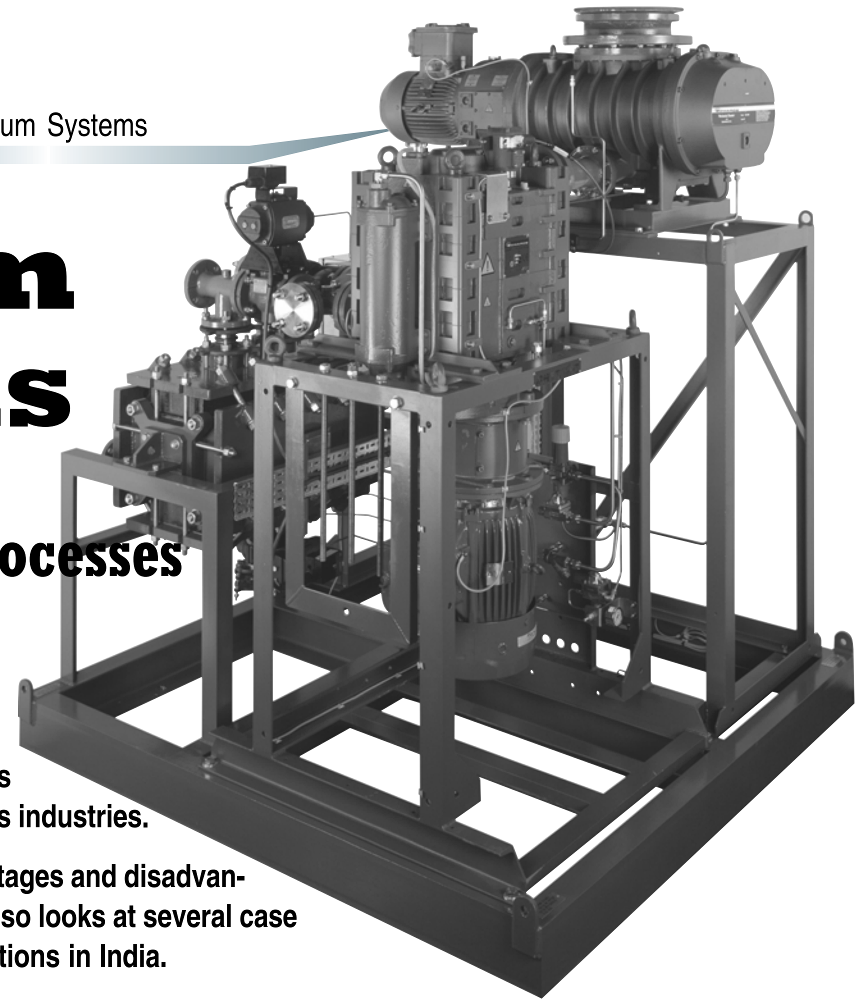
Vacuum Systems

for chemical and pharmaceutical processes

Dr Don Collins



Dry vacuum systems offer many benefits over wet vacuum systems in the process industries.

The author compares the relative advantages and disadvantages of wet and dry technologies. He also looks at several case studies of successful dry pump installations in India.

Dry vacuum pumping is now well established in advanced companies around the world as an efficient, reliable option for pharmaceutical and chemical processing. It offers clear advantages over traditional wet technologies in most applications. these include better reliability and flexibility, and lower environmental impact and utilities requirements than other process vacuum technologies. Therefore, dry vacuum is used to pump some of the most aggressive and problematic gases in a broad range of processes, including distillation, evaporation, crystallization, drying, solvent recovery, deodorization, filtration, and house or general vacuum duties.

Wet vacuum pump technologies

Traditional wet process vacuum technologies include steam ejectors, liquid ring pumps and oil-sealed pumps, including rotary-piston and rotary-vane types.

Steam ejectors

Known for their high reliability and robustness in arduous and corrosive conditions, steam ejectors can cover the full range of vacuum to 10^{-3} mbar with high suction capabilities not easily obtained by other means. However, they can be very sensitive to variations in process conditions and pressure. A single stage ejector can produce only a limited vacuum - not low enough for processing applications such as active ingredients production. Steam ejectors also suffer from low thermal efficiency, making them expensive to run.

