerants have either minimal greenhouse potential or no green house potential at all, nor are they harmful to the environment if small quantities escape. However ammonia and CO_2 do involve hazards for human beings. HERMETIC explains the technical challenges associated with these hazards for refrigerant pumps and provides tips on pump selection.

In addition to environmental compatibility, ammonia is characterised by high economic efficiency. This is due to its good thermodynamic properties. Main disadvantages: Ammonia has an acrid smell and is toxic for human beings. Inhaling ammonia in a highly-concentrated form can be fatal. Consequently, the use of ammonia imposes the most rigorous requirements on safety and tightness of plant and components. Likewise, CO_2 escaping in very large quantities is also dangerous. The major difficulty associated with CO_2 as a coolant is the high operating pressure. The necessity of thicker piping and components that are more compatible with the higher pressure, increase the material expense and engineering effort. In a CO_2 system, there is indeed less pump work to be performed due to the low viscosity, however higher requirements are imposed on the lubrication / wear-resistance of the components. Moreover, modern pump technology requires due consideration of life-cycle costs and assurance of high energy-efficiency.

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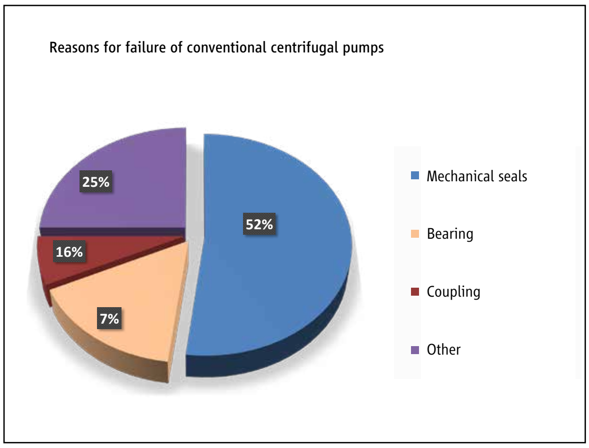

Fig. 2: Reasons for failure of conventional centrifugal pumps, source: Wallace, N. M. David, T. J.: Pump reliability improvements through effective seals and coupling management: Proceedings of the 15th International Pump Users Symposium, HOUSTON 1998

INDUSTRIAL REFRIGERATION PLANTS

Today systems where the refrigerant is circulated on the low-pressure side are preferred for use in industrial refrigeration plants. These systems have a primary and a secondary cooling circuit, in which a higher quantity of refrigerant is circulated than is vaporised in the evaporator under heat absorption. This is relevant for the pump design.

CENTRIFUGAL PUMPS – PREFERRED PUMP TYPE

Centrifugal pumps are the pump type most commonly used as refrigerant pumps. Their advantages include the simple structure, long service life, low wear rate and low maintenance costs. With a conventional centrifugal pump the fluid in the impeller is accelerated to the outside through centrifugal force. The mechanical force of the drive shaft is transferred to the fluid as velocity. In the downstream casing or the guide apparatus this liquid velocity is converted into pressure. Thus a nearly pulse-free flow occurs. This creates negative pressure at the impeller inlet. For this reason, it must be ensured that there is sufficient supply pressure and continuous fluid supply. The weak point of this drive system is the shaft exit out of the casing, which must be sealed. The stuffing boxes or mechanical seals that are used can freeze at low temperatures and break when the pump starts up. Also radial bearings and axial bearings are susceptible to wear for design reasons. Error analyses show: Over 50 % of pump failures are caused by leakage of the mechanical seal / stuffing box and 16 % are caused by ball-bearing failure (Fig. 2). Hermetically sealed canned motor pumps are the best option to avoid these types of failure.

HERMETICALLY SEALED CENTRIFUGAL PUMPS

Use of hermetically sealed centrifugal pumps is recommended for ammonia and CO_2 plants, as rigorous requirements are imposed on tightness. Magnetic coupling and canned motors are available as drive systems.

Canned motor

The canned motor pump integrates hydraulics and drive motor in one unit. Since this design principle requires no exterior rotating parts, it also requires no shaft seals. The rotor lining, which is usually made of stainless steel or Hastelloy, separates the medium-filled rotor chamber from the dry stator. It also represent the first safety containment for the canned motor pump. The motor casing forms a secondary containment as great advantage. This combination ensures the highest possible safety. The partial flow (medium), flowing through the rotor chamber, ensures a permanent lubrication of the hydrodynamic plain bearing and also serves to cool the canned motor. The rotor and the impellers of the canned motor pump sit on a common shaft. A normal three-phase motor is used as the drive system. Through the joined together unit of pump and motor, there is no need to align the shafts. This design principle enables absolutely leak-free operation, since only static seals are used.

