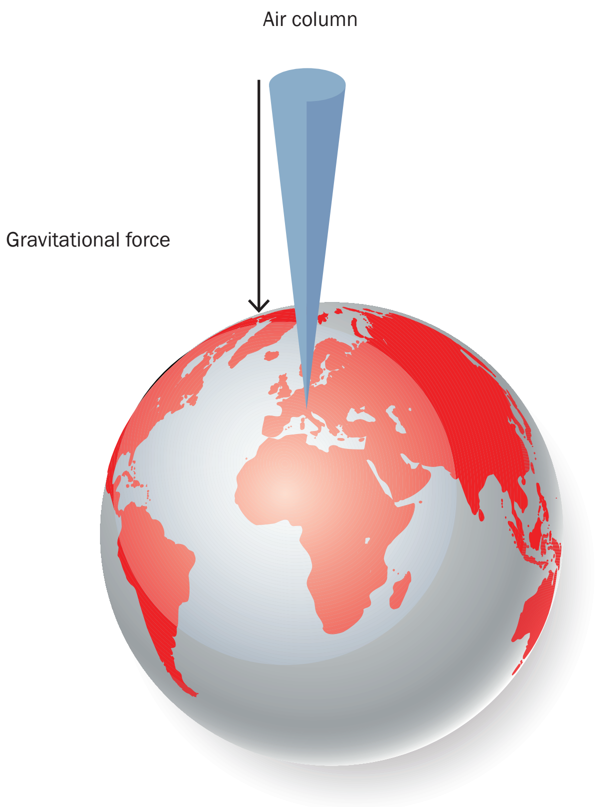
DEFINITION OF ATMOSPHERIC PRESSURE

Before defining what Vacuum is and what is the correct terminology to be used in this field it is important to know the meaning of atmospheric pressure.

The earth is surrounded by layers of gas mixtures (atmosphere).

The atmosphere surrounding the earth has its own weight.
Atmospheric pressure is defined as the force per unit area exerted against a surface by the weight of the air above that surface. And that is exactly the force magnitude we work with when we use the vacuum. It is a limited magnitude: atmospheric pressure cannot be increased.
It is measured in the International System in Pascal and with a measuring instrument called barometer.



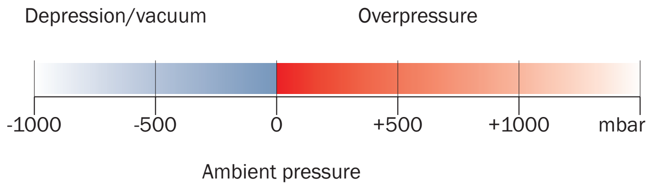
The atmospheric pressure is higher at sea level than at a point on top of a mountain, because the air mass above the point on the mountain is lower than the air mass above the point at sea level.

DEFINITION OF VACUUM

In the industrial vacuum sector, different terms and units of measurement are used with regard to pressure and air flow rate. To this end, the meaning of these quantities should be clarified.

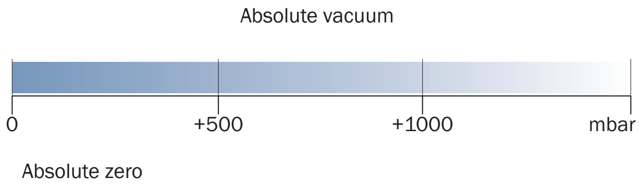
VACUUM AS RELATIVE VALUE

In the field of vacuum technology, vacuum is indicated as a relative value, which means that the depression is indicated in relation to the ambient pressure. The vacuum value indicated is preceded by a negative sign because the ambient pressure is indicated with 0 mbar as a reference point.

