WHITE PAPER

DRY VACUUM TECHNOLOGY

for chemical and pharmaceutical processes

CONTENT

INTRODUCTION

Vacuum plays an essential role in chemical and pharmaceutical processes. Whether in vacuum conveying, inertization, distilling or drying processes, vacuum is used everywhere to make processes safer, faster and more economical or to make them possible in the first place.

The various technologies for generating vacuum are versatile. Liquid ring vacuum pumps and steam ejectors have been the robust workhorses for many decades when it comes to generating vacuum. However, like rotary vane vacuum pumps with recirculating oil lubrication, they have one disadvantage: they require an operating fluid that comes into contact with the process gas. In the mid-1990s, Busch Vacuum Solutions launched the first screw vacuum pump on the market, the COBRA. The major difference to the vacuum pumps known at that time was that screw vacuum pumps did not require any operating fluid to compress the process gas. This is why they are called “dry” screw vacuum pumps (Fig. 1). Dry screw vacuum technology is now also widely used in the chemical and pharmaceutical industries.

Fig. 1: Dry screw vacuum pump for chemical and pharmaceutical processes

FUNCTION

In a screw vacuum pump, two interlocking screw-shaped rotors rotate in opposite directions (Fig. 2). The process gases are drawn in, trapped between the cylinder and screw chambers, compressed and transported to the gas discharge. During the compression process, the screw rotors do not come into contact with each other or the cylinder. Precise manufacturing and minimal clearances between the moving parts enable this operating principle and, in addition, ensure a low ultimate pressure of up to 0.01 millibar (absolute).

The first dry screw vacuum pumps utilized constant pitch screws. With this type of screw, the screws simply moved the gas through the vacuum pump without performing any compression, then compressed the gas at the outlet in order to discharge it against atmospheric pressure. Since practically all compression took place at the outlet, all the heat generated in the process was concentrated at this point. This resulted in high gas temperatures in this area, which led to gas deposition or could exceed the autoignition temperatures of the process gas. Busch then developed screws with a variable pitch in the cylinder and screw coils, which resulted in even compression of the process gas across the entire length of the screw. This results in a more evenly distributed temperature increase throughout the entire compression chamber.

COBRA screw vacuum pumps operate with a cooling system which ensures even heat distribution, greater thermal efficiency and stability throughout the pump body. This allows the temperature to be selected so that it is high enough not to condense the process gas but low enough to avoid potential temperature-related problems such as gas deposition or spontaneous ignition. The absence of operating fluid allows a compression of the process chamber without contamination or reaction.

