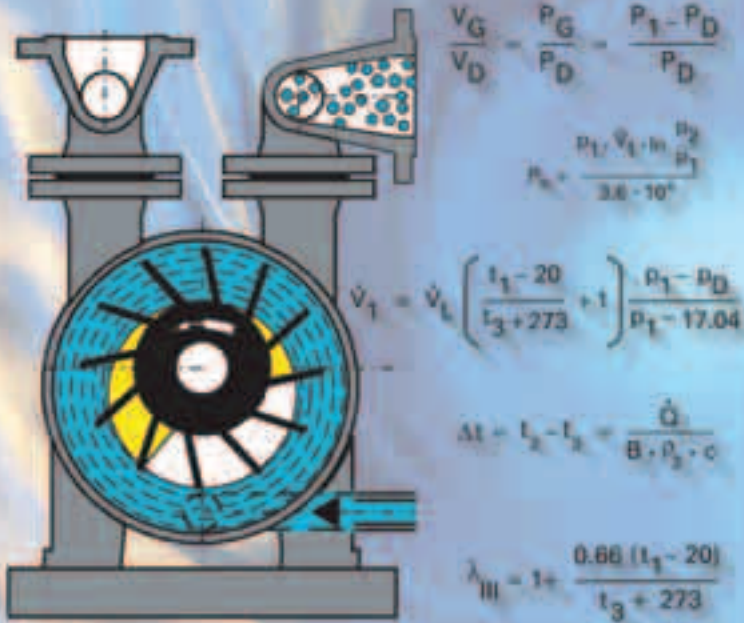


Liquid Ring Vacuum Pumps & Compressors Technical Details & Fields of Application



STERLING FLUID SYSTEMS GROUP
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Liquid Ring Vacuum Pumps and Liquid Ring Compressors

Technical Details and Fields of Application



**Centrifugal Pumps
Vacuum Technology
Engineered Systems
Service Support**



Manufacturing Programme

Liquid Centrifugal Pumps

- Volute Casing Pumps
- Chemical Pumps
- Side Channel Pumps
- Multistage Ring Section
- Pitot Tube Pumps
- Sealless Pumps
- Heat Transfer Pumps
- Self Priming Pumps

Vacuum Technology

- Liquid Ring Vacuum Pumps
- Liquid Ring Compressors
- Dry Running Vacuum Pumps
- Gas Ejectors

Engineered Systems

- Engineered Vacuum Systems
- Engineered Compressor Systems
- Vacuum Based Membrane Systems
- Filling Systems

Service Support

- Field Service
- In-house Report/Service
- Total Pump Management
- Energy Consultancy

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Vacuum pumps and compressors

Compressors

Vacuum pumps and compressors are machines designed for the compression of gases and vapours. They are used for those duties in the field of process technology which would otherwise be uneconomical, unsafe or impossible to carry out.

Vacuum pumps and compressors compress the gases or gas vapour mixtures generated in various processes from the "suction pressure" to the "discharge pressure". With vacuum pumps, the suction pressure is lower than atmospheric, whereas the discharge pressure with compressors is higher than atmospheric. According to DIN 28400, vacuum is divided into the following pressure ranges (values indicated in mbar):

- rough vacuum: 1×10^3 to 1
- medium vacuum: 1 to 1×10^{-3}
- high vacuum: 1×10^{-3} to 1×10^{-7}
- ultra-high vacuum: $< 1 \times 10^{-7}$

Most of the basic operations in process technology are performed in the rough vacuum range. At low suction pressures, it is often necessary to combine several vacuum

Vacuum Ranges

Fig. 1: The Sterling SIHI range of liquid ring vacuum pumps is available in single and two stage designs, with suction capacities up to 12000 m³/h and suction pressures in the range 33 to 1013 mbar.

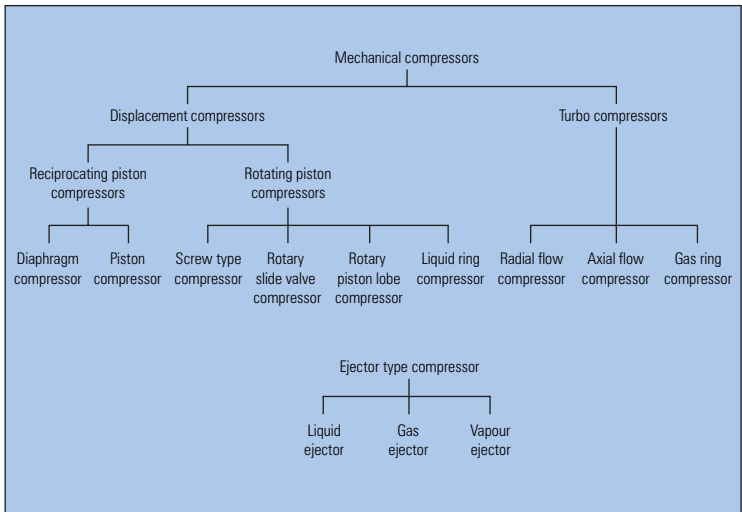


pumps of different design. For example, high-vacuum pumps in general are connected to rough-vacuum pumps.

There are several different types of vacuum pumps and compressors. Figure 2 shows a summary.

The following criteria should be considered when selecting the required design:

Combination of several pumps



- working range i.e. suction and discharge pressure,
- inlet volumetric rate of flow at the required pressures,
- requirements resulting from the type and properties of the gas or vapour to be compressed,
- requirements in respect of the environmental and operating conditions,
- requirements with regard to safety of operation,
- economic efficiency.

Fig. 2: Various types of vacuum pumps and compressors

Liquid ring vacuum pumps and liquid ring compressors

Characteristics

Liquid ring serving as energy transmitter

Liquid ring vacuum pumps and liquid ring compressors are compressors in which a liquid ring formed from the service liquid serves to transmit the energy required for the compression of gases and vapours.

The medium being pumped comes into contact with the service liquid, thus allowing these media to affect each other. Liquid ring vacuum pumps and compressors therefore occupy a special position among the various types of compressors and are characterised by a great number and variety of properties unequalled by any other design:

Many distinctive features

- liquid ring vacuum pumps and compressors are capable of compressing almost any gas or vapour,
- no frictional contact between individual parts; the materials of construction can be selected to suit the operating conditions,
- the compression process is more or less isothermal,
- the pumps offer the highest degree of safety in compressing explosive substances and toxic or carcinogenic media,
- if the medium pumped has condensible constituents, the inlet volumetric rate of flow can increase,
- single or double mechanical seals and magnetic drives ensure low leakage rates,

- operation is characterised by low noise emission and a low vibration level,
- a high degree of operational safety with minimum maintenance,
- liquid can be pumped along with the gas flow.

Operating principle and types of design

Within the scope of this book, the term “liquid ring gas pump” is used whenever the information given refers to both liquid ring compressors.

Liquid ring gas pump

When the medium being pumped comes into contact with the service liquid, this causes thermodynamic effects and makes it possible for the gas to react with the liquid.

When compressing dry gases or vapours which neither condense in the inlet chamber nor during the compression process, the liquid ring gas pump operates as a displacement compressor. With an increase in volume, the medium is drawn in, and with a reduction of volume, it is compressed.

If the medium pumped is a gas/vapour mixture whose vapour portion condenses after entering the inlet chamber or during compression, the liquid ring gas pump operates as a *displacement compressor with a condensing effect*.

When pumping media which are absorbed by or react with the service liquid, the liquid ring gas pump can be regarded as a *displacement compressor-cum-absorption machine*.

In general, large and medium-sized liquid ring gas pumps are of single-acting design.

Single-acting design

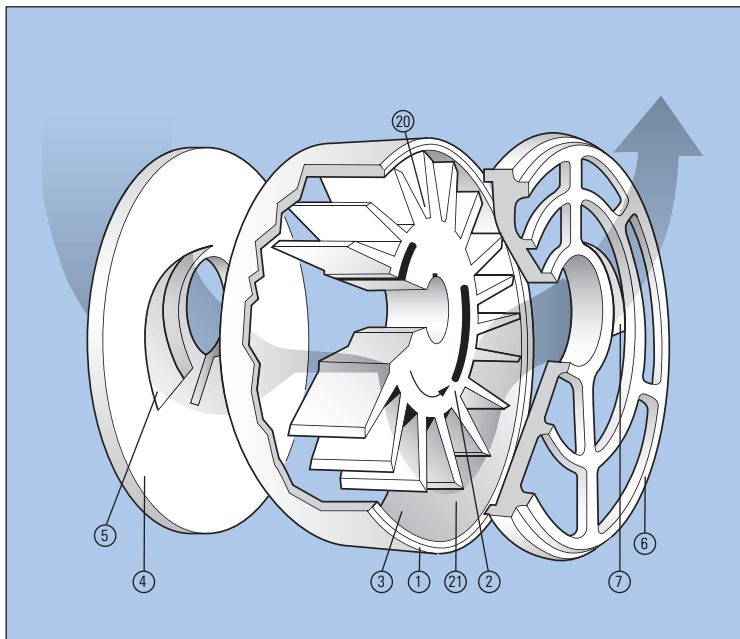


Fig. 3: Operating principle of a liquid ring gas pump

Figure 3 shows an exploded view of the principle of operation.

A multi-bladed impeller (2) is mounted eccentrically in a circular casing (1). When the casing is partially filled with liquid and the impeller is set into rotary motion, this causes the liquid ring (3) to be formed as a result of centrifugal force. Due to the eccentricity, the inside contour of the liquid ring contacts the impeller at points (20) and (21), and the liquid creates a piston action within each set of impeller blades, causing flow into and out of the impeller blade cells. This flow occurs with each revolution of the impeller and results in a volumetric expansion in the section of the outflowing liquid ring, thus causing the medium to be drawn in via the inlet port (5) in the guide

plate (4) connected to the suction nozzle. In the area of the inflowing liquid ring, the volume is reduced, thus causing the medium to be compressed. On completion of compression, the medium is discharged via the outlet port (7) in the guide plate (6) which is connected to the discharge nozzle.

The double-acting design is used for special applications, in particular on compressors employed for high differential pressure. Here, the casing is designed so that the liquid ring flows into and out of the impeller blade cells twice during each revolution of the impeller.

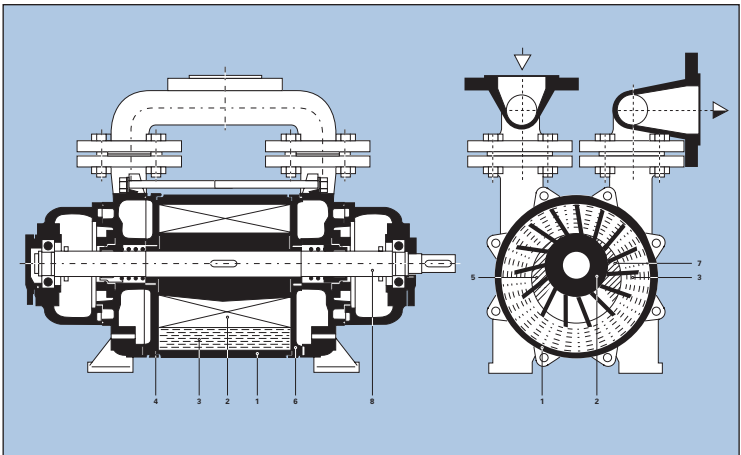
Figure 4 shows a section of a single-acting, figure 5 of a double-acting liquid ring gas pump.

Differing immersion depths of the liquid ring into the impeller, which is a requirement for the proper functioning of a liquid ring gas pump, can also be achieved by means of an impeller rotating concentrically in the casing and channel-like chambers of varying depths arranged next to the impeller.

Double-acting design

Fig. 4:
Longitudinal and
transverse sections
through a single-
stage, single acting
liquid ring gas pump

- 1 Casing
- 2 Impeller
- 3 Liquid Ring
- 4 Guide plate
- 5 Inlet port
- 6 Guide plate
- 7 Outlet port
- 8 Shaft



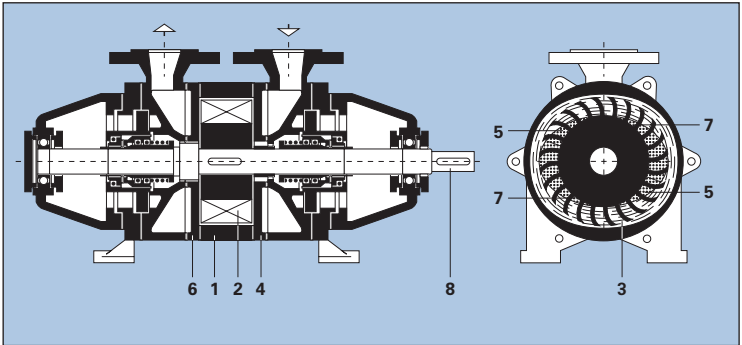


Fig. 5:
Longitudinal and
transverse sections
through a single-
stage, double acting
liquid ring
compressor

- 1 Casing
- 2 Impeller
- 3 Liquid Ring
- 4 Guide plate
- 5 Inlet port
- 6 Guide plate
- 7 Outlet port
- 8 Shaft

Pumps of this type are suitable for pumping small inlet volumetric rates of flow and can also be used for the pumping of liquids. A longitudinal section through a so-called *side channel pump* is shown in figure 6.

