Points to be Considered when Purchasing a Steam Jet Vacuum Pump

By GEA Wiegand

1. Suction Flow Determination

It is advisable to apply utmost care to the accurate determination of the suction flow. The steam consumption of a steam jet vacuum pump once selected is fixed and does not decrease even if the actual suction flow rate turns out to be below that on which the selection was based. It is customary to specify the suction flow rate in mass flow i.e. kg/h at the required suction pressure.

The size selection of mechanical pumps is often done based on the volumetric suction flow requirement. The volumetric suction flow characteristic of these pumps is nearly constant for different suction pressures. This renders the use of volumetric flow requirement specifications as more convenient.

1.1 Air Leakage

A hole of 1 mm ² passes approximately 0.83 kg/h of air into a vacuum system when operating at a pressure of and beyond 530 mbar. Refer to chapter "Air Leakage into Vacuum Vessels".

To estimate the leakage air rates through flange connections of larger pipe sizes, a factor of 200 to 400 g of leakage air per hour and meter of gasket length is applied. These values can be reduced to 50 to 100 g/h if special flange connections (e. g. tongue and grove flanges, smooth flange surface finish or special gaskets) are used.

The air rates leaking into vacuum systems vary considerably depending upon whether the connections are welded or flanged, as well as the number of connections, sight glasses, cocks, valves, stuffing boxes etc. The following chart, Table 1, is based on experience gained from existing plants. It lists the recommended leakage air rates to use for the size selection of vacuum pumps, for different system volumes and types of pipe connection employed.

System volume in m³ / Equipment and pipe connections	0.2	1	3	5	10	25	50	100	200	500
	Leakage air rates in kg/h									
Normal gaskets, mostly flanged	0.15–0.3	0.5–1	1–2	1.5–3	2–4	4–8	6–12	10–20	16–32	30–60
Partly flanged, partly welded	0.1–0.2	0.25–0.5	0.5–1	0.7–1.5	1–2	2–4	3–6	5–10	8–16	15–30
Mostly welded, special flanges and gaskets	< 0.1	0.15–0.25	0.25–0.5	0.35–0.7	0.6–1.2	1–2	1.5–3	2.5–5	4–8	8–15

Fig. 1 Selection of vacuum producers. Recommended leakage air rates

1.2 Gases and Vapours Released by the Product

The non-condensable and condensable constituents of the suction stream must be differentiated. (Refer to chapters "Gases and Vapours under Vacuum" and "Steam and Air under Vacuum").

To determine the condensability of the vapours involved, their vapour pressure curves and molecular weights are required.

Additionally, for discontinuous processes, the amounts of vapours released from the process while lowering the system pressure must be known.

Finally, the temperature of the gas and vapour mixture to be extracted influences considerably the steam jet vacuum pump selection.

Points to be Considered when Purchasing a Steam Jet Vacuum Pump (continued)

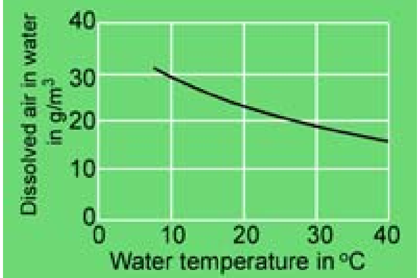


Fig.2

Solubility of air in water at saturation

1.3 Air and Gases Released from the Cooling Water

The cooling water normally contains dissolved air and gases. These are released under vacuum. The quantities of air in solution depend on the water temperature.

Fig 2 illustrates the relationship. Attention should be paid to the possibility of air bubbles and CO_2 being present in the cooling water. These are released under vacuum and, hence, to be added to the steam jet vacuum pump suction flow requirement.

1.4 Load splitting

When the suction flow requirement cannot be determined accurately, often times, excessive safety margins are applied. This entails increased motive steam consumption rates. One way to avoid this is by dividing the total duty into two parallel streams and the use of two parallel jet vacuum pumps. One is selected for 1/3rd and the second for 2/3rd of the total required capacity. When the real requirement is known, after plant start-up, one or the other of the two jet pumps can be turned off to save motive steam and cooling water.

