This is Vacuum... An Explanation

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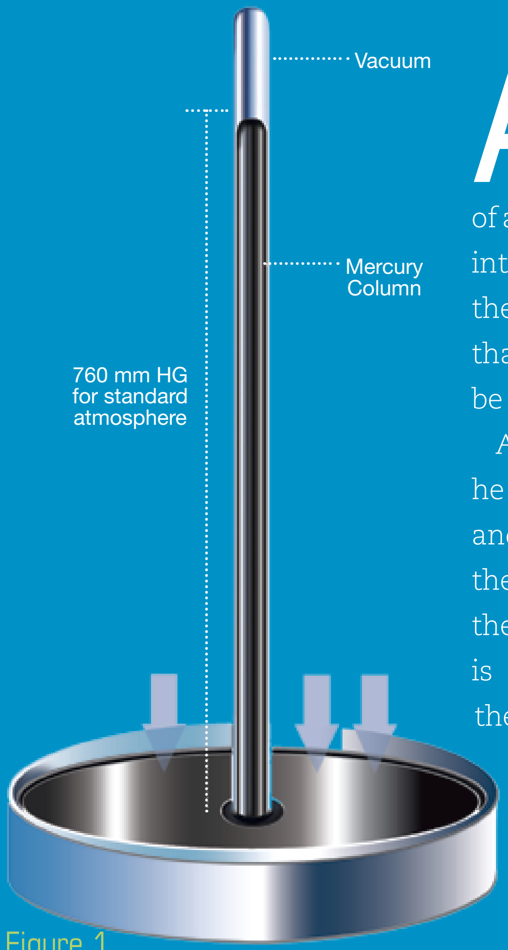


Figure 1.

Approximately four hundred years ago, a young Italian man named Evangelista Torricelli walked up a mountainside with apparatus he had recently put together in his workshop. This apparatus consisted of a bowl of mercury with an open-ended glass tube inserted into it (Figure 1). The young man was attempting to prove that the air in the atmosphere had a physical weight and hoped that by walking up a mountainside, this theory would be confirmed.

After a few thousand paces and much physical exertion, he diverted his gaze from the snowcapped mountains and focused on the contraption in his possession. His theory was proven correct. The column of mercury in the tube had moved downwards. The reason for this is that the atmospheric pressure pushing down on the mercury in the bowl was now less and therefore, the mercury in the tube fell. Consequently, as Torricelli descended down the mountain, the pressure on the bowl of mercury became higher and the column increased in height. The "mercury barometer" was born.

At sea level, the height of the mercury in the tube was 760 mm, but this column receded as the barometer was taken up the mountainside. Torricelli concluded that full atmospheric pressure represented 760 millimeters of mercury (mmHg), as sea level was the farthest point away from the top of Earth's atmosphere, and that this column of mercury moved up or down due to the amount of atmospheric pressure being exerted on the mercury in the bowl. This is the origin of the unit of pressure measurement known as Torr, named after its founder Evangelista Torricelli (1Torr = 1mmHg).

Therefore, the higher the altitude, the lower the atmospheric pressure because there are less air or gas molecules above, pressing down, creating atmospheric pressure. Figure 2 illustrates the different atmospheric pressures at varying altitudes.

The Torricelli experiment proved that atmospheric weight or pressure did exist and explains what a vacuum is. Put simply, *"A vacuum is a known volume with a pressure that is less than the atmospheric pressure surrounding it."* Figure 3 represents a comparable condition of atmospheric pressure and a vacuum. Condition 1 has a complete atmosphere and Condition 2 has had the atmospheric pressure reduced, which means this cube is in a vacuum condition. The atmosphere is made up of trillions and trillions of gas or air molecules. These molecules move around, bumping into one another and creating pressure. As you reduce the amount of molecules, they bump into each other less often, and therefore, the pressure is decreased. Simple enough to visualize.

