Leak Testing Using Vacuum

There seems to be a lot of confusion out there as to how exactly to test a system for leaks using vacuum. You may think the answer is simple: Pump the system down to some low vacuum, blank off the vacuum pump, and watch your vacuum gauge. If the vacuum reading stays put for some time (say a few hours), there is no leak. This simple, common sense, solution is correct if the vacuum gauge you are using is not sensitive to small vacuum changes. Anybody who has used a fast electronic vacuum gauge that has vacuum sensitivity from 1 to 100 microns, knows that once the vacuum is blanked off, the reading will go up right away. As to exactly how much the reading can go up and still be considered OK, is subject to interpretation, and many "rules of thumb" exist.

What the leak testing by vacuum technique is trying to do is to translate the rate of the air leaking into our system (in microns per minute) into a leak rate of the escaping refrigerant (in oz/year). This conversion is more difficult than may first appear. There are differences that we can easily account for, such as the difference in the properties of air and refrigerant, the difference in the pressure differential between the vacuum and the pressurized refrigerant, etc. The other differences are a bit trickier:

- An evacuated system will have different leak sources than a pressurized system. Leaks occurring during vacuum may become closed during pressurization, and vice versa.
- Evacuating a system generates "virtual leaks". These are due to outgassing of the various substances in the system. Even if you assume that all the water vapor is gone, significant outgassing sources remain. These are: Sludge and residues left in the system (refrigeration oils, etc), brass fittings, Teflon tape (brass and Teflon are terrible outgassers), brazing fluxes, refrigeration hoses, and rubber o-rings. These "virtual leaks" will not contribute to the refrigerant escape rate.
- Blank off valves may leak. For instance, you can not use the blank off valve of your vacuum pump. Cheap ball valves almost always leak.

Because of these differences, calculating the refrigerant escape rate based on the behavior of the system under vacuum is virtually impossible. This brings us to the "rules of thumb". These vary a great deal. Here are some examples pulled from various service manuals:

1. Evacuate the system to 1000 microns, valve off the pump. If after 30 minutes the vacuum reading does not rise above 2500 microns, there are no leaks.
2. Evacuate the system to 300 microns, valve off the pump. If after 30 minutes the vacuum reading does not rise above 800 microns, there are no leaks.
3. Evacuate the system to 500 microns, valve off the pump. If after 12 hours there is no rise in the vacuum reading, there are no leaks.
4. Evacuate the system to 500 microns, valve off the pump. If after 5 minutes there is no rise in the vacuum reading, there are no leaks.
5. Evacuate the system to 2000 microns, valve off the pump. If after 24 hours there is no rise in the vacuum reading, there are no leaks.
6. Evacuate the system to 500 microns, valve off the pump. If after 10 minutes there is no rise in the vacuum reading, there are no leaks.
7. Evacuate the system to 29.5 in Hg (10,700 microns), valve off the pump. If after 5 minutes the vacuum reading does not rise above 25 in Hg (125,000 microns), there are no leaks.
8. Evacuate the system to 29 in Hg (23,000 microns), valve off the pump. If after 30 minutes there is no rise in the vacuum reading, there are no leaks.

And more of the same. Note how the specifications go from the most stringent (3) to fairly loose ones (7).

Specifications (1) and (2) are from ASHRAE Guideline 3-1996, “Reducing Emission of Halogenated Refrigerants in Refrigeration and Air-Conditioning Equipment and Systems. (1) (section 6.4.1) is for factory leak testing, (2) (section 7.3.1 (c)) is for field-erected systems. These two guidelines seem to be the most reasonable. There is no explanation, however, as to why they work. For instance, section 6.4.1 of the same ASHRAE guideline states that the factory system leak rate should not exceed 0.1oz/year or 0.5% of the system whichever is grater. Lets do some simple calculations.

A simple equation that governs vacuum leaks is Q = P*S. Q is the leak rate in Torr*ft^3/Minute, P is the Pressure in Torr, and S is the pump rate in ft^3/Minute (CFM). Lets assume that the total volume of our system is 1 cubic foot. We just evacuated it to 300 microns (0.3 Torr) and valved off the vacuum pump. The pressure then rose to 700 microns (0.7 Torr) in 30 minutes. This is acceptable under the ASHRAE standard. This is equivalent to a leak rate of: (0.7 – 0.3) Torr * 1 ft^3/30 minutes = 0.013 Torr*ft^3/Minute. This is equivalent to a refrigerant loss of about 32 oz / year. In order to comply with the 0.5% rule, your system will have to be charged to 400 pounds of refrigerant!!! What’s going on?