Magnetic coupling

Centrifugal pumps with magnetic coupling have permanent magnets as a coaxial central coupling and are driven by a normal three-phase motor. A fixed can between the outer and inner magnet carriers ensures the seal to the outside. The plain bearings are in the fluid of the pump part. Disadvantage of this design principle: In cold weather there is the risk of condensation freezing during operation; condensation will most certainly freeze when the pump is at a standstill. This can only be avoided with a major technical effort, such as permanently flushing the drive with nitrogen. Another major reason for failure: The coupling has a complex design, it extends the system and involves the risk of axial displacement, vibration, as well as leakage at the motor-coupling and coupling-pump interfaces. The design inherently promotes wear and reduces efficiency.

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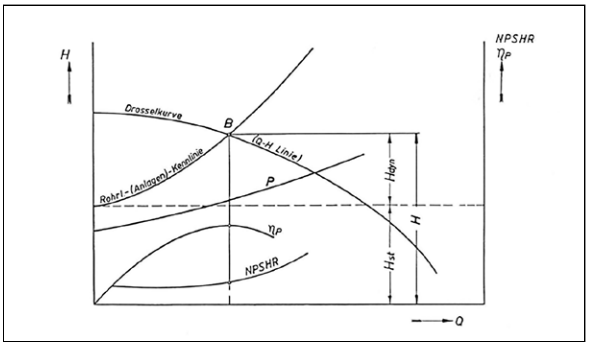

Fig. 3: Plant curve and Q-H curve of a pump, source: Robert Neumaier, HERMETIC PUMPS - The ecological solution - centrifugal pumps and rotary displacement pumps, Verlag und Bildarchiv W.H. Faragallah, 2nd edition, 2008, p. 18

10 TIPS FOR SELECTING AND DESIGNING A PUMP FOR USE WITH AMMONIA AND CO_2 IN THE REFRIGERATION INDUSTRY

1. Tightness of the pump

The toxic effect of ammonia requires the highest standard of safety. However CO_2 escape should also be avoided to the extent possible. Canned motor pumps offer the best solution in this regard; motor and hydraulics are designed as a unit in the pump casing and form a hermetically-sealed system.

2. Investment and life-cycle costs

Conventional pumps are not widely used for the pumped media ammonia and CO_2 . Canned motor pumps statistically show the best MTBF (Mean Time Between Failure) values, as compared to other pumping technologies. Thanks to the low maintenance effort and significantly longer service life, long-term the life-cycle costs of canned motor pumps are lower than they are for other pump types.

3. Technical design of the pump

The most important factor for the technical design of the pump is determination of the operating point (B) based on the plant curve and the Q-H curve (delivery rate and delivery head) of the respective pump (Fig. 3). The operating point should ideally be the point of best efficiency. In addition, a reserve is required when designing the drive motor so that motor overload at fluctuating delivery heads are avoided. At motor power of 7.5 kW this equals a reserve of approx. 20 %. HERMETIC offers an innovative, online expert tool for pump design. The expert tools enables plant planners and plant operators to configure pumps with a few clicks. The browser-based software is easy to operate. Based on input of the refrigeration capacity, the circulation factor, and the medium used, it also allows simulation of the pump design in real time and thus optimisation of the design parameters.

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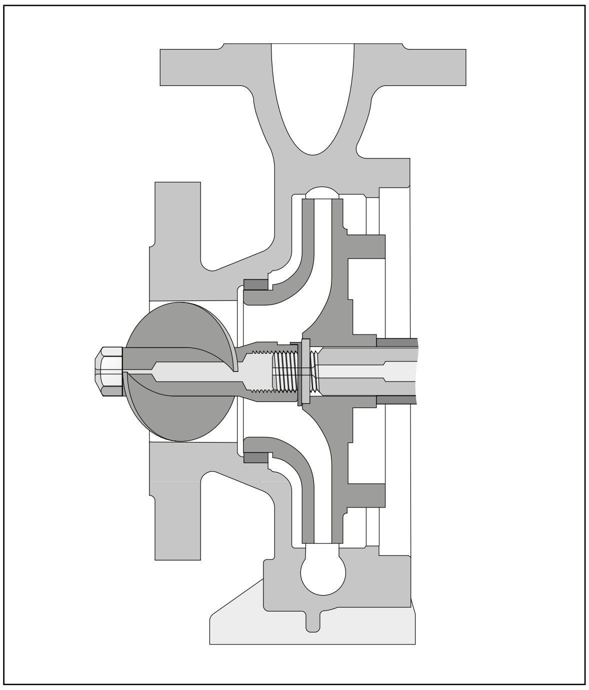

Fig. 4: Inducer - improvement of the NPSHR value

4. Improve the NPSH value
When designing a plant, cavitation-free operation must be provided. This is achieved when the NPSH value of the plant is greater than the NPSH value of the pump. If economically justifiable, NPSHA should be selected as large as possible – with a common safety margin of 0.5 m – to prevent possible pump damage.

