PVA™ PIAB Vacuum Academy

PIAB'S KNOW-HOW FOR COMPETITIVE ADVANTAGES

Reliable and efficient production is an extremely valuable asset for a company. Handling failures, rejection of products, re-settings and breakdowns cause production losses and costs that can never be regained.

We at PIAB work with vacuum technology, but our objective is to improve our customers' profitability by increasing their production capacity. This makes us a superior supplier. Where other firms talk about airflows, valves and filtration, we focus on matters related to set-up times, cycle times, speed, flexibility, product rejection and maintenance.
Would you like to learn how to think along these lines? Here you will find a few examples of fields of knowledge where you can take advantage of the fact that we have gathered our competence and experience in complete educational training programmes. Don't hesitate to ask us about tailor-made training programmes. We do have extensive knowledge that we would like to share with you.

Welcome to the PIAB Vacuum Academy!

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The PIAB Vacuum Academy trains your company's co-workers to make sounder pre-purchasing decisions, find new fields of application, develop production processes and make your business more profitable. Training courses are held wherever PIAB is represented. Moreover, they can be held on your company premises and adapted to meet special needs whenever you desire.

COURSES OFFERED

1. BASIC VACUUM TECHNOLOGY

Training phases:

- Introduction to vacuum technology
- The role played by vacuum technology in pursuit of improved productivity and profitability
- Minimizing cycle times
- Integration of vacuum
- Various types of vacuum systems
- Dimensioning vacuum systems
- Control systems
- Optimal use of energy

2. OPTIMIZING A VACUUM SYSTEM AND ITS PARAMETERS

Training phases:

- Introduction to “OVM”
- Vacuum pump and vacuum system parameters
- Interactive aids for calculating flows, response times, pressure drops, etc.
- Interactive aids for calculating productivity and cost chganges, energy costs, etc.
- “Integration Into Your Own Product”
- Laboratory work and tests
- “Workshops”
- Application examples

3. VACUUM TECHNOLOGY IN THE PACKAGING INDUSTRY

Training phases:

- The role played by vacuum technology in pursuit of improved productivity and profitability
- Packaging applications using vacuum technology
- Integration of vacuum
- Optimal use of energy
- Evaluation of technical solutions

4. VACUUM TECHNOLOGY IN THE AUTOMOTIVE INDUSTRY

Training phases:

- The role played by vacuum technology in pursuit of improved productivity and profitability
- Design and function of vacuum systems for handling metal sheets, glass and plastic parts
- Evaluation of technical solutions

5. VACUUM TECHNOLOGY IN THE GRAPHIC INDUSTRY

Training phases:

- The role played by vacuum technology in achieving improved productivity
- Examples of applications and functions that can be developed and improved by using vacuum technology
- Evaluation of technical solutions

6. VACUUM TECHNOLOGY IN THE POWDER AND BULK INDUSTRY

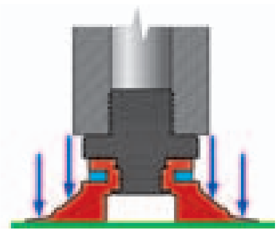
Training phases:

- Basic knowledge of vacuum conveying of powder and bulk
- Design and function of a bulk handling system using vacuum technology
- Integration of vacuum
- Optimal use of energy
- Evaluation of technical solutions

VACUUM THEORY

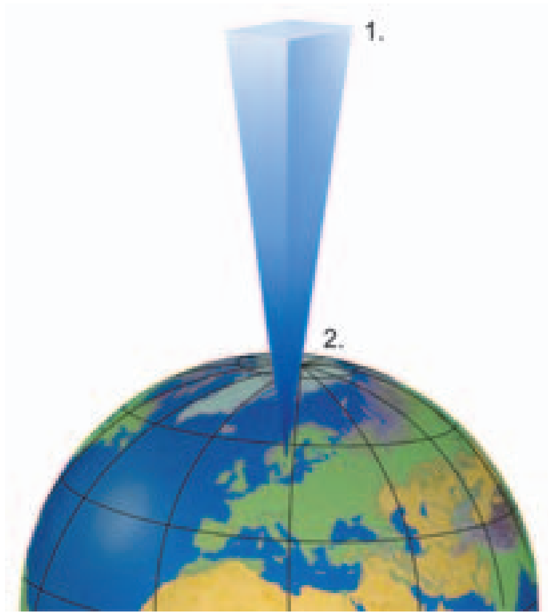
WHAT IS VACUUM?

