Economic Efficiency in Vacuum Generation

Extensive Evaluation Using Vacuum Packaging as an Example

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Content

Abstract

In many industrial processes, the energy efficiency of the vacuum technology used affects the overall efficiency of the process. An overly narrow view of the performance data from individual vacuum pumps is usually misleading. Numerous factors and the characteristics of the vacuum technology used need to be taken into account to optimize the efficiency of vacuum generation. Coupled vacuum pumps (with or without vacuum boosters) or centralized vacuum systems often offer the best solution for providing the required vacuum in the process with the lowest energy consumption. As vacuum pumps also generate heat due to their physical properties, aspects like the need for additional cooling and possible heat recovery also play a role in terms of efficiency.

It is therefore necessary to consider the overall process and coordinate the vacuum technology with the process technology for efficient vacuum generation.

Introduction

Minimizing costs and the environmental impact of the process – these are the basic requirements for any production today. Energy consumption always plays a key role for the economic balance sheet and ecological footprint – in particular, if certification of energy management according to ISO 50001 is desired or required. The more efficiently the applied energy is used, the easier it is to meet these basic requirements.

Vacuum technology is used in increasingly numerous industrial processes. Its energy efficiency thus affects the overall efficiency of operations accordingly. This white paper gives an overview of energy consumption and potential savings in vacuum generation. As an example, we will take a look at applying vacuum technology in the context of packaging foodstuffs with chamber, thermoforming and tray sealer packaging machines.

Efficient energy management includes both the design and operation of the system. For vacuum applications, it is necessary to look at both generation and consumption. The machines' technologies offer versatile options for conserving resources and saving costs, which also contribute to climate protection.

It is important not to narrowly focus on the energy consumption of individual machines in this regard, since possible synergies are only revealed after studying the numerous factors affecting overall efficiency as a whole. These factors include:

- Design and installation overhead
- Life cycle
- Availability
- Operating and training overhead
- Support from the manufacturer / supplier
- Expandability
- Maintenance overhead including downtime
- Operating fluids
- Disposal

The sum of these factors results in the life cycle costs (LCC).

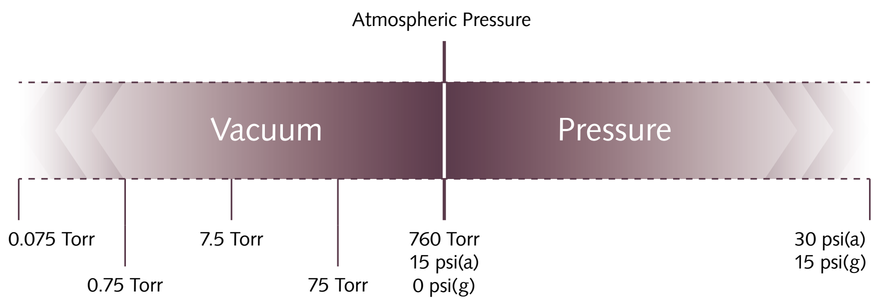
Vacuum technology in industrial processes
Basic principles of vacuum generation

In industry, "vacuum" is understood as pressure that is less than the prevailing atmospheric pressure. When describing different levels of vacuum, the paradoxical peculiarity of the technical jargon can irritate laypeople: the lower the pressure, the higher the vacuum.

There are four basic parameters for selecting a vacuum pump. Of course, they also apply when assessing an existing system:

- Ultimate pressure [Torr]
- Operating pressure [Torr]
- Pumping speed [ACFM]
- Nominal motor rating [HP]

Figure 1
Pressure / vacuum range



Ultimate pressure [Torr]
This is the lowest pressure or the highest vacuum level that the vacuum pump can achieve. As the vacuum pump approaches its ultimate pressure, its pumping speed approaches zero (see figure 2). The ultimate pressure is indicated in Torr.

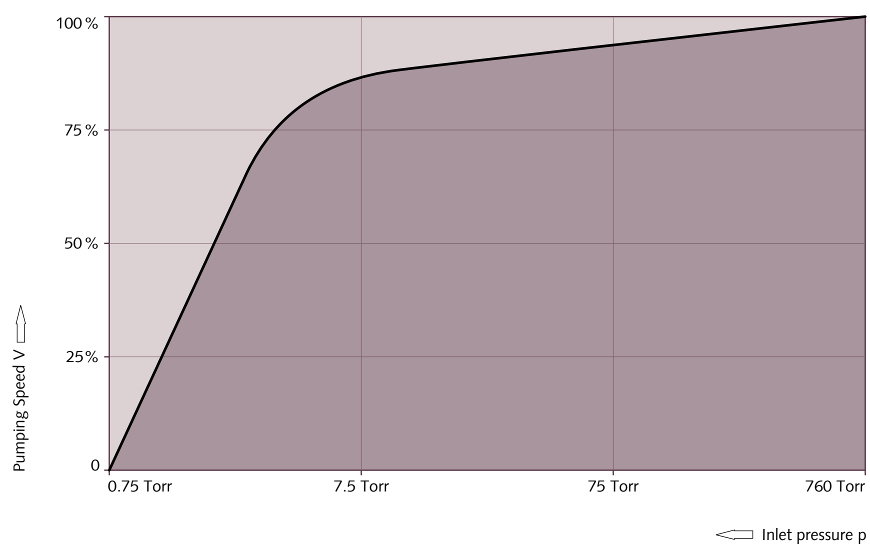
Operating pressure [Torr]
The operating pressure describes the actual process pressure during operation. It is usually higher than the ultimate pressure and can vary during the process.