In figures 3 to 6, the inlet and outlet ports are arranged in flat guide plates located at each

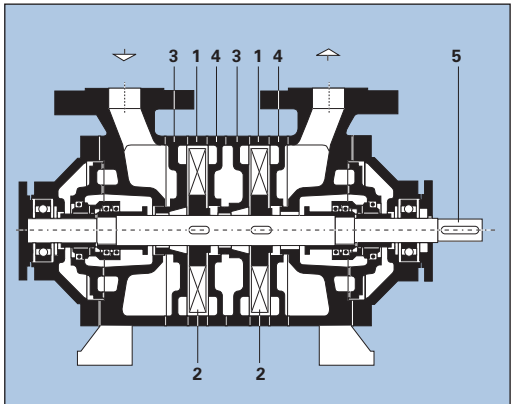


Fig. 6:
Longitudinal section
through a two-stage,
liquid ring gas pump
of the side channel
type

- 1 Casing
- 2 Impeller
- 3 Guide plate
- 4 Guide plate
- 5 Shaft

side of the impeller. The gas enters and escapes by way of the impeller faces.

In another design variation, the inlet and outlet ports are located in guide plates extending into the impeller hub.

With a relatively small impeller width, the inlet and outlet ports need only be arranged on one side to adequately fill the impeller blade cells with gas and empty them. In this case, the ports are either arranged in the same guide plate, or the inlet port is arranged in one guide plate and the outlet port in the guide plate opposite, as shown in figures 3 and 5.

Number of inlet and outlet ports

With comparatively wide impellers, intake and discharge of the gas is effected via ports arranged on either side. Figure 4 shows an example of this arrangement. In contrast, the impeller blade cells of pump stages designed for low suction pressures, and thus for low-density gases, can be adequately fed with gas through a single inlet port, even where relatively wide impellers are used.

The inlet ports extend across almost the entire angle at which the liquid ring flows out of the impeller blade cells.

The outlet ports are located in the section where the liquid ring enters the impeller blade cells. The angular extension and geometrical configuration of the ports are a function of the ratio of the discharge to the suction pressure for which the pump stage is designed, taking into consideration that the stage has to work economically at the specified pressure ratio and also at lower pressure ratios. The starting point of the outlet port represents a "built-in pressure ratio" on each stage. This point should, therefore, theoretically shift for each pressure ratio. In practice, however, this type of pump can be operated across a relatively wide range of pressure ratios.

Location of inlet and outlet ports

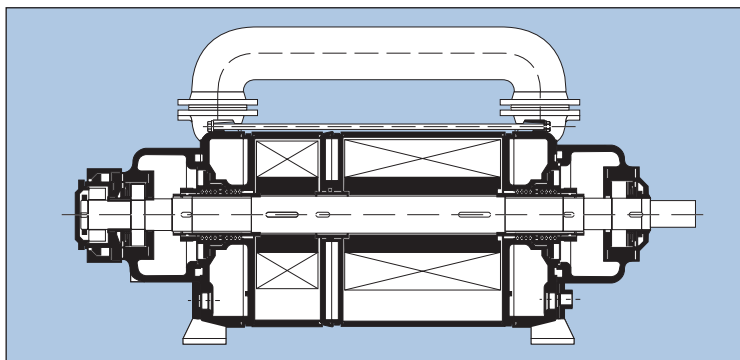
Wide pressure range

Liquid ring vacuum pumps must be capable of operating over a very wide pressure range. If, for example, during a pull-down on a vacuum vessel, the suction pressure, after initially equalling the atmospheric pressure, is lowered to 33 mbar, the pressure ratio rises from 1 to approximately 30.

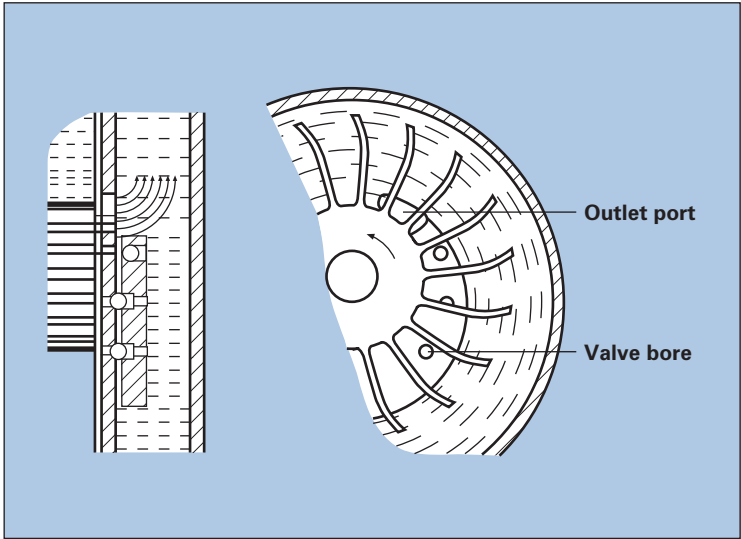
When the ratio of the pressures produced by the stages of liquid ring vacuum pumps exceeds a value of approximately 7, as in the case of vacuum pumps designed for a suction pressure of less than 150 mbar, there are two possibilities:

Either the outlet ports are fitted with some sort of valve, allowing automatic adjustment of the starting point of the outlet port to the pressure ratio, or the liquid ring vacuum pump is designed as a two-stage pump, so that the total pressure ratio is divided between two stages. Figure 7 shows a longitudinal section of a two-stage liquid ring vacuum pump.

*Fig. 7:
Longitudinal section
through a two-stage,
single acting liquid
ring vacuum pump*



The valves can be ball or plate type, the latter subdivided into rigid or flexible plates. The sealing elements of the valve are moved as a result of the different pressures in front of and



behind the guide plates. Figure 8 shows how the ball port valves work: when the pressure in the impeller blade cells exceeds the pressure in the discharge chamber, the ball lifts off the valve seat, allowing the gas to escape from the impeller blade cells into the discharge chamber. As soon as the pressure in the discharge chamber rises above that in the impeller blade cells, the ball is pressed onto the valve seat and stops both gas and liquid from flowing back into the impeller.

*Fig. 8:
Operating principle of
a ball port valve*

Gas and liquid flow passages

Part of the liquid forming the liquid ring is ejected from the outlet ports together with the gas. A liquid ring gas pump must therefore be supplied with an uninterrupted flow of service liquid.

The service liquid is supplied through the service liquid connection at a pressure usually equal to, or slightly lower than that at the pump discharge nozzle.

Supply of service liquid



*Fig. 9:
Liquid ring vacuum
pump with separator
and heat exchanger.*

After the gas/liquid mixture has been discharged from the pump, the liquid can be separated from the gas in a separator and then re-used as service liquid after having been cooled sufficiently, or after having been mixed with an adequate amount of cool liquid.

Re-use of the liquid

Cooling is necessary because most of the heat generated during compression and the various condensation processes is absorbed by the liquid. Only in cases where it is justified from an economic viewpoint is the liquid not circulated for re-use. If there is no economic necessity to separate the gas from the liquid, the installation of a separator may be dispensed with.

By means of a suitably designed separator, the portion of liquid contained by the gas leaving the separator is kept small.

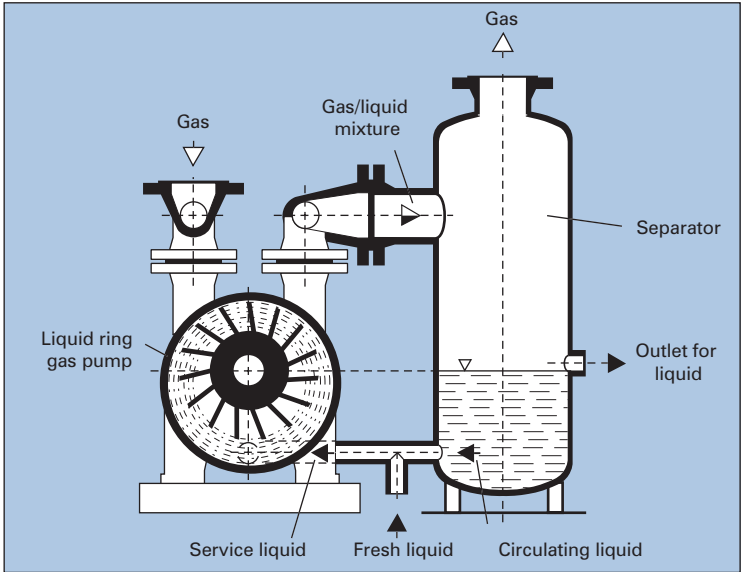


Figure 10 shows the direction of gas and liquid flow in a liquid ring gas pump and separator. The mode of operation depicted is referred to as "combined liquid operation". With this mode of operation, part of the liquid separated from the gas in the separator is re-used as service liquid.

*Fig. 10:
Direction of gas
and liquid flow*

The separator shown in figure 10 may also be of a different design. It can be mounted on top of the discharge nozzle, or serve as a baseplate for the vacuum pump or the compressor and the motor.

Designs of liquid separators

Working ranges

Liquid ring gas pumps are built for inlet volumetric rates of flow ranging from approximately $1\text{m}^3/\text{h}$ to more than $20000\text{m}^3/\text{h}$. The physical properties of the service liquid are particularly critical with regard to

Effect on the suction pressure

the suction pressures vacuum pumps can achieve. If the service liquid is water at 15 °c, suction pressures of up to 33 mbar at relatively good suction volumetric flow rates are feasible.

It should be noted in this context that the discharge pressure is equal to or higher than atmospheric.

Lower suction pressures can be achieved by combining the liquid ring gas pump with a gas ejector pump, a vapour ejector pump or a lobular pump. (Roots blower type)

At atmospheric suction pressure, liquid ring compressors work up to an absolute discharge pressure of approximately 9 bar, dependent on the design.

The working ranges of liquid ring gas pumps are shown in figure 11.

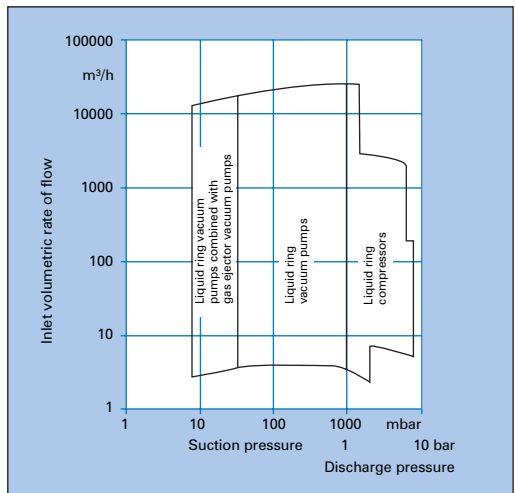


Fig. 11:
Working ranges of liquid ring gas pumps

Operating characteristics

The determining factors for the characteristics and the operating behaviour of liquid ring gas pumps are the method of energy transfer from the liquid ring to the medium being pumped, and the question of whether the medium comes into contact with the service liquid.

Inlet volumetric rate of flow

The inlet volumetric rate of flow \dot{V}_{theor} theoretically possible for a pump working as a positive displacement compressor is equal to the product of the impeller blade cell volume V_{cells} available to the gas during each revolution of the impeller and the speed n :

$$\dot{V}_{\text{theor}} = 60 \times V_{\text{cells}} \times n \quad (1)$$

with \dot{V}_{theor} expressed in m^3/h , V_{cells} in m^3 , and n in r.p.m.

In practice, however, the inlet volumetric rate of flow is smaller because the impeller cells are never entirely emptied of gas, and flow losses in the suction and discharge ports as well as clearance losses are to be considered.

If the gas drawn into the impeller blade cells is dry, it will try to saturate itself with vapour from the service liquid as soon as it has entered the pump. The saturation process causes the temperature of the gas and the liquid to drop, because heat is required for the vapour to form. As a result, the space available for the gas in the impeller blade cells is reduced by the portion taken up by the vapour.

The ratio of the portions of space taken up by the gas and the vapour is expressed by

**Theoretical inlet
volumetric rate
of flow**

Dalton's law of partial pressures, which states that in a mixture of gaseous substances, the ratio of the individual volumes equals that of the ratio of their partial pressures:

Dalton's law

$$\frac{V_G}{V_D} = \frac{P_G}{P_D} = \frac{P_1 - P_D}{P_D} \quad (2)$$

where V stands for volume, and p for pressure, with the indices G for gas and D for vapour; p1 is the suction pressure.