The additional investment is in a set of shut-off valves for each suction connection and motive steam supply line to the two pumps.

Please contact our experienced project engineers for advice.

Required Suction Pressure

The suction pressure is determined by the process requirements. Often, a safety margin is applied, i.e. a lower pressure is specified than is really needed. This is a questionable approach as it leads to:

Excessive steam consumption rates

Excessive cooling water consumption rates

Unnecessarily large diameter of the suction pipe line

Unnecessarily large and therefore expensive steam jet vacuum pumps

According to our experience and as illustrated by the curve in Fig. 1 below, if a safety margin is to be included in the size selection calculation of a steam jet vacuum pump, this factor should be applied to the suction flow rate and never to the suction pressure.

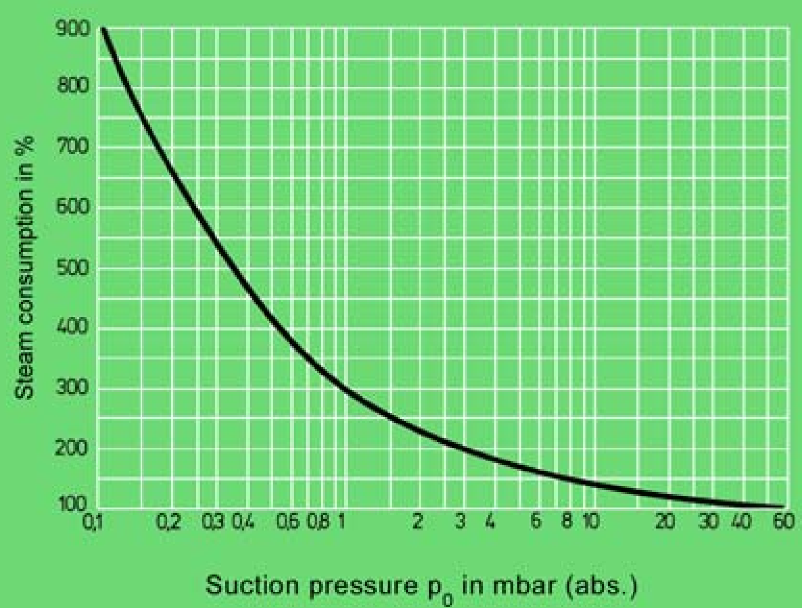


Fig. 3

Fig. 3

The curve shows the percentage increase in steam consumption within the range of 60 to 0.1 mbar taking the steam consumption at 60 mbar as 100%. The curve is based on cooling water of 25°C and on motive steam of 6 bar(g) pressure. As can be seen, at a suction pressure of 1 mbar, the steam consumption amounts to 300% compared to that at 60 mbar. At 0.1 mbar, it is 900%. The chart illustrates the over-proportionally high increase in motive steam consumption for every 1 mbar rise in vacuum at suction pressures below 10 mbar.

3. Direct Contact versus Surface Type Condensers

When utilizing direct contact condensers, the process fluid comes into direct contact with the cooling water. Direct contact condensers are insensitive to fouling and are, therefore, reliable in operation. It should be noted, however, that direct contact condensers cannot be recommended if ammonia is present in the process stream. The contact with the cooling water leads to the formation of non-dissolvable carbonates and fouling. Direct contact condensers are simple in design and therefore considerably cheaper to manufacture than surface type condensers.

Direct contact condensers can be internally rubber lined or otherwise coated against corrosion. Smaller units are easily manufactured in porcelain or in a synthetic plastic material.

Surface condensers offer the advantage of separating the process fluid from the cooling water. They are used in all cases when environmental or other considerations do not permit the contact of the process fluid with the cooling water.