Vacuum technology in industrial processes

Pumping speed [ACFM]
The nominal pumping speed of a vacuum pump indicates how much air or gas it can remove/ extract in a certain period of time. ACFM is the unit usually used for this. As the pressure decreases, the actual pumping speed tends to decrease as well.

The pressure profile is illustrated with the so-called pumping speed curve. It shows the actual pumping speed in all pressure ranges between atmospheric pressure and the ultimate pressure. The shape of this curve affects evacuation times and therefore affects the length of packaging cycles during vacuum packaging, for example.

Figure 2
Typical vacuum pump pumping speed curve showing the correlation between pumping speed and pressure level. On the left, an ultimate pressure of 0.75 Torr can be seen; on the right, 760 Torr is displayed as atmospheric pressure



Nominal motor rating [HP]
The nominal motor rating quantifies the output delivered in horsepower [HP] at the motor shaft at nominal voltage and maximum allowable current. The nominal motor rating is a maximum value that is not always required in practice. The electrical energy that is actually absorbed is calculated based on the real shaft power delivered and the efficiency of the motor.

$$\text{Real power consumption} = \frac{\text{Required shaft power}}{\text{Motor efficiency at this shaft power (and the given voltage)}}$$

CAUTION! Some motor or vacuum pump manufacturers provide the nominal motor rating in conjunction with the so-called service factor (SF). The real maximum motor rating results from multiplying the nominal motor rating by the service factor. It is thus higher than the nominal rating suggests (see section “A brief guide”).

Vacuum technology in industrial processes

Additional parameters
In addition to the parameters mentioned, there are several factors that can have a considerable effect on the process and its efficiency. These should also be taken into account when selecting vacuum technology:

- Operating fluids
  - Type of operating fluid or compression without operating fluids
  - Maintenance overhead due to operating fluids
- Dimensions / footprint
- Heat emissions
- Installation overhead
- Maintenance overhead
- Reliability / life cycle
- Noise emissions

Different operating principles in vacuum technology

Vacuum pumps with different operating principles are used in industrial vacuum generation. They are fundamentally different from each other on a technical level and have specific strengths. It is important to evaluate which type of vacuum generation is ideally suited for each application.

These vacuum pumps are most widely used:

- Rotary vane vacuum pumps (dry-running or oil-lubricated)
- Vacuum boosters
- Liquid ring vacuum pumps (operating fluid is usually water)
- Screw vacuum pumps (dry, also oil-lubricated but less frequently)
- Claw vacuum pumps (dry)

Selecting the vacuum pump according to the operating principle can have a major impact on energy efficiency. However, the vacuum pump with the lowest energy consumption does not necessarily always ensure the highest level of energy efficiency in the process.

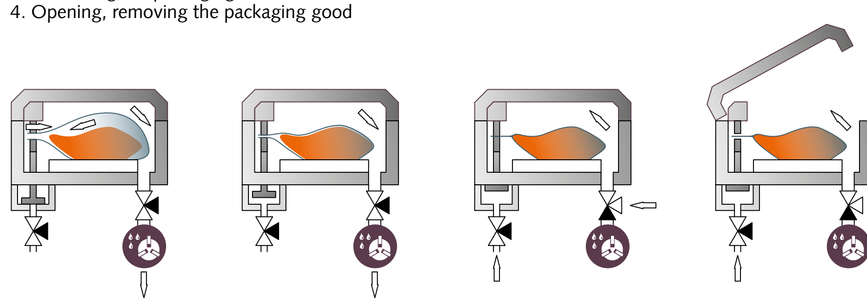
Vacuum generation during vacuum packaging
Why are products vacuum-packed?

Vacuum packaging was introduced over 50 years ago and has continuously advanced since then. Using a vacuum or protective gas during the packaging process is one of today's most common methods for hygienically packaging foodstuffs in portioned packaging attractive to consumers. It is primarily used for meat, fish, cheese and convenience products. Vacuum reduces the activity of microorganisms that require oxygen. When in vacuum, foodstuffs have a longer shelf life, even without preservatives.

How does vacuum packaging work?