When using the terms ”vacuum”, ”negative pressure”, ”suction”, etc., we mean a pressure that is lower than the atmospheric pressure, which is the pressure of the weight of the air above us. At sea level it usually is 1,013 mbar = 101.3 kPa. 1 Pa equals 1 N/m^2, which means that a column of air with a cross-sectional area of 1 m^2 presses on the surface of the earth with a force of around 100,000 N. By reducing the pressure in a closed space the atmospheric pressure becomes a potential energy source.



A vacuum cleaner does not suck. Air and dust are pressed into the vacuum cleaner by the surrounding higher atmospheric pressure.

A suction cup adheres to a surface by the surrounding higher pressure.

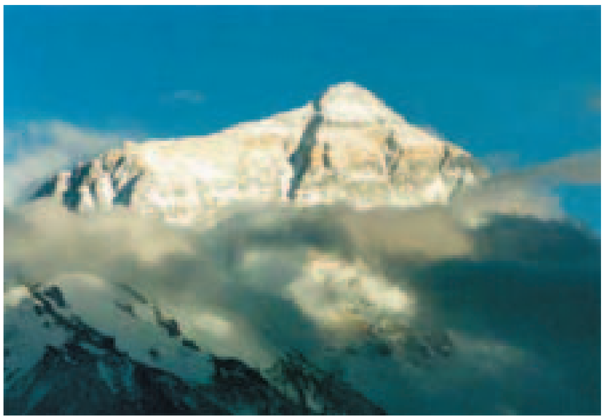


1. *Atmospheric pressure = 0 at an altitude of 1,000 km*
2. *1 bar (101.3 kPa) at sea level*

ALTITUDE ABOVE SEA LEVEL

As the atmospheric pressure is the working force, the force will consequently change with the atmospheric pressure. This means that the present barometric pressure and the altitude above sea level must be taken into consideration. Up to 2,000 m, the pressure is reduced by around 1% per 100 m. An application which is dimensioned to hold 100 kg at sea level, can manage only 89 kg at an altitude of 1,000 m.

The chapter “Tables” shows the effect of the atmospheric pressure on the vacuum level.



At the summit of Mount Everest (8,848 m) the atmospheric pressure is approximately 330 mbar (33 kPa).

A DEFINITION OF VACUUM IS:

”A room without matter”. In everyday language; ”Air-free or almost air-free space”.

Source: Nationalencyklopedin, Bra Böcker, Höganäs, Sweden.

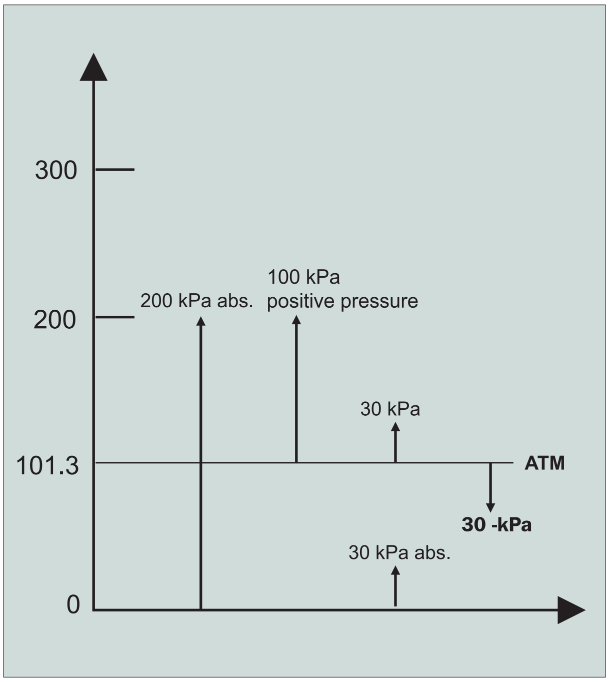
EXPRESSIONS AND UNITS

In everyday speech there are many different expressions and units for pressure below the atmospheric pressure. It is therefore important to relate to the same vocabulary in discussions. The adjoining table shows some common expressions and units used in connection with vacuum. For conversion tables between the different units, see tables No. 1, 2 and 3.

