Vacuum System Training

Section 17

Atmospheric Pressure

The Earth is 7,900 miles (12,715 km) in diameter and is enveloped by a layer of gases about 60 miles (96.6 km) thick which is called the atmosphere. This mixture of gases is comprised of 78% nitrogen and 21% oxygen plus trace amounts of many other gases which collectively make up the atmospheric “air” that we all breathe.

The Earth’s gravitational field holds the atmosphere so that it rotates in unison with the Earth and the atmospheric pressure exerted at any altitude is simply the sum of the weight of all the air molecules in a column above that point. As altitude increases, air density decreases and there will be fewer molecules in the shorter column above the measurement point. It is easy to see why atmospheric pressure decreases with increasing altitude. At an altitude of 62 miles (100km) and beyond, atmospheric pressure approaches zero. Even in deep outer space there are still a few gas molecules per cubic mile so a true absolute zero pressure is not achieved even though it is very close.

Altitude		Barometer		Atmospheric Pressure	
Feet	Meters	inHG	mmHG	s	kPa
-5,000	-1,524	35.58	903.7	17.48	120.5
-4,500	-1,372	35	889	17.19	118.5
-4,000	-1,219	34.42	874.3	16.9	116.5
-3,500	-1,067	33.84	859.5	16.62	114.6
-3,000	-914	33.27	845.1	16.34	112.7
-2,500	-762	32.7	830.6	16.06	110.7
-2,000	-610	32.14	816.4	15.78	108.8
-1,500	-457	31.58	802.1	15.51	106.9
-1,000	-305	31.02	787.9	15.23	105
-500	-152	30.47	773.9	14.96	103.1
0	0	29.92	760	14.7	101.3
500	152	29.38	746.3	14.43	99.49
1,000	305	28.86	733	14.16	97.63
1,500	457	28.33	719.6	13.91	95.91
2,000	610	27.82	706.6	13.66	94.19
2,500	762	27.32	693.9	13.41	92.46
3,000	914	26.82	681.2	13.17	90.81
3,500	1,067	26.33	668.8	12.93	89.15
4,000	1,219	25.84	656.3	12.69	87.49
4,500	1,372	25.37	644.4	12.46	85.91
5,000	1,524	24.9	632.5	12.23	84.33
6,000	1,829	23.99	609.3	11.78	81.22
7,000	2,134	23.1	586.7	11.34	78.19
8,000	2,438	22.23	564.6	10.91	75.22
9,000	2,743	21.39	543.3	10.5	72.4
10,000	3,048	20.58	522.7	10.1	69.64
15,000	4,572	16.89	429	8.3	57.16
20,000	6,096	13.76	349.5	6.76	46.61
25,000	7,620	11.12	282.4	5.46	37.65
30,000	9,144	8.9	226.1	4.37	30.13
35,000	10,668	7.06	179.3	3.47	23.93
40,000	12,192	5.56	141.2	2.73	18.82
45,000	13,716	4.37	111.1	2.15	14.82
50,000	15,240	3.44	87.5	1.69	11.65
55,000	16,764	2.71	68.9	1.33	9.17
60,000	18,288	2.14	54.2	1.05	7.24
70,000	21,336	1.33	33.7	0.651	4.49
80,000	24,384	0.827	21	0.406	2.8
90,000	27,432	0.52	13.2	0.255	1.76
100,000	30,480	0.329	8.36	0.162	1.12

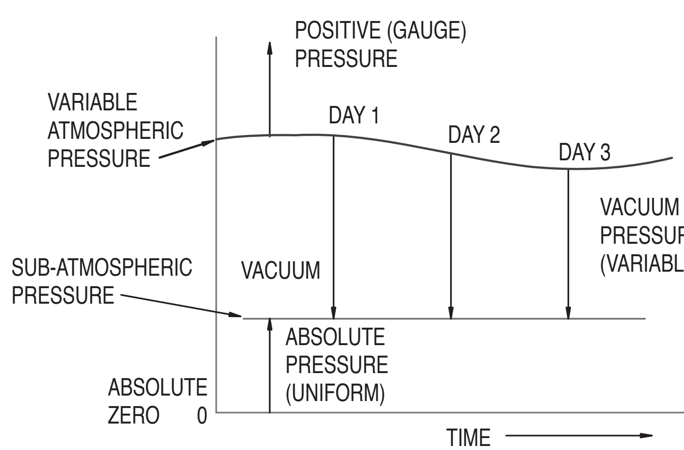
The International Standard Atmosphere (ISA) is defined as a mean atmospheric pressure of 29.92” Hg (760mm Hg) at 59°F (15°C) in dry air at sea level. Other equivalent units are 14.72 psi, 1 bar and 101.3 kPa. To complicate matters, the instrument used to measure atmospheric pressure is a barometer and atmospheric pressure is commonly called barometric pressure so the two terms can be used interchangeably.