Air, and thus oxygen, is removed from the foodstuffs packaging during the vacuum packaging process. This happens during extraction in the vacuum chamber of the packaging machine. When the chamber is opened to remove the products (ventilation), the atmospheric pressure presses the plastic foil onto the surface of the packaging good.

Figure 3
Chamber vacuum packaging machine operating principles:
1. Evacuation of the vacuum chamber, including the packaging bag inside
2. Sealing of the packaging bag
3. Ventilating the packaging chamber
4. Opening, removing the packaging good



The ideal packaging pressure of each foodstuff is the pressure at which the longest possible shelf life is achieved. The lower the ultimate pressure of a vacuum pump is, the more reliably the desired pressure in the packaging can be set. Modern rotary vane vacuum pumps achieve an ultimate pressure of 0.075 Torr. That corresponds to one ten thousandth of the atmospheric pressure at sea level.

Vacuum generation during vacuum packaging
Vacuum or protective gas

After the vacuum has been applied, the final product is either packaged in a vacuum or the evacuated packaging is flooded with a protective gas mixture – usually CO_2 and nitrogen. There are different types of vacuum packaging.

Simple vacuum packaging:
- Vacuum packaging in bags, foils
- Trays, skin tray packaging

Vacuum packaging plus protective gas:
- Modified atmosphere packaging (MAP)
- Equilibrium modified atmosphere packaging (EMAP)
- Controlled atmosphere packaging (CAP)

Among other things, using vacuum and protective gas reduces the activity of microorganisms requiring oxygen and protects aromatic substances from oxidation. Foodstuffs have a longer shelf life in vacuum or protective gas, even without preservatives.

Packaging machines

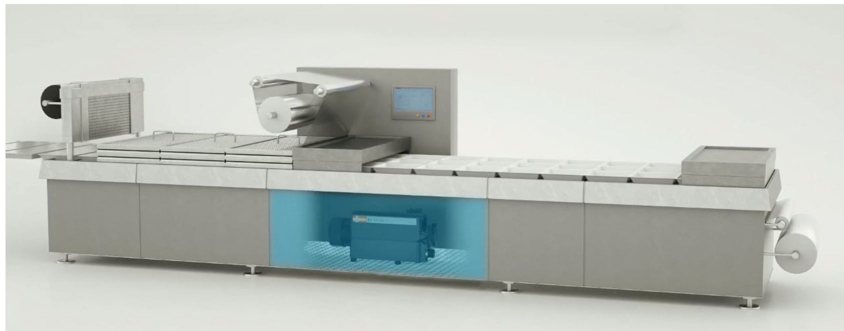
These three types of packaging machines are most widely used in the food industry:

- **Chamber packaging machine** – packaging only using bags
- **Tray sealer packaging machine** – a prefabricated tray is covered with foil and sealed
- **Thermoforming packaging machine** – the packaging shape is manufactured by thermoforming an – often sturdy – base foil in the packaging machine; the actual packaging process is the same as for the tray sealer

The vacuum pumps evacuate the packaging chamber to the desired vacuum level; for fresh meat, this is usually 1.5 to 4 Torr. In thermoforming packaging machines, an additional task must be performed, namely generating the vacuum for thermoforming the base foil. A significantly lower vacuum level is sufficient for this, usually between 75 and 190 Torr.

Vacuum generation during vacuum packaging

Figure 4
Thermoforming packaging machine with integrated rotary vane vacuum pump



Of course, the life cycle costs (LCC) of a packaging machine do not just depend on the vacuum technology and its energy requirements. The entire packaging process must be analyzed to optimize the LLC. When it comes to vacuum generation, these factors should be observed:

- Vacuum pump selection (operating principle)
- Vacuum technology installation location
- Cycle times and packaging cycles
- Control
- Heat emissions and recovery

The life cycle costs (LCC) of a packaging machine do not just depend on the vacuum technology and its energy requirements. A number of additional factors also play a role.

Vacuum generation during vacuum packaging
Selection of vacuum technology

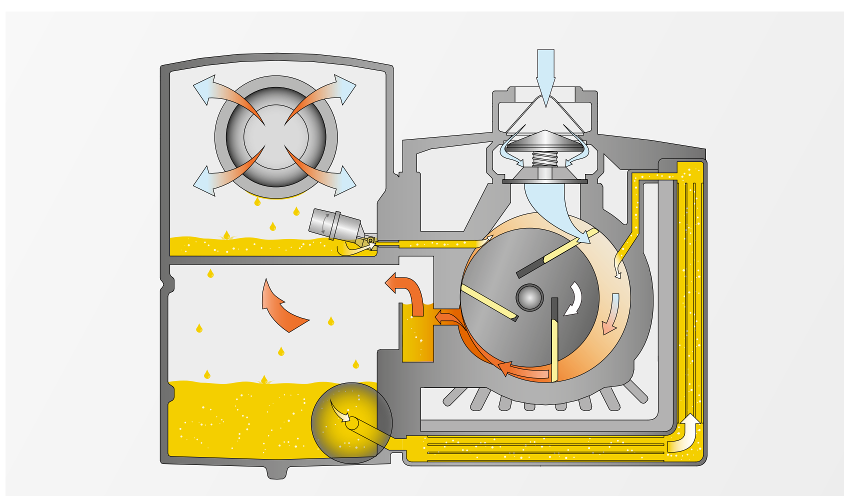
The following types of vacuum pumps are available on the market for chamber machines, thermoforming packaging machines and tray sealers:

