Corrosive media and dry-running vacuum pumps

Dry-running designs of vacuum pump are increasingly becoming the dominant choice of vacuum generating machine within the pharmaceutical industry. The decision to adopt such technology generally being on the basis of reduced effluent/abatement costs. No service liquid or internal lubricant within the machine results in no contaminated waste disposal costs.

Corrosive gasses and vapours, of a particularly wide-ranging nature, can only be handled by machines that offer universal compatibility. Reliance upon corrosion resistant metals and polymers provide a degree of protection, but can be susceptible due to the thermal conditions that are particularly arduous within dry running vacuum pump technology. Additionally, high nickel coatings on ferritic base metals can accelerate galvanic corrosion as soon as any flaws appear.

It is widely recognized that highly corrosive media can be handled without the need for such susceptible exotic materials. On the basis that machines specifically designed for reliable temperature control ensure that corrosive media remains in the vapour phase, ductile irons provide a good metallurgical solution. Machines with a uniform temperature profile throughout, offer the ability to control heat-accelerated degradation/polymerization.

Market demands

Generally, vacuum is utilized within the chemical process industry in order to ensure that product degradation does not take place with heat sensitive media. Therefore applications such as distillation, vaporization, and drying are undertaken at relatively low temperatures. As a rule, there is a pre-condenser located upstream of the vacuum pump in order to reduce the volumetric flow rate by condensing the vapour into a liquid. The purpose of the vacuum pump is, therefore, not really to cope with the excessive free vapour and gas load, but rather to handle an optimum flow of vapour-saturated gas.

The pharmaceutical and fine chemical industry are particularly reliant on multi-purpose plants, i.e. manufacturing plants designed for continuously changing media and process conditions. The list of demands placed upon a vacuum pump that must be reliable, in this field, are extensive and can be prioritized as follows:

Safe operation with flammable vapours:
- Low gas temperature
- No mechanical ignition source

Problem-free handling of corrosive media:
- Elevated gas temperatures avoid condensation, as corrosion occurs only in the liquid phase
- Pumping of thermally sensitive media / covering agents

Reliable temperature profile that ensures (1) gas temperatures that is suitably low enough to avoid cracking, while (2) high enough gas temperatures to avoid crystallization
- Easy rinsing / flushing
- Easy maintenance / clean in place (Figure. 1)

From these demands it is easy to deduce that the ideal temperature condition inside of the vacuum pump is very important. It must neither be too cold nor too warm!
Dry-running vacuum pumps are characterized by almost adiabatic compression with very small mass flow rates. Since the mass flow rate is almost zero during operation at very low suction pressures, and there are no service liquids present, the compression-generated heat cannot be automatically dissipated. Furthermore, the heat created by the extremely high (1,000,000:1) compression ratios is exacerbated further because of the low density of the gas under such levels of vacuum.

The simplest way to remove the heat is through jacket cooling of the pump. Figure 2a, however, illustrates that the low gas density adversely affects heat dissipation through convection to the cooled jacket. In other words, the temperature distribution throughout the pump is relatively inhomogeneous. As the pump becomes larger, so does the heat transfer rate per displacement volume. Peak temperatures in excess of 200°C are commonplace with pump capacities in the region of 250 m³/h. Since elevated temperatures can cause "cracking" products to suffer accelerated polymerization, degradation, or simple sublimation, there exists an increased danger of an active ignition source. In other words, as the clearances within the machine are consumed by product deposition, friction can generate hot-spots to the extent of localized ignition.

Lowering the peak temperature is only possible if the coolant temperature is extremely low. Along with practical constraints of providing coolant at such low temperatures, problems occur with condensation at the inner wall of the jacket. The cold inner surface of the casing chills any corrosive vapours, as they enter the pump, and causes condensation that leads to corrosion.

Consequently, it can be deduced that dry-running vacuum pumps in excess of 250 m³/h must employ a heat dissipation mechanism more advanced than simple jacket cooling, if they are to be suitable for multi-purpose plants.

