Oil based vacuum pumps

The better alternative to water ring pumps for wet lower vacuum processes

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Two previous articles were dealing with steam jet ejectors and water ring pumps. A last type of wet vacuum sources are oil ring, and oil-lubricated rotary vane and multi-cell vacuum pumps.

The working principle of the oil ring pump (Fig. 1) is the same as for a water ring pump, but oil is used for the liquid ring. That oil should have a low vapour pressure, and should be compatible with the process gas mixture and the materials of construction. Most pumps are of carbon steel construction. In oil-sealed pumps, the oil provides a barrier between corrosives and pump metal parts, and may contain detergents and dispersants to aid in the solubility of contaminants. When a low-viscosity oil is used as sealant in a two-stage oil ring pump, ultimate pressures of 5-10 mbar can be routinely achieved (Vibert, 2004).

Once-through oil-lubricated pumps produce good vacuums, but require a complex system of oil addition and collection. The oil eventually becomes contaminated and must be replaced on a regular basis. Often, the oil is recirculated and may have to be cooled. Oil-filtration systems (e.g., strainer filters) should be used to remove particulates formed within the recirculating oil. In oil ring pumps provided with such a recirculation system, the oil ring pump discharges vapour and seal fluid into a separator tank. By centrifugal action and the force of gravity, the vapour and oil are separated, with the vapour exiting the top and the oil discharging at the bottom of the separator tank. The oil is then cooled with the aid of a heat exchanger and recirculated to the pump. On the exhaust of oil sealed vacuum pumps, a coalescing or oil mist filter should be used, to prevent the discharge of oil (visible oil, unsightly oil plumes and smoke, up to 30 µm) into the atmosphere (Aliasso, 1995; Frankel, 2002).

An oil ring pump may never run with a closed suction line (e.g., against a completely closed manual control valve), which causes cavitation and overheating, and will damage and finally break down the vacuum pump.

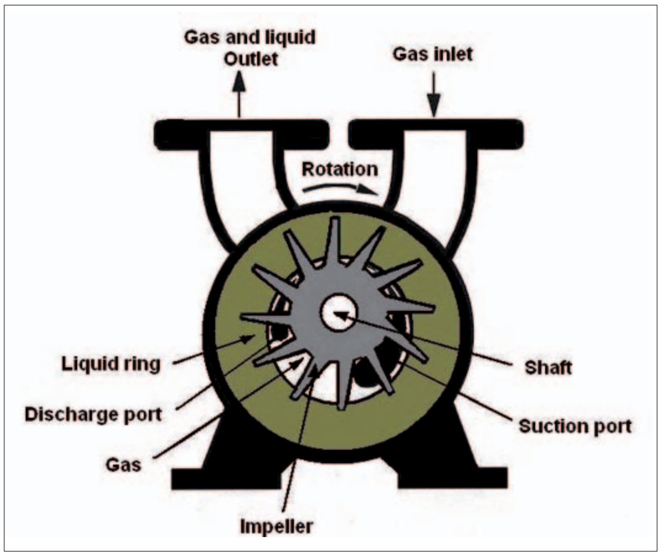

Fig. 1: oil ring pump.

Oil lubricated rotary vane/ multi cell vacuum pumps

The oil lubricated rotary vane pumps (Fig. 2) and multi cell vacuum pumps (Fig. 3) consist of a hollow body with a rotating cylinder mounted off-axis (eccentric). In the rotor, two or more diametrically opposed, radially directed vanes slide into and out of the rotor slots and make contact with the pump body, creating vane chambers that do the pumping work. The vanes are held in contact with the wall by centrifugal forces and the action of springs. Since the rotor is positioned off-axis, its motion causes the volume between the vanes and the body to vary. The gas inlet port is so positioned that the volume behind the last vane to pass increases, allowing gas from the vessel being evacuated to expand into it until the next vane passes. On the discharge side of the pump, the vane chambers are decreasing in volume, forcing the gas and lubricating oil against the discharge valve. The discharge valve opens slightly above atmospheric pressure, and the fluid-gas mixture is expelled out of the pump (Aliasso, 1999; Bannwarth, 2005). In oil lubricated rotary vane/multi-cell vacuum pumps, the oil seals the internal clearances between rotary components and housing to reduce gas slippage, which permits the pump to achieve higher vacuum levels and larger capacities. Because the contact pressure between the vanes and housing is high, resulting in significant frictional effects that increase the internal localized temperatures, the oil acts as cooling medium transferring the heat of gas compression. The oil also serves as protection against contamination and as lubricant to prohibit friction and wear.