Rotary vane vacuum pumps
Oil-lubricated rotary vane vacuum pumps are the state-of-the-art solution for this application and the most widely used vacuum generators (market share >99%).

The benefits:
- Stable pumping speed curve
- Lowest energy consumption at <10 Torr
- Robust and proven
- High reliability
- High water vapour tolerance
- Low ultimate pressure / high vacuum
- Easy operation
- Easy servicing
- Special oxygen (MAP) or aqua versions available

The disadvantages:
- Regular maintenance required
- Regular replacement of exhaust filters required
- Limited speed control range

Figure 5
Cutaway drawing of an oil-lubricated rotary vane vacuum pump

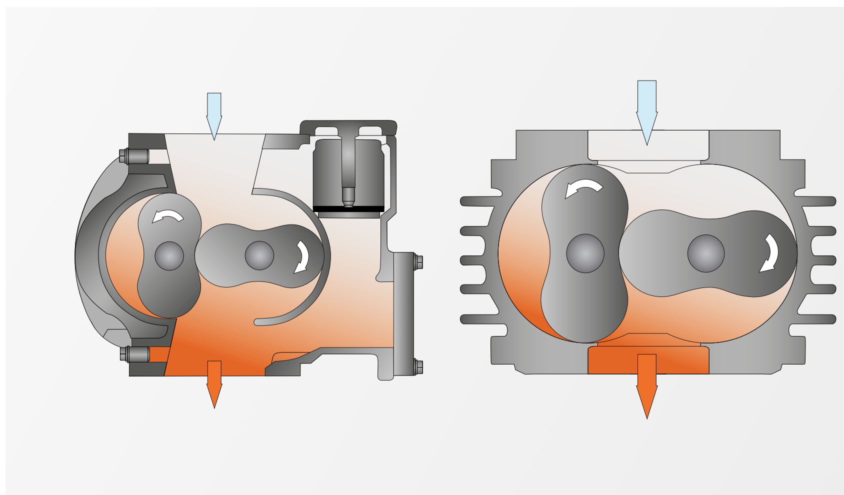


Vacuum generation during vacuum packaging
Selection of vacuum technology

Vacuum boosters
A vacuum booster significantly increases the output of another vacuum pump, the so-called backing pump. The right combination of backing pump and vacuum booster makes it possible to achieve a high pumping speed that would otherwise only be possible with a significantly larger individual vacuum pump – with a much larger motor. The result is much shorter cycle times and increased overall efficiency.

Connecting an oil-lubricated rotary vane vacuum pump as a backing pump to a vacuum booster is typical.

Figure 6
Cutaway drawing of a vacuum booster. On the left with a bypass valve; on the right without a bypass valve



Vacuum generation during vacuum packaging
Selection of vacuum technology

Liquid ring vacuum pumps
Liquid ring vacuum pumps normally work with water as operating fluid. They are therefore particularly well-suited for packaging very wet or hot foodstuffs like soups or mixed pickles, for example. Liquid ring vacuum pumps can be operated as a simple continuous flow system, or as a partial or total recirculation system. The disadvantage when compared to oil-lubricated rotary vane vacuum pumps is increased energy and water consumption.

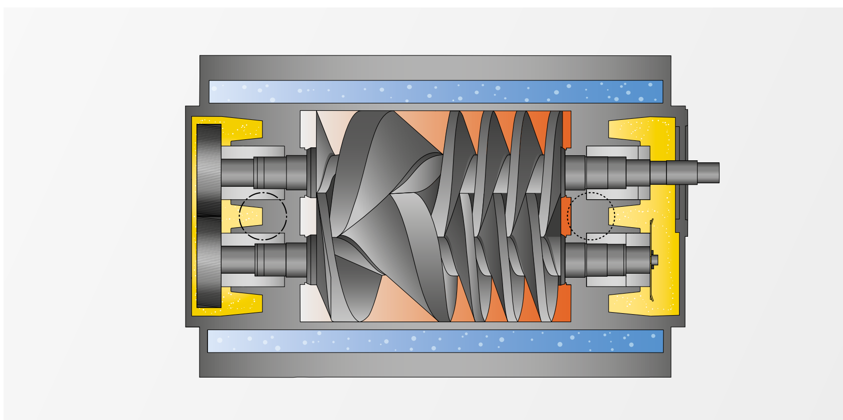
Figure 7
Cutaway drawing of a liquid ring vacuum pump

Vacuum generation during vacuum packaging

Screw vacuum pumps
Dry screw vacuum pumps were originally developed for applications which require compression with no operating fluids in addition to a low ultimate pressure; for example, the semiconductor industry. They achieve a low ultimate pressure of ≤ 0.0375 Torr and thus operate at a higher vacuum level that is not necessarily required in vacuum packaging.

