Construction, Working, Operation and Maintenance of Liquid Ring Vacuum Pumps

By
K. P. Shah
Email: kpshah123[at]gmail.com (Please replace [at] with @)
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The information contained in this article represents a significant collection of technical information on construction, working, operation and maintenance of liquid ring vacuum pumps. This information will help to achieve increased reliability at a decreased cost. Assemblage of this information will provide a single point of reference that might otherwise be time consuming to obtain. Most of the information given in this article is mainly derived from the literature on the subject indicated in the reference list given at the end of this article. For more information, please refer them. All information contained in this article has been assembled with great care. However, the information is given for guidance purposes only. The ultimate responsibility for its use and any subsequent liability rests with the end user. Please see the disclaimer uploaded on http://www.practicalmaintenance.net.

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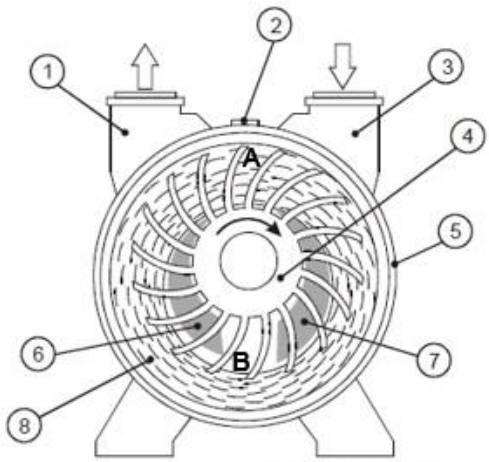
Liquid Ring Vacuum Pumps

Liquid ring vacuum pumps and compressors are rotary machines. They operate according to the positive displacement principle. In these machines, a liquid is made to act as a piston. The liquid is generally water for most of the applications and hence they are also known as water ring water piston or liquid piston rotary pumps and compressors. Information about construction, working, operation and maintenance of liquid ring vacuum pumps is given in this article.

Construction and Working of Liquid Ring Vacuum Pumps



Liquid Ring Vacuum Pump
(Cross Section of Operating Chamber)

Construction

As shown in above figure, in a liquid ring vacuum pump, the pumped gases/vapors (air is a mixture of gases) are sucked via the inlet connection (3) into the pump-motor unit and pushed out via the discharge connection (1).

The impeller (4) with the blades is located in the cylindrical housing (5). The impeller is arranged eccentrically relative to the housing. In addition, the housing also contains the operating/service/seal liquid (8). This liquid is fed in via the operating liquid port (2) and is output together with the pumped gases via the discharge connection (1).

Working

When the impeller turns, the operating liquid is put into motion and accelerated. This forms a liquid ring that also rotates. Due to centrifugal force, this ring is arranged concentrically to the housing and eccentrically to the impeller.

During a complete rotation of the impeller, the following occurs:

- At the upper vertex (point A), the liquid ring is nearest to the rotor axis and completely fills the impeller cells (space between the two adjacent impeller blades) with operating liquid.

- During the first half rotation, the liquid ring lifts off the impeller hub (the moving liquid ring acts as a piston on its suction stroke). The space in the cells increases so that the pumped gases are sucked in through the inlet port (7).

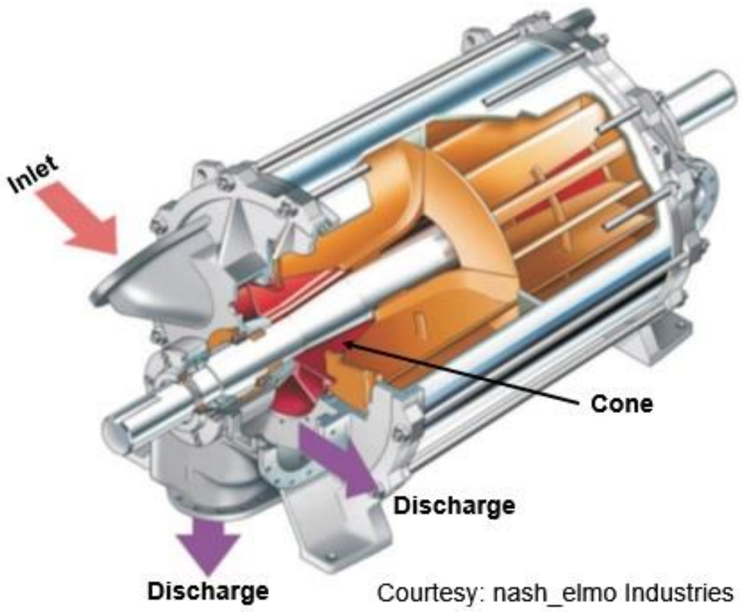
- This continues till the impeller moves to the lower vertex (point B). The space in the cells is largest at the lower vertex as these cells are virtually free of operating liquid.