In addition to altitude, atmospheric pressure is affected by air temperature, local weather conditions and other variables to a lesser extent. The atmosphere is disturbed by weather systems which can cause either “high” or “low” pressure systems by increasing or decreasing the local atmospheric layer thickness. What we usually hear from a weather forecaster is that the barometric pressure is “falling” and bringing in a storm, or, that the barometric pressure is “rising” so sunny days are forecast.

Vacuum

Vacuum is simply a pressure that is less than the surrounding atmospheric pressure. Essentially it is a difference in pressure, or differential, that can be used to do work. Since vacuum is by definition a negative pressure, the common terminology of high-vacuum and low-vacuum can be confusing. The preferred terminology is deep-vacuum or shallow-vacuum. Both of which are relative to local atmospheric pressure. The units of measure for positive pressure and vacuum pressure are the same but a minus sign (-) or the word “vacuum” signifies a negative pressure relative to atmosphere.

A vacuum gauge has a calibrated mechanism that is referenced to local atmospheric pressure so the value displayed is the amount that the measured pressure is below atmospheric pressure. This is convenient since the measured “gauge” vacuum level is the vacuum pressure differential that is available to do work and can thus be used directly for calculations of vacuum force which is directly proportional to vacuum pressure and the sealed area upon which it acts.



Pressure Relationships

The relationship between atmospheric pressure, positive gauge pressure, sub-atmospheric pressure (vacuum) and absolute zero is shown in the previous drawing. An absolute measurement is always positive because it is referenced from absolute zero. A sub-atmospheric pressure line is shown where the absolute pressure is constant over a three-day period. A sine curve represents the normal variation in atmospheric pressure that could occur over the same three-day period. Vacuum pressure is measured from the atmospheric pressure curve down to the sub-atmospheric pressure line and it can be readily seen that the magnitude of available vacuum pressure is different for each of the three days. In effect, the ability to do work (pressure differential), changes in accordance with the atmospheric (barometric) pressure. This is why we recommend using a mid-range rather than a deep vacuum pressure when designing vacuum systems.

On Earth, a vacuum is not self-sustaining since seals leak and most materials are minutely permeable. Over time, enough air molecules will be pulled through the material that the vacuum will be “lost” due to equalization with atmospheric pressure. To maintain a vacuum for a long time period, a vacuum pump must periodically evacuate air molecules to maintain a desired vacuum pressure. Depending on material permeability (porosity), continuous evacuation may be required to maintain a desired vacuum pressure.

Vacuum Flow

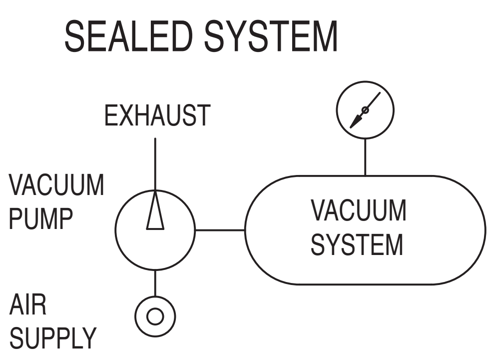
The performance of a vacuum pump is defined by its’ performance curve which is simply a plot of the vacuum flow rate that it is capable of producing at a particular vacuum pressure. As vacuum pressure increases, it becomes more difficult to remove (pump out) additional air molecules, so vacuum flow rate decreases until it becomes zero at the deepest attainable vacuum pressure. Vacuum flow rate will always be highest at atmospheric pressure (zero vacuum) where the pump is under no load. Many pump manufacturers advertise the efficiency of their pumps with this misleading number. In reality this specification is meaningless since force can’t be developed and work can’t be done unless vacuum pressure is being created.