Nevertheless, certain screw vacuum pumps are suitable for use in vacuum packaging. There, they have the advantage of lower maintenance costs and the option for speed control (frequency control). However, if there is any damage (for instance, if larger particles reach the compression chamber of a screw vacuum pump due to an operating error or if water cooling fails), the cost of repair is significantly higher than that associated with an oil-lubricated rotary vane vacuum pump. For this reason, screw vacuum pumps are very seldom used for vacuum packaging.

Figure 8
Cutaway drawing of a typical dry screw vacuum pump. Thanks to its precise geometry, both screws rotate without touching each other or the housing.



The benefits:
- Minimal maintenance
- Speed control possible in a wide frequency range
- High level of energy efficiency
- Compact design

The disadvantages:
- Higher initial investment costs
- Efficiency of screw vacuum pumps with integrated oil circulating lubrication is minimized
- High repair costs in the event of damage

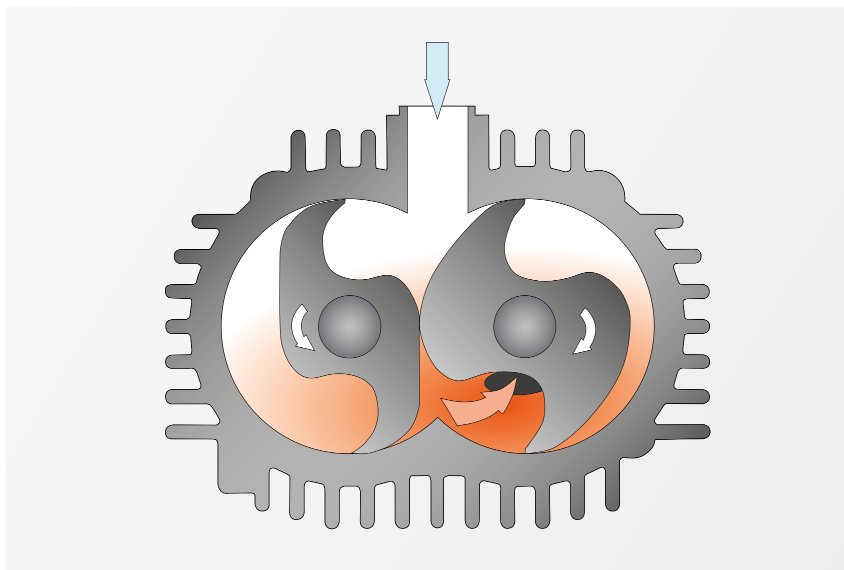
There are screw vacuum pumps with screw profiles based on the simple design of a compressor. They are not optimized for generating vacuum and normally do not achieve the ultimate pressure necessary for packaging (see section "Compressor versus vacuum pump"). This disadvantage can be compensated for with integrated oil circulating lubrication and with operation at very high speeds. With these modifications, however, the major advantages of a screw vacuum pump (minimal maintenance and high energy efficiency), no longer apply. Operating at high speeds can also have a negative effect on the service life.

Vacuum generation during vacuum packaging

Claw vacuum pumps
A claw vacuum pump, like a screw vacuum pump, is dry and does not require operating fluids. However, it only achieves an ultimate pressure of 75 to 150 Torr in the relevant sizes. It is thus not suitable for all types of vacuum packaging. Instead, it is more suitable for packaging with protective atmosphere and for thermoforming base foils in thermoforming machines.

Rotary vane vacuum pumps have proven themselves in the food packaging industry over several decades and are the most widely used in that area. Dry screw vacuum pumps are available if oil-free compression is required.

Figure 9
Cutaway drawing of a dry claw vacuum pump



Vacuum generation during vacuum packaging
Where is the vacuum pump located?

Up to a size of 200 ACFM, rotary vane vacuum pumps are usually installed directly in the packaging machine. Larger rotary vane vacuum pumps are usually installed outside the packaging machine and connected using pipe lines or tubes.

As a basic principle, the distance between the vacuum pump and the packaging machine or packaging chamber plays a considerable role with regard to the efficiency factor. All components between vacuum generation and consumption, like tubes, pipes, curved components or valves, are additional cavities that also have to be evacuated. The larger the overall volume, the longer evacuation takes. In practice, pipe lines are often too long or incorrectly designed with regard to flow. In these cases, pumping speed losses of up to 50 percent are not uncommon. Attempts are often made to compensate for these losses with a larger vacuum pump. Firstly, this is only possible to a certain extent due to the laws of physics. Secondly, this type of misguided solution is predestined to cause excessive energy consumption.