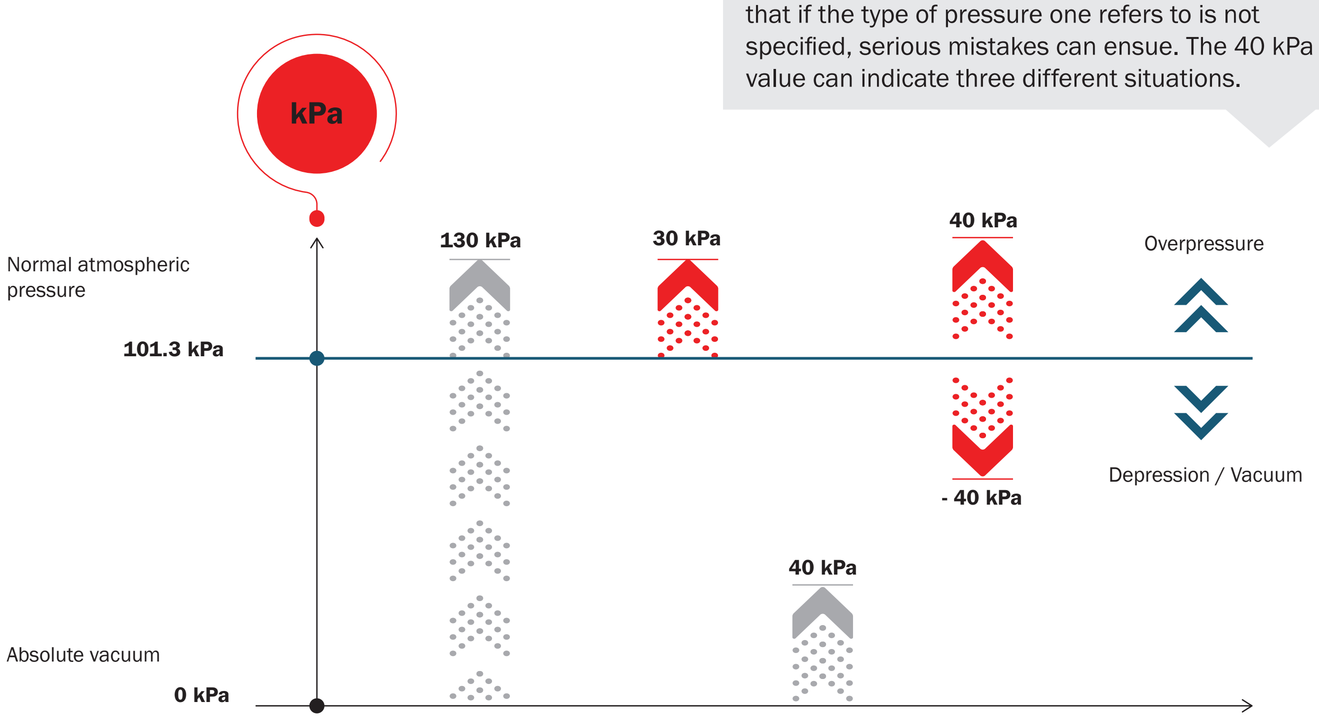


VACUUM AS ABSOLUTE VALUE

In the scientific field vacuum is indicated as an absolute value. In this case, the absolute zero is used as a reference point, i.e. space without air (e.g. cosmic space). In such a way the vacuum value always has a positive sign. The "absolute vacuum" is intended as the absence of matter in a volume, but this cannot be achieved as it is not possible to completely eliminate all gases. Since a zero pressure value is practically unreachable, the vacuum level value will be a decimal number with the more zeros after the decimal point the lower the pressure value is, i.e. the higher the vacuum level value is.



The diagram shows the relationship between absolute, relative and negative pressure. This shows that if the type of pressure one refers to is not specified, serious mistakes can ensue. The 40 kPa value can indicate three different situations.



DEFINITION OF PRESSURE

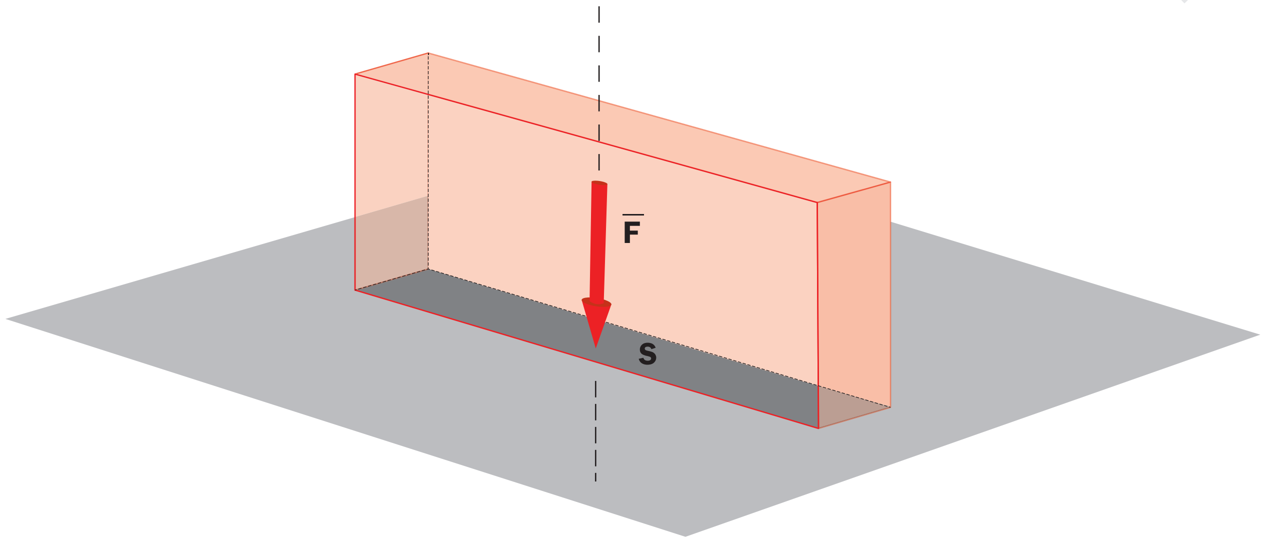
Pressure is defined as the amount of force per unit area applied perpendicularly to the surface of an object.
Gases are made up of a large number of particles, which are constantly moving. When these particles collide on a surface, such collisions generate a thrust, measurable as force. The pressure is the sum of all the forces produced by the particles, per unit area. The particles that make up the gases, when in thermodynamic equilibrium, are uniformly distributed in space, so the gas pressure and composition are uniform at every point of the reference area.
It should therefore be noted that there is only one type of pressure, whose starting value is 0 (absolute vacuum). All values above 0 are indicated as absolute pressure. As mentioned above, the value of atmospheric pressure at sea level is 101.3 kPa and is used as a reference point when talking about relative pressure, which can be either negative (depression) or positive (overpressure).