The inlet volumetric rate of flow \dot{V}_L indicated in lists and catalogues is usually based on dry air of 20°C as the pumped medium, and water of 15°C (20°C in the case of compressors) as the service liquid. if the aspirated dry air has a temperature other than 20°C, the ratio of the absolute temperatures of air and service water as well as the vapour portion of the air/water vapour mixture in the impeller blade cells changes accordingly. The result is a different inlet volumetric rate of flow. The same applies when the service water temperature deviates from the indicated values.

Assuming that the temperature t_1 of the pumped air has changed to temperature t_3 of the service water by the time it enters the impeller blade cells, and that Dalton's law is still applicable to air/water vapour mixtures and to this case in particular, the inlet volumetric rate of flow \dot{V}_1 for an air temperature other than 20°C and a service water temperature other than 15°C would in theory be calculated according to equation (3) as follows:

$$\dot{V}_1 = \dot{V}_L \left(\frac{t_1 - 20}{t_3 + 273} + 1 \right) \frac{p_1 - p_D}{p_1 - 17.04} \quad (3)$$

Here, the figure 17.04 stands for the vapour pressure (in mbar) of water at a temperature of 15°C.

In practice, however, the change in the inlet volumetric rate of flow does not fully comply with these rules. Because they are only valid for ideal gases, there is only a limited amount of time and space available for the vapour to form, and are counteracted by certain conditions specific to the pump itself.

To allow for the dependency of the inlet volumetric rate of flow on the actual vapour pressure of the service liquid to be taken into account, empirical equations were developed from the results of measurements. The inlet volumetric rate of flow is therefore calculated for service liquid temperatures other than 15°C as follows:

Effect of the vapour pressure on the inlet volumetric rate of flow

$$\dot{V}_1 = \dot{V}_L \cdot \lambda_1 \tag{4}$$

For single-stage vacuum pumps and for compressors

$$\lambda_{1\text{one}} = \frac{p_1 (0.27 \cdot \ln p_1 - 0.0783) - 1.05 \cdot p_D}{p_1 (0.27 \cdot \ln p_1 - 0.0783) - 1.05 \cdot 17.04} \tag{5}$$

and for two-stage vacuum pumps

$$\lambda_{1\text{two}} = \frac{p_1 (0.35 \cdot \ln p_1 - 0.1) - p_D}{p_1 (0.35 \cdot \ln p_1 - 0.1) - 17.04} \tag{6}$$

- p_1 = suction pressure in mbar
- p_D = vapour pressure of the service liquid in mbar
- \dot{V}_1 = inlet volumetric rate of flow in m³/h
- \dot{V}_L = inlet volumetric rate of flow in m³/h when pumping dry air (20°C) with water (15°C) as the service liquid.

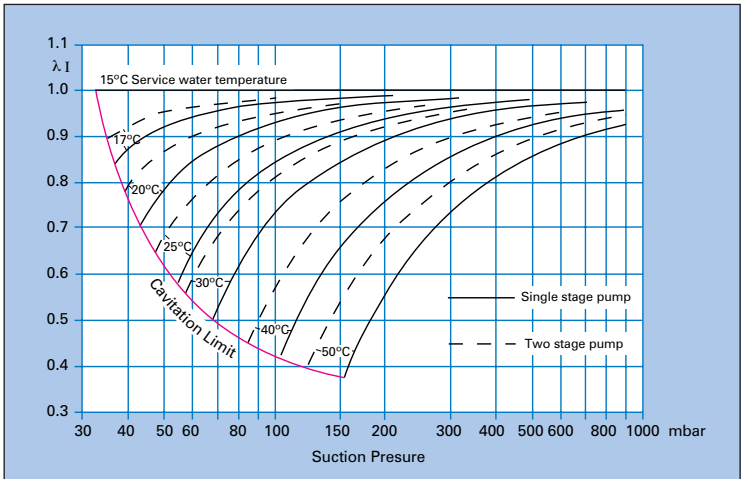
The results of equations (5) and (6) are mean values. These apply to water as the service liquid, an air temperature t_1 of 20°C, a value for p_D of between 17 and 123 mbar, and a p_1 of between 33 and 1013 mbar.

Cavitation

An excessive amount of vapour in the pumped liquid can lead to cavitation in the pump and to damage of pump components, in particular the impellers and guide plates. From practical experience it is known that a certain volumetric flow rate of air under standard conditions or some other non-condensable gas has to be present in the liquid pumped to avoid cavitation. This flow is independent of the service water temperature, yet dependent on the size and the rotational speed of the pump.

Fig. 12:
Effect of the service water temperature on the inlet volumetric rate of flow

The values obtained from equations (5) and (6) are depicted in graphical format in figure 12. The line designated as the cavitation limit is to be considered a standard value for vacuum pumps capable of reaching a suction



pressure of 33 mbar free from cavitation when handling dry air.

To avoid damage due to cavitation, liquid ring vacuum pumps are equipped with cavitation protection in the form of a flow of a non-condensable medium which is either returned or supplied to the impeller cells via a connection provided for this purpose. This connection is normally connected to the gas chamber of the separator.

**Protection
against
cavitation**

If the pumped medium is a dry gas or a vapour which is not condensed in the suction chamber, the inlet volumetric flow rate is only affected by the temperature of the medium pumped, if we leave its solubility in the service liquid out of consideration. Through measurements, the contributory effect has been determined, allowing us to calculate the inlet volume flow rate on handling dry air with a temperature t_1 from the inlet volume flow rate of dry air at 20°C.

**High gas
temperature
increases the
inlet volumetric
rate of flow**

The inlet volumetric rate of flow of dry air with a temperature t_1 and water with a temperature t_3 is thus calculated using the following equation:

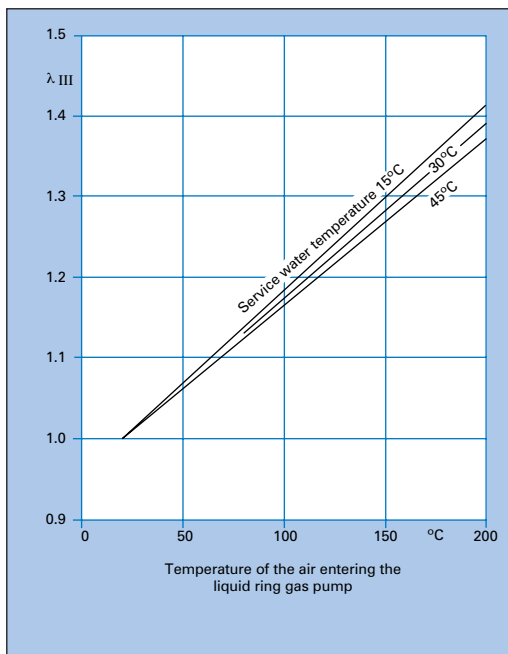
$$\dot{V}_1 = \dot{V}_L \cdot \lambda_1 \cdot \lambda_{III} \quad (7)$$

where

$$\lambda_{III} = 1 + \frac{0.66 (t_1 - 20)}{t_3 + 273} \quad (8)$$

Figure 13 shows a graphic illustration of factor λ_{III} as a function of the air temperature for several service water temperatures.

Fig.13: Inlet volumetric flow rate as a function of the temperature of the medium pumped when pumping dry gas



The temperature of the medium pumped should not exceed certain maximum values. Depending on the pump size, the maximum permissible temperature for volume manufactured liquid ring gas pumps is between 60 and 200 $^{\circ}\text{C}$. The permissible maximum is also influenced by the medium being pumped.

If the medium pumped contains vapours which condense in the pump, the inlet volumetric rate of flow is higher than when handling dry gases. In this case, condensation takes place in the suction chamber or in the impeller cells which are connected to the suction chamber.

Condensing vapours increase the inlet volumetric rate of flow

The increase is dependent on the inlet pressure, the temperature of the gas/vapour mixture, the temperature of the service liquid and on the size of the pump.

On the basis of measured values, an empirical equation has been developed to calculate the increase of the inlet volumetric rate of flow of water vapour, saturated air and water compared to the inlet volume rate of flow for dry air with a temperature of 20°C.

Empirical equation on the basis of measured values

$$\dot{V}_1 = \dot{V}_L \cdot \lambda_I \cdot \lambda_{II} \quad (9)$$

where

$$\lambda_{II} = \frac{[0.75 \cdot p_1 (\ln p_1 - 0.2877)]^E}{[0.75 \cdot p_1 (\ln p_1 - 0.2877)]^E - 0.75 \cdot p_S} \quad (10)$$

$$E = \left(0.082 \cdot \frac{h}{d} + 0.793 \right) \left(\frac{p_D}{17.04} \right)^{0.0369} \quad (11)$$

d = impeller diameter in m

h = impeller width impinged with gas/vapour through an inlet port expressed in m

p_1 = suction pressure in mbar

p_D = vapour pressure of the service liquid in mbar

p_S = vapour pressure of water at the temperature of the air/water vapour mixture in mbar

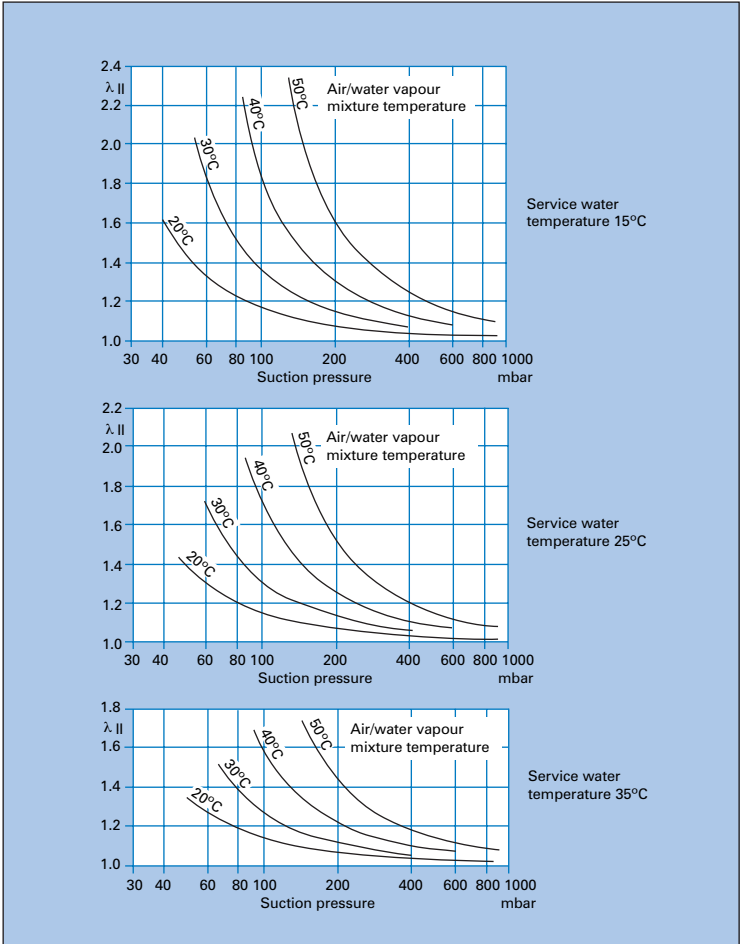
\dot{V}_1 = inlet volume rate of flow in m³/h

\dot{V}_L = inlet volumetric rate of flow when handling dry air (20°C) with water (15°C) as the service liquid in m³/h.

Equation (9) is valid for air/water vapour mixtures and values for p_D and p_S of between 17 and 123 mbar, and for a p_1 of between 33 and 1013 mbar.

Figure 14 shows factor λ_{II} as a function of the above-mentioned contributory factors for a design size h/d of 0.43.

As far as the cavitation limit is concerned, the rule also applies here that a certain volumetric



rate of flow of air, or of some other non-condensable gas under standard conditions, has to be present in the product being pumped.

In most applications the service liquid is water. However, in the field of process technology, it is often necessary to use liquids whose chemical and physical properties are very different from those of water. The service liquid varies according to the process requirements. It is important to note that the vapours contained by the medium pumped condense for the most part inside the pump and are discharged through the discharge nozzle together with the gas/liquid mixture in the form of condensate. The obvious choice of a service liquid in this case is a liquid which is already available as condensate.

Where the physical properties of the service liquid vary from those of water, this has an effect on the inlet volumetric rate of flow, the pump input power, the service liquid flow and on the temperature of the mixture of gas and liquid on the discharge side.

Considering the fact that the vapour pressure is determined by the type of liquid, and that it increases with rising temperature, the inlet volumetric rate of flow is dependent on the type of liquid, particularly in the case of low suction pressures. The inlet volumetric rate of flow theoretically tends to zero as soon as the inlet pressure becomes equal to the vapour pressure of the service liquid which, therefore, represents the lower physical limit of the attainable suction pressure.