Rotary vane/multi-cell pumps operate in a once-through oiling system or an oil recirculating system. In a once-through system any contamination of the oil by the process vapour is passed out of the pump and not allowed to build up and cause additional problems. The design also avoids any increase in the operating pressure due to the vapour pressure of residual process vapours. The drawback of an once-through oiling system is the need for waste oil disposal, which is an environmental and cost issue. In an oil recirculating system, particles formed in the processing should be filtered out by an oil-filtration systems (e.g. strainer filter), because these particles otherwise can cause abrasive wear and loss of lubrication in the oil sealed pumps. Contaminant fluid in the pump oil degrades the performance of the pump, as the vacuum is limited by the vapour pressure of the contaminant fluid. Moreover, condensate buildup in the oil bath can cause corrosion. The rotary-vane pump can be air-cooled or water-cooled, and the oil-filtration system can include an oil cooler (Aglitz, 1995; Vibert, 2004; Ban-

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Vacuum source	Max. absolute vacuum (mbar)	Advantages	Disadvantages
Oil ring pump	15-20	- Higher achievable vacuum than water ring vacuum pumps - Modest gas flows - Capable of taking slugs of water - Oil can solubilize and avoid deposition of oil-soluble contaminants - No rust & scale problems - Low operation cost - Reliable - Simple repair & maintenance - Low noise level	- Ultimate vacuum is limited by vapour pressure of the seal oil at the working temperature. - Oil contamination and disposal - Oil is often toxic - High oil consumption - Requires an oil purifier circuit - Process contamination risk - Corrosive gases can damage the seals and other components - More complex than other designs - Higher investment cost
Rotary vane pump Multi-cell pump (oil lubricated)	0,5	- High achievable vacuum - Medium gas flows - Effective for pumping non-condensable loads - Balanced, compact design - Long life span - No rust & scale problems - Reliable - Little periodic maintenance needed - Low operating costs - Low noise level and no vibration - Can be fabricated of cast iron	- Cannot take a slug of water - Not able to pump large quantities of water vapour and other vapours - Vanes and stator operate in physical contact and can suffer wear in the presence of particulates - Vanes are sensitive to breaking due to deterioration of the lubricant or ingestion of process liquid - Requires knock-out pot and filter - Check-valve needed to avoid contamination of process material by backstreaming oil and vapour - Oil contamination and disposal - Oil is often toxic - High service requirements: pump is often off-line for frequent oil changes, increasing the pump downtime - High oil consumption - Relative high investment cost - High heat emission - Costly to repair or rebuild

Table 1: overview of oil vacuum pumps, and their advantages and disadvantages.

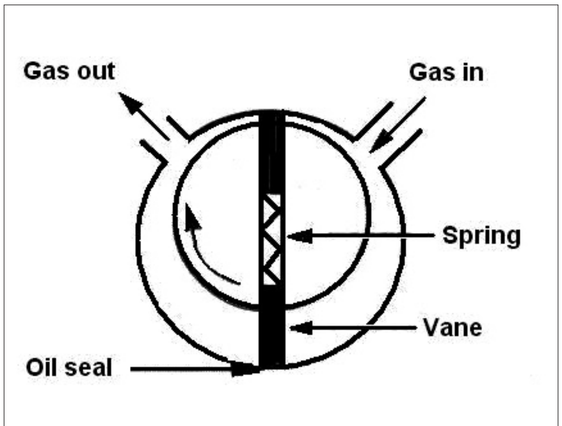

Fig. 2: oil lubricated rotary vane vacuum pump.