UNIT FOR MEASUREMENT OF PRESSURE

The S.I. unit for measurement of pressure is the Pascal (Pa):
1 Pascal corresponds to the force of 1 N acting on an area of 1 m^2.
Pa multiples are kPa and MPa.

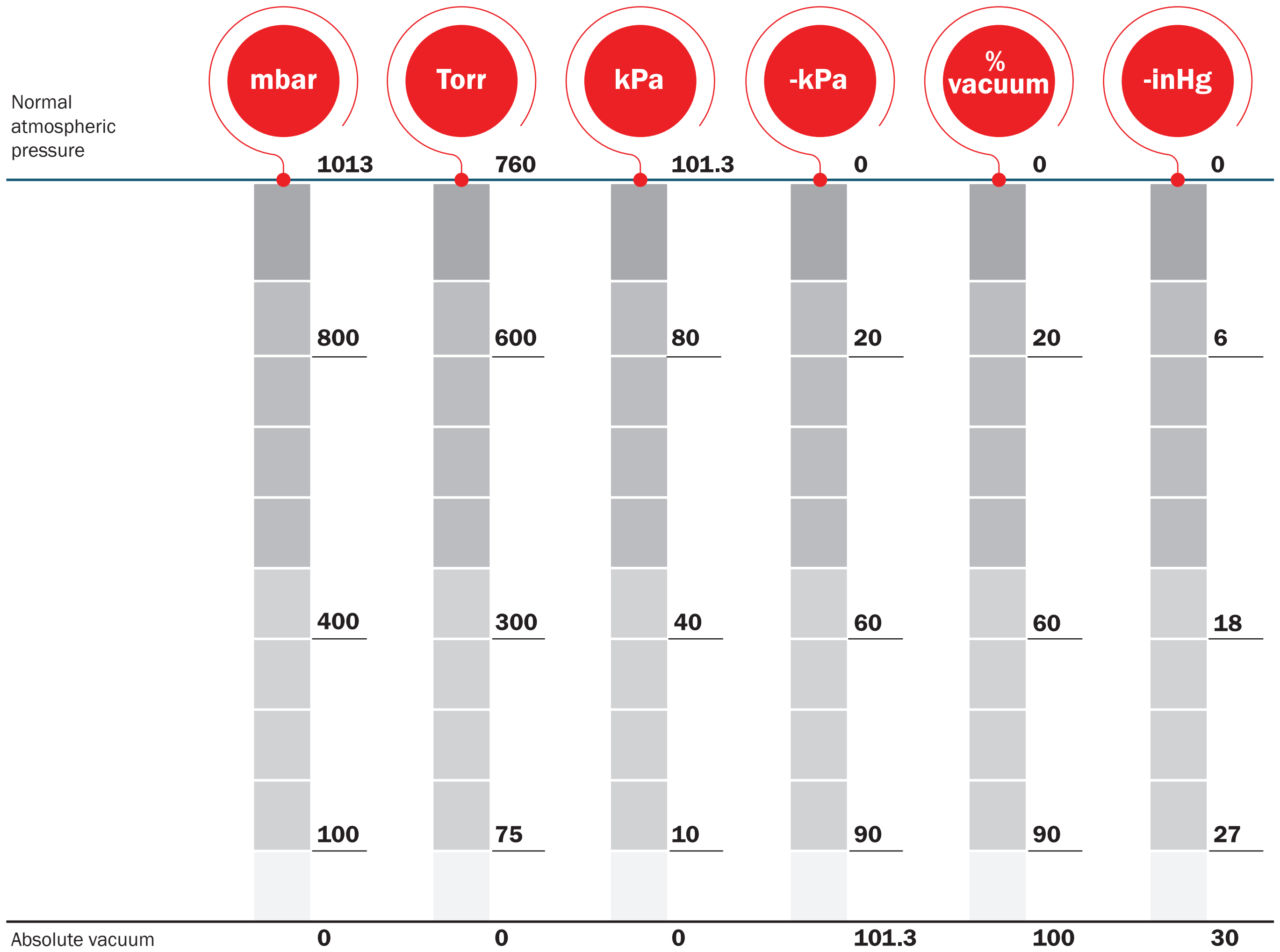
Let us consider a surface S, arranged horizontally, and a force F acting perpendicular to it.
Pressure is defined as the ratio between the force F and the surface on which it acts:

$p = F / S$



UNITS FOR MEASUREMENT OF VACUUM

In the industrial vacuum sector, different terms and units of measurement are used with regard to pressure and air flow rate.