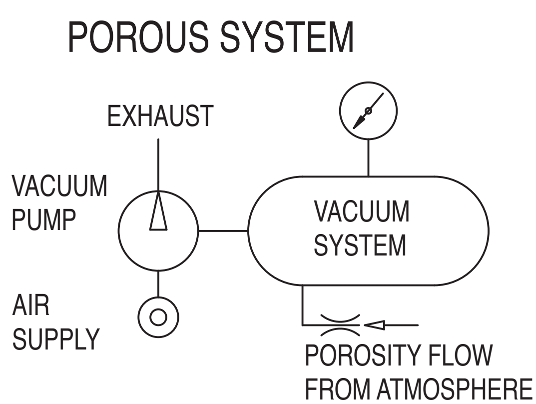
Vacuum pressure determines the amount of force that can be developed to hold a work piece or to carry a load. For a sealed system with no leakage, the two main concerns are; how much vacuum pressure is needed and how quickly can the system be evacuated to the required vacuum pressure? Since the system is sealed, using a larger vacuum pump will reduce evacuation time but will not increase the system vacuum pressure since, given enough time, even a small vacuum pump will attain maximum vacuum pressure. A larger vacuum pump will consume more energy without increasing the system load capacity so it is important to not over-specify vacuum pump capacity for a sealed system.

However, when the work piece is porous (permeable) or the system otherwise leaks, the vacuum pump must produce enough vacuum flow rate to overcome the leakage and still attain the necessary vacuum pressure. The pump must also have enough excess capacity to overcome possible future variations in work piece porosity. We have found corrugated board porosity variations of 4:1 among vendors supplying boxes to the same end user.

System porosity flow increases directly with increased vacuum pressure while pump flow decreases with increased vacuum pressure in accordance with its’ performance characteristics. As a result, doubling the vacuum pump capacity in a porous system will double the energy usage (air consumption) but will only cause a smaller incremental increase in vacuum pressure. At deeper system vacuum pressures the diminishing-returns effect becomes more pronounced so this is another reason to design systems for proper operation at mid-vacuum pressure by simply increasing the effective area upon which the vacuum pressure acts.

We offer free porosity evaluation and assistance with vacuum pump selection. EDCO USA will do the calculations for you and help you select the correct pump for your application.





Air-Powered Vacuum Generators

A vacuum pump is a device that is capable of evacuating (removing) air molecules from a closed volume so that a less-than-atmospheric pressure condition is attained. Compressed air-powered vacuum pumps are also called vacuum generators and can be simple mono-stage pumps (venturi), or more complex high-flow multi-stage, multi-ejector designs. EDCO USA manufactures both types, so we can recommend the best pump for your application without bias.

Vacuum pumps are designed to be capable of evacuating a specific percentage of air molecules to attain a vacuum pressure that is dependent upon the available atmospheric pressure. For example; a pump that is capable of attaining an 80% vacuum will develop 23.9” Hg (608mm Hg) when the barometric pressure is 29.9” Hg (760mm Hg), but the same pump will only develop 20.7” Hg (524mm Hg)at 4000 feet above sea level where the local barometric pressure is only 25.8” Hg (655mm Hg). Local weather conditions can also reduce vacuum pressure, as, for example, when barometric pressure drops from 29.9” Hg to 28” Hg during a storm. It is important to realize that vacuum pressure fluctuations are a normal characteristic of vacuum systems and are not necessarily caused by a vacuum pump problem.

To minimize the effect of vacuum pressure variations, we recommend that systems be designed for mid-range vacuum levels of 12-18” Hg (305-457mm Hg) that are consistently attainable no matter what the weather conditions may be.

Air-powered vacuum pumps are compact and lightweight so they should be mounted close to the point of vacuum usage to minimize the internal volume of vacuum hose and tubing. Vacuum is produced immediately when compressed air flows into the pump, so it is not necessary to turn the pump on long before contacting a work piece as is common with electro-mechanical pump systems.