If used as pre-condensers (i. e. upstream of the first steam jet vacuum pump), the condensate can be recovered in a pure state.

When installed downstream of a steam jet vacuum pump, the condensate of the motive steam and that of the process fluid mix. Depending upon the nature of the process, a solution is formed.

Jet pumps can be designed to operate with a suitable process vapour as motive fluid. This is done in all cases when any contact of steam with the process fluid is to be avoided.

Surface type condensers are available with fixed or removable tube bundles.

Condensers with fixed tube bundles cannot be mechanically cleaned on the shell side, whereas removable tube bundles can be cleaned on both the tube and the shell side.

Surface type condensers operate without problem if ammonia is present in the process fluid as the cooling water does not come in contact with the process stream.

It remains to be mentioned that direct contact condensers require less cooling water than surface type condensers.

If you have any questions, please feel free to contact our experienced engineers.

4. Installations

4.1 "Barometric" Installation

Whenever possible, steam jet vacuum pumps are installed "barometric" permitting the cooling water and condensate to drain out freely through the barometric legs without pumping. The same applies to the removal of condensate from surface type condensers.

A column of mercury of 760 mm equals the pressure of the atmosphere. Water is 13.6 times lighter than mercury. Therefore, the corresponding height of water is 760 x 13.6 = 10,330 mm WC or 10.33 m WC. This height is referred to as "barometric height". Depending upon the individual condenser pressures of a multi-stage steam jet vacuum pump, this height less the equivalent height of the actual pressures is required to ensure free drainage of the cooling water/ condensate through the barometric legs.

Because the draining water may be carrying entrained gases when passing down through the barometric legs, and to overcome any pressure losses, it is recommended to add to the theoretically required height a safety margin of approximately 0.5 m.

Fig. 1 shows schematically a barometric installation. If a barometric installation is not feasible due to insufficient available height, a semi-barometric installation should be considered.

4.2 "Semi-barometric" Installation

Depending upon the available height there are various alternatives of installation.

Fig. 2 illustrates a four-stage steam jet vacuum pump using a closed hotwell. The pressure difference between the 1st and the 3rd stage condenser amounts to 400-40 = 360 mbar corresponding to a water-column of 3.7 m height. The dimensions shown in fig. 2 indicate that the installation requires an overall height of 7 to 8 m.

The height requirement can be reduced further by the installation of a float valve in the hotwell (fig. 3). In this way, the necessary height of the barometric legs is reduced to 1.5 m which considerably reduces the overall height of the steam jet pump.

In exceptional cases a siphon can be installed between two condensers. This allows that cooling water and condensate is drawn from the condenser operating under higher pressure into the condenser with the lower pressure. From here, the liquid is extracted by means of a water pump.

Advice: If for any reason, the extraction pump fails (e.g. due to a power failure), the water level in the condensers may rise to the point of entering into the system to be evacuated. If this is to be prevented a variety of precautions are at hand. For instance: Quick-acting automatic shut-off valves can be installed in the steam and cooling water supply lines. These cut off the steam and water supply in case of an extraction pump failure.

4.3 Non-barometric Installation

Steam jet / liquid ring pump combinations per fig. 4 require a total installation height of less than 2 m. Please refer also to chapter "Steam Jet / Liquid Ring Vacuum Pumps". A multi-stage steam jet vacuum pump (without liquid ring pump) with surface type condensers has the identical low installation height, if the condensate is drained off via two alternately working collector tanks. Please refer also to chapter "Arrangement of Steam Jet Vacuum Pumps, fig.13".