CORRECT TERMINOLOGY TO BE ADOPTED IN INDUSTRIAL VACUUM

The terminology used in the vacuum sector must be consistent in the case of either electromechanical or compressed air systems. Only by speaking the same language can real comparisons be made. The most important terms to understand and use when performing a vacuum circuit are the following:

FLOW RATE

The rate at which atmospheric pressure is evacuated within a system, or the amount of air flowing through a pump. Q = V/t
The flow rate also determines the ability to compensate for any leaks. The evacuation speed is inversely proportional to the vacuum level.

FREE AIR FLOW RATE

Determines the amount of air evacuated at a pressure equal to atmospheric pressure. The term is often used by manufacturers of vacuum pumps to indicate their characteristics.

VACUUM LEVEL

The term defines the pressure level within a circuit, which is usually measured in kPa.
The vacuum level determines the lifting force of a suction cup, or the amount of residual atmosphere.
As the vacuum level increases, the evacuation rate decreases.

COMPRESSED AIR

It is the energy source that powers a pneumatic vacuum pump. Compressed air is comparable to the electricity that powers an electromechanical vacuum pump.
It is supplied by a compressor and is distributed by means of suitably dimensioned pipes.

COMPRESSED AIR PRESSURE

The compressed air pressure is measured in bar.
The optimum performance of a compressed air pump is achieved by balancing the pressure delivered by the compressor with the required vacuum level.

EVACUATION TIME

The time required to evacuate a given volume of air at a specific vacuum level measured in s/l.

$$\text{Evacuation time} = \frac{\text{Required gripping time}}{\text{System volume}}$$

CONSUMPTION

In industrial vacuum, the consumption of an air pump is measured in Nl/min or Nl/s

NORMAL LITRE (Nl)

The normal litre is the volume that a certain amount (mass) of gas would occupy if it were returned to atmospheric pressure.
We can therefore say that the normal litre is used to measure the mass of a gas.
The gases are compressible, therefore their quantity cannot be indicated by simply indicating the volume they occupy, but the pressure at which they are must also be indicated.
Using normal litres is useful to compare gas volumes at different pressures.
In the case of mechanical vacuum pumps it is used to clearly indicate the suction air flow rate.
In the case of pneumatic vacuum pumps, it also serves to correctly indicate the consumption of compressed air that generates the vacuum.

LIFTING FORCE

The lifting capacity of a suction cup is determined by the ratio between the pressure and the contact surface area.

VOLUME

The total area of a circuit including all spaces as well as the application area.

VACUUM CLASSIFICATION

The vacuum is usually divided into three application areas, which depend on the vacuum level required.

LOW VACUUM LEVEL

Used in all those applications where a high air flow rate is required. The vacuum level is usually between 0 and -20 kPa.
Electromechanical impeller pumps are usually used in this segment. Screen printing on fabrics is one of the typical applications that require a low vacuum level and a high suction flow rate. (Application for ventilation, cooling or cleaning).

INDUSTRIAL VACUUM

The term industrial vacuum means a vacuum between -20 and -99 kPa. This range covers most applications.
Industrial vacuum is used in applications that require material handling, lifting and sealing.

PROCESS VACUUM

These are applications where the vacuum level reached can exceed -99 kPa. Usually the unit of measurement used is Torr. The suction flow rate is minimal and scientific applications include space simulations. (Coating with molecular deposit)
The highest vacuum level reached on earth deviates significantly from the absolute vacuum value, which remains a purely theoretical value. Even in space and therefore in the absence of atmosphere there is a minimal presence of atoms.

GIMATIC
A business of BARNES GROUP INC

VACUUM PRODUCTS
HOW TO CREATE A VACUUM

Although there are several ways to create vacuum, two are the main methods used to generate it, and they employ:

PNEUMATIC EJECTOR PUMPS

COMPRESSED AIR PUMPS

Vacuum pumps, usually defined as vacuum generators, use the Bernoulli's principle which states that a relationship exists between pressure and speed: as the speed of a moving fluid (air or water) increases, the pressure within the fluid decreases and vice versa.

EJECTOR

The principle of operation of air vacuum generators consists of injecting compressed air into a conical nozzle called ejector. The compressed air through the conical nozzle reaches a supersonic speed that attracts low pressure molecules.
The external atmospheric pressure will flow, trying to restore balance to the system. The mix of compressed air passing through the ejector and the air at external atmospheric pressure flows through the exhaust.
The vacuum level that an ejector can reach depends on the ejector configuration.

SINGLE-STAGE EJECTOR

MULTISTAGE EJECTOR

GIMATIC MULTISTAGE EJECTOR

Gimatic develops and produces (in Italy) multistage ejectors, identified with the acronym EJ.
Our cartridge ejectors are available in three sizes (EJ-SMALL, EJ-MEDIUM, EJ-LARGE). These ejectors ensure excellent performance at both high and low feed pressures.