Different service liquids

Fig. 14: (opposite): Effect of the medium pumped on the volumetric rate of flow when pumping water-vapour-saturated air

The power P_{is} required for the isothermal compression of a gas from an inlet pressure p_1 to a discharge pressure p_2 is proportional to the suction pressure, the inlet volumetric rate of flow \dot{V}_1 and the natural logarithm of the compression ratio:

**Isothermal
compression
power**

$$P_{is} = \frac{p_1 \cdot \dot{V}_1 \cdot \ln \frac{p_2}{p_1}}{3.6 \cdot 10^4} \quad (12)$$

where

p_1 = suction pressure in mbar

p_2 = discharge pressure in mbar

P_{is} = isothermal compression rating in kW

\dot{V}_1 = inlet volumetric rate of flow in m³/h

As the compression power is derived from the energy generated by the rotary movement of the liquid ring, the amount of energy it contains should be at least equivalent to the isothermal compression rating.

In order to evaluate the amount of energy contained by the liquid ring, it can be assumed that it varies in proportion to the volume of the rotating liquid, its density and to the square of the rotational speed of the liquid ring. At a given impeller speed, the density of the service liquid is therefore critical for the energy contained in the liquid ring, and consequently for the possible compression power.

In addition to this, the inner limit of the liquid ring is influenced both at the suction and discharge end. As a result, the inlet volumetric rate of flow and the power requirement are dependent on the density of the service liquid. On the basis of the similarity law, it is possible

to calculate the inlet volumetric flow rate and the power required for a change in density of the service liquid from given operating data.

Similarity law enables conversion

If the service liquid consists of immiscible components and the densities of its components vary, they will form a layered liquid ring. The inlet volumetric rate of flow then depends on whether the portion with the lower boiling point has the lesser or greater density.

In general, the viscosity of the service liquid has only a minor effect on the inlet volumetric rate of flow. The improved sealing effect in the clearances between the impeller and the guide plate which comes with a higher viscosity is lost, because the rate of flow of the service liquid entering the flow is smaller than usual.

Influence of the viscosity

At 20°C, water has a specific heat of 4.183 kJ/(kg K). The liquids used in process technology often have a lower heat capacity. As a result, the temperatures of the liquid ring and the gas/liquid mixture exiting the discharge nozzle are higher.

Specific heat capacity

The evaporation heat is the physical quantity which is critical for the heat flow generated by the condensation of the vapour particles in the pumped medium, the greater portion of which is absorbed by the liquid ring, and for the heat required for saturation, which is mainly taken from the liquid ring when dry gases are handled.

Evaporation heat

The data indicated in lists and catalogues apply to the compression of air. Liquid ring gas pumps, however, are suitable for handling most media in the gas or vapour state as well as mixtures of the two.

The following properties, conditions and effects of the medium pumped have a direct influence on the inlet volumetric rate of flow:

Effects of the medium pumped on the inlet volumetric rate of flow

- temperature
- saturation state
- condensation in the suction chamber
- density (usually significant only in the case of hydrogen and helium, and gas mixtures including these gases)
- solubility in the service liquid
- entrainment of liquid with the gas flow (other than the service liquid)
- reaction with the service liquid

The following have an indirect effect:

- condensation during compression
- specific heat capacity
- evaporation heat

Power requirement

The power input required by liquid ring gas pumps depends only to a negligible extent on the vapour pressure of the service liquid. The viscosity of the service liquid affects the friction losses and thus also the power input. If power input P_L is known for water as the service liquid, input power P can be calculated by solving equation (13) for a mean circumferential speed of the impeller and a kinematic viscosity ν of the service liquid of up to $6\text{mm}^2/\text{s}$:

$$P = P_L \cdot \nu^{0.05} \tag{13}$$

Impeller speed

The speed of the impeller determines the inlet volumetric rate of flow and the power input of the pump. Figures 15 and 16 show the inlet

Characteristic curves

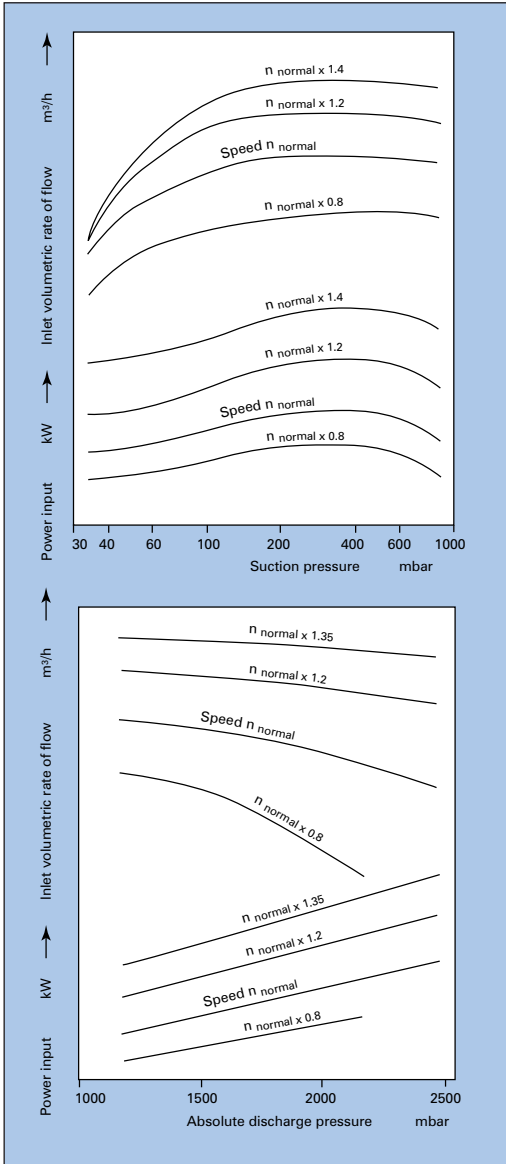


Fig. 15:
 Inlet volumetric rate of flow and power input of a liquid ring vacuum pump at different speeds
 Medium pumped: air, 20°C; service liquid: water, 15°C; discharge pressure 1013 mbar

Fig. 16:
 Inlet volumetric rate of flow and power input of a liquid ring compressor at different speeds
 Medium: air, 20°C; service liquid: water, 20°C; suction pressure 1013 mbar

volumetric rate of flow and the input power as a function of speed n for a vacuum pump and a compressor, respectively.

Variations from atmospheric pressure

Discharge pressure and suction pressure

The discharge pressure of liquid ring vacuum pumps and the inlet pressure of liquid ring compressors can deviate considerably from the atmospheric pressure prevailing under normal circumstances, and can therefore result in a change in inlet volumetric rate of flow and pump power input. If the difference in pressure levels results in a high mechanical loading of components, its acceptability should be examined.

Figures 17 and 18 show the inlet volumetric rate of flow and the pump power input at constant speed using water as the service liquid for a single-stage vacuum pump at several discharge pressures, and for a single-stage compressor at several inlet pressures, respectively.

Outlet temperature

With vacuum pumps and compressors, all the power needed to compress gaseous substances is converted to heat.

Generation of heat

If the medium contains vapours which condense in the suction chamber or during compression, condensation heat is generated which has to be eliminated.

The heat produced inside the pump caused by the medium reacting with the service liquid also has to be eliminated.

If liquid is pumped with the gas, its temperature change releases a heat flow. It is

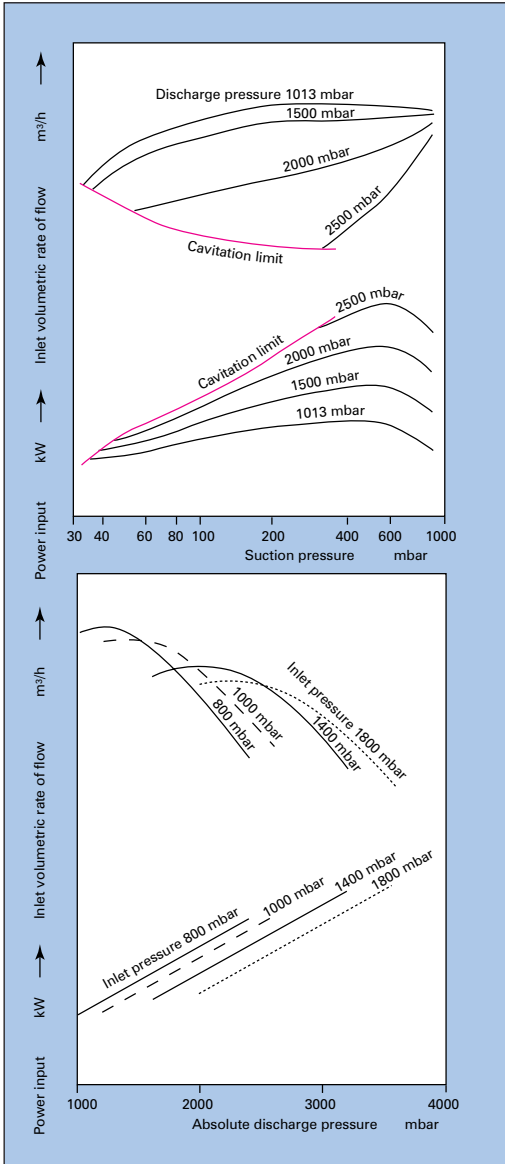


Fig. 17:
 Inlet volumetric rate of flow and power input of liquid ring vacuum pump at different discharge pressures
 Medium pumped: air, 20°C; service liquid: water, 15°C

Fig. 18:
 Inlet volumetric rate of flow and power input of a liquid ring compressor at different suction pressures
 Medium pumped: air, 20°C; service liquid: water, 20°C

Heat transferred to the liquid ring

only in the case of extreme differences in temperature that any heat worth considering dissipates via the surface of the pump.

A large portion of the heat generated in liquid ring gas pumps is transferred to the liquid ring and discharged together with the gas/liquid mixture. The following heat flow rates are a result of this process:

Compression rating and friction losses:

$$\dot{Q}_V = P \cdot 3600 \quad (14)$$

P = pump power input in kW

\dot{Q}_V = heat flow rate in kJ/h

Heat exchange between the medium pumped and the service liquid:

$$\dot{Q}_G = \dot{m}_G \cdot c_p (t_1 - t_2) \quad (15)$$

where

\dot{Q}_G = heat flow rate kJ/h

c_p = specific heat capacity of the product pumped in kJ/(kg K)

\dot{m}_G = mass flow of the gas in kg/h

t_1 = temperature at the suction nozzle in °C

t_2 = temperature at the discharge nozzle in °C

Condensation heat:

$$\dot{Q}_K = r \cdot (\dot{m}_{D1} - \dot{m}_{D2}) \quad (16)$$

where

\dot{m}_{D1} = mass flow of condensing vapour in kg/h

\dot{m}_{D2} = mass flow of the vapour escaping through the discharge nozzle in kg/h

r = evaporation heat in kJ/kg

\dot{Q}_K = heat flow rate in kJ/h

If both the cooling of the vapour to the

condensation temperature, and the cooling of the condensate to the temperature of the liquid ring plus any reaction heat available are not taken into consideration, the heat flow rate \dot{Q} absorbed by the liquid ring is calculated using equation (17) as follows:

$$\dot{Q} = \dot{Q}_V + \dot{Q}_G + \dot{Q}_K \tag{17}$$

Heat flow rate

If the mass and heat flows, or their equivalents, flowing in and out of the pump are in equilibrium, the following applies:

$$\dot{Q} = B \cdot \rho_3 \cdot c \cdot (t_2 - t_3) \tag{18}$$

where

- \dot{Q} = heat flow rate in kJ/h
- B = service liquid flow rate in m³/h
- ρ_3 = density of the service liquid in kg/m³
- c = specific heat of the service liquid in kJ/(kg K)
- t_2 = temperature at the discharge nozzle in °C
- t_3 = temperature at the service liquid connection in °C

This results in a temperature increase in the liquid ring gas pump of:

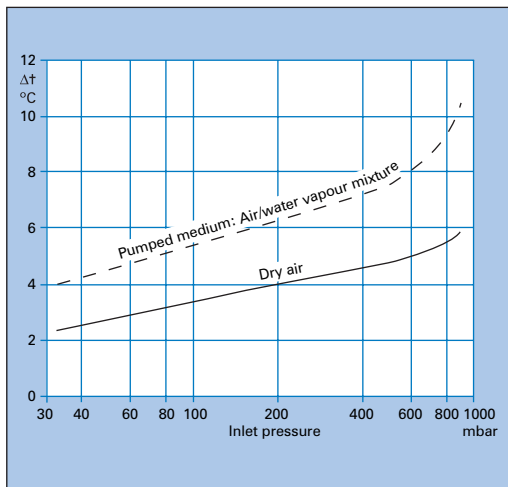
$$\Delta t = t_2 - t_3 = \frac{\dot{Q}}{B \cdot \rho_3 \cdot c} \tag{19}$$

Temperature increase

Heat flow rates \dot{Q}_G and \dot{Q}_K can only be calculated if temperature t_2 in the discharge nozzle of the pump and the vapour pressure of the substances present in the vapour state at this temperature are known. Temperature t_2 can, therefore, not be directly derived from equation (19). In practice, it is determined by means of an iterative calculation which can be performed after establishing the coherence of the temperature and the vapour pressure in the form of an equation.