Expressions	Units	
Under pressure	-kPa	bar
Absolute pressure	inHg	mm H_2O
% vacuum (% of vacuum)	mmHg	torr
Negative pressure	hPa	mbar

DIFFERENT TERMS FOR PRESSURE IN RELATION TO "ABSOLUTE VACUUM"

Physically there is only one kind of ”pressure” and that is the one that starts from ”0” or absolute vacuum. Everything above ”0” is pressure and correctly named absolute pressure. Normal atmospheric pressure (101.3 kPa) is used as a reference, which is why the term “positive pressure” or “negative pressure” is used. Earlier the term “% vacuum” was used, where 0% was atmospheric pressure and 100% absolute vacuum. Consequently, in industry, -kPa is the unit used most often since it nearly corresponds to “% vacuum”. In the chemical branch of industry, and in deep vacuum, mbar is generally used. Thus, it is very important to be clear about which unit and reference point are used. In this catalogue, -kPa is generally used (as in industry), and for laboratory pumps, mbar absolute is specifically used.



This diagram shows the relation between absolute, negative and positive pressures. It also illustrates the problem that may occur if the pressure is not clearly specified. 30 kPa can ”carelessly spoken” imply three different values.

APPLIED VACUUM CAN NORMALLY BE DEVIDED INTO THREE MAIN CATEGORIES

Blowers or low vacuum	0–20 -kPa	For ventilation, cooling, vacuum cleaning, ...
Industrial vacuum	20–99 -kPa	For picking, holding, automation, ...
Process vacuum	99 -kPa –	Deep vacuum for laboratories, manufacturing of microchips, plating, ...

ENERGY NEEDS FOR DIFFERENT VACUUM LEVELS

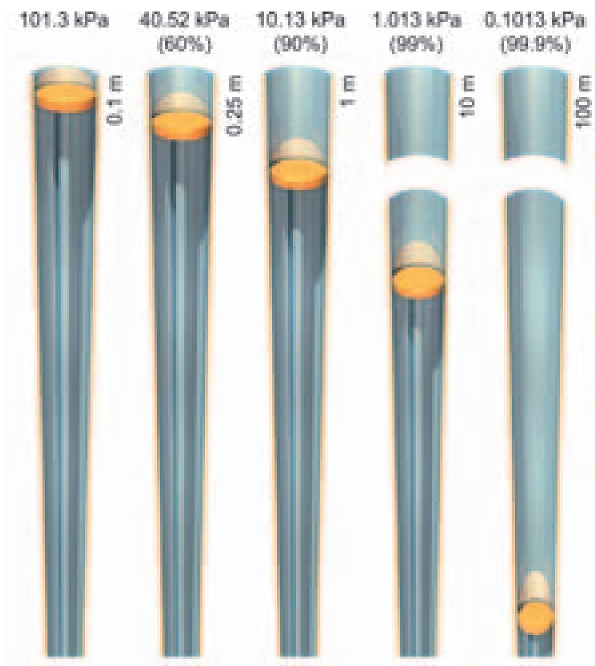
The energy required to create vacuum increases asymptotically towards infinity with increased vacuum. To obtain optimum energy exchange it is very important to choose the least possible vacuum. To illustrate the energy needs, a cylinder with a piston (piston pump) is suitable.

According to Boyle's Law the pressure (p) in a gas is inversely proportional to its volume (V) at constant temperature:

$$P. \times V. = P_1 \times V_1$$

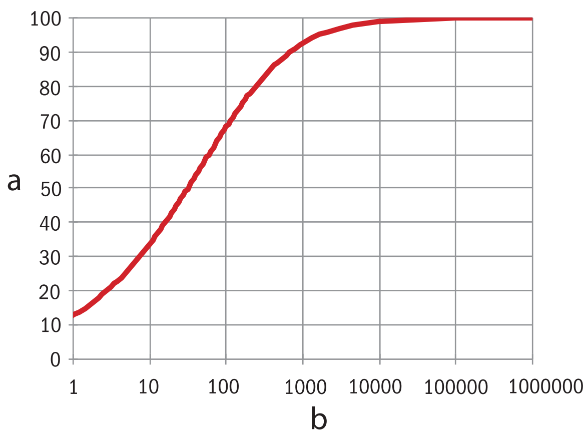
This means that increased volume gives a lower pressure.

By pulling the piston slowly, the distance extended will show the increased energy needs. The temperature is not constant in practice. However, at slow operation the temperature effect is negligible.



ENERGY REQUIREMENT AT INCRAESED VACUUM

The diagram illustrates the energy requirement at increased vacuum. As can be seen, the energy requirement increases drastically above 90 -kPa, which is why a vacuum level below this is always advisable.



a) Pressure below atmospheric -kPa,
b) Energy factor

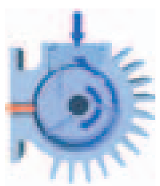
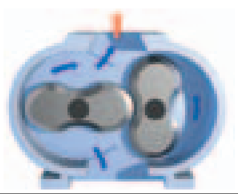
VACUUM PUMPS

MECHANICAL PUMPS

The main principle for all mechanical pumps is that they convey, in one way or another, a certain volume of air from the suction side (the vacuum side) to the exhaust side. In that way they create a vacuum.