Improper installation can also negatively affect the ultimate pressure. The longer a pipe is, the more connecting pieces and valves are required, so the risk of leakage increases. The vacuum pump may not be able to achieve the desired pressure in the packaging chamber at all because leaked air is constantly being sucked in.

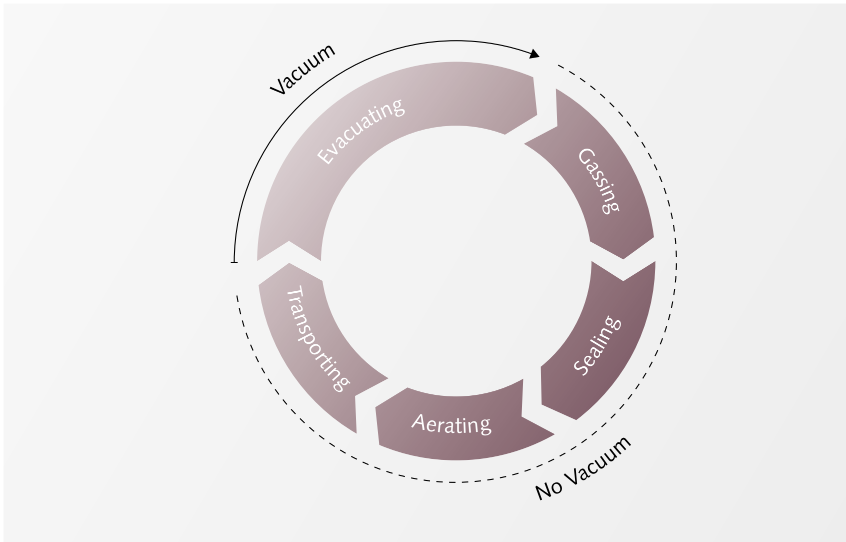
Nevertheless, there are good reasons to install the vacuum pumps outside of production or packaging rooms. Noise and heat emissions play a role here, among other factors (see section "Heat emission/recovery"). Possible disadvantages of this type of vacuum pump installation can be prevented by carefully configuring the vacuum system. When properly installed, a pipe connection can be useful as a vacuum buffer (see section "Central vacuum supply").

Improperly installed pipe connections can lead to considerable losses when it comes to pumping speed, whereas correctly installed pipe lines can be used as a vacuum buffer.

Vacuum generation during vacuum packaging
Cycle times and packaging cycles

An important parameter in industrial vacuum packaging is the speed at which the goods are packaged. It is usually important to achieve the shortest possible cycle times. The actual packaging process of a thermoforming machine begins after the base foils have been thermoformed and the goods have been positioned. Evacuating the packaging chamber is a decisive factor. When packaging using a protective atmosphere, the packaging is subsequently flooded with protective gas. The next steps are sealing the packaging, ventilating the packaging chamber and transporting the packaged good out of the chamber. At the same time, the new batch is conveyed.

Figure 10
Packaging cycle



Vacuum generation during vacuum packaging

Evacuation makes up approximately one third of the packaging cycle. One could infer from this that the vacuum pump is being operated unnecessarily two thirds of the time and that this represents potential for energy savings. In practice however, vacuum pumps cannot simply be switched on and off efficiently.

Example:
Packaging machine: 20 cycles per minute
Cycle time: 3 seconds
Evacuation time: 1 second

If you were to switch the vacuum pump on and off during the cycle, it would be turned on ten times in one minute to be operated two seconds each time. This process does not make any sense with regard to energy since the vacuum pump consumes the most energy in the start-up phase. Speed control is also not a practical option. It reacts too slowly and energy consumption in the phase between idling and full capacity is higher than when the vacuum pump is operated at a constant speed.

Speed control can only be used efficiently when the packaging cycles are relatively long. In addition, continuous operation of the vacuum pump provides a further advantage: even if nothing is being evacuated at a certain point in the packaging cycle, the vacuum pump maintains the vacuum in the pipe line, directly up to the valve upstream from the vacuum chamber. As a result, the vacuum does not have to be completely “built up” each time. Instead, it is already there when the valve is opened. This makes it possible to minimize pump-down time (you can find additional options for optimizing cycle times in the next chapter).

The vacuum pump consumes an excessive amount of energy in the start-up phase. The same applies if the pump motor is operated outside of the optimal speed range – such as when speed control is used.