Electro-Mechanical Vacuum Pumps

Premature wear will result from frequent starting and stopping of an electro-mechanical vacuum pump so they are primarily suited for systems requiring constant, or nearly constant, vacuum flow so the pump is powered continuously. Most types are also not suited for operating at maximum vacuum and zero flow conditions which causes poor lubrication and over-heating of the pumping mechanism.

Electro-mechanical vacuum pumps tend to be noisy, bulky, heavy and hot so they are usually mounted some distance away from the point of vacuum use. In order to be used in a pick & place system (pick something from one location and place in another), several additional components are required such as a motor starter, vacuum relief valve, exhaust muffler, large diameter vacuum hoses and a 3-way vacuum control valve.

Collectively these components, and the associated assembly labor, add substantially to the installed cost of the vacuum system and each is an additional potential failure mode when evaluating system reliability. Operating costs will also be increased because electro-mechanical pumps are high-maintenance items and must be overhauled frequently.

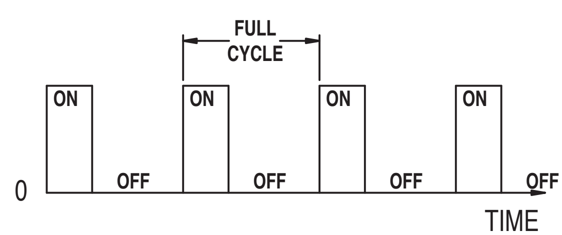
Electro-mechanical pumps efficiently convert electrical power into vacuum flow and pressure, but, because they must run continuously, they can’t take advantage of the system duty-cycle to reduce overall energy consumption. However, for systems requiring constant large vacuum flows, they may be the best solution.

Duty Cycle & Energy Consumption

During a pick & place cycle, a vacuum source is turned on for the “pick” and remains on during the traverse to the place location and then turns off to “place” the work piece. Vacuum is not necessary for the traverse back to home position nor for the dwell time before the next “pick” is required. If vacuum is on for 1/4 of the full machine cycle then the duty-cycle is 25%. An air-powered vacuum pump consumes compressed air only while it is creating vacuum. In this example the average air consumption would be reduced to 25% of the cataloged pump air consumption rate whereas an electro-mechanical vacuum pump must run continuously and consumes energy 100% of the time.

A good rule-of-thumb is to consider an air-powered vacuum pump whenever an adequate supply of compressed air is available, especially if the system has an intermittent vacuum requirement or duty-cycle.

ON/OFF CONTROL:
DUTY CYCLE = PUMP ON TIME / CYCLE TIME



Air-Powered Vacuum Generator Controls

Air-powered pumps can be simply controlled by a single air valve. When air is supplied to the pump, vacuum is supplied to the system and when the air supply is stopped, atmospheric air is drawn into the vacuum system through the pump exhaust to dissipate vacuum and release the work piece. A 3-way valve mounted close to the pump is recommended for fast operation.

Release / Blow-Off

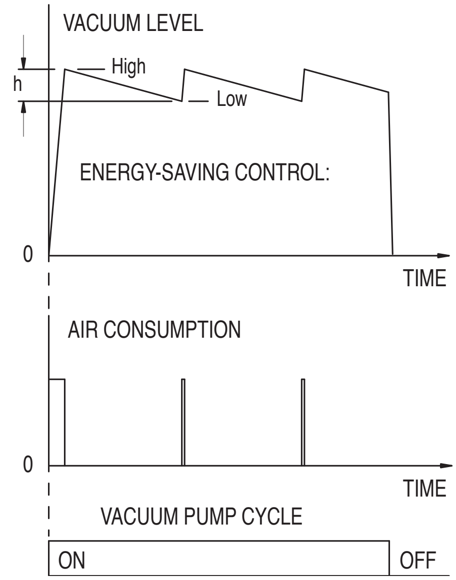
A compressed air assist will provide a faster part release for high-speed systems. A stored-volume automatic blow-off is commonly used for small systems and consists of a volume chamber that is charged with the same air supply that operates the vacuum pump. When the 3-way air supply valve is turned off, a brief pressurized air pulse from the chamber is directed into the vacuum system so the part is quickly released. For larger systems, or those requiring a greater degree of control, an air valve can be connected to the vacuum system via a Release Check valve that prevents loss of vacuum through the blow-off air valve. The blow-off pulse duration is controlled by how long the blow air valve is left on. During the blow-off mode a flow path exists from the vacuum system to atmosphere via the pump exhaust port, so it is normal for air to escape at this point. This also means that no significant positive pressure can be developed in the vacuum system so long restrictive tubing lengths to suction cups may cause part release delays, especially when bellows style cups with higher internal volumes are used.