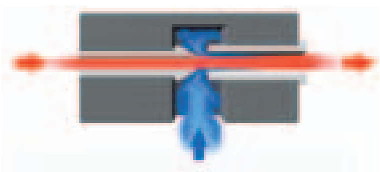
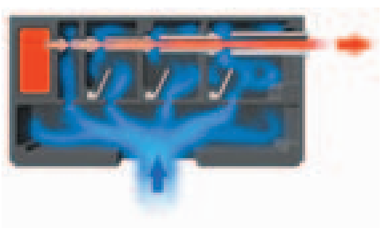
Mechanical pumps usually have an electric motor as power source, but it can also be an internal combustion engine, a hydraulic or a compressed air-driven pump.

Fans			
Vacuum pump		**Advantages**	**Disadvantages**
	Centrifugal blower	Few moving parts Large suction volumes Strong	Low maximum vacuum Slow start-up and long stop time High noise level
	Regenerative blower	Few moving parts Large suction volumes Low energy consumption	Low maximum vacuum Slow start-up and long stop time High noise level

Displacement pumps			
Vacuum pump		**Advantages**	**Disadvantages**
	Piston pump	Relatively low price	High heat emission Low maximum vacuum
	Membrane pump	Few moving parts Compact Low price	Small suction volumes
	Vane pump	High vacuum and flow Relatively low noise level	Sensitive to contamination Relatively high price High service requirements High heat emission
	Roots pump	High flow Low service requirements	High price High heat emission High noise level

COMPRESSED AIR-DIVEN EJECTOR PUMPS

All ejector pumps are driven with pressurised gas, usually compressed air. The compressed air flows into the ejector pump, where it expands in one or more ejector nozzles. When expanding, the stored energy (pressure and heat) is converted into motive energy. The speed of the compressed air jet increases rapidly, while the pressure and the temperature go down, attracting more air and thereby creating a vacuum on the suction side. Some ejector pumps may also be used to blow air.

Compressed air-driven ejector pumps			
Vacuum pump		**Advantages**	**Disadvantages**
	Single-stage ejector	Low price No heat emission Compact	High noise level Gives either high flow or high vacuum Poor efficiency
	Multi-stage ejector	High efficiency Low energy consumption High reliability Low noise level No heat emission	
	COAX® technology	High efficiency Low energy consumption High reliability Low noise level No heat emission Operates even at low feed pressure Integrated features Modularly built Easy to supplement and upgrade later on Easy to clean	

VACUUM FLOWS

In order to obtain a pressure that is lower than atmospheric pressure in a container, some of the air mass must be removed by the aid of a vacuum pump. Half of the air mass must be removed to obtain a vacuum level of 50 -kPa. The air sucked into the pump per unit of time is called the vacuum flow and is a measure of how quickly the pump is working. Many manufacturers of vacuum pumps, for example, cylinder pumps, state displacement flow instead of flow in normal litres. Displacement flow = Cylinder volume per number of revolutions. This value is constant and can incorrectly influence the observer to believe that the vacuum flow is constant during the entire emptying process; it is given in l/s (litre per second). The air becomes thinner and thinner for every stroke of the cylinder until the pump reaches the maximum vacuum level when the vacuum flow = 0. Displacement flow is often called volume flow.

The air mass sucked out is given as Nl/s (normal litre/second), and refers to the air flow pumped out to the atmosphere. Here, consideration is taken for the air becoming thinner and thinner as it is being pumped out. The air mass sucked out is also called gas flow.