How is a vacuum created? Basically, the atmospheric pressure is reduced by "sucking" out the gas molecules by means of a pump or venturi, and the end result is Condition 2 (shown in Figure 3). The less gas molecules, the less pressure. This is how we increase atmospheric pressure. Pump more air molecules into a known volume such as a car tire. When a car tire is not inflated, this means the same atmospheric pressure exists on the outside as it does inside the tire. Pump more gas molecules into the tire, and the tire pressure increases. Vacuum is simply the opposite of this.

Flow in a Vacuum System

What is sometimes confusing to engineers is the understanding of flow within a vacuum system. Vacuum flow is simply referring to the rate at which the gas molecules are evacuated or "sucked" out (the rate at which the atmospheric pressure is reduced). Most vacuum apparatus data or even model numbers of vacuum pumps refer to flow at the atmospheric pressure or SCFM (standard cubic feet per minute).

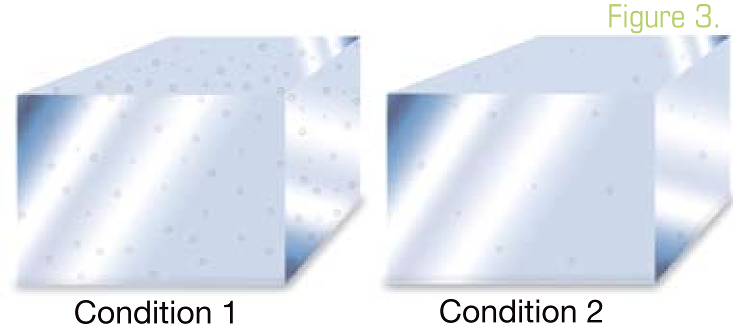
For example, a vacuum filter is sized to operate at 50 SCFM. SCFM is referring to how many standard cubic feet of atmospheric pressure will flow per minute. Therefore, if your vacuum system is running at 380 Torr, which is a 50% vacuum (remember Torricelli's barometer), the filter can handle 100 ACFM which is Actual Cubic Feet per Minute with *actual* being the pressure of the system (380 Torr).

Confused? Refer to Figure 3. Two conditions. Let's assume that Condition 2 is at 380 Torr or 50% vacuum. That means it has half the amount of gas molecules as Condition 1. So therefore, two cubes of Condition 2 has the same amount of air molecules as one cube of Condition 1. Consequently, 50 SCFM is the same as 100 ACFM @ 380 Torr. And 50 SCFM is also the same as 500 ACFM @ 76 Torr. There is no global definition of a standard cubic foot, which would include such conditions as temperature, atmospheric pressure, humidity, etc. However, for your information, a popular SCFM is 760 Torr and 60ºF (Temperature has a big effect on pressure). One final note about this is that ACFM should always be followed by the pressure condition. For example, 100 ACFM @ 100 Torr.

The normal reason for wanting to size apparatus such as a vacuum pump in a vacuum system is to determine how quickly the user needs to reach a specific vacuum level. There are many different sizes of vacuum pumps. If you have ten different models of vacuum pumps and they can all achieve a final vacuum of 20 Torr, the only other defining characteristic is how quickly they can reach it, and that is based on the flow capacity/size of the vacuum pump.

Vacuum is used throughout industry in manufacturing processes. One of the most common applications is material handling, where vacuum cups are used to pick up and move

Figure 3.