Points to be Considered when Purchasing a Steam Jet Vacuum Pump (continued)

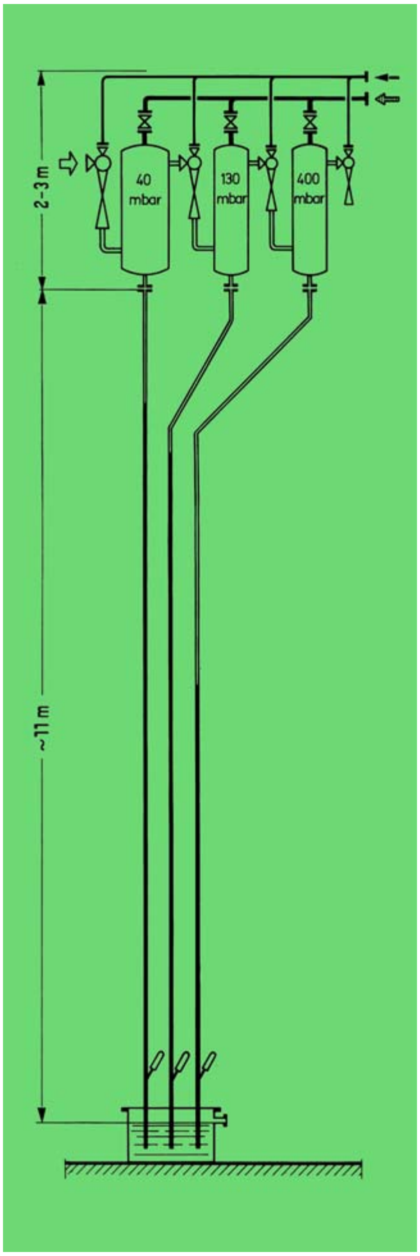


Fig. 1
Barometric installation of a steam jet vacuum pump utilizing direct contact condensers

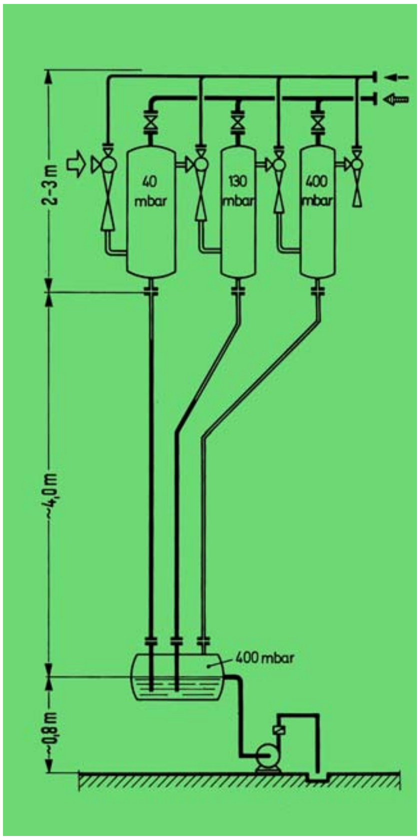


Fig. 2
Semi-barometric system with closed hotwell and water extraction pump

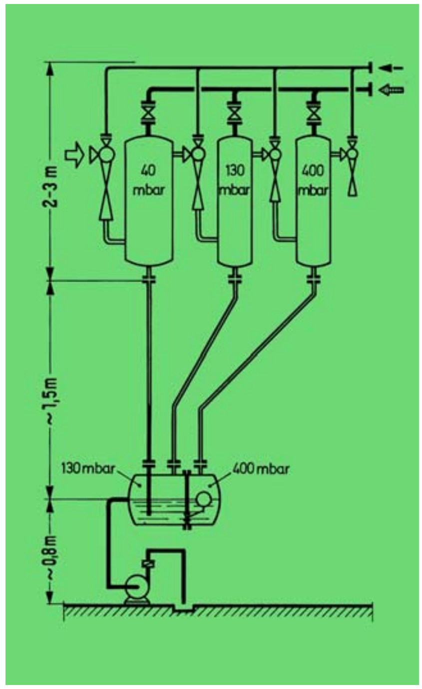


Fig. 3
Semi-barometric system with closed hotwell, float valve, and water extraction pump

The same principles applied in figs. 1-3 are also applicable to surface condensation.