MECHANICAL PUMPS

The fundamental characteristic, common to all mechanical pumps, is that they convey a certain volume of air from the suction area to the discharge area, thus creating a depression. Mechanical pumps are generally driven by an electric motor, sometimes by an internal combustion engine, hydraulic or pneumatic.

VOLUMETRIC PUMPS

Volumetric pumps mechanically move the trapped fluid volumes through the system. On the inlet side the volume expands, while on the outlet side (exhaust) the volume contracts. Therefore the volume per revolution is fixed, and in theory is constant, regardless of outlet pressure, inlet depression or fluid properties. The volumetric pumps are self-priming, i.e. they create strong depressions at the inlet. The behaviour of volumetric pumps is different from that of centrifugal pumps, as the latter rely on the pulse of the accelerated fluid to provide flow rate to the pressure and are very sensitive to pressure changes. Volumetric pumps include vane pumps and lobe pumps.

VANE

LOBE

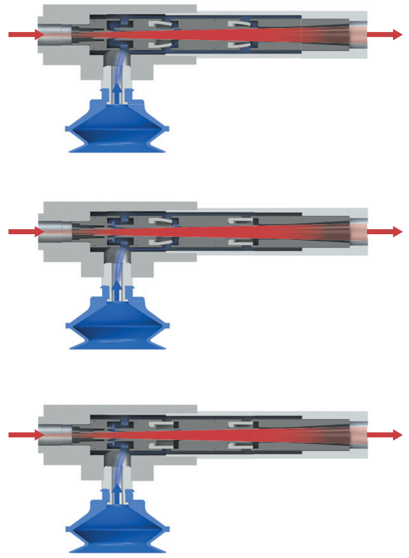
BLOWER PUMPS

The centrifugal blower pump is composed of a suction pipe that conveys the gas sucked at the inlet. The pump contains a closed impeller with axial inlet and radial outlet.
A radial diffuser, located inside, converts the impeller’s output kinetic energy into pressure energy. These pumps work at very low vacuum levels, are able to move large masses of air and have a high suction flow rate.

VACUUM PRODUCTS
PRINCIPLES OF OPERATION

GIMATIC MULTISTAGE EJECTOR

The Gimatic "EJ" ejectors are composed of several De Laval nozzles arranged in series that use the exhaust air from the previous nozzle for their feeding, thus reducing noise and increasing pump efficiency.
The diameter of the nozzle is proportional to the air suction capacity and is inversely proportional to the vacuum level generated.
The better performance resulting from a higher number of stages with relevant ejector, allows to optimise the performance of the pump. Every stage can reach a different level of vacuum. When, due to the combined action of the various ejectors, the pressure present in the common stage reaches a value higher than the reference ejector, this causes the closure of the individual rubber membranes (flaps) in sequence, leaving only the high vacuum stage open. The external atmosphere flows through the common stage in an attempt to rebalance the pressure in the system. Compressed air and external atmosphere are mixed and flow through the exhaust.



SINGLE-STAGE EJECTOR	VS	GIMATIC EJ MULTISTAGE EJECTOR

SINGLE-STAGE EJECTOR

COMPRESSED AIR CONSUMPTION

The ratio of air consumed to suction flow rate is rarely higher than 1:1. Historically, this has led to considering the system to be inefficient.

NOISE LEVEL

90 decibel.

GIMATIC EJ MULTISTAGE EJECTOR

COMPRESSED AIR CONSUMPTION

It exploits the kinetic energy of compressed air that passes through De Laval nozzles. The passage of compressed air through a series of suitably sized ejectors allows a gradual expansion of the air.
In this case the ratio of consumption to suction air flow rate is on average three times more efficient, with an efficiency equal to 3:1.

NOISE LEVEL

In the case of the Gimatic multi-stage ejector, the noise level is reduced to values between 55 and 75 decibels.

MECHANICAL PUMPS

VOLUMETRIC VANE PUMPS

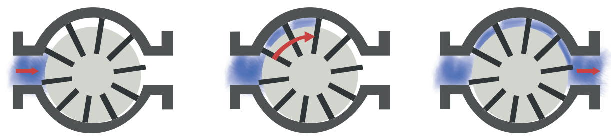
Vane pumps have only one rotating element pointing in an eccentric direction with respect to the pump cavity. The rotating element contains several vanes that can slide or deform to fit the profile of the cavity wall. The vanes form a sliding seal positioned against the cavity wall, holding the volume of the fluid at the inlet and allowing it to flow out towards the outlet. Vane pumps are particularly insensitive to pressure changes, as the vanes are in contact with the cavity wall. However, the sliding movement between the vanes and the wall creates noise, risk of pollution of the conveyed fluid and a frequent need for maintenance. (Figure 1)