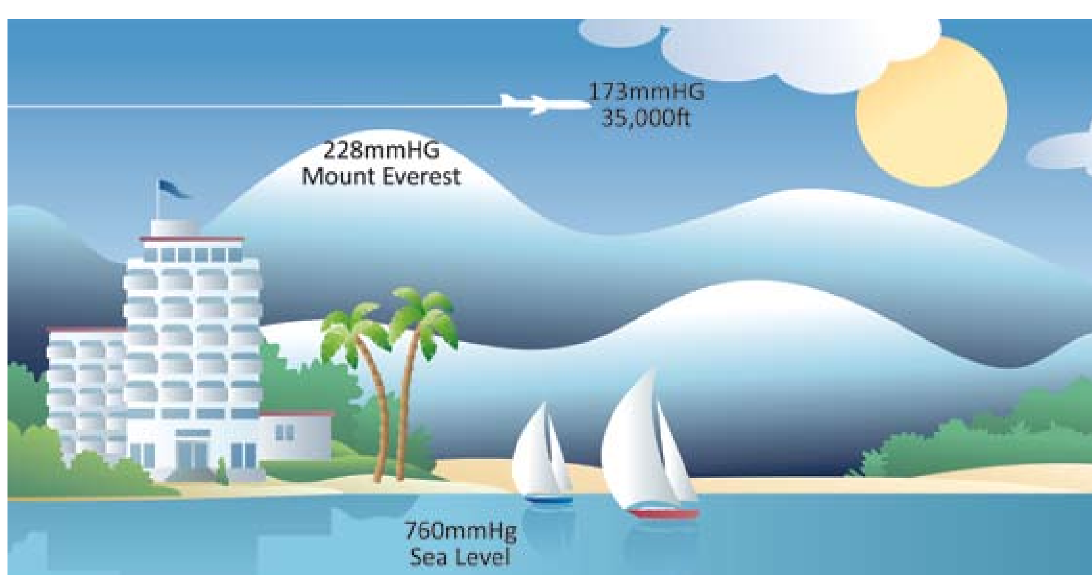


Figure 2.

material from point A to point B. Figure 4 shows how a vacuum cup actually works. When the cup is sealed against the load to be lifted, such as a piece of glass, the volume of air beneath the vacuum cup is trapped. This is a known volume. Condition 1 shows the vacuum cup with the vacuum generation device (pump) turned off and the cup remains in its original shape. When the vacuum device such as a pump or venturi is attached to the vacuum cup, the atmospheric pressure inside the vacuum cup is reduced. If, for example, the atmospheric pressure is reduced to 100 Torr, this creates a pressure difference of 660 Torr. This pressure difference (differential pressure) pushes down on the vacuum cup, squashing it against the glass. On the underside of the vacuum cup, the same differential pressure pushes the glass up against the lower pressure inside the vacuum cup. The glass is clamped between two areas of higher pressure. This is how a vacuum cup works.

How does atmospheric pressure determine how much weight a vacuum cup can lift? First of all, move this to a more familiar territory by using another unit of pressure measurement, PSI. The PSI unit indicates pounds of pressure per square inch and is the common pressure unit used in North America. As stated earlier, the average atmospheric pressure is 760 mmHg at sea level. 760 mmHg is equivalent to 14.7 PSI or 14.7 pounds of pressure over a single square inch of area. This is written as 14.7 PSI(a). The (a) indicates an absolute pressure where 0psi(a) is a full vacuum or zero atmospheric pressure. If you reduce the atmospheric pressure by 80% inside the vacuum cup, you have reduced the pressure to 2.94 PSI(a). If the atmospheric pressure is 14.1 PSI(a), you have an 11.76 PSI (14.7 – 2.94) differential pressure available. Consequently, the following will apply.

1. If the vacuum cup is 4 inches in diameter, the area of this cup is 12.57 in^2. [(πr^2 = 3.142 × (2×2)]
2. The differential pressure is 11.76 PSI (lbs per square inch)
3. Consequently, for every square inch, there is a force of 11.76 lbs over an area of 12.57 square inches (cup area) and therefore, the vacuum cup's lifting force is 147.82 lbs (11.76 × 12.57 = 147.82).

That is how you calculate the lifting force of a vacuum cup.

So far, Torr (mmHg) and PSI have been used to describe atmospheric pressure. However, the most common unit of vacuum measurement used in North America is inches of mercury ("Hg). Inches of mercury is simply the same as mmHg (convert mm to inches: 760 / 25.4 = 29.92"Hg) but unlike mmHg, "Hg is a differential measurement from the atmospheric pressure condition, which as we know is a variable. And, mmHg is an absolute measurement with 0 mmHg indicating zero atmospheric pressure. However, 0"Hg is indicating zero vacuum or zero pressure differential at the current atmospheric pressure. This unit of measurement should not be used for HIGH vacuum applications as the datum point of 0 "Hg is not a constant as the atmospheric pressure is always changing. That is why mmHg, an absolute unit, is used for applications where a known, higher vacuum is required, such as 3 mmHg etc. Figure 5 explains this graphically.