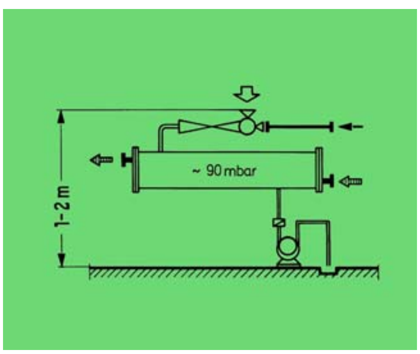


Fig. 4
Non-barometric system with surface type condenser and water-ring pump

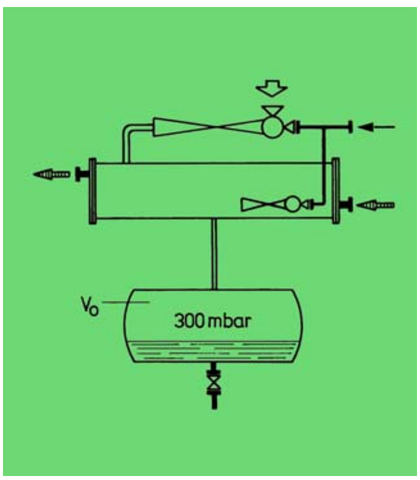
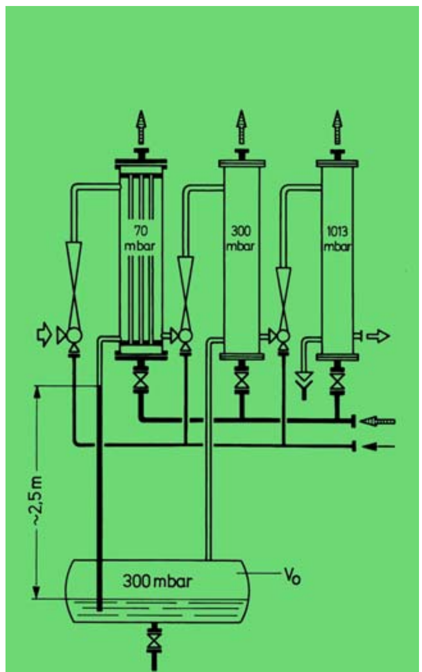


Fig. 5
Non-barometric system with surface type condenser and condensate collector tank, also to be used for continuous operation by the utilization of two alternately working collector tanks



V_o = Vessel volume for total condensate during batch

Fig. 6
Semi-barometric system with surface type condensers and condensate collector tank for batch operation, also to be used for continuous operation by the addition of an alternately working collector tank.

Points to be Considered when Purchasing a Steam Jet Vacuum Pump (continued)

5. Motive Steam Properties

Steam ejectors are available for steam pressures ranging from 1 to 40 bar(g).

Motive steam of less than 1 bar can also be used, for instance for multi-stage jet pumps, if a liquid ring pump is used as the final stage.

If designed for a low suction pressure, a steam jet vacuum pump can even be operated with below atmospheric pressure steam, drawn, for instance, from the pressure side of a down stream condenser stage.

If any source of heat is available, a suitable evaporator is needed to produce motive steam. For example, the condensation heat of a distillation column condenser can be used to generate motive steam. In this way the heat of condensation is recovered rather than passed onto the cooling water or the atmosphere and lost.

Jet vacuum pumps can be operated utilizing a motive fluid other than steam. This may be desirable for environmental reasons. In these cases, a suitable process vapour is used. The condensate of the motive vapour and product can be recycled without burdening the environment.

In cases when motive steam is available at different pressure levels, the question arises which pressure is the most economical and efficient to be used.

For small suction flows of approximately 1 kg/h, it is advisable to choose the lower pressure because higher steam pressures require smaller nozzles sizes, which causes manufacturing problems. In fact, a steam jet vacuum pump required for 1 kg/h and 10 bar motive steam would have to be designed oversize to enable the manufacture of the nozzle. Further, small nozzles sizes are sensitive to blockage by rust flakes, weld spatter, or other foreign particles.