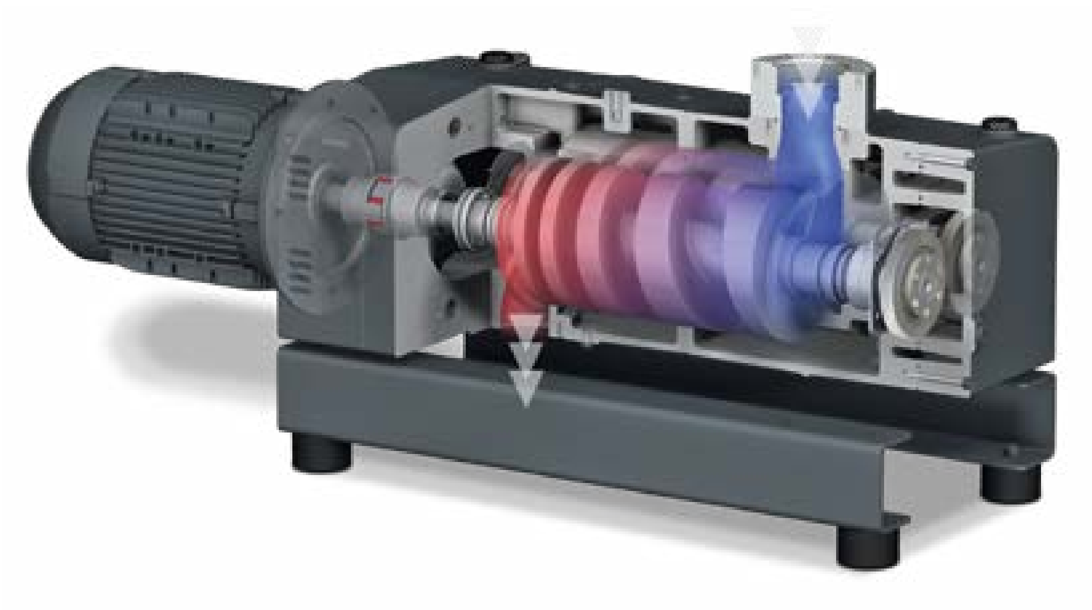

Fig. 2: Modern screw vacuum pumps have variable pitch screws, which allow an even temperature distribution inside the vacuum pump

PROTECTING THE VACUUM SYSTEM

Depending on the process gas, the vacuum pump can be exposed to certain risks. It is therefore important that the process gases are sufficiently known to minimize these risks. Different components are often required, which can be installed on the inlet or pressure side, in order to convey the process gas without damaging the vacuum pump. This is called a vacuum system, which can also consist of several vacuum pumps (Fig. 3).

For safe operation of the vacuum system, it is important to protect it from corrosion and deposits caused by crystallization or polymerization, and to increase the material resistance.

Fig. 3: Vacuum system with four screw vacuum pumps as backing pumps

PROTECTION AGAINST CORROSION

Various measures can be effective in protecting the vacuum system or the individual vacuum pumps against corrosion. The first possibility is to prevent corrosive substances from entering the interior of the vacuum pump. This can be implemented by upstream condensers or gas scrubbers.

The second possibility to avoid corrosion is to keep the process stream in the gas phase. In a screw vacuum pump this can be implemented by setting a certain operating temperature. In addition, the process gas can be diluted by a supplied ballast gas to reduce the partial pressure of the condensable gases. So, the following simple logic applies: suction in gaseous form and ejection in gaseous form. The minimum temperature must therefore be selected so that it is high enough to prevent gases from condensing out. The maximum temperature must be selected so that the vacuum pump is not damaged or so that the maximum permissible temperature according to ATEX classification is not exceeded.

A third possibility is to use compatible materials for the vacuum pump.

In COBRA screw vacuum pumps from Busch Vacuum Solutions, for example, all parts in contact with the process are made of ductile cast iron by default and have a special coating that is resistant to almost all chemicals. For extreme cases, other coatings are available to provide additional protection.

PROTECTION FROM PARTICLES ENTERING THE SYSTEM

Screw vacuum pumps should always be operated with an inlet screen or an inlet filter. This is to prevent particles from entering the inside of the vacuum pump. Due to the precise manufacturing of screw vacuum pumps with the associated small clearances and tolerances, there is a certain sensitivity to entrained particles. Dry screw vacuum pumps are frequently used with particulate dryers, especially in the pharmaceutical industry. A certain number of such particles can easily pass through the vacuum pump together with the process gas or be flushed out at the end of the process. Nevertheless, it is advisable to take appropriate precautions in order to prevent particles from being sucked in on a regular basis. For example, Busch offers a large number of different particle filters for every application.

LEAK-TIGHTNESS OF THE VACUUM PUMP/VACUUM SYSTEM

Vacuum pumps and vacuum systems in a chemical environment must be so tight that no or still a minimum of ambient air can enter and create a potentially explosive atmosphere, or toxic or explosive gases can escape. Polymer o-rings are generally used to prevent leaks between two stationary parts. The resistance depends on the selected polymer. The seal material therefore also needs to be adapted to possible process gases. Busch Vacuum Solutions has had a dynamic sealing concept for rotating shaft feedthroughs certified by TÜV SÜD in accordance with the Technical Instructions on Air Quality Control (TA Luft). These seals are considered technically leak-tight.