- During the second half rotation, the liquid ring approaches the hub again (the moving liquid ring now acts as a piston on its discharge stroke). The space in the cells decreases so that the pumped gases are compressed and pushed out through the discharge port (6).

Thus during every rotation, the gases are sucked from the inlet port, compressed and delivered to the discharge port. Due to large number of blades, the operation is continuous and the discharge is non-pulsating.

In a vacuum pump/compressor, when the inlet is connected to a closed system and the outlet to the atmosphere, the machine will draw gases from the system and will discharge it into the atmosphere and will act as a vacuum pump. However, when the inlet is connected to the atmosphere and the outlet to a closed system, the machine will draw the air (gases) from the atmosphere and discharge it into the system and will act as a compressor.

Liquid ring vacuum pumps are designed in two different types: cone type and flat plate type. The following figure shows construction of a typical cone type vacuum pump.

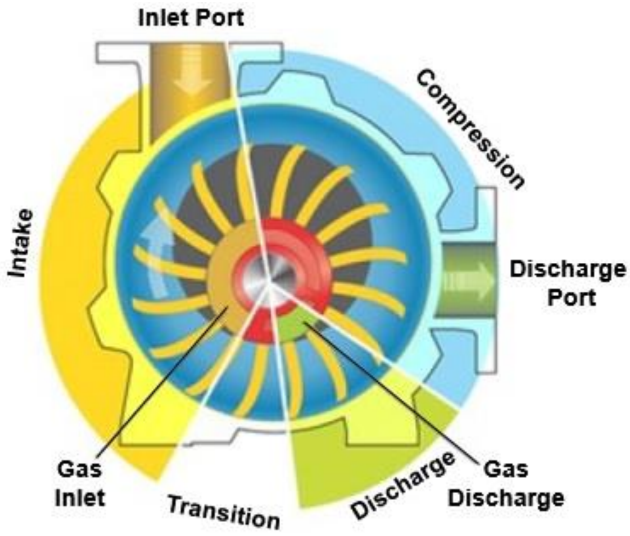


Cone Type Vacuum Pump

In this design, the cells between the impeller/rotor blades, are open around the periphery. The cells are open on the inside, as well. The inner edges of the rotor blades are machined to rotate around the cone surface (shown in red), with a close non-contact fit. The effectiveness of the pump is very much dependent on an efficient sealing action between the rotor blades and the cone (rotor blades and port/end plate in case of a flat plate type design). Hence a close non-contact fit is absolutely essential.

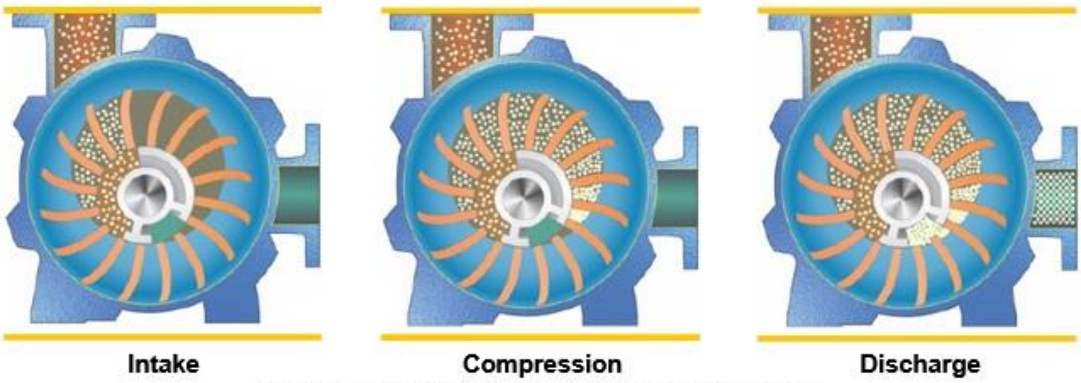
An internal passage joins the openings from the pump inlet to an inlet port in the cone. There is also a passage from the cone discharge to the pump discharge connection.

