Ohio Medical Corporation

Affects of Altitude on Vacuum Systems

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TERMINOLOGY

ACFM – Actual Cubic Feet per Minute
CFM – Cubic Feet per Minute
MDCFD – Thousand Standard Cubic Feet per Day
psia – Pounds Per Square Inch in Absolute pressure
SCFM – Standard Cubic Feet per Minute

INTRODUCTION

This paper discusses the affect of atmospheric variation on a vacuum pump's performance. To simplify the understanding, vacuum pumps are compressors operating in reverse, where inlet pressure is below the atmospheric pressure, and compressed to the discharge at atmospheric pressure. The operating range of a vacuum pump will be between atmospheric pressure down to absolute zero (a perfect vacuum). Realistically, we can not achieve a perfect vacuum (29.9 in-Hg), and the vacuum pumps used for medical and industrial applications require approximately 95% (28.5 in-Hg) of the atmospheric pressure to be evacuated in a tank. Cryogenic applications require nearly a perfect vacuum, and will achieve more than 99.9% (greater than 29.8 in-Hg) of the atmospheric pressure to be evacuated from a chamber.

This paper supplements the Squire-Cogswell white paper titled: *ACFM vs. SCFM vs. ICFM* published in 2004 and explains the differences in compressor performance with respect to the varying atmospheric conditions. The paper also addresses appropriate "CFM" terminology that should be use in comparing compressors (SCFM) and sizing them properly (ACFM) for the off "Standard" conditions for the altitude and conditions for the area.

Due to the atmospheric variation in air pressure, temperature and density – the fluid properties are constantly changing (i.e. - conditions are dependent on location, time of the year, altitude, etc.) Thus, it is important to understand that the conditions in Los Angeles vary significantly from the conditions in Denver, and a vacuum pump's performance (capacity and operation) will vary significantly. The intent of this paper is to provide a better understanding of how vacuum pump's capacity varies with respect to altitude, so we can properly select and size vacuum pumps for their specified and intended applications.

DESCRIPTION

The term *cubic feet per minute* (***CFM)*** describes the fluid flow rate, (measured in volume - ft^3) not the weight per minute on the inlet side of a compressor. The vacuum pump's performance capability is measured in how many one ft^3 cubes of fluid are able to move per minute through the system.

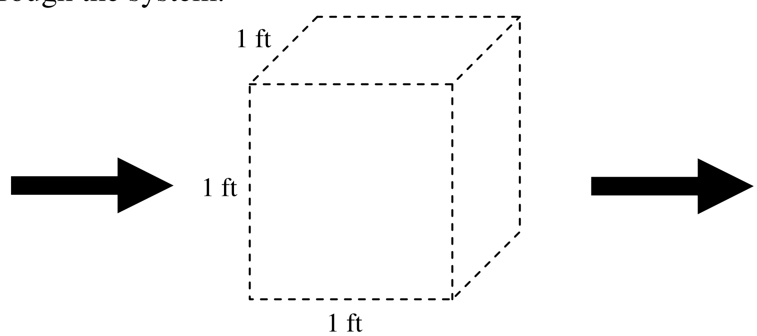

Figure 1 – One Cubic Feet of Volume

Now consider the conditions in Los Angeles, where one cubic foot of air weighs 0.075 lbs., and in Denver, where one cubic foot of air weighs 0.062 lbs. Even though the volume is the same, the weight (mass) of the air is different.

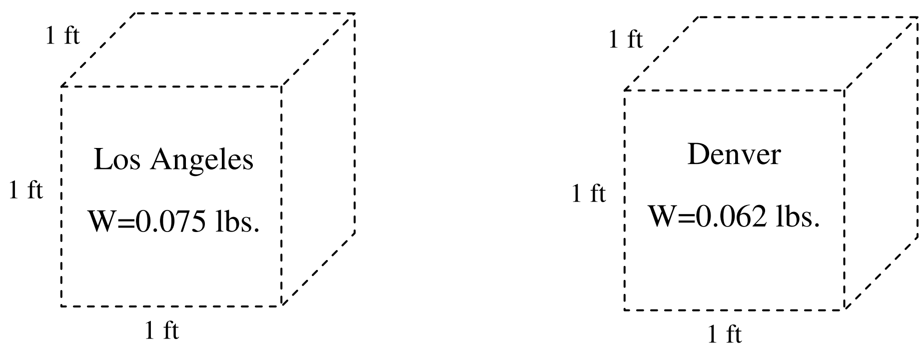

Figure 2 – Constant Volume

Now consider a constant weight (mass) condition. A balloon filled with 31 actual cubic feet of air in Los Angeles is then taken up to Denver. The balloon now contains 38 standard cubic feet of air.