Summary

Remember the most important fact about vacuum: It is a volume of a lesser atmospheric pressure. Once this is realized, everything else should fall into place. Furthermore, it is NOT suction. Suction is purely an event, not an engineering condition. Suction is simply a higher atmospheric pressure rushing into a lower atmospheric area, which is exactly how a vacuum cleaner works, with the higher atmospheric pressure pushing dirt into the cleaner. It does not suck the dirt up.

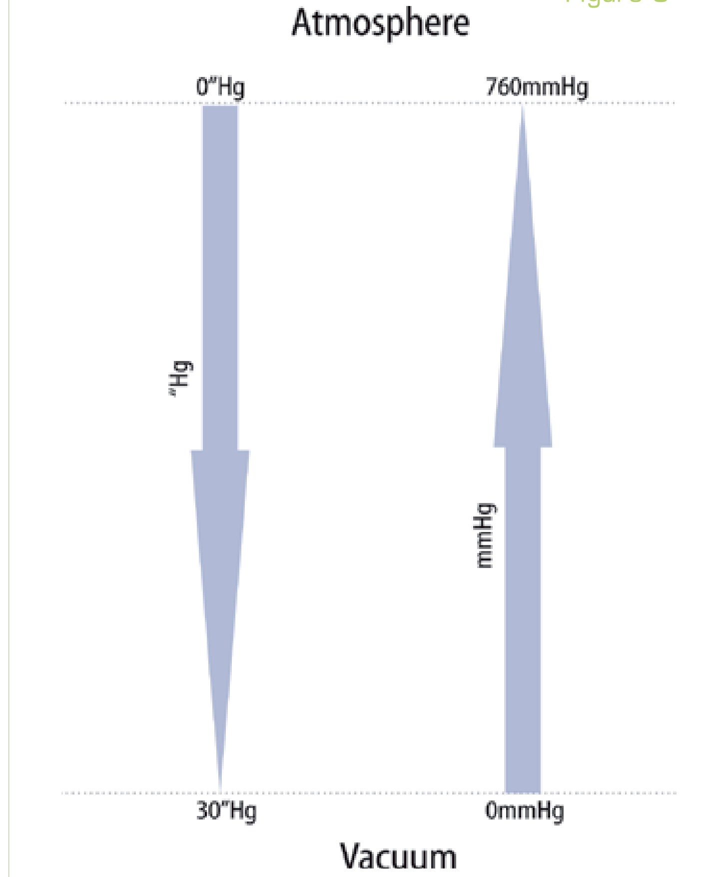


Figure 5

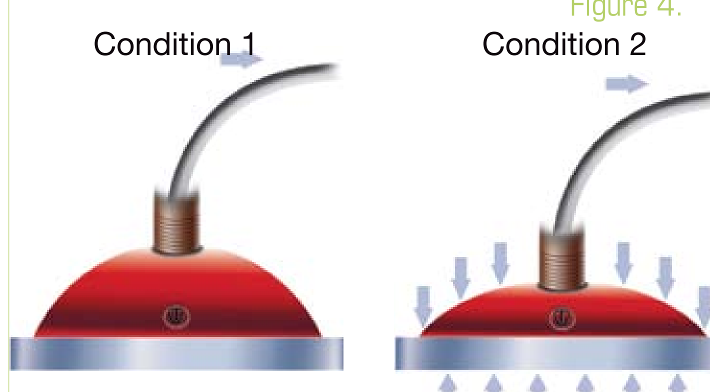


Figure 4.

Vacuum is a pressure condition that is less than the surrounding atmospheric pressure.

For more information, contact Daniel Pascoe at www.vacuforce.com. Vuototecnica USA is a brand of Vacuforce, Inc. (Graphic design for this article provided by Shamy Kaul.)