The answer is in the assumptions we made. We assumed that the leak comes exclusively from air leaking into the system. The truth is that the outgassing virtual leaks contribute a great deal to the rise. In fact, unless you are under laboratory conditions, using specialty materials that went through bakeout to remove all outgassing components, you will see a rise in the vacuum reading once you valve off the pump.

So how about all the guidelines that expect the vacuum not to rise for as long as 24 hours? The answer here lies in the gauge. Lets say you don’t have an electronic vacuum gauge and you are using the manifold gauges. What can you expect to see? A typical manifold gauge has 1 division for each inch of mercury, that’s 30 divisions. Lets say we have really good gauge that has 120 divisions (that’s one division for every 0.25 inches of mercury). Pumping the system down to 500 microns will basically put the gauge at 30 inches of vacuum. A change of one division (0.25 inches of mercury) is equivalent to a vacuum loss of about 6500 microns. So, yes, if you are using your manifold gauges, you should not see an increase in pressure for 24 hours, or you have a leak.

Lets look at some test results. The first system is a sealed canister about 1.5 liter in volume (0.05 cubic feet). The system was connected to the vacuum pump using copper tubing. The system was evacuated to a vacuum under 20 microns, the vacuum pump was then blanked off using a good quality ball valve. The plot of the vacuum rise is shown in Figure 1. Note that this system does meet the ASHRAE specification (2) above. From the 300 micron point the vacuum only rises to about 700 microns in 30 minutes.

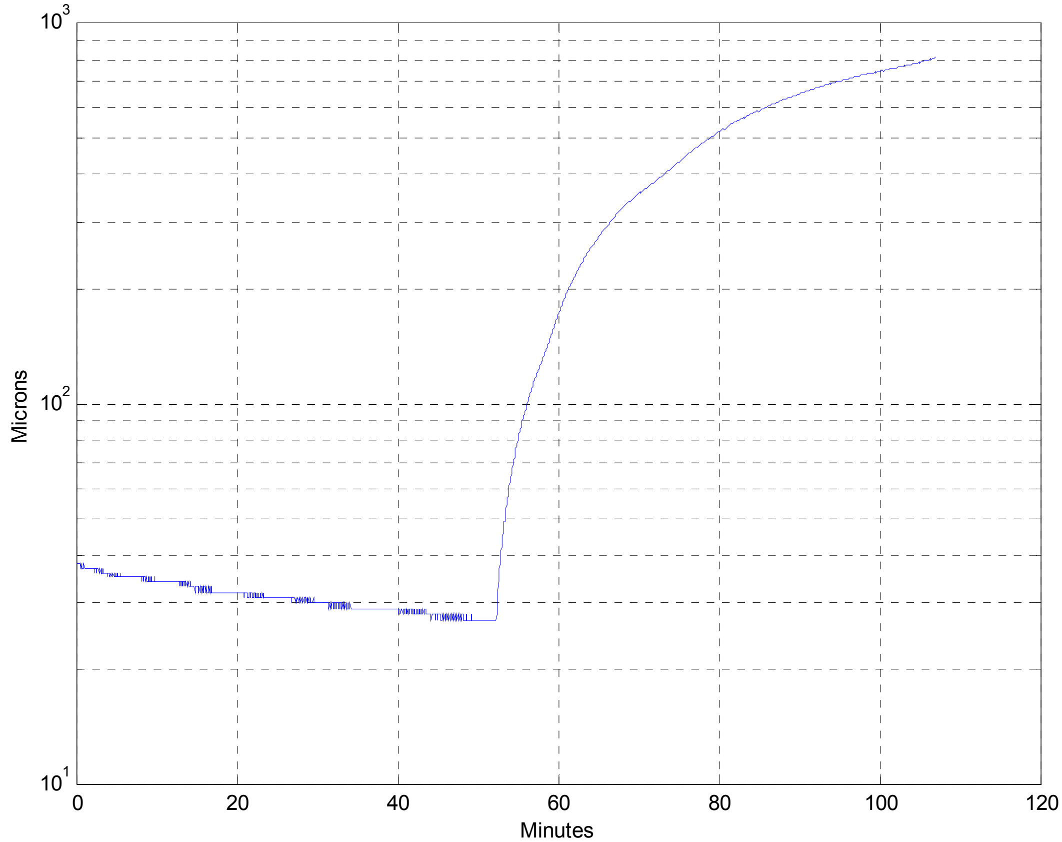

Figure 1: Short Term Pressure Rise in a Sealed System

A longer term test on a similar system is shown in Figure 2.