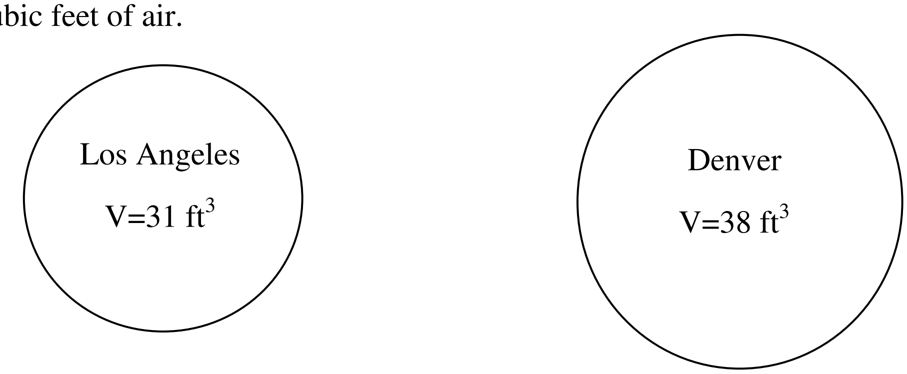

Figure 3 – Constant Mass

The two examples illustrate the confusion of measuring volume due to the fact air is compressible. In this instance, the number of gas molecules occupying a particular volume, depends primarily on the pressure and temperature conditions of that location. At a microscopic level, the air molecules are closer together (greater air density) in Los Angeles compared to the air molecules in Denver.

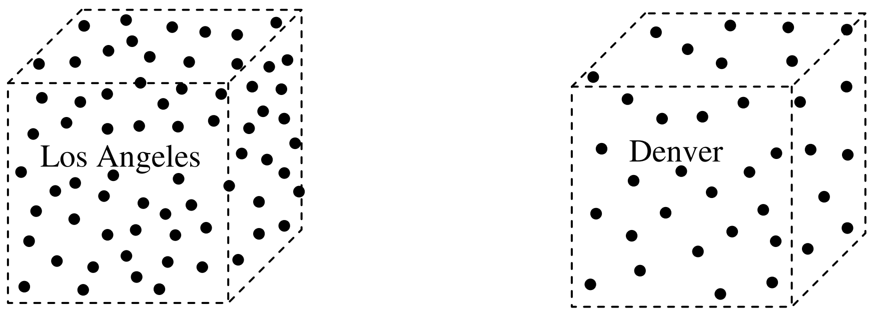

Figure 4 – Variation in Air Molecule Density

A variation in air pressure results in a variation in air density, as show in Figure 4, and is consistent with constant volume concept in Figure 2. Another way to look at this is to analyze the number of air molecules in a 120-gallon receiver tank at atmospheric pressure at Los Angels and at Denver, where the former (higher pressure) tank occupies a greater number of molecules. The weight and density vary primarily because the atmospheric pressure is significantly different between the two cities, as show in Table 1. Note the terms for "actual" and "standard" for the volumes described above leads us to "SCFM" and "ACFM".

City	Altitude (ft)	Atmospheric Pressure (psia)	Atmospheric Pressure (in-Hg)
Los Angeles	0	14.69	29.92
Denver	5280	12.12	24.68

Table 1 – Variation in Atmospheric Pressure between the Two Cities

THE "GENERAL RULE"

To simplify the understanding of the affect of vacuum pumps with respect to variation in altitude, the following illustration simplifies and points out the concept to understand prior to proceeding with a more theoretical view point on the matter. For this paper, we will assume only the attitude is varying, while keeping other conditions constant (like temperature, humidity, etc,).

The first general rule is to understand that the maximum vacuum level that can be achieved is with respect to the atmospheric conditions in the area. For example, assume the maximum vacuum that can be achieved theoretically in Los Angeles (sea level) is 29.92 in-Hg, but in Denver (5280 feet above sea level) is 24.68 in-Hg.

City	Altitude (ft)	Atmospheric Pressure (in-Hg)	Atmospheric Pressure (in-Hg using the rule)
Los Angeles	0	29.92	29.92
Denver	5280	24.68	24.64

Table 2 – "Rule of Thumb" for Atmospheric Pressure

As a general "Rule of Thumb", for every 1000 feet above sea level, the maximum possible vacuum is reduced by approximately one in-Hg (0.491 psi). By using this rule one can quickly determine the maximum possible vacuum for the area. Note the accuracy of this "Rule", as there is only a 0.16% difference between the approximated and the actual pressure (shown in Table 2).