The following figure (copyright 2016 © Gardner Denver Nash) shows various stages in a cone type pump during one complete rotation of the impeller.



Operation Stages

The following figure (copyright 2016 © Gardner Denver Nash) shows working of each stage (Intake, Compression and Discharge) as the rotor rotates during operation.



Working of Intake, Compression and Discharge

Intake

In above figure, gases/air entering the pump during intake is shown as white dots at the inlet connection. The gases traverse the internal passage to the cone's inlet port. As the white dots indicate, the gases are drawn into the rotor cells/chambers by the receding liquid ring, similar to the suction stroke of a piston in a cylinder. The liquid ring does the job of pistons, while the rotor cells play the part of cylinders.

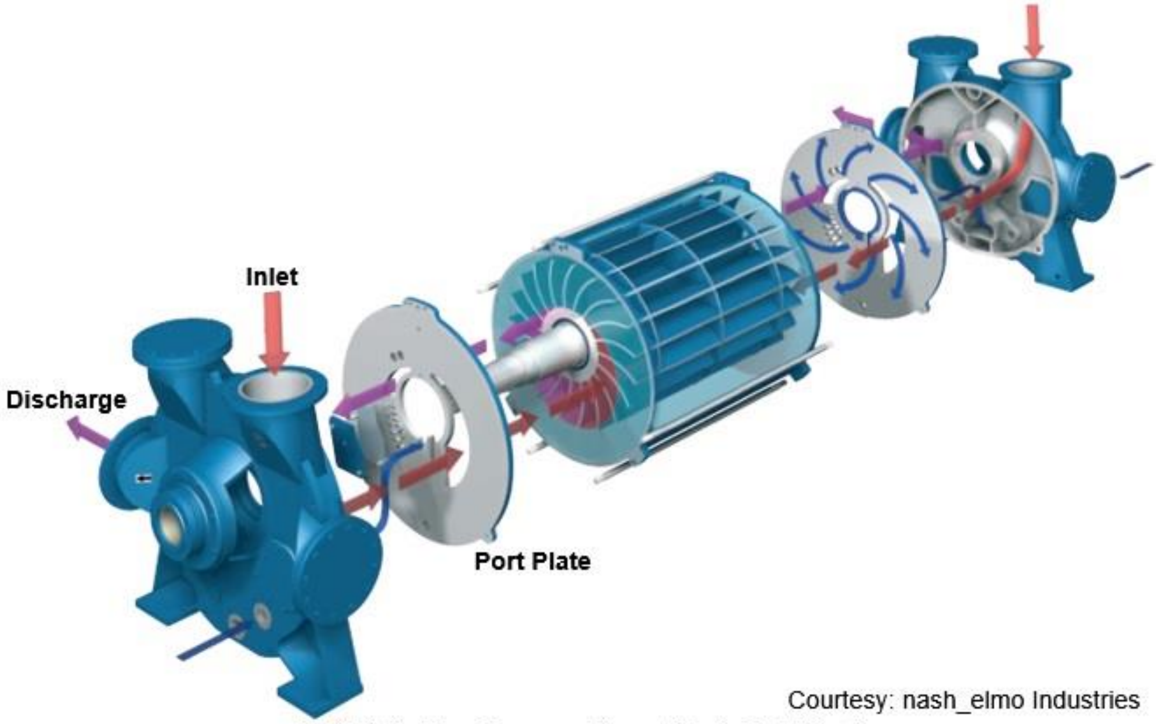
Compression

As each cell rotates past the inlet port, the cell carries a volume of gases around with it. The white dots are confined between the cone and the ring of rotating liquid. The gases are compressed as the liquid ring converges with the cone. This represents the compression of gases from vacuum up to atmospheric pressure, or from atmospheric up to positive pressure in a liquid

Discharge

When each cell rotates to the discharge port opening, the compressed gases escapes from that cell through the discharge port to the internal discharge passage.

Flat plate type vacuum pumps have a port plate configuration rather than a cone, but the working principle is the same.