Multistage ejectors with direct or indirect interstage condensation can offer an alternative, but these require very large quantities of steam and cooling wa-

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Dr Don Collins is the Market Development Manager for the chemical and pharmaceutical dry pump section at Edwards Ltd, UK, and has designed many vacuum systems, successfully installed in many countries. Before joining Edwards in 1995, he worked with several major companies and has accumulated experience in research and development, business development, mathematical modelling and plant simulation, design, optimisation and troubleshooting.

The key advantage of dry pumps, including roots, claw and screw technologies, is that they do not use water or oil for sealing or lubrication of the vacuum stages. This eliminates the risk of process contamination and the generation of effluent. Dry pumps usually also offer clear savings in maintenance and running costs.

ter. This makes for high energy bills and usually creates a condensate that is contaminated with process vapour, requiring appropriate, costly disposal.

Liquid ring vacuum pumps (LRPs)

These reliable, simple pumps use water or oil as a sealing fluid. They can be built in a variety of materials with capacities up to 50,000 m^3h^{-1} and pressures down to 33 mbar (water) or 10 mbar (oil). However, because of their condensing mode of operation, 'once-through' LRPs require large amounts of cooling water, which can become contaminated with process materials. Proper disposal of wastewater or oil in these systems can be difficult and costly. This can be reduced by using partial- or total-recirculation systems.

A further potential problem with LRPs is their tendency to cavitate when the seal fluid vapour pressure approaches the system pressure. This can cause severe damage to the pump. And finally, LRPs can only be used successfully with more corrosive vapours such as hydrogen chloride, bromide and fluoride if they are made from expensive, exotic materials.

Oil-sealed pumps

Introduced to solve the problems of disposal of contaminated wastewater from steam ejectors and liquid ring pumps, oil-sealed pumps initially offered a reliable and popular alternative. These pumps offer a high ultimate vacuum to 10^{-3} mbar and near constant volumetric capacity. However, as environmental standards have improved all over the world, the oil used in these designs has become a significant disadvantage of the technology.

Oil-based pumps require intensive maintenance, including routine oil changes and a regular strip-down and rebuild. Up to about 90 litres of oil may be used in each pump for lubrication and sealing, and as virtually all of any particulates from the process become trapped in the oil, these pumps must be taken offline for frequent oil changes.

Corrosive gases may condense when process vapours come into contact with the pump oil. This can do significant damage to the seals and other components. This, and the normal oil degradation from thermal and mechanical stresses, means that frequent, regular oil changes must be carried out, consuming significant quantities of fresh oil over time and generating large volumes of waste oil which must be disposed of in accordance with local environmental regulations.

During normal operation, 'back-streaming' of oil (migration of oil vapour from the pump back into the process) can also occur, usually when the pump is held at its ultimate vacuum. In practice, significant oil condensation can often be found along colder sections of the pipe-work joining these pumps to the process vessels. This may have implications for the cleanliness of the vacuum process itself in some cases.

Advantages of dry pump technology

The key advantage of dry pumps, including roots, claw and screw technologies, is that they do not use water or oil for sealing or lubrication of the vacuum stages. This eliminates the risk of process contamination and the generation of effluent. Dry pumps usually also offer clear savings in maintenance and running costs. It is true that for many standard applications, the capital cost of a dry pump may be higher than, for example, an equivalent oil-sealed or cast iron liquid ring vacuum pump. However, when the cost of the total installed package and the running costs are taken into account, dry vacuum systems can be considerably more cost-effective.

Performance

Dry pumps have very similar performance characteristics to those of oil-sealed pumps, typically covering the pressure range 1000 to 1 mbar at near constant volumetric efficiency with ultimate pressures of 10^{-1} to 10^{-2} mbar. Their operating range can be extended with the addition of one or two roots pump stages, thereby increasing the pump capacity to many thousands of m^3h^{-1} and decreasing the ultimate vacuum

Dry pumps do not suffer from problems of compatibility with process gases as oil-sealed pumps do. Even though the pumps are made from ductile cast iron, there is no corrosion when operating in the vapour phase.