PERFORMANCE BASED ON CAPABILITY

Next consider that a vacuum system's performance is a percentage of the atmospheric pressure that it can exhaust from a closed system. At sea level, Los Angeles has a barometric pressure at 29.92 in-Hg. Thus, a vacuum pump with a maximum capability of 24.00 in-Hg will have are rating of 80.2%.

$$\frac{24.00\ psi}{29.92\ psi} = 0.802$$

Then, the 80.2% rating can be assigned to the vacuum pump to determine its capability in Denver.

$$0.802 \times 24.68 = 19.79\ in - Hg$$

The 80.2% rating applied to the maximum possible vacuum (24.68 in-Hg) results in a maximum vacuum of 19.79 in-Hg for this pump in Denver. This is a very important point to understand and consider for vacuum performance and sizing for your location. If the user needs a vacuum that can achieve 22 in-Hg in Denver, a pump with at least a 89% vacuum capability is needed, or a pump that will achieve at least 26.7 in-Hg capability in Los Angeles.

PERFORMANCE BASED ON CAPACITY

In a closed system vacuum pumps use kinetic energy to move air through a closed system. At low vacuum levels large volumes of air can be evacuated through the system, but at higher vacuum levels, the capacity decreases, due to increased leakage from a larger pressure differential with the environment and there is additional resistance to flow. This phenomena is illustrated in Figure 5.

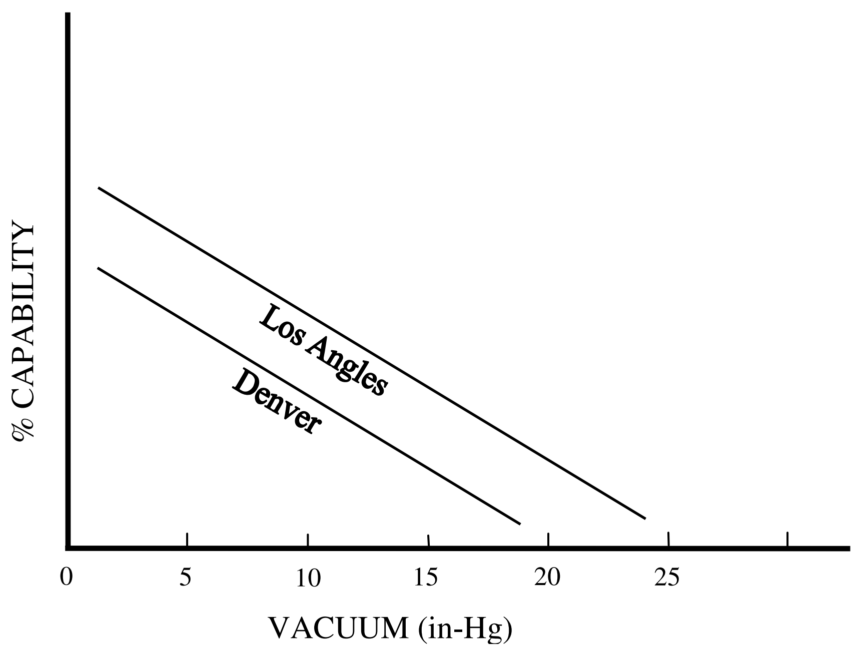

Figure 5 – Vacuum Capacity for Los Angels and Denver

SUMMARY

This paper summarized the affect of atmospheric variation on a vacuum pump's maximum performance. By comparing conditions in Los Angeles from the conditions in Denver (capacity and operation) and using the general "Rule of Thumb" (for every 1000 feet above sea level, the maximum possible vacuum is reduced by approximately one in-Hg), we can quickly determine the maximum possible vacuum for the area.

Finally, a specifier can use the "Rule of Thumb" for sizing a vacuum system properly. In addition, the reference pressure, temperature, and required vacuum must be specified, in addition to the required capacity and capability. When specifying the vacuum requirement, the worst case conditions should be used (i.e. - generally hot days – lower air density). Other important factors to consider in vacuum system sizing are:

- Vacuum requirement or demand in a given day
- Normal operating conditions
- Other operating conditions (hot days are the worst)
- Single-stage or two-stage vacuum
- Electrical characteristics and power requirement
- Area classification (Elevation)