nwarth, 2005; Collins, 2009; Mattox, 2009). If any vapours are admixed to the gas, they can condense in the pump during the compression process. Thus the resulting condensate can mix with the pump oil and impair its lubricity or evaporate at the suction side and diminish efficiency. Therefore, it is necessary to let enter a certain quantity of gas into the suction chamber through a gas ballast valve with each compression. The gas can be ambient air, or another gas. Shortly before compression begins, a measured ballast quantity of gaz (maximum 10%) is let into the chamber, after which the partial pressure of non-condensing gases increases compared to the partial pressure of vapours. As the saturated vapour pressure of the existing vapours is not exceeded, condensation inside the pump is avoided. Of course, the functioning of the pump is negatively influenced by the ballast, which means the final vacuum of the pump will decrease. On the other hand, the quantity of added ballast gas is limited and depends on the pressure of the respective kind of pump (Bannwarth, 2005).

Application of oil based vacuum pumps

Table 1 gives an overview of the different advantages and disadvantages of these type of vacuum pumps.

For vacuum transport of solids, oil lubricated rotary vane vacuum pumps that can generate 200-500 mbar vacuum absolute are the cheapest investment. However, the rotary vane pump shall only be used for clean powder transport applications, where there is little risk for particles to be entrained within the rotary vane pump. With a rotary vane pump, a filter before the pump shall always be applied. However, it is still necessary to filtrate the oil of the rotary vane pump to remove powder particles.

Dry vacuum cleaning can be considered as a specific type of vacuum solid transport. A dry vacuum cleaning system consists of a vacuum producer (often a rotary vane pump, provided with a filter in front of the pump), a dry separator (tubular bags or a centrifugal separator), and tubing to convey the air and material to that separator. The required vacuum capacity (between 600-900 mbar absolute) depends on the frequency of cleaning, the maximum expected number of simultaneous users, the pressure drop over separators, filters, etc. and the loss of vacuum pressure due to friction of the air in the piping system.

For vacuum pumping of liquid, a vacuum level of 100 mbar lower than that required to overcome the difference in height is required (400-500 mbar vacuum absolute). Rotary vane pumps can be used for that application, but these vacuum pumps can't take a slug of water or liquid. Therefore, locks and check-pots are required to avoid contamination of the oil within the oil lubricated rotary vane pump. Remark that for the transfer of liquids, ordinary pumps are still the most appropriate for that duty, while blowing and vacuum are less recommended.

Lifting and displacement of loads by means of vacuum occurs via suction cups, that adhere to non-porous surfaces thanks to the vacuum created between the cups and the surface of the loads to displace. Vacuum levels of just a few mbars (max. 200-300 mbars) are satisfactory, and for that purpose oil lubricated rotary vane pump with a filter installed just in front of the pump is applicable, or a dry pump (in dusty environments). The required vacuum for the opening of bags is determined by the same parameters, as those applicable for the lifting of loads.

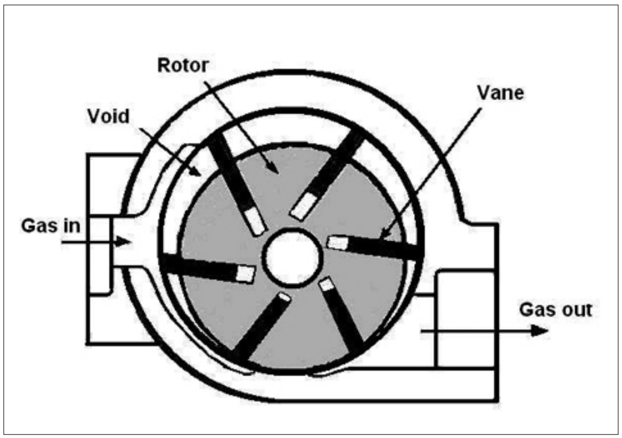

Fig. 3: multi-cell vacuum pump.

An oil lubricated rotary vane pump or an oil ring pump are also commonly used as vacuum source for vacuum packaging operations (e.g. vacuum packaging of food). For vacuum packaging operations, the required absolute vacuum may not be too high (max. 100 mbar). A too high vacuum increases the risk for food being drawn into the vacuum system. It is speed that is essential in vacuum packaging operations.