Internal rotor cooling provides a solution to this problem when utilized in conjunction with the typical jacket cooled system. Figure 2b illustrates the principle of dissipating heat from all gas-contact surfaces. Importantly, the jacket temperature can subsequently be increased in order to remove problematic quench zones, whilst maintaining internal temperatures of less than 200°C.

As discussed earlier, however, the heat transfer rate per displacement volume becomes detrimentally affected as the vacuum pump size is increased.

Moreover, peak temperatures below 200°C are seen to be achievable only with a suction capacities less than 400 m³/h.

The third, and most effective, way of cooling is through direct gas cooling and is shown in Figure 2c. This system feeds cold gas directly into the compression cycle, and permits heat transportation through the unit. Such effective cooling is not only achieved through the mixing of hot and cold gas, but also by two additional aspects: (1) The coefficient of heat transfer (Cp) is improved with an increase in gas density, and (2) The increased mass flow enhances heat dissipation. The result is a very homogeneous temperature profile that allows further elevated jacket temperatures without reaching detrimentally high internal gas temperatures.

With regard to the pumping of corrosive media, this solution offers additional advantages. As stated earlier; corrosion will not occur whilst it remains in the gas/vapour phase. It will only take place if the media is allowed to condense. Furthermore, condensation will only take place if the partial pressure of the condensable component reaches saturation during compression from vacuum to atmospheric pressure. The dilution effect of the Direct Gas Cooling system reduces the partial pressure of the condensable(s) within the pump and actually prevents condensation.

Should the vacuum pump be equipped with a post (abatement)
condenser, relatively cold gas can be taken from the exhaust flow. Importantly, this downstream condenser must be constructed from suitable corrosion-resistant materials. As Figure 3 shows, the cold gas is injected into the machine at a point where compression is greatest. Because this point is significantly downstream of the pump suction, neither suction pressure nor flow rate is compromised.

**Practical mode of operation**

The key to pumping corrosive media with dry-running vacuum pumps is to avoid condensation. Moreover, this is basically achieved by utilizing the heat associated with very high compression ratios within the pump. A prerequisite, however, is that the pump is always at the required operating temperature when corrosive media is introduced. Control of such temperatures is predominantly important during periods of start-up and shutdown.

When shutting down the pump and process, it is important that the pump/system is completely clear of any residual corrosive media. Otherwise, condensation can occur within the pump and/or surrounding pipe-work and valves during the cooling phase. Once the process is complete, the suction-line valve should be closed whilst the pump continues to run for a given time. However, with the suction-line valve closed there is insufficient inert gas flow needed to remove all remaining corrosive substances. For this reason, it is important to flush the machine with an inert media such as nitrogen. Only when the nitrogen inertization is complete, should the pump be switched off.

In many process plants, several vacuum pumps are connected in parallel and linked together by means of a common exhaust manifold. A cold vacuum pump that is open to the exhaust, acts as a condenser.

In order to avoid warm vapour-saturated corrosive gas from getting into a cold static machine, suitable isolation measures are advisable. This is possible by incorporating an isolation valve on the discharge side of the each vacuum pump.

**Variable speed for efficiency and cost saving**

Many fields of application do not permanently require a vacuum pump. Although continuous running is ideal for the pump, this would be a blatant disregard of cost. Because of the necessary warm-up and shutdown cycles, it is only worth switching off the pump if it is to be idle for long periods. Pumps with variable speed operation, and those with switched phase modes of operation, provide the optimal solution. In other words, when there is no requirement for vacuum the pump automatically switches to a stand-by speed in order to retain heat while ensuring that the pump is inertized. During such times, the suction valve remains closed. Importantly, the power absorbed is significantly reduced in order to save energy and subsequent cost. As soon as vacuum is required, the suction valve can immediately be opened to corrosive flow without the need for additional warm-up cycles.

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![Figure 3. The cold gas is injected into the machine at a point where compression is greatest.](image-url)