Tips for operation
For most applications it is recommended that the vacuum pump is warmed up for a certain lead time before process operation. This allows the specified temperature to be set. After the end of the process, it is recommended to purge the vacuum pump with non-condensable inert gas to completely remove the process gas from the vacuum pump before switching it off. Nitrogen is normally used for this flushing process. Flushing the vacuum pump with a cleaning liquid at the end of the process is also possible and recommended if there is a risk of deposits forming inside the vacuum pump during cooling.

EXPLOSION PROTECTION

With different sealing systems, various coatings and appropriate accessories, COBRA screw vacuum pumps from Busch can be configured to be compatible with virtually any chemical. In addition, various ATEX versions are available for COBRA screw vacuum pumps in accordance with EU Directive 2014/34/EU. Also, any other national regulation can be adapted for these vacuum pumps like EX-proof in US or KOSHA in South Korea. This means that these vacuum pumps can also be used worldwide in potentially explosive areas and for conveying explosive gases and vapors. Flame arresters may also be integrated if necessary.

The advantages of dry screw vacuum pumps at a glance:

- Dry compression, therefore, no contamination or reaction possible between process gas and operating fluid
- High vacuum level
- Economical as no operating fluid is required or needs disposal
- Can be designed for nearly all process gases thanks to material selection and temperature regulation
- Easy to clean with purge gas or flushing liquid at the end of the process
- Energy savings due to possible demand-driven control thanks to variable speed drive (Option)
- Can be used in potentially explosive atmospheres and conveying explosive gases thanks to different ex-proofed versions in accordance with international and national regulations and standards

CAUTION!
In addition to suppliers of dry screw vacuum pumps, there are also suppliers of oil-lubricated screw vacuum pumps on the market.

Although both versions work with screw rotors, they should never be confused with each other. Oil-lubricated screw vacuum pumps operate with screw rotors that were originally developed for compressors. They work with considerably coarser tolerances. In order to make up for this shortcoming, they are operated at much higher rotational speeds than dry screw vacuum pumps and must also be lubricated with oil to ensure the gaps are better sealed. This means that the operating fluid oil comes into contact with the process gas. This completely eliminates all the advantages of dry screw vacuum technology.

VACUUM SYSTEMS AND COMPONENTS

It is essential to consult a vacuum expert when selecting and designing vacuum technology for complex chemical and pharmaceutical processes. Only an experienced vacuum specialist can select the most suitable type of vacuum generation based on the given technical parameters and the gases or vapors to be conveyed. In addition to operational safety, the specialist must take into account all aspects, from safety-related issues to economic efficiency and energy consumption. And the entire process must be examined in order to provide the perfect vacuum generation solution.

The solution is often not a standard vacuum pump out of the catalog, but rather a customized vacuum system (Fig. 4), the core of which can be made up of one or more screw vacuum pumps.

Fig. 4: Complex vacuum system

Busch Vacuum Solutions has established a worldwide network of vacuum experts for applications in the chemical and pharmaceutical industry. Busch has competence centers in all industrialized countries where individual vacuum systems are designed and built. This allows to conform to international or national standards.

COBRA dry screw vacuum pumps are often used as individual vacuum modules and supplemented by a variety of other components.

Here is an overview of the most important components:

Vacuum booster
Vacuum boosters (Fig. 5) act as boosters through which the process gas flows first before it enters the screw vacuum pump (backing pump).

Fig. 5: PANDA vacuum booster for efficient increase of pumping speed and improvement of ultimate pressure in vacuum systems

Thanks to the combination of vacuum booster and screw vacuum pump (Fig. 6), both the pumping speed and the ultimate pressure of the vacuum system can be increased considerably in an extremely economical way (Fig. 7).

Fig. 6: Vacuum system with a screw vacuum pump as backing pump and a vacuum booster

This is known as a two-stage vacuum system. Depending on requirements, further vacuum boosters can be added. Even three-stage or four-stage vacuum systems can be technically useful and are quite common. Since vacuum boosters are also dry, i.e. free of operating fluids, the process gas in the complete vacuum system does not come into contact with operating fluids. PUMA and PANDA vacuum boosters from Busch are, like COBRA screw vacuum pumps, available in various ex-proofed versions.