TABLE OF CONVERSION UNITS FOR SOME WAYS OF STATING VACUUM FLOW

Units		Vacuum level -kPa									
		0	10	20	30	40	50	60	70	80	90
Vacuum flow	l/s	10	10	10	10	10	10	10	10	10	10
	m^3/h	36	36	36	36	36	36	36	36	36	36
Free air	Nl/s	10	9	8	7	6	5	4	3	2	1
	Nm^3/h	36	32.4	28.8	25.2	21.6	18	14.4	10.8	7.2	3.6

VACUUM SYSTEMS

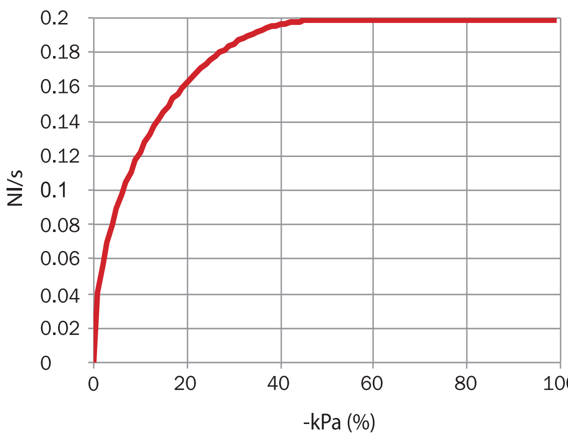
When making a vacuum system/lifting device there are several different methods to increase safety and reliability. To give efficient operation and good economy it is important that the designed system is made for a specific application. In addition to the choice of suction cups with attachments, the type and size of vacuum pumps, accessories, safety level and type of system must also be decided upon.

SEALED SYSTEMS

For sealed systems the capacity of the pump is determined by how fast the system can be evacuated to a certain vacuum level. This capacity is called the evacuation time of the pump and is normally specified in s/l. This value is multiplied by the volume of the system in order to obtain the evacuation time to the desired vacuum level.

NON-SEALED SYSTEMS

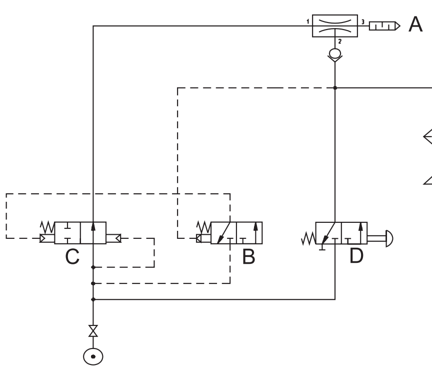
With non-sealed systems (lifting of porous materials) the case is different. To maintain the desired vacuum level the pump must have the capacity to pump away the air leaking in. Leakage can be due to, for example, porous material or that one is forced to lift over holes. By establishing the leaking flow, it is possible, by reading the pump data, to find the right pump for the application in question.
If the leakage occurs via a known aperture, the flow can be established according to the adjoining diagram. The diagram gives values for leakage flow when the leakage area is known. The leakage flow is valid when there is an opening of 1 mm^2 (normal atmospheric pressure at sea level). To obtain the total flow, the value is multiplied by the total leakage area. See also table No. 7 in the “Tables” chapter.
When the leakage occurs through a porous material or in an unknown way, the flow can be established by a test with a vacuum pump. The pump is connected to the system and the obtained vacuum level is read. (It should be at least 20 -kPa.) The flow that is pumped away at this vacuum level can be seen on the page of the particular pump. This flow roughly corresponds to the leaking flow.



At 47 -kPa the air reaches sonic velocity, and consequently the flow is constant.

ENERGY-SAVING SYSTEMS

Electrically driven, mechanical vacuum pumps normally work during the whole operating cycle and the vacuum requirements are controlled by a valve on the vacuum side. In systems with compressed air-driven vacuum pumps it is often possible to save a lot of energy. As these pumps have a faster reaction time (fast start-up and stop time) the pump can be shut off when the vacuum is no longer needed. The principles of a simple energy-saving system are shown to the right. Many pumps can be delivered with an energy-saving system as standard.

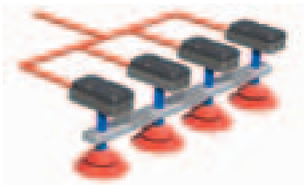


A = Vacuum pump with non-return valve.
B = Vacuum control unit.
C = Feed valve for compressed air.
D = Release valve.

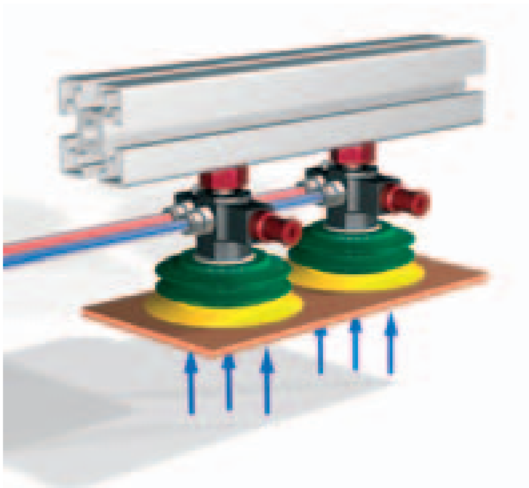
WHY A DECENTRALIZED VACUUM SYSTEM?