Flat Plate Type Vacuum Pump (Exploded View)

Above figure shows construction (exploded view) of a typical flat plate type vacuum pump. The flat plate type design is easier to manufacture. However, the flat plat type design is less efficient then the cone type design.

Piping

The weight of the piping connected to the inlet/suction and outlet/discharge flanges should be independently supported to avoid putting excessive weight on the pump.

Gradual slope should be provided in the piping for the smooth flow by gravity of any liquid entering the piping. For this reason, suction/inlet side piping should slope down towards the pump and discharge/outlet side piping should slope down towards away from the pump. When the liquid entering along with the incoming gases is more, separator with arrangement for removing the liquid from the system before it enters the pump should be provided.

The exhaust from the pump is composed of a high velocity mixture of gases and liquid. It should be freely discharged into the atmosphere to avoid excessive back pressure which can overload the motor. Standard motors will handle a modest amount of back pressure; however, a larger motor may be required where excessive back pressure is unavoidable.

Use of a separator/muffler attached to the exhaust port will avoid back pressure by separating the high velocity mixture of gases and liquid. The liquid can gently flow down through a bottom fitting which can be piped directly to a drain while the exhaust gas rises and discharges freely into the atmosphere through a fitting at the top. The exhaust can be piped outside or to any other location, provided that the pipe is sized large enough to avoid back pressure and is not connected directly to a drain.

A separator/muffler also results in more quiet operation since the high pitched sound from the pump discharge gets attenuated due to change in the direction of the exhaust.

Avoid back pressure by not piping the pump exhaust to a location above the pump. This requires the pump to work harder in order to push the exhaust mixture up hill.

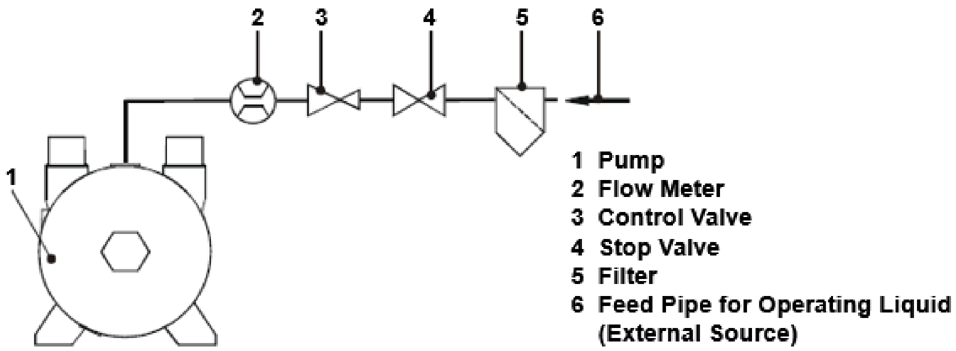
The inlet pipe should be free from rust, scale deposits, weld-shots, weld-slag, cut pieces of metal and other solids like bolts, nuts, washers when they are installed. A perforated sheet or wire-mesh strainer should be fitted to the suction flange and should remain in the piping for at least 24 hours after the initial startup of the pump.

Operating Liquid

Because part of the operating liquid also flows out of the pump along with the discharged gases, it has to replenished by fresh liquid. The continuous flow of the operating liquid also takes away part of the heat of compression from the gases handled thereby cooling the pump. The liquid must not contain solid materials, e.g. sand, otherwise the casing will be subject to heavy wear or the impeller will jam. The three methods/schemes to replenish operating liquid are: once-through system (no recovery), partial recovery system and total recovery system.

Once-through System (no recovery)

In this method, the operating liquid discharged along with gases is separated from the gases in a separator and allowed to flow into a drain. The lost quantity of operating liquid is replenished by fresh operating liquid (full quantity) from an external source. This is a popular method and is used where there is an abundant supply of fresh liquid and its conservation or contamination is not a concern. It is recommended that the operating liquid should be supplied to the pump with a pressure, approximately 0.5 to 1 bar (7.25 and 14.5 psi) above the inlet pressure of the gases. The flow rate of the operating liquid depends on the pump capacity and the operating vacuum.