Energy Saving

For sealed vacuum systems, a non-return vacuum check valve can be added to prevent back-flow from the pump exhaust when the pump air supply is stopped. This allows the vacuum pump to be cycled on until a desired vacuum pressure is achieved and then turned off to conserve energy (compressed air). A vacuum switch senses when vacuum pressure has decreased and cycles the pump on to restore the vacuum pressure. A separate vacuum volume chamber can be added to decrease the "leak-down" rate but proper ES system operation still entirely depends on maintaining a sealed system. If the system will handle a porous work piece, do not use an Energy Saving control.

Vacuum Cups

Suction cup is the usual industrial term for a vacuum cup. Most cups are round because that is a strong shape that resists collapse under vacuum pressure and it efficiently distributes load forces through the cup walls to the fitting. A circular shape also provides the greatest area for the amount of space it occupies. Industrial cups usually employ a metal fitting for mounting the cup and for connecting a vacuum source to allow the inner volume to be evacuated.



Suction cups are made of rubber and include a flared lip to form a flexible seal against a work piece to allow the cup to be evacuated with a vacuum pump. Several cups can be connected to a central pump, or a small vacuum pump can be used for each cup. When the cup is evacuated an attraction force is developed that holds the cup to the surface of the work piece, which for a vertical cup axis is the same as "lifting" capacity. However, if the load is perpendicular to the cup axis (shear load) then the attractive force must be multiplied by the appropriate coefficient of friction to determine an allowable shear load. In either case, an additional factor-of-safety must be applied for prudent design. When rapid movement occurs in automation systems, a designer must consider the combined magnitude of both lifting and shear loads when selecting components.

Depending on the contours of the work piece the allowable cup diameter may be limited, so multiple cups may be required to increase the total area and achieve a desired load capacity plus a generous factor-of-safety. We do not recommend increasing the required vacuum level to make a system work. Instead, increase the number or size of cups so the total effective area is large enough for proper system design. Suction cups are relatively inexpensive so additional cups are cheap insurance against potential system failure.

The vacuum force equation $F = P \times A$ (Force = Pressure times Area) is difficult to apply to rubber suction cups because cups are approximately sized according to the outer lip diameter which is misleading because it is much larger than the actual effective diameter that the vacuum pressure acts upon.

A rubber cup also changes shape under load, so the effective area varies somewhat depending on the vacuum level inside the cup. Because of this, it is more expedient to use the rated force at a particular vacuum pressure from a table of suction cup specifications. For instance, EDCO tabulates rated loads at 6 and 18” Hg (152 and 457mm Hg). Loads at other vacuum pressures are directly proportional so, for example, the load at 15” Hg is simply 15/18 times the rated load for 18” Hg.

The force equation can be useful for vacuum “clamps” where a cavity with a seal formed around its’ perimeter is used to hold flat work pieces such as wood or stone. The area within the seal can be calculated with some degree of accuracy so the force equation F = P x A calculation is straightforward. Of course, the equation units must be consistent with each other, so vacuum pressure must be converted to an appropriate unit of measure.

Vacuum Cup Selection

Total load capacity of a vacuum system can be increased in two ways. (1) Increase the required system vacuum pressure, or (2) increase the total area that the vacuum pressure acts upon by either using larger suction cups, or a greater number of suction cups, or both. As explained previously, increasing the required vacuum pressure above a comfortable mid-range vacuum level is not a good practice. Increasing the suction cup area is the favored method. Refer to the table for selection of suction cup type by work piece characteristics. These are typical guidelines and there can be exceptional cases. Every application is a little different so sometimes a trial is the only way to determine what works best.