The impact of losses in a centralized vacuum system due to tubing, bends, fittings, valves, filters, etc., is substantial and has to be compensated by increasing the size of the vacuum pump. A decentralized system with the vacuum pump/ cartridge placed right at the suction cup eliminates the risk for losses in the vacuum piping and the need for expensive oversized components. Furthermore, the response time will be reduced substantially without unnecessary volume to be evacuated, and each cup is independent. A pressure loss in one cup will not affect the others.

1. Centralized system. a) Compressed air, b) Vacuum, c) Vacuum filter



2. Traditional decentralized system.



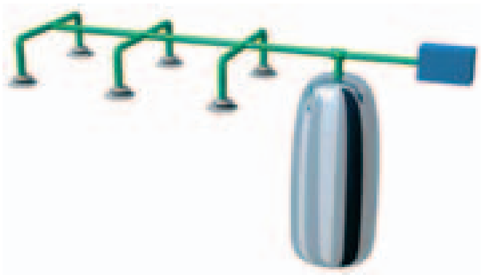
3. The ultimate decentralized system.

SAFETY

Special safety requirements govern manual vacuum lifting devices (SS 765 5801 in Sweden). When designing these devices, allow for at least a double safety margin on the lifting force at the designated vacuum level. The release is blocked during lifts so that the load is not released by mistake. Further safety is achieved by using sound or light signals that give a warning if the vacuum level falls below a certain set value.

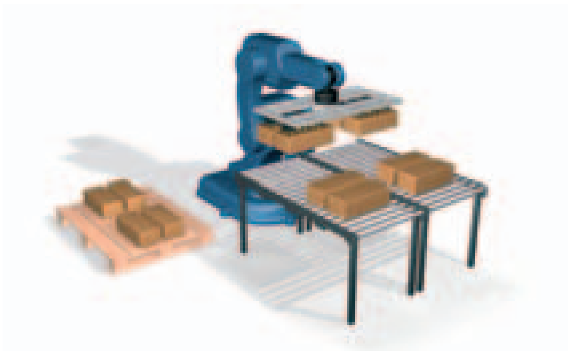
VACUUM TANK

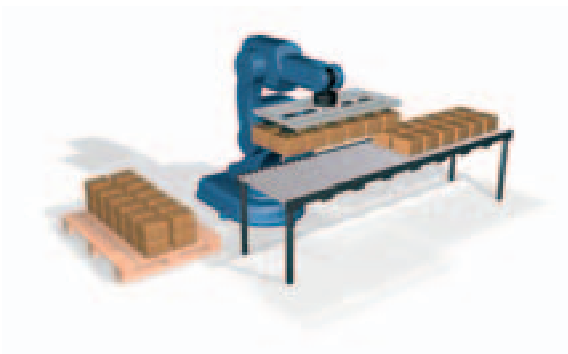
As a protection against loss of vacuum, for example, if a compressed air hose would break, a non-return valve is normally fitted near the pump. A vacuum tank between the vacuum pump and the suction cup gives an extra safety margin if an unexpected leakage or loss of vacuum should occur.



DUAL CIRCUIT SYSTEM

Lifting devices with several suction cups are often built as two independent vacuum systems with separate vacuum pumps, each of them capable of holding the load with sufficient safety factor.





CONCLUSION

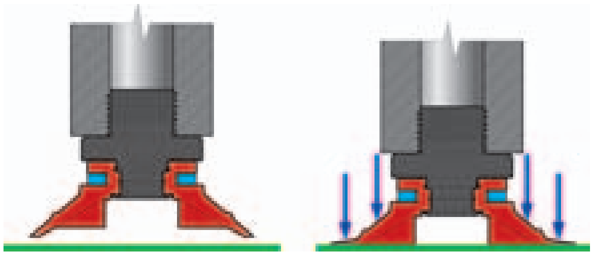
Deep vacuum requires a lot of energy. Furthermore, preferably the vacuum pump should be located as close as possible to the suction point in order to minimize the volume that needs to be evacuated. A vacuum tank should be used in applications when a ”rapid”, high-flow vacuum is needed.

SUCTION CUPS

HOW DOES A SUCTION CUP WORK?