Vacuum generation during vacuum packaging
Regulating the packaging process

As a rule of thumb, the packaging machine control system should also control the vacuum pump. This enables both to be optimized with respect to each other. For example, it is possible to prevent the vacuum pump from operating when nothing is being packaged. The control system is usually provided by the packaging machine manufacturer. If different packaging sizes are used in one machine, the length of cycle times can vary considerably. To work as energy-efficiently as possible, it is thus practical to adjust the control system to the cycle times in these circumstances.

Vacuum system with two or three rotary vane vacuum pumps
It is generally possible and often logical to not just install one individual vacuum pump that is designed for the maximum required pumping speed. Different products are often packaged at the same packaging machine at different times. Dimensions, packaging volumes and cycle times can vary considerably. In these cases, it is often worthwhile to use two or three smaller vacuum pumps in parallel. The vacuum pumps can be controlled in such a way that only those vacuum pumps needed for providing the required pumping speed in each case are in operation. To shorten packaging cycles, a duplex vacuum system can be considerably more efficient than one individual large-scale vacuum pump.

Figure 11
Two rotary vane vacuum pumps combined into a duplex vacuum system

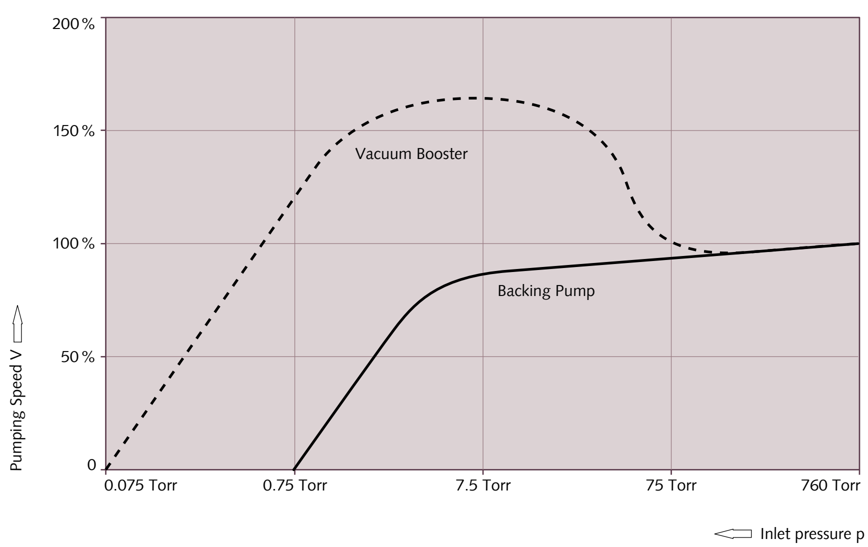
Vacuum generation during vacuum packaging

Vacuum system with rotary vane vacuum pump and a vacuum booster
An additional option is to connect two vacuum pumps with different performance features. Combining their specific strengths creates a technical solution that shortens cycle times and thereby provides the highest level of efficiency. Connecting a rotary vane vacuum pump as a backing pump and a vacuum booster is typical. The vacuum booster increases the pumping speed in a pressure range in which the speed of an individual vacuum pump is dramatically reduced. Figure 13 shows how one such combination can drastically increase the pumping speed or reduce the ultimate pressure. Although both vacuum pumps operate constantly, they require less energy together than an equivalent individual vacuum pump. At the same time, this combination facilitates very short cycle times with comparatively low energy consumption.

Depending on the specific process requirements, several connected vacuum pumps can often work more efficiently than one individual device.

Figure 12
Vacuum system with a rotary vane vacuum pump as a backing pump and a vacuum booster

Figure 13
Vacuum system pumping speed curve with a rotary vane vacuum pump and a vacuum booster



Vacuum generation during vacuum packaging

Heat emissions / recovery

Motor and pump mechanisms generate heat during operation and emit it into the environment. These heat emissions contaminate the indoor climate. In air-conditioned rooms, the heat emitted by the vacuum pumps has to be compensated for by the air conditioning system. So, waste heat requires additional energy costs for cooling. On the other hand, waste heat can also be avoided by using a heat exchanger. An additional option is to use the waste heat from the vacuum pumps for heating. For example, a water-oil heat exchanger can be used to recover a large portion of the waste heat as heat energy.

With a water-oil heat exchanger, 50–70% or more of the motor's energy consumption can be recovered and used as heat energy. The rule of thumb for the balance between waste heat and cooling needs is: for three horsepower of waste heat from vacuum pumps, one horsepower of additional cooling energy is required.

Centralized vacuum supply

Operations with a larger number of packaging machines have proportionately large vacuum requirements. If this exceeds a certain level, centralization of the vacuum supply can be the most efficient option. Possible energy savings then have to be weighed against the investment costs. The following factors play a role:

- Number and type of packaging machines
- Additional vacuum consumers
- Space required
- Distance between the vacuum system and the machines

Centralized vacuum systems can provide many benefits when designed specifically for the application by vacuum specialists:

Overall economic efficiency
It is not necessary to have a separate vacuum pump for each packaging machine. Depending on the system's design, it is possible to considerably reduce the number of vacuum pumps and also the costs of procurement, energy consumption and maintenance. Existing vacuum pumps can be integrated (see the sample case at the end of this section).