A steam jet vacuum pump should always be operated with the steam pressure for which it is designed. If the steam pressure is lower than the design, the proper functioning can not be ensured. A higher steam pressure results in a higher steam consumption without increasing the pump performance.

In case of a fluctuation in the steam supply pressure, it is advisable to install a pressure regulator. Further, it is essential to ascertain the available steam pressure at the point of the steam jet vacuum pump installation. Often this is considerably lower there than the boiler pressure.

Steam jet vacuum pumps operate most efficiently when supplied with dry saturated or slightly superheated steam. Wet steam erodes the nozzle or diffuser and must be dried by means of an effective water separator.

The motive steam temperature must be known for the design a steam jet vacuum pump as a higher degree of superheating influences its geometry.

6. Cooling Water Properties

Steam jet vacuum pumps must be selected for the most unfavourable conditions, e. g. for the maximum cooling water temperature. Usually, well water temperatures remain constant throughout the year. River and sea temperatures, however, vary from approximately 3 to nearly 30°C. The same applies to cooling tower water, which varies considerably between summer and winter. The motive steam and cooling water consumption of a steam jet vacuum pump is highly dependent on the cooling water temperature on which the selection is to be based. This is especially true if condensable vapours are to be compressed.

For example: To extract 100 kg/h of water vapour from a system at 6 mbar using 3 bar motive steam and cooling water of 15°C, the motive steam consumption is approx. 200 kg/h. When using 28°C cooling water, the motive steam consumption becomes 400 kg/h.

It may be advisable to adjust the steam supply in relation to the changing cooling water temperatures over the year. This can be accomplished by exchanging the motive steam nozzles for new ones designed for the changed conditions or by altering the motive steam pressure. In the latter case, an automatic steam pressure control station is recommended.

The cooling water supply pressure to direct contact condensers should not fluctuate because this affects the vacuum. Direct contact condensers require a relatively low supply pressure. A pressure of 0.2-0.5 bar gauge is sufficient. (Spray condensers are different and require a higher water supply pressure). Under certain conditions, direct contact condensers can pull their own cooling water requirement since they are working under vacuum. When using surface type condensers, the cooling water supply pressure must be sufficient to overcome the pressure losses of the water boxes and the tubes.

Often the cooling water return temperature is limited to a maximum, for example to 40°C, to avoid calcium carbonate fouling problems. The max. return temperature must be specified for the equipment selection.

The nature of the water (sea or fresh water) and the chemical properties must be known to determine the most suitable condenser design and the maximum tolerable temperature rise.

If you have any questions, please contact our experienced engineers.

Points to be Considered when Purchasing a Steam Jet Vacuum Pump (continued)

7. Materials of Construction

It is customary to manufacture the steam jet vacuum pump from the same or an equally resistant material as the process plant which the pump is to keep under vacuum. Frequently used materials are steel and stainless steels. When sea or brackish water are used for cooling, as a minimum requirement, the direct contact condensers are internally coated with a corrosion protecting coat or rubber lined. Surface type condensers are manufactured in seawater-resistant bronze. If carbon steel is used, the surfaces are coated by a corrosion protecting coat.

If the process plant is made of enamel or high alloy steel such as Hastelloy, the required steam jet vacuum pumps are generally made of porcelain, glass or graphite.

In all cases when standard materials cannot be used, the steam jet vacuum pumps are available in materials complying with our customers' specific requirements.

If you have any questions, please contact our experienced engineers.

8. Evacuation Time

The time required to reduce the process plant's system pressure from atmospheric pressure to the required vacuum depends upon following five variables: The system space, the kind and capacity of the vacuum pump used, the leakage air rates entering and the amount of gases and vapours released by the product and the cooling water.