Contamination of upstream vacuum applications

Transfer of oil from an oil ring pump or rotary vane pump's inlet into the pumping line can occur due to several mechanisms. The simplest occurs whenever the pumping line stays under vacuum when the pump is shut off or as the result of power failure. The pump may "suck-back", bringing gases trapped within the pump or even air from atmosphere from the high-pressure side back through the pump. By this action, some of the pump oil may be literally forced into the fore (pumping) line (Mattox, 2009).

Additional liquid/vapour backstreaming occurs due to droplets of hot oil that can be physically flung from the pump's inlet during operation due to mechanical breakdown of the oil films sealing the vane/body interface. A slightly similar effect occurs when microbubbles of oil break on the surface. This is most often caused by either the expansion of trapped light gases or from the almost explosive expansion of condensed gases, such as liquid water which can be converted into steam. When the bubble expands and breaks, the surface tension is such that the bubble explosively breaks down and imparts sufficient energy to the oil to allow it to leave the pump either as liquid or vapour.

However, direct oil vapour-state transfer from the oil ring pump or rotary vane pump to the chamber is the major source of oil contamination. When a pump operates continually, the oil within the pump will become hotter and hotter, due to simple mechanical energy heat transfer, until some maximum temperature is achieved. This increase in oil temperature will result in an increase in oil vapour pressure, also determined by the quality of the oil. Undistilled or poorly distilled oil will contain light fractions (low boiling components) which will volatize at low temperatures.

A simple practical test is to sniff the inlet of a hot pump. If a fishy odour is detected, the oil is undistilled or of poor quality. High quality, vacuum-distilled oil will be either odour-free or close to it, and should be of food-grade quality. Using a high quality oil will lower the risk for backsteaming of oil. Remark also that chemical breakdown of the seal oil can occur at high oil temperatures. Ordinarly, a sliding vane pump is provided with a safety valve closing the suction side of the pump in case of power failure or standstill of the pump. In such case, the pump is vented at the same time, so that it will not have to run against the vacuum after restarting. The effect of oil lubrication may be considered to be the largest disadvantage of sliding vane pumps. Thanks to the installation of filters and automatic safety valves (e.g. check valves), the return flow of oil vapours from the pump into the vacuum vessel can be avoided to a great extent. Additionaly backstreaming traps of the condensation, absorbent or adsorbent type can be used. During their cleaning or regeneration, the captured oil may not be allowed to escape into the upstream side of the trap. Oil-sealed pumps should not be used to evacuate equipment containing sensitive products (e.g. food, pharmaceutical components, micro-electronics, etc.) (Bannworth, 2005; Mattox, 2009). <<

References:

Aglitz, J., Bhatnagar, R., Bolt, D.E. & Butzbach, T.L. (1995), 'Installing Liquid-Ring Vacuum Pumps', Chemical Engineering, 102 (11), 132-138.

Aliasso, J. (1995), 'How to Control Liquid Ring Vacuum Pumps', Pumps & Systems Magazine, November 1995, 2 p.

Aliasso, J. (1999), 'Choose the right vacuum pump', Chemical Engineering, 106 (3), 96-100.

Bannwarth, H. (2005), 'Machines for vacuum generation', Ch. 2, Liquid ring vacuum pumps, compressors and systems: conventional and hermetic design, Weinham, Germany, Wiley-VCH Verlag GmbH & Co. KgaA, pp.111-156.

Collins, D. (2009), 'Vacuum pumps for pharmaceutical processes', pharma-mag.com, 5 (3), 42-44.

Frankel, M. (2002), 'Vacuum air systems', Ch. 15, Facilty Piping Systems Handbook, 2nd edition, New York, United States, McGraw-Hill, pp. 15.1-15.64.

Mattox, D.M. (2009), 'Vacuum technology: Mechanical Vacuum Pumps', Education Guide to Vacuum Coating Processing N°97, Albuquerque, United States, Society of Vacuum Coaters, p. 53-54.

Vibert, P. (2004), 'Mechanical pumps for vacuum processing', Chemical Engineering, 111 (10), 44-51.