As an example, figure 19 shows the differential temperature $\Delta t = t_2 - t_3$, as a function of the suction pressure for a liquid ring vacuum pump handling dry and water-vapour-saturated air at $t_1 = 20^\circ\text{C}$.

Fig. 19:
Differential temperature $\Delta t = t_2 - t_3$ for a liquid ring vacuum pump handling dry water-vapour saturated air



Similarity law

The similarity law states that with geometrically similar vacuum pumps or compressors, if the pressure ratio p_2/p_1 and the k-value are equal, the compression processes are similar, and the impeller utilisation and the isothermal efficiency are also equal. In this context the term impeller utilisation λ_R is defined as the volumetric efficiency of an impeller.

Impeller utilisation

$$\lambda_R = \frac{1}{60} \cdot \frac{\dot{V}_1}{d^2 \cdot \frac{\pi}{4} \cdot b \cdot n} \tag{20}$$

- d = impeller diameter in m
- b = impeller width in m
- n = impeller speed in r.p.m.

The isothermal efficiency η_{is} is the ratio of the isothermal compression power to the pump power input. Equation (21) gives the following:

Isothermal efficiency

$$\eta_{is} = \frac{p_1 \cdot \dot{V}_1 \cdot \ln \frac{p_2}{p_1}}{3.6 \cdot 10^4 \cdot P} \quad (21)$$

where

p_1 = suction pressure in mbar

p_2 = discharge pressure in mbar

\dot{V}_1 = inlet volumetric rate of flow in m³/h

P = pump power input in kW

The k-value is the ratio of the isothermal compression power to the power of the rotating liquid ring, and hence a relative measure indicating to what extent the energy of the liquid ring is consumed in generating the compression power:

$$k = 10^2 \cdot \frac{p_1}{\frac{\rho_3}{2} \cdot u^2} \quad (22) \quad \text{k-value}$$

where

p_1 = suction pressure in mbar

ρ_3 = density of the service liquid in kg/m³

u = circumferential speed of the impeller in m/s

In equation (22), the inlet volumetric rate of flow cancels out the volumetric flow rate of the liquid ring, and the natural logarithm from the pressure ratio p_2/p_1 is taken to be equal to 1.

Operating modes

The following methods detail how the service liquid is handled outside the pump.

Figures 20 to 22 show some examples of single pumps and separators of standard design. Generally, the illustrations also apply to separators of different design and to arrangements of several pumps connected to a common separator. A distinction is made between three modes of operation which are briefly described below:

- combined flow operation
- recirculation flow operation
- make-up liquid operation

Combined flow operation

Combined flow operation is the mode commonly used under normal circumstances. The flow of make-up liquid is limited to the capacity required to remove the heat.

Small supply of make-up liquid required

The arrangement is shown in figure 20: Service liquid B consists of a mixture of make-up liquid F and circulating liquid U. The make-up liquid is tapped from the mains supply, whereas the circulating liquid is obtained from the separator. Before entering the service liquid connection, the two flows U and F are mixed to form flow B. The required make-up liquid flow F is calculated using the following equation:

Make-up liquid flow rate

$$F = B \cdot \frac{t_2 - t_3}{t_2 - t_4} \quad (23)$$

where

F = make-up liquid flow rate in m³/h

B = service liquid flow rate in m³/h

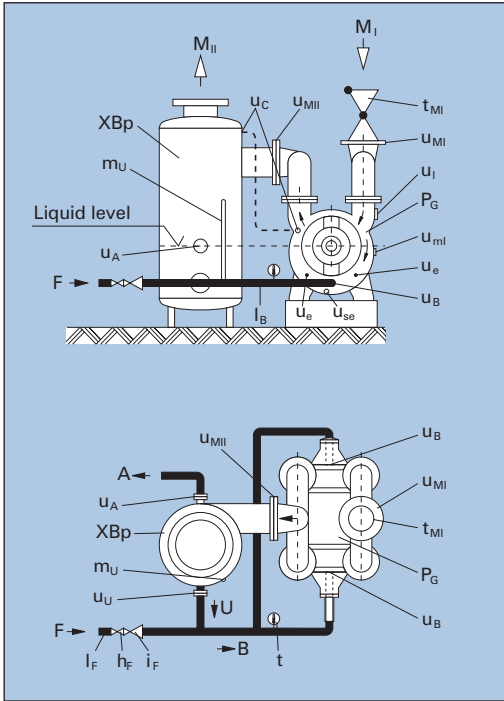


Fig. 20:

Combined flow operation

- A Drainage liquid
- B Service liquid
- F Make-up liquid
- M₁ Medium pumped-suction side
- M₁₁ Medium pumped-suction side
- P_G Liquid ring vacuum pump or compressor
- XBp Separator
- U Circulating liquid
- h_F Shut-off valve
- i_F Regulating valve
- l_B Service liquid line
- l_F Make-up liquid line
- m_U Liquid level tube
- t Thermometer
- t_{M1} Non-return valve
- u_A Liquid outlet
- u_B Service liquid connection
- u_c Cavitation protection
- u_e Drain
- u₁ Connection for vent clock
- u_{M1} Suction line connection
- u_{M11} Discharge line connection
- u_{ml} Connection for drain valve
- u_{se} Dirt drain
- u_U Circulating flow connection

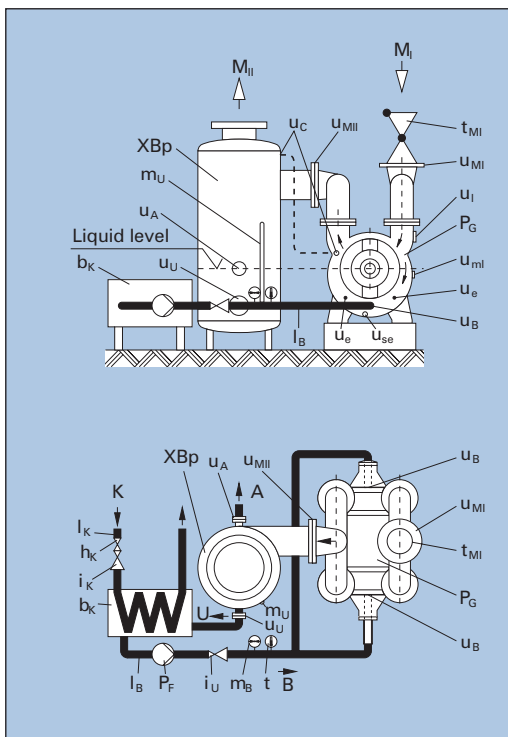
t₂=temperature at the discharge nozzle in °C
 t₃=temperature of the service liquid in °C
 t₄=temperature of the make-up liquid in °C

The discharged liquid flow A is the sum of the following: make-up liquid flow F, vapour portions of the pumped product condensing in the pump, and any liquid portions of the product flow available.

If the discharge pressure is higher than atmospheric, the drainage liquid either has to be removed via a liquid trap, or the separator must be fitted with a regulating device to ensure that the liquid is maintained at the required level.

Fig. 21:
Circulating flow
operation

- A Drainage liquid
- B Service liquid
- K Cooling liquid
- F Make-up liquid
- M_1 Medium pumped-suction side
- M_{11} Medium pumped-discharge side
- P_F Liquid pump
- P_G Liquid ring vacuum pump or compressor
- XBp Separator
- b_K Heat exchanger
- h_K Shut-off valve
- i_K Regulating valve
- i_U Regulating valve
- l_B Service liquid line
- l_K Cooling liquid line
- m_B Manometer vacuum gauge
- m_U Liquid level tube
- t Thermometer
- t_{M1} Non-return valve
- u_A Liquid outlet
- u_B Service liquid connection
- u_c Cavitation protection
- u_e Drain
- u_1 Connection for vent clock
- u_{M1} Suction line connection
- u_{M11} Discharge line connection
- u_{ml} Connection for drain valve
- u_{se} Dirt drain
- u_U Circulating flow connection



Recirculation flow operation

This mode of operation is used for processes involving corrosive, waste-water-polluting or hazardous fluids, as well as in condensate recovery systems.

Figure 21 illustrates the principle of operation. In this mode of operation, the liquid separated from the product flow is re-used as service liquid. The liquid contained in the system is therefore continuously recirculated (closed circuit).

During continuous operation, the liquid heated up during compression has to be

cooled by means of a heat exchanger installed in the circulating flow line. The pressure drop of the heat exchanger has to be small if there is no liquid pump installed in the circulating flow line.

The heat flow rate to be discharged through the heat exchanger is calculated according to equation (17).

A liquid pump must be installed in the circulating flow line to boost the pressure whenever the viscosity of the service liquid is high ($>2\text{mm}^2/\text{s}$), or if the liquid ring gas pump is operated with a small differential between the discharge and suction pressures.

Booster pump

The portions of the flow condensing in the liquid ring gas pump as well as the liquid constituents of the product being pumped will drain out of the separator. If the discharge pressure is higher than atmospheric, either the drainage liquid is removed via the liquid trap, or the separator is fitted with some sort of control device in order to maintain the required liquid level.

If the gas outlet from the separator (product from the discharge line M_{II}) has a higher vapour mass flow rate than the product entering the pump (M_I), the difference has to be made up to prevent the liquid level in the pump from dropping below a given minimum level. Gas must be prevented from entering the recirculation line.

Monitoring the liquid level

Make-up liquid operation

This mode of operation is used when re-use of the service liquid as such is not required. In this case, the entire volume of service liquid needed to operate the system is taken from the mains water supply.

Fig. 22:

Make-up liquid operation

A Drainage liquid

B Service liquid

F Make-up liquid

M_1 Medium

pumped-suction side

M_{11} Medium

pumped-discharge side

P_G Liquid ring vacuum pump or compressor

XBp Separator

h_F Shut-off valve

i_F Regulating valve

l_B Service liquid line

l_F Make-up liquid line

m_B Manometer vacuum gauge

m_U Liquid level tube

t Thermometer

t_{M1} Non-return valve

u_A Liquid outlet

u_B Service liquid connection

u_c Cavitation protection

u_e Drain

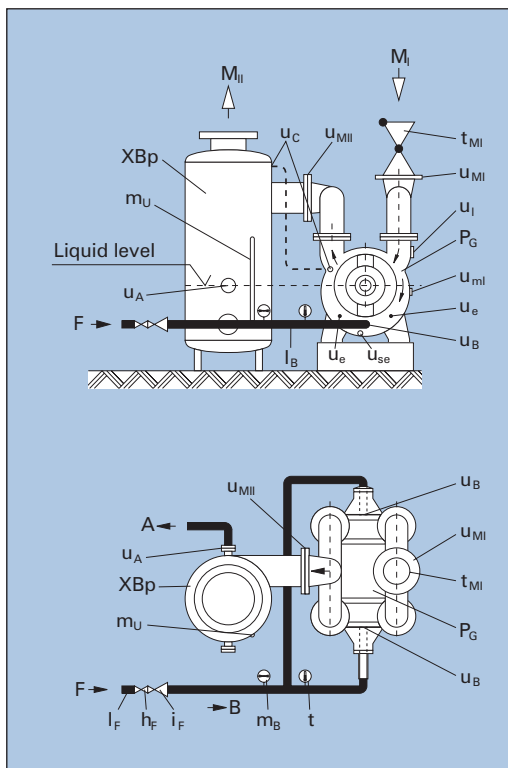
u_1 Connection for vent clock

u_{M1} Suction line connection

u_{M11} Discharge line connection

u_{ml} Connection for drain valve

u_{se} Dirt drain



The principle of operation is shown in figure 22. Drainage flow A is the sum total of the following: Make-up liquid flow F, the vapour portions condensing in the pump, and any liquid constituents contained in the product. If the discharge pressure is higher than atmospheric, either the drainage flow has to be removed via a liquid trap, or the separator must be fitted with some sort of control device for the purpose of maintaining the required liquid level. There is no need for a separator as long as the medium being pumped and the liquid do not have to be drained separately.

Drive.

Motors

Liquid ring gas pumps are normally driven by three-phase electric motors suitably protected in accordance with the operating conditions. For higher drive ratings, high-voltage motors are used. Other prime movers such as internal combustion engines or steam turbines can also be used.

Direct drive by means of an electric motor

Torque transmission

As liquid ring gas pumps have a relatively uniform torque, its transfer to the pump does not call for any sophisticated technical solutions.

The small to average pump sizes are usually direct driven via a flexible coupling. Larger pumps running at a relatively low speed are normally driven by a four-pole motor and a gear to reduce the pump speed.