BLOWER PUMPS

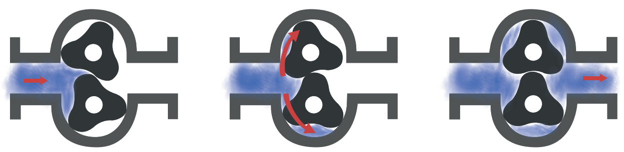
In this type of pumps, the gas is sucked into the chamber from the loading opening. When the gas enters through the side channel the movement of the impeller transmits a certain speed to the gas in the direction of rotation. The centrifugal force of the impeller vanes accelerates the gas outwards and the pressure increases. Each rotation increases the kinetic energy, with a further increase of the pressure in the side channel. The channel narrows towards the rotor, dragging the gas away from the impeller vanes to discharge it through the exhaust silencer. (Figure 3)

VOLUMETRIC LOBE PUMPS

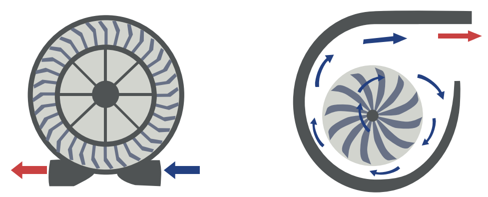
These pumps have lobe-shaped elements instead of gears. Each lobe-shaped element is driven by a motor. This eliminates contact between the two lobes, reducing wear and minimising fluid friction. Usually this type of pumps are characterised by high heat emissions and high noise levels. (Figure 2)



1. Volumetric vane pump operation



2. Volumetric lobe pump operation



3. Blower pump operation

SIZING OF VACUUM SYSTEMS

In order to achieve greater efficiency and good energy savings, it is important that the systems are expressly designed for the specific application. Likewise, suction cups and their fittings, the model, the size of the vacuum pumps, and relevant accessories and piping, must also be chosen according to the application.
It is extremely important to fix the safety factor during the dimensioning of a vacuum system as well as the type of circuit to be adopted.

FACTOR OF SAFETY

When handling any type of object, the most important condition to be met is the safety of the grip. It is necessary to be sure that the object does not detach from the suction cups before the set release point. For this reason it is always necessary to multiply the weight (plus any inertia force) of the object to be moved by an appropriate safety coefficient:

- 2 in the case of static applications or low-speed handling applications.
- 2.5 or more in the case of medium- and high-speed handling applications.

A parameter that is frequently underestimated when sizing a vacuum system is the choice of the suction cup. It is the device that physically "connects" the object to be manipulated to the gripping system.

TYPE OF CIRCUIT

SEALED SYSTEMS

When designing this circuit it is necessary to consider the volume, the vacuum level and the evacuation time.
In sealed systems, the pump capacity is determined by the speed at which the circuit is evacuated at a certain vacuum level.
This capacity is called evacuation time and is normally specified in s/l.
By multiplying this value by the volume of the entire system, the evacuation time is obtained as a function of the desired vacuum level.

SYSTEMS WITH LEAKS

In systems with leaks, where it is necessary to handle cardboard boxes, perforated sheet metal or objects with micro-holes, the situation is different. To maintain the desired vacuum level, the pump must have a higher capacity to compensate for leaks. Once the leakage flow has been determined, the most suitable pump is chosen by checking the characteristic curves of the various pump models. In the case of leaks through a hole with a known cross-section, the extent of the leak can be determined. To obtain the total leak flow, multiply the value obtained by the total area.
When porous materials have to be handled or when the geometry of the leak path is unknown, the flow rate can be determined by a practical test to be performed with a pump and a vacuum gauge.

GENERAL INFORMATION FOR CORRECT VACUUM SIZING

A vacuum circuit can be sized following a centralised or decentralised design.

CENTRALISED SYSTEM

A centralised system is characterised by a vacuum pump connected to several suction cups. Often used to handle sealed materials such as sheet metal or glass.

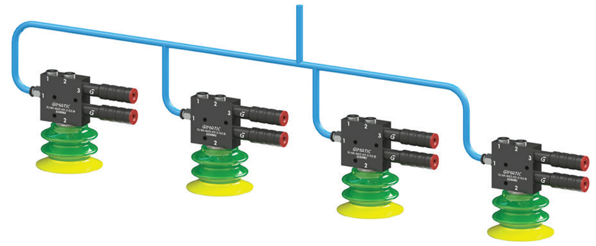
ADVANTAGES

- Single source of vacuum
- Simple blow-off arrangement
- Easy vacuum level control

DISADVANTAGES

- Long pipes with larger diameter
- Risk of pressure drops
- Requires blow-off valve or vacuum breaker for release of the object

DECENTRALISED SYSTEM



A decentralised system is designed so that each suction cup has a dedicated vacuum generator, which means that all suction cups are independent of each other, usually used in applications with porous surfaces.