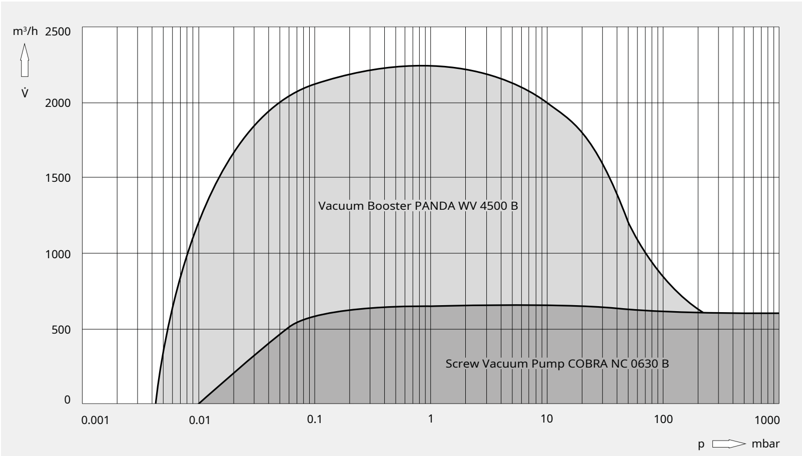

Fig. 7: Pumping speed curve of a COBRA screw vacuum pump compared to the pumping speed curve when operating in combination with a PANDA vacuum booster

Condensers

Depending on the process and the gases or vapors to be conveyed, condensers can be installed on the inlet side upstream of the vacuum booster, between the vacuum booster and the screw vacuum pump or at the outlet of the screw vacuum pump.

Especially in processes with a large amount of condensable gases that have to be conveyed at elevated temperatures, condensers are often used to condense a portion of the gas stream so that the amount of gas to be conveyed is reduced and thus a smaller vacuum system can be used.

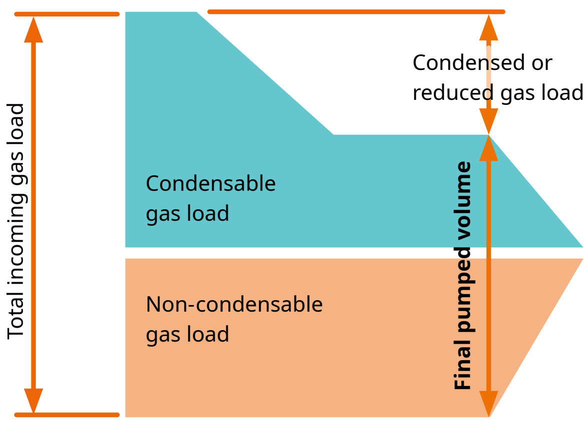

Fig. 8: Condensers help to reduce the gas load for a vacuum pump. Therefor a smaller vacuum pump with less pumping speed can be used

If the operating pressure and the temperatures in the vacuum pumps are appropriate, a condenser can be installed at the gas inlet of the vacuum system to condense a portion of the process gases (Fig. 8).

In cases where the operating pressure is too low to allow condensation at the gas inlet of the vacuum system, a vacuum booster may be used to increase the pressure of the gas stream to allow for condensation between the vacuum booster and the vacuum pump, i.e. a condenser can be installed between the vacuum booster and the screw vacuum pump. This is still advantageous because, while the vacuum booster must pump the full gas load, the vacuum pump only pumps the uncondensed gas exiting the condenser. A smaller screw vacuum pump can therefore be used as a backing pump.

Condensers as vacuum boosters?
In a vacuum system, condensers can have a similar effect as vacuum boosters. As vapors in the condenser change from a gaseous to liquid state, they considerably reduce their volume and thus generate additional pumping speed. Furthermore, a condenser between vacuum booster and backing pump always provides protection for the screw vacuum pump used as a backing pump. Since the vacuum pump always compresses against atmosphere, condensation of vapors may occur inside the vacuum pump. If they are already separated in the condenser upstream of the backing pump, this condensation is avoided in the backing pump.