The types of reduction drives used are gear boxes, V-belt or flat-belt drives.

Belt drives generate a radial load acting on the shaft and bearings which is dependent on the power to be transmitted, the speed and the diameter of the pulley, and on the initial tension of the belt. For these reasons, and in order not to reduce the operating life of the belt, the minimum diameter of the pulley has to be specified.

Belt drive is possible

As the single-acting stage of a liquid ring vacuum pump also exerts a radial force on the pump shaft, the direction of pull of the belt is important. The overhung belt load can result in a higher bearing load and therefore increase the deflection of the shaft, or can lower the load on the bearings and therefore reduce the deflection of the shaft.



*Fig. 23:
Package Unit with a
lobular vacuum
pump and a liquid
ring vacuum pump*

Moment of inertia and load torque

Vacuum pumps and compressors have relatively low moments of inertia and load torques. The moment inertia is specific to the machine. Besides being dependent on the pump size, the torque during start-up also depends on the liquid level inside the pump, the type of liquid, and on the pressures prevailing in the suction and discharge nozzles during the starting phase.

Start-up

Generally speaking, direct-on-line starting is the preferred starting method. Motors with star-delta-starting can be used, if the requirement is for an extremely low starting current. However, it must be checked whether the torque of the star-connected motor is sufficient.

**Preference given
to d.o.l. starting**

By using a soft starter, the current surge accompanying the start-up of an electric motor is avoided, and the drive can be started with an almost constant torque. Soft starters or acceleration rate controllers are also used as a starting aid for the drives of large liquid ring vacuum pumps with magnetic couplings. Soft starting prevents decoupling of the magnetic coupling.

Start/stop frequency

The permissible start/stop frequency depends more on the drive than on the pump. As a result of the high starting currents needed for the start-up, electric motors become very hot. Acceleration of the rotating element, and in many cases the gears, leads to high loads acting on the couplings.

Under normal circumstances, 15 starts per hour are considered acceptable. Under exceptional conditions, consultation with the coupling and motor manufacturer is recommended. When starting larger pumps, the loads on the mains power should also be considered.

**High frequency
of start/stop
cycles**

Controlling the inlet volumetric flow rate

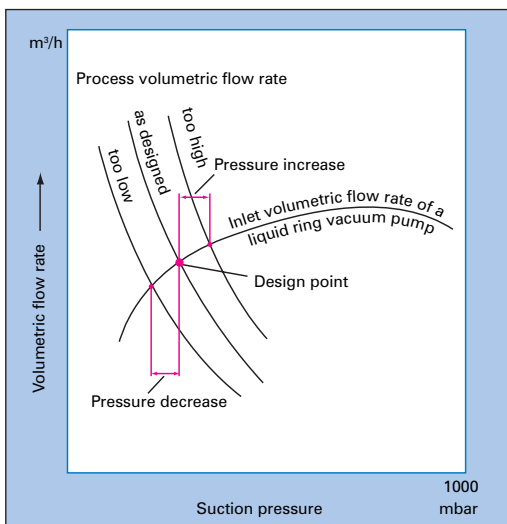
Against the background of the rising cost of electricity, the end-users of vacuum pumps and compressors increasingly analyse the commercial efficiency of their machines with a view to minimising running costs.

If the inlet volumetric flow rate is not controlled, the pump automatically runs up to the suction pressure at which the process volumetric flow rate is equal to the inlet volumetric flow rate. This can entail an

unnecessarily high power and cooling water consumption.

Figure 24 shows how the suction pressure of a liquid ring vacuum pump responds to a change in the process volumetric flow rate. The different types of control generally used

Fig. 24:
Effect of a change in suction pressure on the volumetric rate of flow



with liquid ring gas pumps to adjust the inlet volumetric rate of flow to specified operating conditions are explained below. Measures for saving energy are highlighted.

Speed Control

By controlling the speed, it is possible to adjust the inlet volumetric flow rate to suit the requirements of the installation and save energy at the same time. However, certain limiting parameters must be observed when selecting the speed.

Energy Saving

The *minimum speed* is determined by the circumferential speed of the impeller required to produce the necessary compression power. In this context, it is to be noted that the maximum compression power of a vacuum pump is given at a suction pressure of approximately 400 mbar, if the discharge pressure is 1013 mbar (compare to figure 15).

Minimum speed

The *maximum speed* is determined by the load-carrying capacity of the rotating components in the pump, in particular the shaft and the impeller.

Maximum speed

As well as a change in the compression power, a change in the speed will also result in a change in the power loss. On average, liquid ring vacuum pumps are characterised by an exponential dependency of the pump power input on the circumferential speed of the impeller and, therefore, on the speed of rotation. In order to save energy, it is therefore important to select as low a speed as possible.

The inlet volumetric rate of flow can be controlled by speed in the range from, say, 50 to 100% of the maximum inlet volumetric flow rate. In practice, however, the control range is usually much smaller, because the liquid ring gas pumps available are not ideally suited to the individual pumping requirement of the application.

Control range

Controlling the service liquid temperature

The costs of make-up and cooling liquids represent a major portion of the total running costs. By selecting a suitable method of operation and ensuring that there is a large difference between the temperatures of the service liquid and the make-up liquid or the

Automatic adjustment of the make-up liquid flow rate

cooling liquid, and if the control is effected by means of the make-up or cooling liquid flow rates, it is possible to reduce the running costs to a minimum.

Furthermore, it must be remembered that the inlet volumetric flow rate of a liquid ring vacuum pump also depends on the vapour pressure and therefore on the temperature of the service liquid. By making the make-up liquid flow rate constant, the efficiency of the unit cannot be maximised. This flow must be adjusted automatically. In practice, thermostat-type control dependent on suction pressure is the better solution, although it is more complicated.

Attempting to save liquid by reducing the service liquid flow rate would result in an uncontrolled reduction of the inlet volumetric rate of flow, which could lead to unacceptable vibration of the pumps

Increased availability**Connecting liquid ring gas pumps in parallel**

By sharing the process volumetric flow rate among several pumps, pump operation can be adapted more efficiently to the requirements of the installation. In addition to the regulating aspect, there is the advantage of operating at a reduced flow rate should one pump fail.

Bypass control

This is the type of control most frequently used, because it allows the process volumetric flow rate to be set from zero to a maximum. This method of control is not optimal if energy saving is the objective.

Figure 25 shows a typical example of bypass control: the excess gas discharged by the

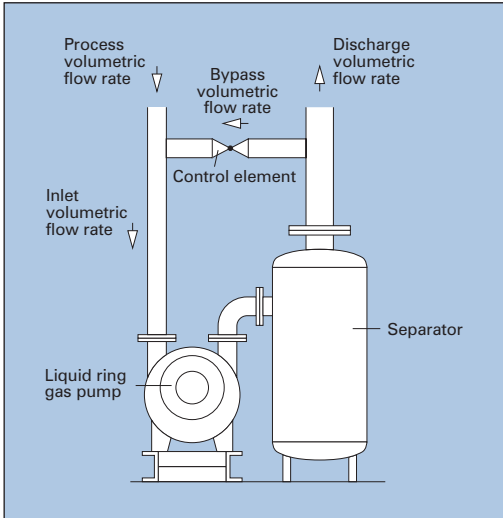


Fig 25: Bypass control

liquid ring gas pump is returned to the suction pipe via a pipe equipped with a control valve, this being fitted between the gas outlet line of the separator and the pump suction pipe.

Under no circumstances should the gas bypass line be connected between the discharge pipe containing the gas-liquid mixture and the suction pipe of the pump, because a mixture of gas and liquid of undefined composition would enter the suction nozzle. If the gas being handled by the liquid ring vacuum pump is allowed to be mixed with air, the discharge of this gas can be reduced by feeding air to the suction nozzle of the pump.

Types of construction

Liquid ring gas pumps are produced in various configurations. The difference is in the

number of stages, type of bearings, method of sealing the shaft, the materials of the pump components and the static test pressures.

Number of stages

The compression power to be generated as well as the operating behaviour and economic efficiency of the stages are all critical when selecting the number of stages required by the pump.

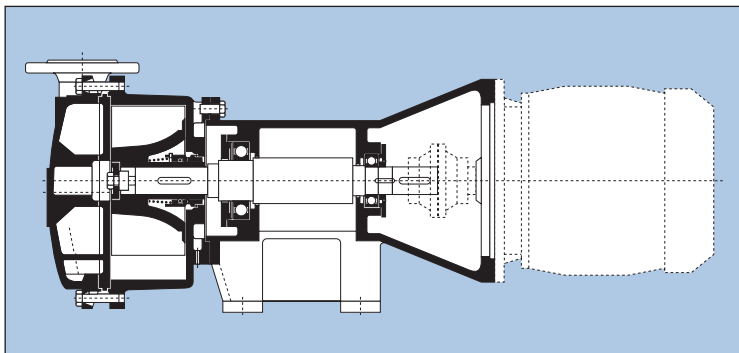
Single or multistage

Liquid ring vacuum pumps are designed with one or two stages. Liquid ring compressors for absolute discharge pressures of up to approximately 3.5 bar usually have one or two stages, but two or more stages where higher discharge pressures are required.

Shaft bearings

As a rule, the shaft has two radial bearings. These can be arranged either one at each end of the shaft or two at one end. Examples of a shaft arrangement with one bearing at each end are illustrated in figures 4 to 7. Figures 26 and 27 show designs with two bearings mounted at one end of the shaft.

Fig 26: Longitudinal section of a liquid ring vacuum pump of motor pedestal design



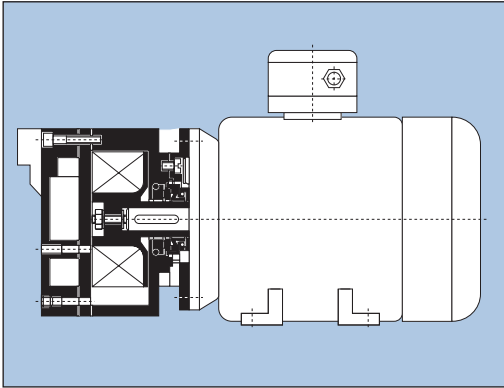


Fig 27: Longitudinal section of a liquid ring vacuum pump of motor pedestal design

Shaft seals

The type of seal is selected according to the degree of sealing integrity required. Compared with other types of compressor, the advantage of liquid ring gas pumps is that liquid is available at the shaft seals, and can be used for sealing or flushing purposes, for lubricating mating sliding components, or for removal of friction heat. The types of seal usually fitted on liquid ring gas pumps are single or double stuffing boxes.

Glandless pumps

Where liquid ring gas pumps are used for pumping toxic, carcinogenic or malodorous gases and vapours, or for compressing radioactive media, the requirements to be met in respect of sealing are so stringent that they can only be fulfilled by glandless pumps. This type of pump is fitted with either a magnetic coupling or a canned motor.

The common characteristics of both designs are a shrouded can and a shaft running in plain bearings. Magnetic couplings basically consist

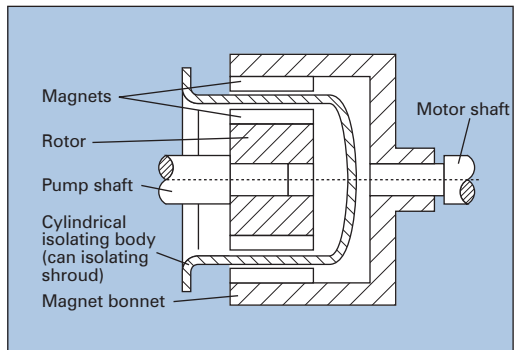
Conforming to the requirements of operation

Emphasis on sealing capability

of two magnet holders, one rigidly connected to the pump shaft, the other to the motor shaft. The can is positioned between the two magnet holders. This thin-walled tube is secured tightly to the pump casing at one end, and closed at the other (for this reason it is also called an isolation shroud). The design principle is illustrated in figure 28.

The magnets are made from rare earth metal cobalt alloys and rare earth metal iron alloys which are renowned for their superior density of magnetic energy and their magnetic

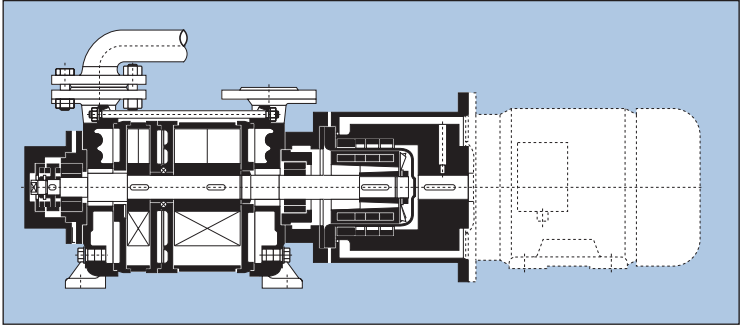
Fig 28: Design principle of a magnetic coupling



stability. Metal cans give rise to eddy current losses which generate heat. The magnitude of the heat loss depends on the magnetic mass and the speed of the coupling. To remove the heat, the inner magnet (rotor) is surrounded by service liquid.