ADVANTAGES

- Minimised volumes to be evacuated >High gripping and release speed
- Zeroing of pressure drops > Compact pump sizes
- Each suction cup is independent
- Smaller feed pipes

DISADVANTAGES

- More complex management of blow-off (non-return valves are required)
- More complex detection of object being picked up
- Possible problems resulting from dirt in the system

CHOICE OF THE PUMP

After selecting the components that precede it, the pump must be sized considering some of the following parameters:

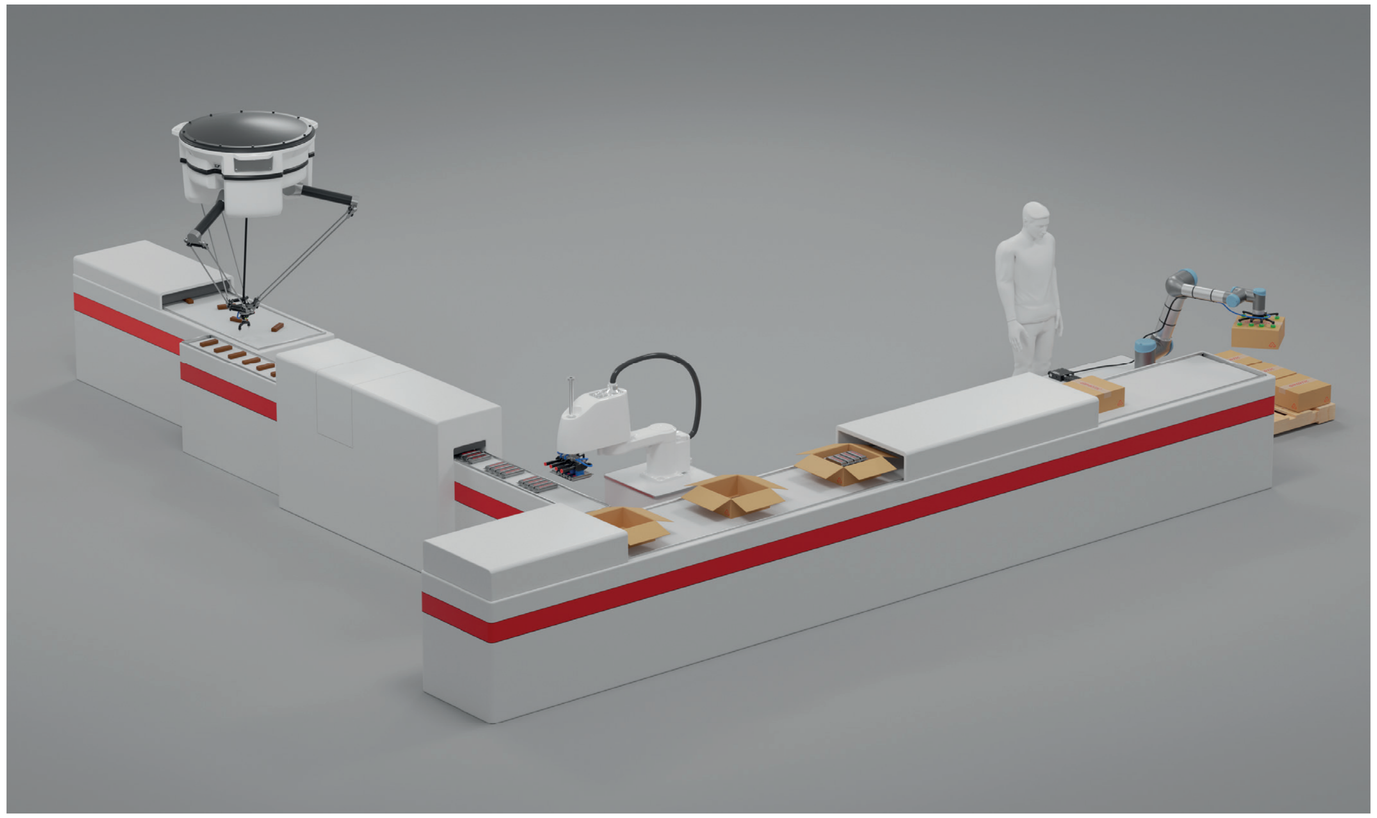
IS THE CIRCUIT CENTRALISED OR DECENTRALISED?

WHAT IS THE SPEED OF THE APPLICATION?

POROSITY OF THE MATERIAL?

WHAT IS THE VOLUME TO BE EVACUATED?

WHAT IS THE REQUIRED VACUUM LEVEL?



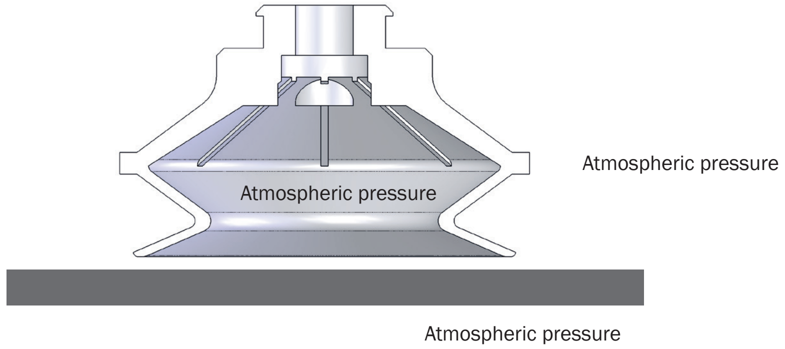
SUCTION CUPS

OPERATING PRINCIPLE OF THE SUCTION CUP

When a vacuum-based handling system is implemented, it is necessary to develop a magnitude of forces that will enable the safe handling of products. The suction cup plays a key role in this phase.
Two are the main factors to be considered:
- The shape of the suction cup;
- The characteristics of the lip.