A suction cup adheres to a surface as the surrounding pressure (atmospheric pressure) is higher than the pressure between the suction cup and the surface. To create the low pressure in the suction cup it is connected to a vacuum pump. The lower the pressure (higher vacuum), the greater the force on the suction cup.

$$\Delta p = P_{AT} - P_1$$



ADVANTAGES AND LIMITATIONS OF THE SUCTION CUP

Material handling with suction cups is a simple, inexpensive and reliable technique. It is therefore a solution worth considering before going over to more complicated methods. Suction cups can lift, move and hold objects that weigh just a few grams up to several hundred kilograms

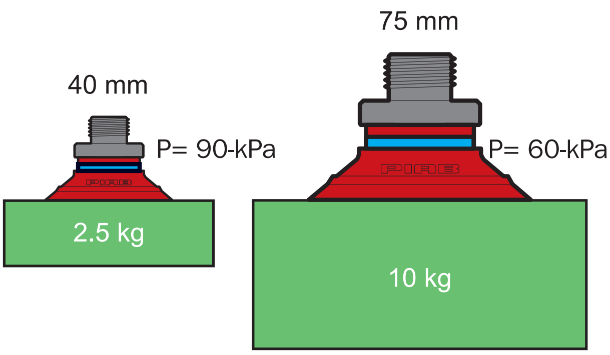
Advantages	Limitations
Easy installation Low service requirements Low price Does not damage the material handled Quick attachment and detachment	Limited force (atmospheric pressure) Positioning accuracy

SIZING SUCTION CUPS

Suction cups have quite different capacities depending on the design. Please see the values in the tables.

ENERGY REQUIREMENTS AT DIFFERENT VACUUM LEVELS

A deep vacuum means that the suction cup has to work harder and thus wears out quicker; also the energy requirements increase at higher vacuum levels. If the vacuum level increases from 60 to 90 -kPa, the lifting force increases by 1.5 times but with ten times the energy requirement. It is better to maintain a lower vacuum level and instead increase the suction cup area. In many applications, a good target for the vacuum level could be 60 -kPa; at this level you get a high lifting force with relatively low energy requirements.



CONSIDER THE HEIGHT ABOVE SEA LEVEL

Atmospheric pressure decreases with increased height. This means that the available force decreases at the same rate. An application designed for lifting 100 kg at sea level, can only manage to hold 89 kg at 1,000 metres. A vacuum gauge is normally calibrated with atmospheric pressure as a reference. This means that the gauge shows available vacuum levels at different heights.

LIFTING FORCE IN DIFFERENT DIRECTIONS

A suction cup can be used irrespective of whether the force is perpendicular or parallel to the surface. If the force is parallel, it is transferred through friction between the suction cup and the surface. A suction cup with cleats is most suitable in this case because it is rigid and provides high friction.

TABLES

In everyday speech, many different expressions and units are used for both pressure and flow. It is important to agree on what is meant by them.

PRESSURE

P=F/A (Force/Area).
SI unit (Système International d'Unités): Pascal (Pa). 1 Pa = 1 N/m².
Common multiple units: MPa and kPa.

Pa (N/m²)	bar	kp/cm²	torr	psi (lbf/in²)
1	0.00001	10.1972×10^{-6}	7.50062×10^{-3}	0.145038×10^{-3}
100 000	1	1.01972	750.062	14.5038
98 066.5	0.980665	1	735.559	14.2233
133.322	1.33322×10^{-3}	1.35951×10^{-3}	1	19.3368×10^{-3}
6 894.76	68.9476×10^{-3}	0.145038×10^{-3}	51.7149	1

Table No. 1
1 torr = 1 mm HG à 0°C,
1 mm column of water = 9.81 Pa

PRESSURE ABOVE ATMOSPHERIC

kPa	bar	psi	kp/cm²
1,013	10.13	146.9	10.3
1,000	10	145	10.2
900	9	130.5	9.2
800	8	116	8.2
700	7	101.5	7.1
600	6	87	6.1
500	5	72.5	5.1
400	4	58	4.1
300	3	§43.5	3.1
200	2	29	2
100	1	14.5	1
0	0	0	0

Table No. 2

PRESSURE BELOW ATMOSPHERIC

	kPa	mbar	torr	-kpa	-mmHg	-inHg	% vacuum
Sea level	101.3	1,013	760	0	0	0	0
	90	900	675	10	75	3	10
	80	800	600	20	150	6	20
	70	700	525	30	225	9	30
	60	600	450	40	300	12	40
	50	500	375	50	375	15	50
	40	400	300	60	450	18	70
	30	300	225	70	525	21	70
	20	200	150	80	600	24	80
	10	100	75	90	675	27	90
Absolute vacuum	0	0	0	101.3	760	30	100

Table No. 3

CHANGE IN ATMOSPHERIC PRESSURE IN RELATION TO ALTITUDE (HEIGHT ABOVE SEA LEVEL)

A vacuum gauge is normally calibrated with normal atmospheric pressure at sea level as a reference, 1013.25 mbar, and is influenced by the surrounding atmospheric pressure in accordance with the table below.