Once-through System for Operating Liquid Feed (Non-automatic Operation)

As shown in above figure, a non-automatic once-through system consists of a flow meter, a control valve, a stop valve, a filter and an external source of the operating liquid. The filter will prevent solids entering the pump along with the operating liquid. It should be checked at regular intervals and cleaned. The stop valve (manual) is used for either fully opening or fully closing the operating liquid supply to the pump, before starting or after stopping the pump respectively. The control valve is a regulating valve and is used for regulating the operating liquid entering the pump for its optimum performance (the flow rate should be set as per pump manufacturer's recommendation). Once this valve is adjusted for the optimum performance of the pump, its setting is not disturbed. A flow meter (rotameter) of a suitable flow range will indicate the actual flow rate of the operating liquid.

For automatic operation, instead of a manually operated stop valve, a solenoid valve, connected to the motor and a bypass valve to bypass the solenoid valve may be installed.

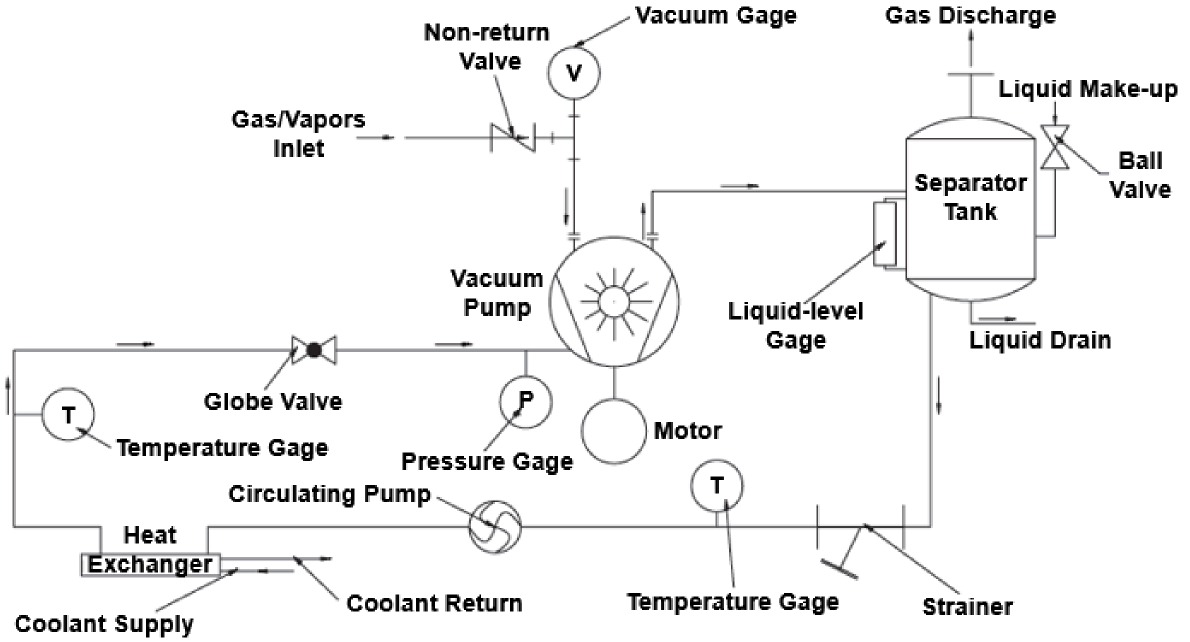
If pump manufacturer's recommendation is not available, for every operating condition, the optimum quantity of operating liquid can be adjusted as described below.

Fully open stop valve and control valve in the operating liquid line. While watching the vacuum gauge gradually close the control valve till the vacuum starts to fall. Now slightly open the valve to maintain the maximum vacuum. Excessive operating liquid reduce the pump's capacity to handle gases and increase the power input to the pump. The setting of control valve should be left without disturbing it and the stop valve should be used for fully opening or closing the operating liquid supply to the pump before starting or stopping the pump.

Partial Recovery System

This method is used where it is desired to minimize the use of fresh operating liquid. In this method, the operating liquid enters and leaves the pump like the once-through system. However, part of the discharged liquid is recycled from the discharge separator and the balance is continuously supplied from an external source. The temperature of the mixed liquid supplied to the pump will be higher than the temperature of the fresh make-up liquid. Its final temperature will depend upon the amount of the recycled liquid. It is important to remember that with higher operating liquid temperature, the pump performance (capacity) will decrease with the possibility of operating the pump in the cavitation area. Hence, fresh make-up of the operating liquid should be introduced in a sufficient quantity to maintain the proper temperature of the operating liquid that is essential for good performance.