A suction cup with the proper shape is necessary to match perfectly the morphology of the gripped object. The lip, on the other hand, must be able to follow with precision and repeatability the roughness and alterations that the surface of the object may present (the corrugations of a cardboard box or the roughness of a wooden panel).

The suction cup adheres to the surface when the pressure of the surrounding area (atmospheric pressure) is greater than the pressure between the suction cup and the surface. In order to create a depression inside the suction cup, the suction cup is connected to a vacuum pump. The higher is the vacuum level inside the suction cup, the higher is the force that the suction cup can exert.
Finally keep in mind the force of the suction cup will be higher:
- If the contact surface is large
- If the vacuum level is high
- If its shape can properly match with the object



SIZING OF THE SUCTION CUPS

Besides being influenced by the vacuum level, the lifting force is also strongly influenced by the model of suction cup. To design the circuit it is necessary to start from the point of contact between the suction cup and the object and then go back to the vacuum pump. This method allows the proper sizing of the components and the best performance.
Before selecting a suction cup, the surface, structure, lifting direction, weight and porosity of the object must be considered.

THE HIGHER THE VACUUM LEVEL, THE GREATER THE ENERGY REQUIREMENT WILL BE

When vacuum is created inside a suction cup that rests on a surface, the suction cup adheres to the surface not just on its own account, but also thanks to the higher external pressure. The lifting force is proportional to the contact surface and the vacuum level. If the vacuum level increases from 60% to 90%, the lifting force increases by a maximum of 1.5 times. In order to limit the energy consumption, it is preferable to limit the vacuum level and instead increase the surface area of the suction cup.

SURFACE AND STRUCTURE

As well as highlighting the object's dimensions, a visual assessment identifies whether the object is curved or flat. Using the suction cup that best fits the surface is essential. A further contribution could come from the analysis of the structure of the object.
A more careful examination could reveal a certain roughness which, in addition to limiting the use of suction cups, represents a potential leak.

POROSITY

What is the porosity of the material? This question is very important for the definition of the suction cup format and for the sizing of the pump. Porosity is defined as the amount of air at atmospheric pressure passing through a material subjected to a depression. Glass does not allow air to pass through, while paper, for example, is full of tiny pores.

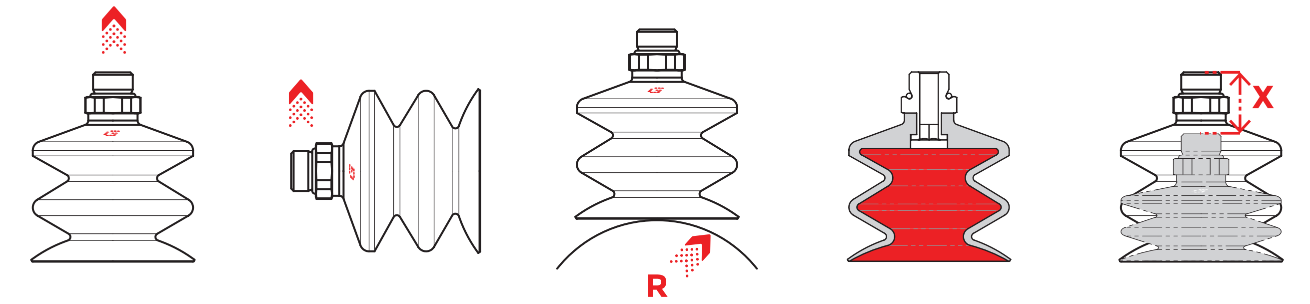
MATERIAL

It is often necessary to check the operating temperature required to perform that particular application.
Too high temperatures, as in thermoforming, or too low, require the use of suction cups made with special compounds. Silicone is the best solution even if there is a risk of releasing small particles (halo), which makes it difficult to perform a subsequent painting. In this case our HNBR suction cups are the ideal solution.

SELECTION OF THE SUCTION CUP

Once the weight and size of the object have been determined, the type and diameter of the suction cup must be determined. The use of the largest possible suction cup allows to reduce the vacuum level.
This solution offers a number of advantages including shorter evacuation time, reduced power consumption and longer suction cup life.

PARAMETERS



Lifting force [N] perpendicular to the surface, at various vacuum levels	Lifting force [N] parallel to the surface, at various vacuum levels	Min curve radius	Volume	Max vertical movement

USEFUL PARAMETERS TO VERIFY

- Use the suction cup that is suitable for the application.
- Pay attention to the type of material and the structure of the surface.
- Determine the type of suction cup material suitable for the application
- Design the system with a suitable safety factor
- Know the possible dynamic forces that could influence the application.
- Distribute the suction cups in relation to the centre of gravity.
- Use the appropriate accessories for the application.
- Consider the type of finish of the surface.