The vacuum gauge shows the differential pressure between atmospheric pressure and absolute pressure. This means that the gauge shows what vacuum level is available at different heights.

ATMOSPHERIC PRESSURE

Barometric pressure			The reading on the vacuum gauge at 1,013.25 mbar				
mmHg	mbar	Equivalent m above sea level	60 -kPa	75 -kPa	85 -kPa	90 -kPa	99 -kPa
593	790.6	2,000	37.7	52.7	62.7	67.7	76.7
671	894.6	1,000	48.1	63.1	73.1	78.1	87.1
690	919.9	778	50.7	65.7	75.7	80.7	89.7
700	933.3	655	52.0	67.0	77.0	82.0	91.0
710	946.6	545	53.3	68.3	78.3	83.3	92.3
720	959.9	467	54.7	69.7	79.7	84.7	93.7
730	973.3	275	56.0	71.0	81.0	86.0	95.0
740	986.6	200	57.3	72.3	82.3	87.3	96.3
750	999.9	111	58.7	73.7	83.7	88.7	97.7
760	1,013.25	0	60.0	75.0	85.0	90.0	99.0

Table No. 4
**) at normal barometric pressure.*

FLOWS

Flows, volume per unit of time. Quantity designations: Q, q, = V/t (volume/time).
SI Unit: cubic metres per second (m^3/s).
Common multiple units: l/min, l/s, m^3/h.

m^3/s	m^3/h	l/min	l/s	ft^3/min (cfm) *
1	3,600	60,000	1,000	2,118.9
0.28×10^{-3}	1	16.6667	0.2778	0.5885
16.67×10^{-6}	0.06	1	0.0167	0.035
1×10^{-3}	3.6	60	1	2.1189
0.472×10^{-3}	1.6992	28.32	0.4720	1

Table No. 5
**) 1 ft » 0.305 m*

FLOWS, IMPORTANT VALUES

l/s	m³/min	m³/h	cfm
1	0.06	3.60	2.12
2	0.12	7.20	4.24
3	0.18	10.80	6.36
4	0.24	14.40	8.47
5	0.30	18.00	10.59
6	0.36	21.60	12.71
7	0.42	25.20	14.83
8	0.48	28.80	16.95
9	0.54	32.40	19.07
10	0.60	36.00	21.19
11	0.66	39.60	23.30
12	0.72	43.20	25.42
13	0.78	46.80	27.54
14	0.84	50.40	29.66
15	0.90	54.00	31.78
16	0.96	57.60	33.90
17	1.02	61.20	36.02
18	1.08	64.80	38.13
19	1.14	68.40	40.25
20	1.20	72.00	42.37
25	1.50	90.00	52.97
30	1.80	108.00	63.56
35	2.10	126.00	74.15
40	2.40	144.00	84.74
45	2.70	162.00	95.34
50	3.00	180.00	105.93

Table No. 6

LEAKAGE FLOWS

The table below shows the leakage flow at different levels and through an opening of 1 mm².

Vacuum level -kPa	Leakage flow l/s and mm²
10	0.11
20	0.17
30	0.18
40	0.2 *)

Table No. 7
**) From about 47 to 100 -kPa the flow is constant.*

PRESSURE DROP IN COMPRESSED AIR HOSES

When installing compressed air hoses it is important that the dimension (diameter) and length do not lead to excessive pressure drops. PIAB vacuum pumps are supplied with recommended hose dimensions that will not cause excessive pressure drops at lengths below 2 m.
In cases when the pressure drop has to be calculated, the formula below can be used.

Δ P = Pressure drop in kPa
qv = Flow in m³/s
d = Inner diameter in mm
L = Length of compressed air hoses in m
P1 = The absolute starting pressure in kPa

$$\Delta P = \frac{1{,}6x10^{12}xqv^{1{,}85}xL}{d^{5}xP1}$$

$$\Delta d = \left(\frac{1{,}6x10^{12}xqv^{1{,}85}xL}{\Delta PxP1}\right)^{0{,}2}$$