Total Recovery System



Total Recovery System for Operating Liquid

As shown in above figure, this method provides for total recirculation of the operating liquid. A heat exchanger is added to the system to remove the heat of compression and condensation from the operating liquid before it is reintroduced into the pump. To overcome the excessive pressure drop in the system (heat exchanger, piping, valves, etc.), a circulating pump may be necessary.

Losses of operating liquid from the closed loop must be compensated with an equal amount from an outside (make-up) source.

With partial or total recovery arrangements, the operating liquid level in the separator or the recirculation tank should be at, or slightly below, the centerline of the pump shaft. Provision may also be made for high-level overflow on the partial or the total recovery systems. This level control will prevent starting of the pump with the casing full of water, which will overload the motor.

Accessories

Liquid ring vacuum pumps come with many accessories, supplied by the pump manufacturer or by other companies in the field. An application's particular requirements, mode of operation, and type of control scheme dictate the necessity of various items. The following covers some of the more commonly used items.

Non-return / check valve prevent the gas and operating liquid from flowing back in to the inlet/suction pipe when the pump is stopped. It is mounted on the inlet connection of the pump. The non-return valve is basically a valve with a plate seat.

Inlet vacuum relief valve protects the pump from cavitation. When the pump's suction pressure falls below the setting of a vacuum relief valve, the valve will open and bleed in atmospheric air or process gas (if connected back to the pump's discharge side). Most inexpensive vacuum relief valves are based on atmospheric pressure and need to be calibrated periodically.

Liquid separator separates the discharged operating liquid from the discharged gas coming out of the pump. The separator can be either mounted on the floor, mounted on a baseplate with the pump (and used for partial and total recovery systems), or supported by the discharge piping (used on once-through systems).

Gas Ejectors provide suction pressures lower than that the liquid ring vacuum pumps are capable of when operating alone. A gas ejector may be added to a pump, to provide an inlet pressure as low as 3 torr (4 mbar / 0.058 psia).

The operation of gas ejectors is similar to that of steam ejectors. Atmospheric air or recycled gas from separator discharge is used as the motive force for compressing the process gas from the system's design pressure up to that of the inlet pressure of the liquid ring vacuum pump.

When evacuating containers, the gas ejector operates as a throttle in the range from 1000 mbar (14.5 psi) to approx. 100 mbar (1.45 psi). To achieve fast venting times here, the gas ejector can be bypassed with a bypass pipe. The bypass pipe must be closed if the gas ejector is to be effective. The best point for switching over to operation with the gas ejector is at approx. 40 mbar (0.580 psi).

Cavitation

Cavitation is the formation and subsequent sudden collapse of gas/vapor bubbles in the operating liquid. If the pressure in the vacuum pump drops below the evaporation pressure of the operating liquid (on the intake side or in constricted areas), gas/vapor bubbles form.

When the pressure increases above the evaporation pressure again along the flow path (on the discharge), these gas/vapor bubbles collapse quite suddenly and shock condensation occurs with great rapidity, in the nature of an implosion. If this implosion does not occur in the body of the operating liquid but at the wall of a component guiding the flow (rotor blades and casing), it will result in the component's material being eroded.

Before the occurrence of material disintegration, which incidentally does not necessarily arise in all cases of operation under cavitation condition, cavitation makes itself noticed by an increase in the noise level and/or by rough running (vibration). The typical cavitation noise in a pump can best be compared with the noise made by gravels in a concrete mixer.

Gas/vapor bubbles, like in boiling of water, form in a liquid at a specific pressure and temperature. For example, at atmospheric pressure, water boils at 212°F, while at a lower pressure (vacuum) it will boil at a lower temperature [for example, at 52.12 mm Hg absolute (1.0078 psig), water boils 102°F (38.9°C)]. Conversely, as the pressure increases, water will not boil until it reaches a higher temperature, like in a pressure cooker. The Steam Tables are referenced to determine the vapor pressure of water at various temperatures.

Therefore, in order to prevent cavitation, the temperature of the operating liquid must remain below the saturation point corresponding to the inlet pressure of gas/vapours.