Dry Pump Vs Steam Ejector			
	Units	**Steam Ejector System**	**Dry Vacuum System**
Operating hours	h yr^{-1}	8,000	8,000
Steam			
- Flow rate	kg h^{-1}	180	0
- Unit cost	₹ per kg	1.45	1.45
Steam cost	₹ per year	20,88,000	0
Cooling water			
- Flow rate	m^3 h^{-1}	30	0.3
- Unit cost	₹ per m^{-3}	2.2	2.2
Water cost	₹ per year	5,28,000	5,280
Effluent treatment			
- Flow rate	m^3 h^{-1}	0.18	0
- Unit cost	₹ per m^{-3}	68	68
Treatment cost	₹ per year	97,920	0
Nitrogen			
- Flow rate	m^3 h^{-1}	0.18	0
- Unit cost	₹ per m^{-3}	8.00	8.00
Nitrogen cost	₹ per year	0	64,000
Power			
- Power	kW	0	7.8
- Unit cost	₹ per kWh^{-1}	4.6	4.6
Power cost	₹ per year	0	2,87,040
Total Utility Cost/yr	₹ per year	27,13,920	3,56,320
Maintenance Cost/yr	₹ per year	20,000	40,000
Yearly Operating Cost for this exercise	₹ per year	27,33,920	3,96,320
Operating Cost/month	₹ per month	2,27,827	33,027
Dry System Cost Savings/yr	₹ per year		23,37,600
Dry System Cost Savings/month	₹ per month		1,94,800
Capital Cost	₹	0	14,00,000
Installation Cost	₹	0	70,000
Total capital and installation cost for this example	₹	0	14,70,000

Table 1: Cost analysis of a steam ejector system vs a reverse claw dry vacuum system
(Dry pump investments and running costs paid back within 7.5 months, savings thereafter of over ₹23 lacs per year)

to 10^{-3} or 10^{-4} mbar. With the addition of one or more mechanical boosters in series, pump speeds up to nearly 40,000 m^3 h^{-1} can be achieved in a single train. These trains can be combined in parallel to increase capacities even further. Inlet and inter-stage condensers and knockout pots are also very efficient non-polluting ways of increasing dry pump capacities.

Dry pumps do not suffer from problems of compatibility with process gases as oil-sealed pumps do. Even though the pumps are made from ductile cast iron, there is no corrosion when operating in the vapour phase. This is because the pressure and temperature profile inside the pump is maintained above the dew point of the process media, ensuring reliable operation even while pumping highly corrosive media. Solvents can be recovered relatively easily by inlet and/or exhaust condensation and recycled without any need for further purification. Hence, the dry vacuum pump system is a particularly good solution for processing organic solvents and very corrosive vapours.

Performance of dry pumps is more consistently reliable than that of wet pumps. This is because the presence of contaminants in an oil-sealed pump can degrade its performance and the temperature of water can affect the performance of the inter-stage condensers in steam ejectors systems and the pump pressure in an LRP. In a dry pump, no such problem exists.

Cost of ownership and energy consumption

The capital cost of a dry vacuum pump is often higher than that of an equivalent wet pump, but there tends to be very little difference when the total instal-

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lation cost is considered. And when running costs are taken into account, the dry system often shows a considerably lower cost of ownership.

Dry pumps offer the best thermal efficiency of any process vacuum-producing system. Not only does the dry system use significantly less energy when it is running but, unlike a steam ejector, it can be switched off between cycles so that it uses no energy at all when it is not required. Inverters can also be used to minimise the power usage when in standby mode. Dry pumps are energy efficient and the reduced power consumption results in lower carbon footprint and environmental impact.