Condensers are also frequently used at the outlet of the vacuum pump to condense the process gases for recovery. This is a major advantage of the dry screw vacuum pump: Since there is no operating fluid in the compression chamber of the vacuum pump, the process gases leave the vacuum pump uncontaminated. They can thus be condensed, recycled and reused. In addition, the amount of effluent is reduced.

Liquid separators
Like particles, liquids do not normally pose a mechanical problem if small amounts get into the screw vacuum pump. However, it is good practice to take measures to protect them from regular liquid carry-over mainly for corrosion protection. Liquid can enter the vacuum system from the process or by ingestion from a condenser. Condensation when the process gas enters the vacuum system can also lead to liquid formation. This can be remedied by upstream liquid separators.

With liquid separators, gas and liquid are separated in several stages to completely remove entrained liquids from the gas stream. If required, liquid separators can also be provided with integrated particle filter elements to eliminate the need for a separate inlet filter assembly.

Automatic start/purge function

As already described, dry screw vacuum pumps are designed to operate at temperatures sufficient to prevent process gases from condensing in the vacuum pump. However, it is critical when conveying condensable gases to allow the vacuum pump to reach that operating temperature prior to starting the process in order to prevent condensation. The automatic start also ensures most of air is removed from the system before the process gas entering it. Thus is increasing the safety. It is also important to purge the process gases from the vacuum pump prior to shutdown in order to prevent condensation as the vacuum pump cools and to prevent corrosion or other detrimental factors. A package with an automatic start/purge function is available for this purpose.

The flushing stream generated by a purge gas during warm-up before the process starts ensures a uniformly rising temperature until the desired operating temperature is reached. When the vacuum pump is switched off, the purge gas frees the inside of the vacuum pump from remaining process gases.

The automatic start/purge function includes an actuating valve to separate the vacuum pump from the process and a solenoid valve to supply purge gas. Sequencing of the valves can be performed by a skid-mounted control panel or the customer’s control system.

Automatic flushing function with liquid

In some applications, it is inevitable that process material will collect in the vacuum pump in spite of attempts to prevent it. An automatic liquid flushing device should be provided for such cases. This allows particles and other residues to be removed from dry screw vacuum pumps during operation. Flushing simply consists of injecting a small amount of a solvent into the vacuum pump while it is running to remove the process residues. As the solvent passes through the vacuum pump it dissolves the residues and carries them out. In addition, a flushing process always takes place when the vacuum pump is switched off. The flushing processes can also be incorporated into the customer’s clean-in-place procedure to prevent cross-contamination in multi-purpose process units.

Control unit
Screw vacuum pumps can be operated by virtually any type of control unit and communicate with the customer’s control system.

For example, Busch offers various options from the simple motor control unit of an individual vacuum pump to the complex PLC control unit of a vacuum system.

Frequency control
Typically, a variable speed drive is utilized in combination with a pressure transmitter instead of a control valve to control the vacuum pump’s inlet pressure by varying the pumping speed to match the capacity of the vacuum pump to the process requirements. They can also be programmed to provide pressure ramping functions as needed by the process conditions. If a vacuum booster is used in conjunction with a dry screw vacuum pump, it can also be controlled by a variable speed drive.

When operating screw vacuum pumps with a variable speed drive and automatic flushing device, the vacuum pump can be reduced to a minimum pumping speed during the flushing cycle.

Due to the reduced speed of the screw rotors, the vacuum pump runs cooler and cleaning is faster and more effective.

SUMMARY

Dry screw vacuum pumps are ideal vacuum generators in processes where the process gas to be conveyed should not come into contact with an operating fluid inside the vacuum pump. This prevents the process gas from contaminating or reacting with the operating fluid. The elimination of operating fluids in the compression chamber of the vacuum pump also eliminates the need to source and process them or dispose of them – and the associated costs. It is essential to consult a vacuum expert to find the best possible vacuum generation solution for a process, because only a proven expert can design and configure a vacuum system in such a way that it masters the requirements of the process, meets all safety-related regulations and at the same time operates as reliably and economically as possible.