Figure 29 shows the longitudinal section of a two-stage liquid ring vacuum pump with a magnetic drive. The shaft is supported by two radial bearings and a thrust bearing. The

Fig 30 (opposite): Liquid ring vacuum pump system



bearings are flushed with service liquid for lubrication and heat dissipation purposes.

Under more difficult starting conditions, where, for example, there is a high density service liquid, an automatic soft starter is used to stop the magnets becoming desynchronised when the pump is started. It is recommended that the drive of a magnetic coupling be switched off immediately after loss of synchronisation to prevent the components from being damaged.

*Fig 29:
Longitudinal
section of a two
stage liquid ring
vacuum pump
with a magnetic
coupling*



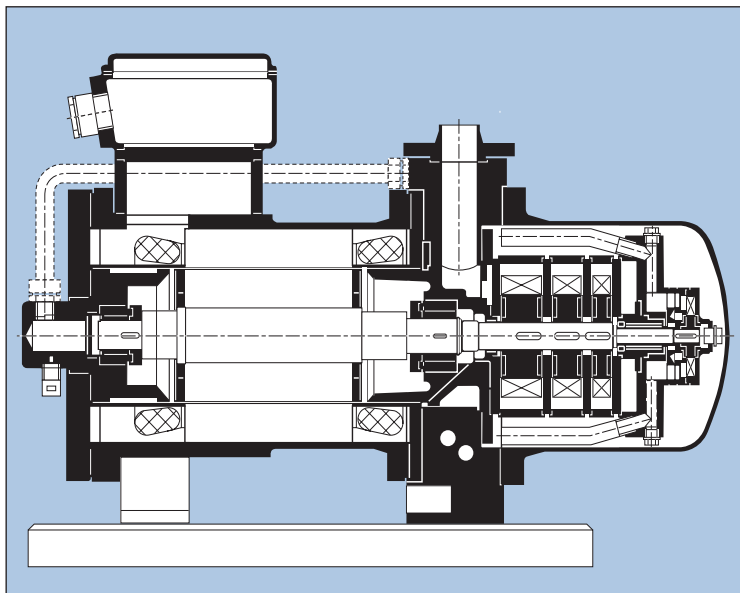


Fig 31: Longitudinal section of a liquid ring compressor with a canned motor which meets the most stringent sealing requirements

Figure 31 shows liquid ring compressor with a canned motor capable of meeting the most stringent sealing requirements.

Materials of construction

Liquid ring gas pumps are manufactured from a combination of different materials best suited to meet the operational requirements (see appendix) The materials of the accessories such as the separator, pipes and fittings are selected to suit the materials of the basic pump design.

Static test pressures

Explosion-protected pumps are used for handling inflammable substances (explosive

gases or vapours). They are subjected to high static test pressure.

Emissions

Sound

A pump in operation produces vibrations, some of which are emitted in the form of sound. All moving solid, liquid and gaseous parts and substances are sources of sound, which travels as an air or structure-borne noise from its source to the casing and any other surfaces of the pump, from where they are emitted to the surroundings in the form of air and structure-borne noise.

The speed of the liquids and gases flowing through the pump is a function of the speed of the impeller and the suction and discharge pressures of the pump. These values, therefore, have a direct effect on the sound power emitted. It is possible to establish a relationship between the sound power and the sound pressure by means of the size of the sound emitting area.

National and international standards (e.g. DIN EN 23742 and ISO 1996) specify the measuring techniques and instruments to be used in sound measurement.

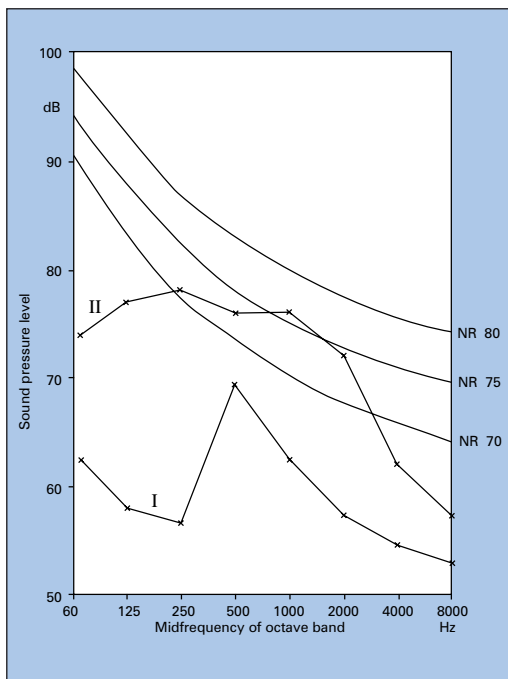
The sound pressure levels measured in two different sized liquid ring vacuum pumps are shown in figure 32. The peaks of the curves are found at a frequency which is the product of the speed and the number of impeller blades. The letters NR stand for "noise rating".

Sources of sound

Sound pressure and sound power

Low sound pressure level

Fig 32:
Measuring the
sound pressure
level of liquid ring
vacuum pumps



The operating data of these pumps and the A-rated sound pressure and sound power levels are listed in table 1.

Tab. 1:
Operating data and
A-rated sound
pressure and sound
power levels

Pump size		I	II
Suction pressure	mbar	80	80
Discharge pressure	mbar	1013	1013
Pump power input	kW	9.5	64
Speed	r.p.m	1450	735
Sound Pressure level	dB(A)	68	79
Sound pressure level	dB(A)	81	94

Vibrations

The magnitude and acceptability of vibrations are evaluated according to VDI guideline 2056, which gives details about the measuring devices, mounting arrangement of the test

piece and evaluation of the vibration intensity. The vibrations produced by liquid ring gas pumps result from the imbalance of their rotating parts and the sudden changes in the pressure levels taking place in the impeller blade cells and discharge chambers each time an impeller blade cell passes over the discharge port. Those places where the vibration energy is transmitted to other parts, i.e. the bearings, feet and pump flanges, usually serve as measuring points.

VDI guideline 2056 divides the test pieces into different groups distinguished by the fact that the acceptable vibration level increases with increasing machine size. Figure 33 shows a comparison of the measured values with the limiting values of an average-sized liquid ring vacuum pump. The term "effective velocity" is a measure of the vibration intensity.

Little vibration experienced

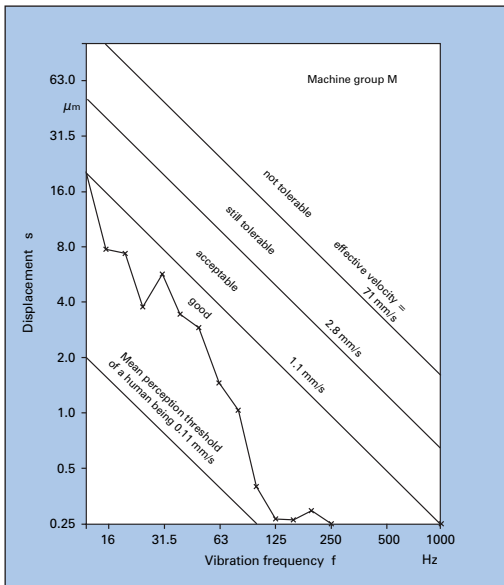


Fig 33:
Measuring the
vibration velocity of
a liquid ring
vacuum pump

Avoiding leakage**Leakage**

When handling harmful, explosive or malodorous media, every precaution must be taken to prevent leakage to the atmosphere. In many applications, leakage from the atmosphere into the system is equally undesirable, whether it be for safety or technical purposes. Even in those cases where both the medium being pumped and the service liquid added are harmless, should leakage be avoided, if only because it is unsightly.

It is obvious that any requirement in respect of sealing implies that testing must be carried out. Hydrostatic pressure tests including visual examination of the test piece are not considered sealing tests in this sense. The sealing between static components greatly influences the overall degree of sealing.

Low leakage flow rates

Leakage rates of less than $1 \cdot 10^{-3}$ mbar l/s can be achieved with clean, carefully machined standards parts. The leakage rate of shaft seals is given in the information and warranties provided by the seal manufacturer. Leakage tests can only be performed on machines which are not in operation.

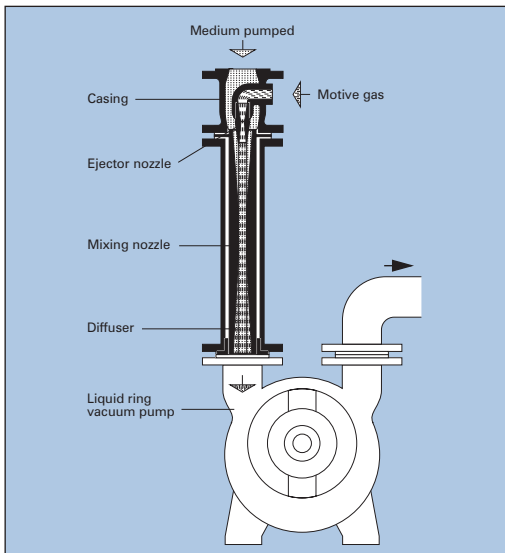
Extremely low leakage rates can only be attained on glandless designs such as on pumps driven via a magnetic coupling.

Combining liquid ring vacuum pumps with gas ejector vacuum pumps

The vapour pressure of the service liquid limits the operating range of liquid ring vacuum pumps on account of the suction pressure. The operating range can be extended to approximately 4 mbar by connecting the pump to an ejector which utilises the pressure gradient between the atmospheric pressure and the suction pressure of the liquid ring vacuum pump.

The arrangement of a gas ejector vacuum pump is shown in figure 34. In the ejector nozzle, the motive gas, i.e. atmospheric air or gas from the separator compressed to atmospheric pressure, is propelled at a velocity governed by the suction pressure of the ejector.

Extending the range of operation



*Fig 34:
Liquid ring vacuum pump combined with a gas ejector vacuum pump*

The right combination is crucial.

This causes the gas being pumped to be drawn into the mixing nozzle via the suction chamber of the ejector. Inside the diffuser, the velocity energy of the mixture is converted to pressure energy.

Ejectors are designed for use with liquid ring vacuum pumps by selecting their dimensions according to the suction pressures and inlet volumetric flow rates required. The right combination of pumps is therefore crucial. There are pump combinations for different pressure ranges and for water at different temperatures than the service liquid. The inlet volumetric flow rates of a liquid ring vacuum pump with and without ejectors are illustrated in figure 35.

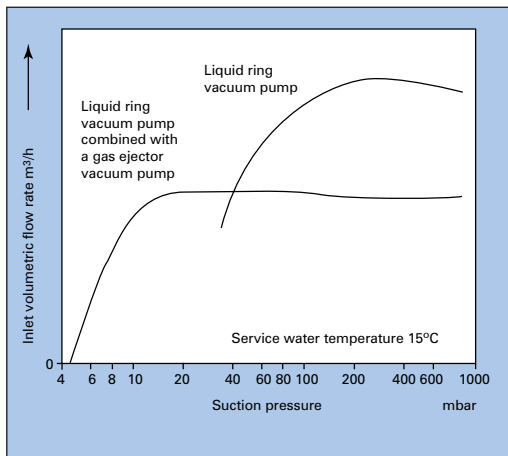
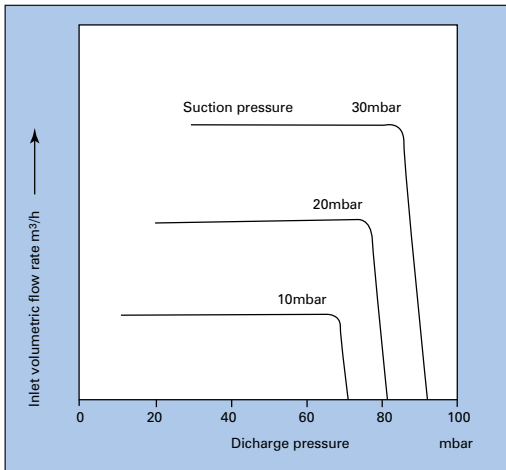


Fig 35: Inlet volumetric rate of flow of a liquid ring vacuum pump with and without a gas ejector vacuum pump

By reducing the inlet volumetric flow rate of the liquid ring vacuum pump, the discharge pressure of the ejector increases. However, this pressure must not exceed a given limit. If this is exceeded, the inlet volumetric flow rate

of the ejector drops. An increase in the inlet volumetric flow rate of the liquid ring vacuum pump will reduce the discharge pressure of the ejector. However, over a wide range this does not affect its inlet volumetric rate of flow. The operating behaviour of an ejector can be seen from the example of a characteristic curve shown in figure 36.