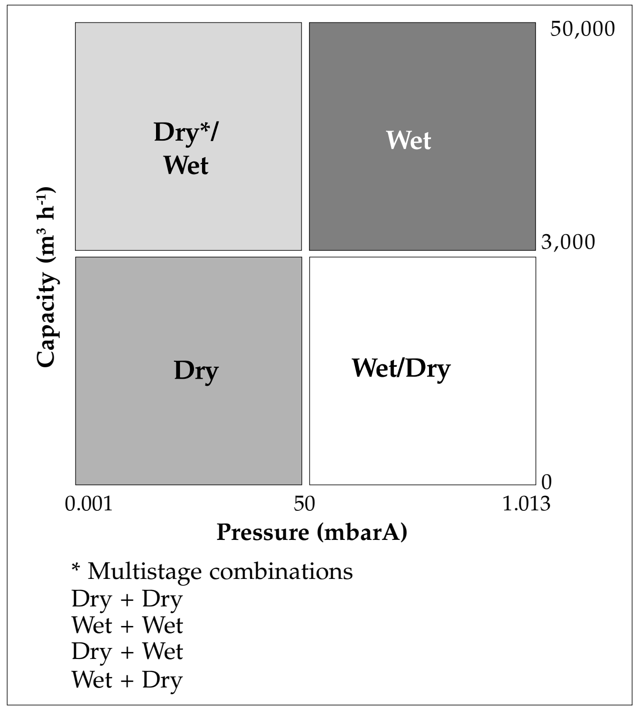
The dry vacuum pump costs up to 90% less to run than its steam ejector equivalent. Similarly, compared to a liquid ring pump system, the running cost of a dry pump can be significantly cheaper. Even when the higher capital cost of a dry pump system is taken into account, the lower cost of ownership of the dry system means that it often pays for itself very quickly (Table 1).

Safety

Dry pumps are designed to pump flammable materials safely because they are contact-free pumping mechanisms with no ignition sources in normal operation.

Two ignition sources are generally considered with dry pumps: spark ignition and auto-ignition (ignition by temperature alone). Auto-ignition is simple enough to deal with by running the pump in a pre-tested configuration which avoids auto-ignition. However, spark ignition can never be ruled out entirely in a fault condition, no matter how rare. Therefore, a suitable protection strategy when pumping explosive gases must be implemented as per the European Union's ATEX 100a and 137 directives. These directives require manufacturers to supply equipment for safe use in explo-

Table 2: Most likely vacuum technology selection matrix



sive atmospheres and for process operators to undertake a risk analysis of the whole process and to identify protection strategies to mitigate the risks. The protection strategies are as follows:

Identify explosive atmospheres

First understand where the explosive atmosphere is and where an ignition might take place. Consider the external atmosphere surrounding the pump and the internal atmosphere including a) the process interface to the inlet flange of the dry vacuum pump and b) from the inlet flange on the dry vacuum pump to the exhaust interface.

Avoid explosive atmospheres

Operation outside the flammable range ensures that even if an ignition source is present there will not be an explosion.

Eliminate ignition sources

Spark ignition and auto-ignition should be consid-

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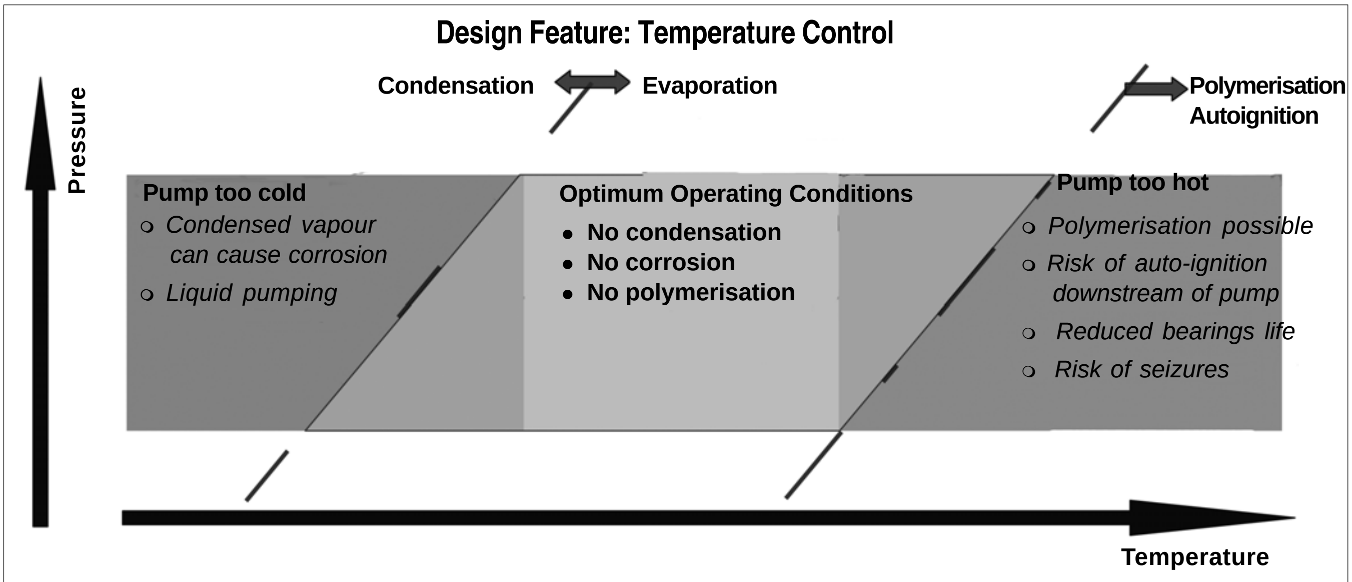