Vacuum Cup Selection

For economy, always use the lowest cost material unless there is a good reason not to. AMERIFLEX (50A) is an outstanding replacement for competitors blue vinyl (PVC) cups in moderate, factory temperature, applications – Excellent wear resistance and lower priced than nitrile. DURAMAX (45A) is a soft and supple non-marking (no residue) material for moderate temperature applications including glass and other high gloss surfaces. NITRILE (50A) is a general purpose material with good wear characteristics, making it well suited for most industrial room-temperature environments. SILICONE (50A) has a very wide temperature range and is suitable for both sub-freezing applications and for elevated temperatures. Silicone is inherently more supple than other rubbers so it may seal better on textured surfaces. Silicone also has the reputation for causing problems with painted or plated parts so some plants will not allow it to be used. CONDUCTIVE SILICONE (50A) provides a conductive path to dissipate static electrical charges so electronic components will not be damaged. VITON (60A) provides the highest temperature rating but is also harder so sealing on textured surfaces may be affected.

General Rules

Three points define a plane. So, for good stability use three or more cups that are spaced apart as far as possible. Start with the largest cup size that can be reliably placed on the work piece and then increase the number of cups until a suitable factor of safety is achieved. For handling boxes and other containers, apply the suction cups in corners and near the outer vertical walls. Remember, the box contents sit on the box bottom so the weight load is transferred to the box top via the side walls.

	B - Bellows	2B - Double Bellows	BL - Multi-Bellows	BF - Bellows Flat	D - Deep	F - Flat	FC - Flat Concave	U - Universal	OC - Oval Concave	OF - Oval Flat
Work Surface	Cup Style									
Flat	X	X	X	X		X		X	X	X
Concave - Slight	X	X		X				X		
Convex	X	X	X	X	X		X	X	X	
Compound	X	X	X	X				X		
Spherical	X	X			X		X			
Cylindrical	X	X	X		X			X	X	X
Flexible	X	X	X					X		
Plastic Flim			X							
Shear Loads	X	X		X		X	X			X

Thread Systems

ISO Thread:

- Cylindrical Metric Thread - Designated with the letter M. (Example: M5x0.8)
- Cylindrical Inch Thread (Unified) - Designated with the letters UN. (Example: 10-32 UNC)

Dry Seal Thread (American System Pipe Thread):

- Conical Thread - Designated with NPT or NPTF. (Example: 1/4-18 NPTF)
- Cylindrical Thread - Designated with NPSF. (Example: 1/2-14 NPSF)

G Thread (Whitworth Pipe Thread):

- Cylindrical thread designated with the letter G. (Example: G 1/4-19)
- BSPP is a tighter tolerance G thread. We use G threads on our products unless otherwise noted.

Thread Compatibility

Some combinations of G (BSPP) threads and NPT threads will mate if the engagement length is short. EDCO uses an odd thread description such as G 1/8" NPSF for a female thread to indicate that either 1/8" NPTF or G 1/8" male threads will mate with it. By using straight threads, the fitting shoulder will bottom out against the mating surface so that all cups are at the same installed height. If tapered threads were used, the cup installed height would vary depending on the length of thread engagement after tightening. Pipe dope sealant is usually unnecessary but will positively eliminate even small leaks. Tape sealant can shred slivers that tend to migrate and cause problem so it's best to avoid using it.

Please note, some thread sizes in different systems do not always fit.

	M5 Male	M5 Female	G 1/8 Male	G 1/8 Female	G 1/4 Male	G 1/4 Female	G 3/8 Male	G 3/8 Female	G 1/2 Male	G 1/2 Female	G 3/4 Male	G 3/4 Female	G 1 Male	G 1 Female	G 2 Male
10-32 UNF Male or Female	•	•••													
1/8 NPSF Female			•												
1/8 NPT Male or Female			X	•											
1/4 NPSF Female					•										
1/4 NPT Male or Female					X	X									
3/8 NPSF Female							X								
3/8 NPT Male or Female							X	X							
1/2 NPSF Female									•						
1/2 NPT Male or Female									X	•					
3/4 NPSF Female											•				
3/4 NPT Male or Female											X	•			
1 NPT Male or Female													X	X	
2 NPT Male or Female															X

••• Fits

• Fits w/ Short Thread Engagment

X Does Not Fit