To improve the NPSHR an inducer can be attached directly upstream of the first impeller (Fig. 4). The inducer causes an additional admission pressure in the impeller inlet and co-rotation of the fluid to the impeller blade. The inducer is also used preventatively when the resistances and the inflow of the plant cannot be precisely determined. For gas fractions up to 7 % in the fluid the inducer can reliably prevent cavitation. At optimal design of the inducer the NPSH values of the pump can be reduced by almost 50 %.

5. Regulation of the delivery rate
For automatic safeguarding of the pump and for fault-free, cavitation-free operation HERMETIC also recommends installing regulating devices when using CO_2 and ammonia. The limits for the minimum and maximum delivery rate (Q_{min} and Q_{max}) can be reliably determined with a heat balance calculation and testing of bearing load capacity. A simple Qmin orifice can be used for compliance with the Q_{min} rate.

For maximum pump capacity there are three alternatives: A calculated Q_{max} orifice, a flow control valve, or a frequency converter with Δp measurement. The Q_{max} orifice (orifice plate) is installed in the pressure line. It safeguards the delivery rate at initial filling of the plant or at simultaneous opening of multiple consumers. The advantage of the Q_{max} orifice is the simple and cost-effective design, the disadvantage is the strong throttle effect and associated early drop in the curve (Q-H). The advantage of the flow control valve is a later drop in the curve (Q-H), since throttling only occurs near the maximum rate. The flow rate is regulated by especially shaped openings in a spring-loaded, moveable piston. The flow control valve is mounted on the discharge nozzle of the pump.

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Use of a frequency converter with Δp measurement (suction-side and pressure-side of the pump) permits regulation at different operating points. The pump capacity can be precisely adjusted to the required refrigeration capacity of the plant. Thus up to 70 % of the energy capacity can be saved, relative to 50 Hz network operation. A real pay-off, especially during continuous operation and long-term use.

6. Delivery time

Whether a new project or assuring operation in the event of pump failure – delivery time is also a crucial criteria, in light of the market dynamics in the refrigeration industry. HERMETIC-Pumpen GmbH has a solution in this area; namely a modular principle that enables delivery of standard pumps within a few weeks and even immediately if there is an emergency. The modular concept enables short-notice adaptation for major or minor change requests.

7. Efficiency

Depending on the refrigerant used, the efficiency of the overall plant and the correlation with the pump used is a hotly debated topic today – even though the pump is only a marginal part of a refrigeration plant. With proper pump design, possible influences on efficiency are negligible. On the other hand, the areas of a plant that offer the greatest energy-saving potential are prevention of deposits in narrow piping, avoidance of unfavourable line routing and the compressors. Nevertheless, the pump impeller can be adapted for the highest efficiency of the plant and pump operating point.

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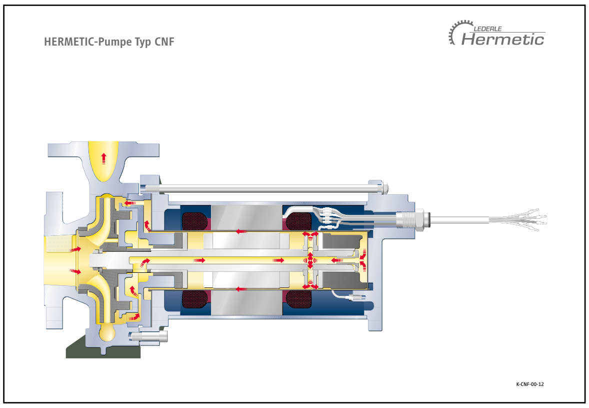

Fig. 5: Single-stage hermetically sealed centrifugal pump for ammonia and CO_2, type CNF from HERMETIC-Pumpen GmbH, internal company document