Scale/Calcium Build Up

Calcium Coated Rotor and Cone

Scale builds up due to calcium (lime) deposition. Above figure shows rotor and cone coated with calcium. Scale/Calcium build up can cause higher horsepower consumption, reduction in pump capacity, shortened seal life and vibration. In hard water areas, use of a water softener is desirable; otherwise, descaling can be carried out periodically.

Check the pump every two weeks after installation to get a feel for how fast scale builds up. This will determine how frequently descaling should be carried out.

If required, descaling of the pump may be carried out as follows:

Drain the pump. Fill the pump with decalcifying liquid through one of the connection openings. Use 10% solution of acetic acid or another commercially available decalcifying agent. Allow the decalcifying liquid to soak for at least 30 minutes. Turn the shaft occasionally during this time. Drain the decalcifying liquid out of the unit. Flush with clean water. In case of heavy deposits, clean by disassembling the pump.

Maintenance and Troubleshooting

The pump hardly needs any maintenance except for the lubrication of the bearings. Follow the instructions issued by the pump supplier for lubrication of the bearings. Generally, in case of grease lubricated bearings, it is recommended to pack the interior of the bearing full and the bearing covers half full with the recommended grease.

However, if dirt or solid matter (e.g. sand) or lime deposits get into the pump through the operating liquid and/or the pumped gases, then it is necessary to clean the pump at regular intervals to prevent the impeller from jamming up and to avoid wearing of the impeller and the vacuum pump housing.

If at any time trouble is experienced in obtaining the specific discharge and vacuum, the following points should be checked before deciding to dismantle the pump.

Improper direction for rotation: After servicing, the motor might be connected in reverse direction of rotation.

Failure of operating liquid: Required vacuum cannot be obtained and maintained without proper quantity of operating liquid. Check for blocked operating liquid supply line, check strainer.

Hot sealing water: Cooler the operating liquid, higher the maximum vacuum that can be obtained. Above 30°C, the shutoff vacuum will fall rapidly with the increase in operating liquid temperature.

Restriction in suction and discharge piping: Blocked suction and discharge piping will reduce the capacity of the pump.

Leakage in the system: Leaks might have developed in the system thereby increasing the discharge and lowering of the obtained vacuum.

In case no problem is found after checking above points, pump may be dismantled for repair.

Pump Repair

For efficient operation of a vacuum pump, the rotor blades do not touch the cone/s (rotor blades and port plate/s in case of a plate type design) but runs with a predetermined running clearance between its conical bore/s and conical surface of the cone/s. The clearance is sealed by the operating liquid present inside the pump. If the clearance increases beyond recommended value, pump's capacity/efficiency will decrease. In such case, machining and shimming, repair by welding and re-machining or replacement by new parts will be required.

Pump parts can also get damaged due to cavitation, erosion, corrosion etc. and may require repair or replacement.

The repair should also include inspection to determine the root cause for the problem or failure so that corrective action can be taken during its repair to prevent reoccurrence.

Ensure to assembled the pump parts in their original places because the pump's performance will not be satisfactory if the parts are not assembled in their original places.

After pump repair, carry out the coupling alignment.

Bearing Failures

Most bearing failures are not caused by a bearing manufacturing defect. Bearing failure is usually caused by lubricant breakdown or above-normal bearing loads.

Bearings for pumps working in standard conditions should be lubricated every 2000/2500 working hours with a quality grease. Bearing temperature should not exceed 85°C during normal working conditions and normal environments.

In case of a belt drive, belt over-tension can cause serious damage to the bearings of the pump and electric motor, belt under- tension can cause a premature wear of the belts.

Bearings can overheat for reasons such as too much grease, misalignment of flexible coupling, wrong bearings, excessive vibrations and bearing wear.

Advantages and Disadvantages

Comparing with other mechanical vacuum pumps, the liquid ring vacuum pump has many advantages. There is no need to lubricate the pump cavity because there is no metal to metal contact. Their operation and maintaining is easier. As the gases in the pump cavity are compressed under almost the same temperature, the liquid ring vacuum pump can pump the gases that are flammable/explosive.

In addition to the limit on vacuum that can be achieved by a liquid ring vacuum pump, its major disadvantage is low efficiency.

References

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Note:
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