In most cases (particularly when continuous processes are involved) the evacuation time as is reached by the chosen vacuum pump is sufficiently short. If, however, the required time is shorter, an auxiliary start-up pump is needed. Depending upon the required vacuum, single or two stage vacuum pumps are installed.

Normally, the utility requirements of auxiliary pumps are not of any greater importance as they operate only for a short period of time. However, care must be taken to ensure that the steam pipe lines are large enough in diameter to pass the relatively high steam flow rate needed without any excessive pressure losses.

Start-up pumps are best operated with the highest pressure steam available on site. The motive steam requirement is considerably reduced. For example, the 10 bar steam requirement amounts to only 40% of that of 3 bar.

Start-up steam jet pumps are put into operation simultaneously with the vacuum pumps for normal operation. They can be shut off manually or automatically (using a pressure switch) by closing the suction and the motive steam supply line. To determine whether or not an auxiliary start-up pump is needed we require the following information:

- Required pull-down time
- Volume of the system to be evacuated
- Leakage air entering the system
- Gases and vapours in kg/h released during the evacuation
- Kind and suction capacity of the vacuum pump used

For further information refer to chapter "Leakage Air into Vacuum Pumps"

If you have any questions, please contact our experienced engineers.

Points to be Considered when Purchasing a Steam Jet Vacuum Pump (continued)

9. International Design Codes

In accordance with national and international safety rules, steam jet vacuum pumps and condensers for steam jet vacuum pumps do not require any acceptance procedures by official authorities, such as for instance TÜV, ISPESL, Dutch Dienst voor het Stoomwezen, etc, because they operate under vacuum.

Nevertheless, surface type condensers are often required to be designed to a pressure vessel code to permit their later use for duties involving above atmospheric pressures.

In such cases, the necessary stress calculations are carried out in accordance with the requirements of various codes such as AD-Regelwerk, ASME-Code etc.

If the condensers are to be built to any other design codes such as TEMA, HEI or any Works Standard Specifications, we need to know. If the requirements are not known to us, we will offer our own standard execution which is based on the "Allgemeinen Regeln der Technik" adjusted to the latest "Stand der Technik" (State-of-the-Art).

Flanges are supplied to DIN PN 10 or 16 as standard. ANSI or BS flanges are available on request. The equipment is also available with only the outside connecting flanges to ANSI or BS or with all flanges to these standards i.e. including the flanges internal of the package.

Our experienced project engineers are at your disposal for advice.

10. Steam Jet Vacuum Pump Versus Steam Jet / Liquid Ring Pump Combination

There are applications for which steam jet/ liquid ring pump combinations are advantageous and economical. This especially applies when:

- The available motive steam pressure is less than 1.5 bar
- The head room available for the installation of a steam jet vacuum pump with barometric condenser is insufficient
- A liquid ring pump is already available and the pressure required by the process is considerably lower than can be reached by a liquid ring pump. It is the specific advantage of a 1st stage steam jet / liquid ring pump combination (over a liquid ring pump utilizing an air ejector as a 1st stage) that motive steam is condensed upstream of the liquid ring vacuum thus considerably reducing the air load for the liquid ring pump.
- Large suction flows at suction pressures below approx. 60 mbar are to be extracted. This is the case for example in mineral oil refineries. Here, each requirement must be examined individually especially as the suction streams contain a number of components: These are non-condensable and condensable hydrocarbons which are partly dissolvable one in the other, and inert gases which are partly dissolvable in the operating water

To optimise the selection of a steam jet vacuum pump / the liquid ring pump, combination a variety of factors have to be taken into consideration. These are:

- Fractions of non-condensable gases and condensable vapours
- Cooling water temperatures, min/max.
- Motive steam pressure
- Utility costs including costs of motive steam
- Investment costs
- Maintenance costs
- Required pay back time
- Required materials for construction
- Expected service life
- Spare parts requirement

Depending upon these factors, the optimum inter stage-pressure normally turns out to be in the range 50 and 300 mbar.