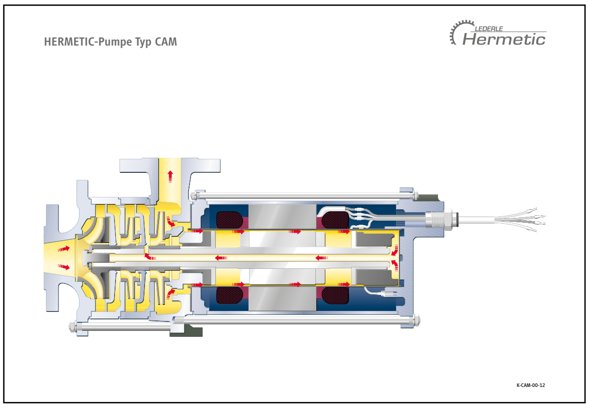

Fig. 6: Multi-stage, hermetically sealed centrifugal pump for CO_2, type CAMh / CAM from HERMETIC-Pumpen GmbH internal company document

8. Single-stage vs multi-stage pump

Different pumps can be used for ammonia and CO_2, depending on the requirements of the overall system. Unlike multi-stage pumps, single-stage pumps only have one impeller. They are primarily used when high pump capacities at low delivery pressures are needed. Thanks to the integrated auxiliary impeller, the HERMETIC single-stage CNF series (Fig. 5) is also suitable for fluids with a steep temperature-pressure behaviour.

On the other hand, thanks to the internal pressure build-up, multi-stage designs offer a great advantage if a low pump capacity with high pressure must be delivered.

HERMETIC offers single-stage and multi-stage for all kind of refrigerants. If the operating pressure increases over –10°C, the multi-stage CAMh (Fig. 6), which is especially designed for CO_2 applications, is used to master the high operating pressure of the natural refrigerant. In addition, the CAM / CAMh series from HERMETIC have an improved NPSH value thanks to the upstream, optimised impeller (see for NPSH improvements point 4).

9. Alignment of suction and pressure nozzles

The alignment of the suction and pressure nozzles depends on the piping and the conditions of the refrigeration plant. Basically two different versions are available on the market: Suction and pressure nozzles attached axially or suction nozzle attached axially and pressure nozzles radially. For the utmost flexibility, particularly when installed in compact plants with low suction head, HERMETIC's CAMR series offers radial attachment of suction and pressure nozzles. The pump can be suspended directly under the tank without 90° bends, to save space. For the CAM / CAMh and CNF series the suction nozzle and the pressure nozzle are attached radially.

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As the world market leader in the canned motor pump segment with over 280,000 pumps sold, HERMETIC offers the most comprehensive pump portfolio for the industrial refrigeration technology market, regardless of which refrigerant is being used. 24 standardised pumps and well over 400 pre-defined pump variants are available. Thanks to standardised assemblies and components, the automated design process and modern lean production, customers get a standard canned motor pump that is optimally configured for their plant, within a few work days. Without exception, all pumps meet the high HERMETIC quality standards, including the unique ZART® (Zero Axial and Radial Thrust) principle for contact-free and wear-free operation. More information or particular information for CO_2 is provided on our website at: **www.hermetic-pumpen.com/en/co2**

10. Pressure rating

While pumps for ammonia plants must be suitable for a rated pressure of maximum 40 bar, CO_2 imposes higher requirements on compressive strength. In addition, the low viscosity of CO_2 must be taken into account. The pump design must be adapted appropriately for the respective pressure rating relative to material composition, casing wall thickness and condition of the plain bearings.

The CAMh series, especially developed for CO_2 applications, is characterised by a rated pressure of 52 bar and a test pressure of 78 bar. In this regard the operating temperature can be between -50°C and +15°C. Medium can be pumped at delivery rates from 1 m3/h to 14 m3/h up to a delivery head of 85 m. Hydrodynamic plain bearings especially designed for CO_2 and low viscosity media minimize the mixed friction, which ensures a long service life and absolute reliability.

Images:

- HERMETIC_fb_1906_1: Percentage of natural refrigerants in industrial refrigeration plants by 2020
- HERMETIC_fb_1906_2: Reasons for failure of conventional centrifugal pumps
- HERMETIC_fb_1906_3: Plant curve and Q-H curve of a pump
- HERMETIC_fb_1906_4: Inducer
- HERMETIC_fb_1906_5: Single-stage hermetically sealed centrifugal pump for ammonia and CO_2 , type CNF from HERMETIC-Pumpen
- HERMETIC_fb_1906_6: Multi-stage hermetically sealed centrifugal pump for CO_2 , type CAMh / CAM from HERMETIC-Pumpen

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