Energy savings thanks to on-demand control
The unavoidable strong fluctuations in vacuum requirements for individual machines are levelled out. The overall output can be controlled so that it is constantly near or within the range of the optimal efficiency. This makes considerable energy savings possible.

Heat recovery / cooling requirements
As the systems are installed in separate rooms, no waste heat is emitted into the air-conditioned production or packaging areas. No additional cooling requirements arise for compensating for waste heat emitted into air-conditioned areas. At the same time, waste heat is extensively and efficiently used. Both effects have a considerable influence on the energy balance and CO_2 footprint.

Vacuum generation during vacuum packaging

Reliability
When vacuum pumps undergo maintenance or fail, another vacuum pump in the centralized vacuum system is automatically switched on. Downtime and performance and productivity losses are prevented.

Short cycle times, high level of performance
The pipework between central vacuum generation and the packaging machines can be used as a vacuum buffer. It is also easy to install additional buffer tanks in the vacuum room. The desired vacuum volume in the packaging chamber is thus available almost immediately at any time. This guarantees the fastest possible evacuation of packaging and leads to especially short cycle times

Easy maintenance
As the centralized vacuum system is installed outside of the production or packaging area, maintenance can be performed during ongoing operation. During maintenance of the vacuum pump, the other vacuum pumps continue operation so there is no downtime. Maintenance personnel does not have to access hygienically sensitive areas.

Fully-automatic operation
Thanks to the demand-driven control system and the connection to the process management system, it is possible to continuously monitor the process. Defined target values are automatically maintained.

Figure 14
Example of a fully centralized vacuum supply

Vacuum generation during vacuum packaging

Example case
Potential savings from a centralized vacuum system

9 thermoforming packaging machines, chamber volume approx. 14 litres
1 rotary chamber packaging machine, chamber volume approx. 34 litres
Total volume for all sealing tools: approx. 160 litres
Thermoforming packaging machine cycle rate: 10 cycles / minute
Rotary chamber packaging machine cycle rate: 20 cycles / minute
Energy costs: $ 0.12 / kWh

Decentralized vacuum supply (individual vacuum pumps)

Power consumption (including cooling power):	approx. 1,270,000 kWh / year
Energy costs:	approx. $ 152,000

Central vacuum supply

Power consumption (including cooling power):	approx. 430,000 kWh / year
Energy costs:	approx. $ 52,000

Centralization of vacuum supply can considerably reduce energy consumption. In this sample case, the savings come to approximately $ 100,000 per year (without additional savings for maintenance costs).

A brief guide
Speed control (frequency control)

Speed or frequency control – both terms can be used interchangeably – describes the option of changing the speed of the pump motor. At first glance, increasing or decreasing the motor speed seems like a simple and practical method for reacting to fluctuations in demand in a vacuum application. However, this method also has disadvantages. Firstly, the speed controlled motor often operates outside of the range of its highest level of energy efficiency. Secondly, changing the speed has a delayed effect on the actual vacuum performance. Depending on the system and vacuum requirements, considerable delays can occur, which, in turn, significantly lengthen cycle times.

Vacuum boosters

A vacuum booster is a vacuum pump used in combination with another vacuum pump, the so-called backing pump. Here, pumps with different operating principles and performance classes are combined. The right combination of a backing pump and a vacuum booster can considerably increase the overall output of both pumps and ensure high overall efficiency at the same time.

A brief guide
Service factor

The service factor is defined as a standard by the US American National Electrical Manufacturers Association (NEMA) in the NEMA MG1-2011 handbook. It is listed on the name plate as a multiplier and indicates the degree to which a motor can be loaded beyond the rated power. The rated power is multiplied by the SF value to calculate this. A rated power of 15.0 HP and SF of 1.25 results in a maximum permissible rated power of 15 x 1.25 = 18.75 HP. The actual rated power is thus 25 percent higher than indicated by the rated power value.

Compressor vs. vacuum pump

The basic principle of compressors and vacuum pumps is the same: they convey air (or other gases). Both take in gases from one side and discharge them on the other. Connecting to the inlet side creates a vacuum, whereas connecting to the outlet side results in overpressure. The big difference here is the compression ratio (a compressor at 30 PSIG has a compression ratio of 3 : 1 and vacuum pump at 1 Torr has a compression ratio 1 : 760). This difference has considerable technical consequences. For example, screw compressors thus usually have a larger gap between the screws and the housing than screw vacuum pumps. On the inlet side, they do not achieve nearly the vacuum level that a vacuum pump does in a comparable operating mode.