To avoid or significantly reduce the costs for waste water, it is advisable to pass the liquid ring pump operating water through a decanter and re-circulate the water through a cooler to remove the heat of compression and condensation.

On the basis of our extensive experience and aided by computer programmes, we are in the position to determine the most favourable steam jet / liquid ring vacuum pump combination for the specific requirements and conditions of our customers. Regarding the make of the liquid ring, we have the liberty of choice and can attend to the preferences of our customers.

Questionnaire

for the planning of a steam jet vacuum pump or a vacuum condensation plant

1. Suction flow[1])

Air .... kg/h, mol weight .... kg/kmol, Incondensable vapours [2] .... kg/h, mol weight .... kg/kmol

Water vapour .... kg/h, mol weight .... kg/kmol, Condensable vapours [2] .... kg/h, mol weight .... kg/kmol

Suction temperature .... °C

[1]) In case of discontinuous operation state masses and time. .... [2]) Several components to be stated separately.

2a. Suction pressure .... mbar (abs.) 2b. Discharge pressure .... mbar (abs.)

3. Condensation

Mixing condenser (direct contact) ☐ Surface condensers ☐ Installation: horizontal ☐ vertical ☐

Tube bundle: fixed ☐ removeable ☐ max. allowable tube length: .... mm; external tube dia. .... mm; wall thickness .... mm

Fouling factor: cooling water side .... m²K/W vacuum-/product side .... m²K/W

Cooling water: tube side ☐ shell side ☐ After condenser: yes ☐ no ☐

4. Type of installation

Barometric ☐ Semi-barometric ☐ Non-barometric ☐

5. Motive steam condition

Pressure: min.: .... bar norm.: .... bar max.: .... bar Pressure (abs.) ☐ Pressure (g) ☐

Temperature: min. .... °C norm.: .... °C max.: .... °C

6. Cooling water

River water ☐ Tower water ☐ Well water ☐ Sea water ☐ Brackish water ☐

Temperature: max. .... °C min. .... °C Pressure min. (abs.) .... mbar; Allowed pressure drop for surface condensers .... mbar

7. Materials

Ejectors: .... Motive nozzles: ....

Mixing condensers: ....

Surface condensers: Tubes .... Tube sheets .... Shell side.................... Tube side ....

8. Pre-evacuation

Volume of total system .... m³ to be evacuated in .... min from atm. pressure to .... mbar

Motive steam pressure: .... bar (abs.)

9. Special construction

Flanges

	DIN	ANSI	RF	FF	BS
Vacuum side ext. connections	PN	................lbs	☐	☐	Table ....
Vacuum side int. connetions	PN	.... lbs	☐	☐	Table ....
Motive side:	PN	.... lbs	☐	☐	Table ....
Water side	PN	.... lbs	☐	☐	Table ....

Counter flanges yes ☐ no ☐

Jet pump stage ...... to ..... jacketed heating medium with transfer media: fluid ☐ vapours ☐ Pressure (g) ...... bar Temp. ...... °C

Design codes Surface condensers: AD ☐ ASME ☐ other ☐ ....

Design Shell side: Vac. ☐ .... bar (g) .... °C Shell side: Vac. ☐ .... bar (g) .... °C

Mixing condensers: AD ☐ ASME ☐ other ☐ ....

Special requirements: TEMA ☐ Works standard ☐

Inspection by: .... Other requirements: ....

10. Combination: Steam jet-/liquid ring vacuum pump

with ☐ / without ☐ heat exchanger to recool the operating liquid; cooling water temperature .... °C

Operating liquid media ....; temperature: .... °C

Motor data: .... V .... Hz; Ex-Protection: yes ☐ no ☐ Type of protection: .... Temperature class: ....

11. Particulars on optimization

Operating hours/Year: .... h; Amortization period ....; Utility costs: motive steam .... cooling water .... electricity ....