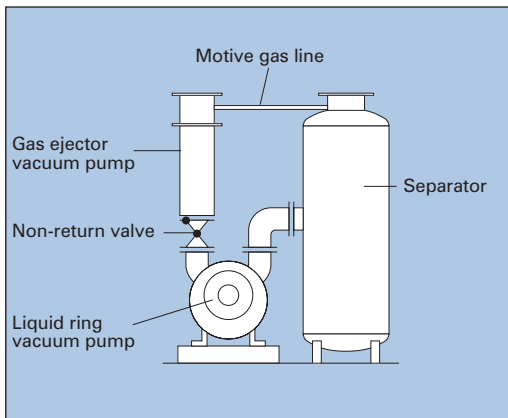
*Fig 36:
Characteristic
curves of a gas
ejector vacuum pump*

The connection of an ejector in front of the liquid ring vacuum pump does not affect the operating behaviour of the latter. When the suction side of the ejector is closed, the suction pressure of the liquid ring vacuum pump is outside the cavitation range, provided that the correct pump combination is selected. The ejector is either mounted directly on the suction nozzle of the liquid ring vacuum pump, or fitted inside the suction pipe. If required, a non-return valve can be fitted between the two pumps. Care must be taken to ensure that the valve produces no more than a small pressure drop (1 to 2 mbar). If, for process reasons, it is not possible to use

**No change in
the operating
behaviour**

air as the motive gas, gas from the gas outlet line of the separator is used for this purpose. This arrangement is shown in figure 37. In the high pressure range, the inlet volumetric flow rate of a pump combination is

*Fig 37:
Tapping the gas
from the separator*



smaller than that of the liquid ring vacuum pump alone (see figure 35). In those applications where the requirement is for a short evacuation period, the ejector is bypassed in this pressure range, or the motive gas connection has to be at least shut.

It must be noted that with atmospheric air as the motive gas, the altitude of the installation has an effect on the motive gas pressure.

The materials of construction of the ejector can be selected to suit the conditions of operation.

Accessories

Separators

The main purpose of a separator is to separate the mixture of gas and liquid discharged from the discharge nozzle of the

liquid ring gas pump into a gas and a liquid flow. However, separators are also used for other purposes, such as:

- service liquid ring storage tanks
- gas storage tanks
- settling tanks for the separation of dirt, or to separate liquids of different specific density
- heat exchangers for cooling liquid.

Additional uses

Separators are available in different designs. The basic designs are:

- upright standing version – stands beside the pump
- top-mounted version – mounted on top of the pump
- base-mounted version – arranged underneath the pump
- integrated version – integrated in the pump

Types of designs

When selecting the appropriate design, the duties of the separator, the required quality of separation, and the conditions prevailing on site all have to be considered. The separator design is determined by the inlet volumetric flow rate of the liquid ring gas pump, its dimensions and the flow rate of the service liquid.

Separators intended for use in recirculating or closed-circuit operation must have a sufficient supply of liquid and should be equipped with means of monitoring the level of the liquid.

Separators intended for use on liquid ring compressors must be provided with a safety valve connection. The regulations for construction and operation of pressure vessels have to be observed.

Fig 38:
Upright standing
version of a
separator

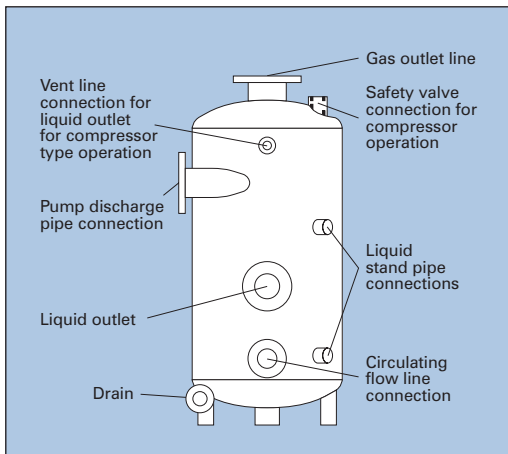


Fig 39:
Top mounted
version of a
separator

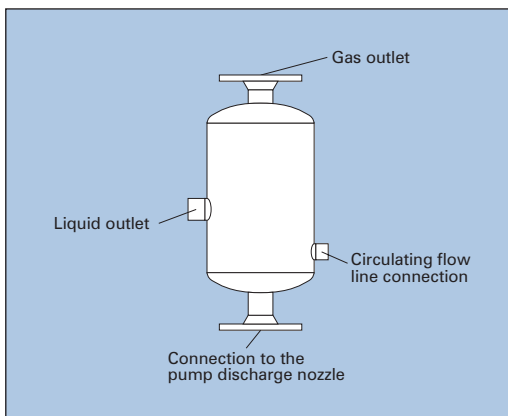


Figure 38 shows an example of an upright standing separator; the top-mounted version of a separator is shown in figure 39, each type with the necessary connections.

Discharge of liquid at working pressure

Liquid outlet

The liquid outlet of separators used in conjunction with liquid ring compressors must not be open to the atmosphere, as this

could result in a mixture of gas and liquid escaping. This is prevented by means of valve type traps.

Baseplates and baseframes

Small and medium-sized liquid ring gas pumps are usually mounted together with the motor on a common baseplate. For the larger pump sets, baseframes made from rolled steel sections are used.

Flexible couplings

Couplings are selected according to the torque to be transmitted, the starting frequency and the period of operation. Large pump sets are preferably fitted with couplings which have a spacer unit, because this allows the pump and driver to be disconnected without impairing their axial alignment.

Coupling guards

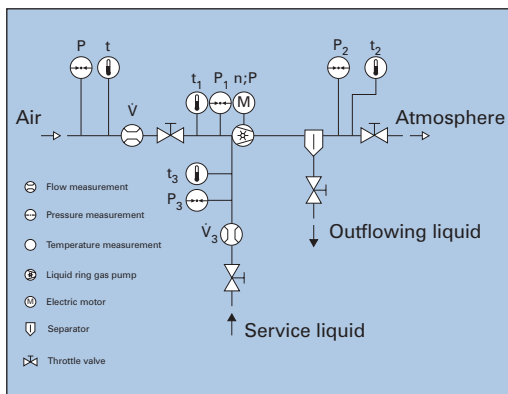
According to industrial safety regulations, couplings, belt drives and exposed shaft ends must be guarded so that they cannot be touched accidentally. Standards (PD 5304; DIN 31001) specify the details to be observed for the design of the guard. In installations subject to explosion hazards, the safety guard must be spark proof.

**Observe
industrial
safety
regulations**

Acceptance specifications

The acceptance specifications include a description of the test equipment and the test procedures applied during acceptance testing. In some cases, the equations given in the various acceptance specifications for correcting the inlet volumetric rate of flow and the pump power input vary from those applied by individual manufacturers.

Fig 40:
Test arrangements
on the basis of
DIN 28431



DIN 28431

Acceptance ruled for liquid ring vacuum pumps.

Although this standard has been written especially for liquid ring vacuum pumps, it can also be applied without restrictions to liquid ring compressors.

The usual tolerances of the inlet volumetric flow rate and the required power input are listed as maximum deviations in a table forming part of this standard. An example of a test arrangement is shown in figure 40.

PNEUROP 6612

Acceptance specification and performance tests for liquid ring vacuum pumps.

ISO 1217

Acceptance tests; Ref. No. ISO 1217
Displacement compressors.

HEI

Performance standard for liquid ring vacuum pumps.

HEAT EXCHANGE INSTITUTE (HEI),
Cleveland, Ohio 44115, USA.

Applications

In many cases, the typical properties of liquid ring gas pumps render this pump type the most favourable or even the only suitable pump capable of meeting the specified requirements. Some of its outstanding features to be highlighted in this context are:

- it is capable of handling almost all gases and vapours used in the chemical and pharmaceutical industries. For each requirement, the service liquid is selected to suit the product being pumped.
- compression accompanied by a very small temperature increase.
- liquid ring vacuum pumps are also capable of compression to overpressures, and liquid ring compressors can also be operated at suction pressures far below atmospheric.

**Advantages
due to
specific
properties**

Without claiming to be complete, the following summary lists the numerous possibilities for the application of liquid ring gas pumps:

Chemical process technology

Liquid ring gas pumps are used for distilling, drying, condensing, absorbing, evaporating and filtering purposes.

**Fields of
application**

Venting of steam turbine condensers

Liquid ring vacuum pumps are used for the start-up and condensing operations of steam turbine condensers.

Filter installations

Liquid ring vacuum pumps are suitable for use with any type of vacuum filter.

Steam and gas sterilisers

Before and after sterilisation, the steriliser chambers are evacuated with the help of liquid ring vacuum pumps.

Plastics extruders

Liquid ring vacuum pumps are used to de-gas and dry the plastic compound.

Vacuum calibration of plastic profiles

Liquid ring vacuum pumps are employed to generate a vacuum which draws the plastic profile against the walls of the mould.

Fields of application**Paper machines**

De-watering of the wet section of paper machines is performed with liquid ring vacuum pumps.

Sugar mills

In sugar mills, liquid ring compressors are used for compressing carbon dioxide; liquid ring vacuum pumps are employed in the vacuum-pan house and for drying purposes.

Vacuum driers

For the purpose of vacuum drying, liquid ring vacuum pumps are used in connection with different types of vacuum drier.

Solvent recovery

To avoid health hazards and environmental pollution, exhaust flows containing solvents are cleaned. The processes applied to recover the solvents could not be carried out without the use of liquid ring vacuum pumps or liquid ring compressors.

Lowering of the ground water table

Liquid ring vacuum pumps are used to evacuate a tank. Air and ground water are extracted from filter pipes over the tank.



*Fig 41:
Liquid ring
compressors
installed in a
drinking water
treatment plant*

Drying and impregnation of wood

Wood can be dried quickly and without cracking if it is put under vacuum before being dipped into an impregnation bath.

Sludge extraction vehicles

A liquid ring vacuum pump is used to produce a vacuum in a collecting tank into which the sludge is then pumped automatically.

Water works

Liquid ring compressors are used in water works for the oxidation process, to aerate the water, and to effect a reverse flow through the filters.

Vacuum toilets

Sewage is pumped pneumatically into a collecting tank under vacuum.

Mineral water production plants

The gases contained in natural mineral water are removed by means of evacuation.

*Fig 42:
Liquid ring vacuum
pump on a
chemical plant*



Automobile manufacture

The cooling, braking and air conditioning systems are evacuated before being filled with liquid.

Milk collecting tank trucks

Milk is drawn out of the tanks in dairy farms and into the tanker by means of a liquid ring vacuum pump.

Brick manufacture

To improve the quality of the clay used in brick manufacture, it is de-gassed before pressing.

Automatic bottling plant

Bottles and cans are evacuated before filling. This process creates a low-oxygen atmosphere which prevents the beverage from oxidizing.

Bleaching of chemical pulp

Liquid ring compressors are used in oxygen - ozone - bleaching section for chemical pulp

Vacuum mixing equipment

Vacuum mixing equipment is used in production of liquid and paste - like products; by continuous deaeration and degassing, a very high degree of homogeneity of products is achieved.

Fields of application**Mine gas extraction**

The gas which forms during coal mining is drawn off continuously to eliminate all risk of explosion.



Appendix

Vapour pressure of water

Temp. °C	Press. mbar	Temp. °C	Press. mbar	Temp. °C	Press. mbar	Temp. °C	Press. mbar
10	12.7	18	20.62	26	33.60	45	95.8
11	13.12	19	21.96	28	37.78	50	123.4
12	14.01	20	23.37	30	42.41	55	157.4
13	14.97	21	24.85	32	47.53	60	199.20
14	15.97	22	26.42	34	53.18	65	250.1
15	17.04	23	28.08	36	59.40	70	311.60
16	18.17	24	29.82	38	66.24	75	385.5
17	19.36	25	31.66	40	73.75	80	473.60

Materials and material combinations commonly used in the manufacture of liquid ring gas pumps

Component	Material combination				
	0A	0B	3B	4A	4B
Suction/discharge cover	0.6025	0.6025	2.1050	1.4308	1.4408
Guide plate element (port plate)	0.6025	0.6025	2.1050	1.4308	1.4408
Casing	0.6025	0.6025	2.1050	1.4038	1.4408
	1.0038	1.0038		1.4541	
Impeller	2.0196	0.7040	2.1052	1.4460Cu	1.4460Cu
	2.0975	0.7043		1.4541	1.4571
		1.4027			
		1.0570			
Shaft, in contact with the liquid	1.4021	1.4021	1.4301	1.4301	1.4571
Shaft not in contact with the liquid	1.0060	1.0060	1.0060	1.0060	1.0060
Shaft protection sleeve	1.4027	1.4027	1.4410	1.4410	1.4410
					1.4581
Bearing housing, bearing cover	0.6025	0.6025	0.6025	0.6025	0.6025

The numbers indicated are material numbers as per DIN 17007.