Fig 1: Internal temperature-pressure profile of a dry pump

ered.

Auto-ignition can be avoided altogether by configuring the pump correctly, but it is impossible to eliminate all potential sources of spark ignition in a dry vacuum pump. Like other mechanical, rotating equipment, dry pumps contain bearings that can fail with the possibility of metal-to-metal contact and debris or solids build-up. Therefore, if pumping in the flammable zone is unavoidable, take steps to minimise potential spark ignition sources through good pump design, operation and maintenance practices.

Limiting the effect of an explosion

If, despite the above precautions, an ignition does occur, it is important that it does not cause a major incident or any damage. Pumps constructed to European standard EN13463-5, and designed and independently tested to prevent flame propagation, are well suited to limiting the effects of an explosion. Flame arrestors are often used and these should always be tested with the pumps to prove their performance in combination.

Dry vacuum pump systems in action in India

Users worldwide regularly report significant process and cost benefits as a result of the installation of new dry vacuum pump technology. The following examples from India are typical:

Improving reliability of vacuum drying and distillation

A manufacturer of pharmaceutical intermediates in Maharashtra was using oil-lubricated, reciprocating piston-type vacuum pumps in a drying and distillation process. The system suffered from corrosion issues, frequent failures and loss of performance in the pumps because of blockages in the exhaust valves. The systems were replaced with four sets of dry vacuum pumps. These pumps have been in operation for more than seven years and in that time they have required nothing more than routine annual maintenance of typically about half an hour.

Handling aggressive agrochemicals

A major global agrochemicals manufacturer based in Gujarat needed to pump aggressive chemicals including phosphorus oxychloride, thionyl chloride and hydrogen chloride. To use the existing liquid ring pumps would have meant installing an expensive upstream scrubber with high operating costs and potential pollution issues. Instead, a dry vacuum pump was installed and configured to operate relatively hot so that the pumped vapours could not condense internally during compression. After 12 months of operation, the pump was still in pristine condition.

Slashing the cost of ownership for a chemicals manufacturer

Another agrochemical manufacturer based in Andhra Pradesh, switched from multi-stage steam ejectors to dry vacuum pumps and in a 12-month trial project, calculated significant savings as a result of reduced energy consumption. The company found that it was able to recover almost all of the valuable uncontaminated speciality chemicals at the exhaust, for reuse in the process.

Increasing house vacuum capacity

Another pharmaceutical plant was using oil-sealed piston pumps in its house vacuum system. The pumps were reliable, but they produced an oily waste that required disposal. The existing pumps were replaced with four dry vacuum pumps configured for maximum flexibility and driven through inverters to ensure better control of the vacuum levels. Because of the cocktail of pumped media, full protection with flame arrestors and differential pressure measurement were specified. Solvents are now being recovered by exhaust condensation, capacity is increased and there is better pressure control.

Multipurpose and safe operation for specialty polymer R&D

A specialty polymer manufacturer needed a vacuum pump system that could cope with a wide range of process media and duty conditions for its new R&D facility in Karnataka. They chose a dry vacuum pump with Hastelloy element flame arrestors fitted at the inlet and outlet so that the system would be safe to operate under any process media composition, even if it was potentially corrosive or flammable. Four years on, the pump continues to run well.

Conclusion

Dry vacuum pumping offers major benefits over traditional wet pumping technologies for pharmaceutical and chemical processing, largely because it has none of the problems associated with the oil or water in wet pumps. Dry pumps are clean, reliable, provide low to high vacuum and require minimal maintenance. Importantly, they can be used quite safely even when pumping flammable and corrosive vapours.

SOURCING

(Please note that nly a selection of companies are listed here)

Companies into Vacuum Systems

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