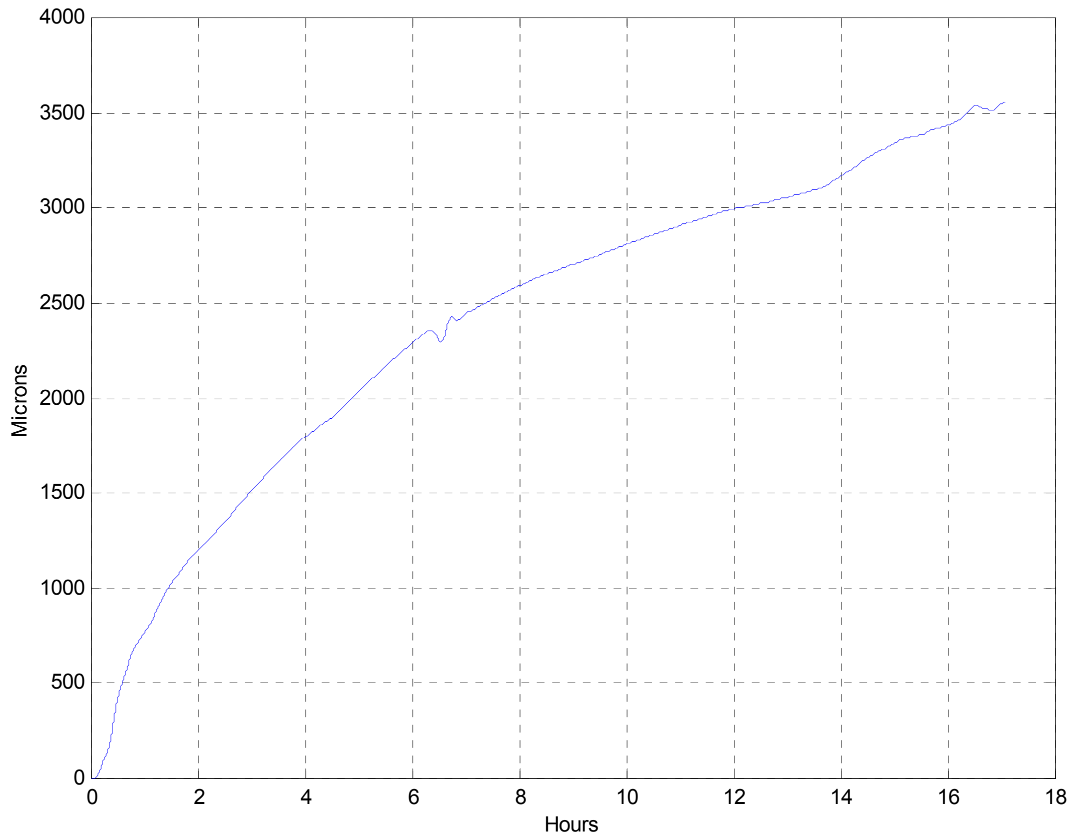

Figure 2: Long Term Pressure Rise in a Sealed System

Figure 3 below shows the same system, but instead of copper tubing, new refrigeration charging hoses were used to connect the system to the vacuum pump. Note the very fast rise in the vacuum reading once the pump is isolated from the system. This fast rise is due to the outgassing of the new hoses.

Outgassing is a serious problem that can contribute "virtual leaks" to the system. This makes it look like the system has a leak because the micron reading is rising, but the rise is actually caused by various gasses being released by porous materials. It may take many hours (24 to 48 hours is not unreasonable) for all the gasses to be released, and outgassing to stop. What's more, once these materials are exposed to atmosphere, they will once again absorb moisture and air and their outgassing properties will return. This means that it is not sufficient to "pretreat" a refrigeration hose, for instance, by exposing it to vacuum for 24 hours. Once the hose is removed from vacuum, it will once again regain its outgassing capacity.

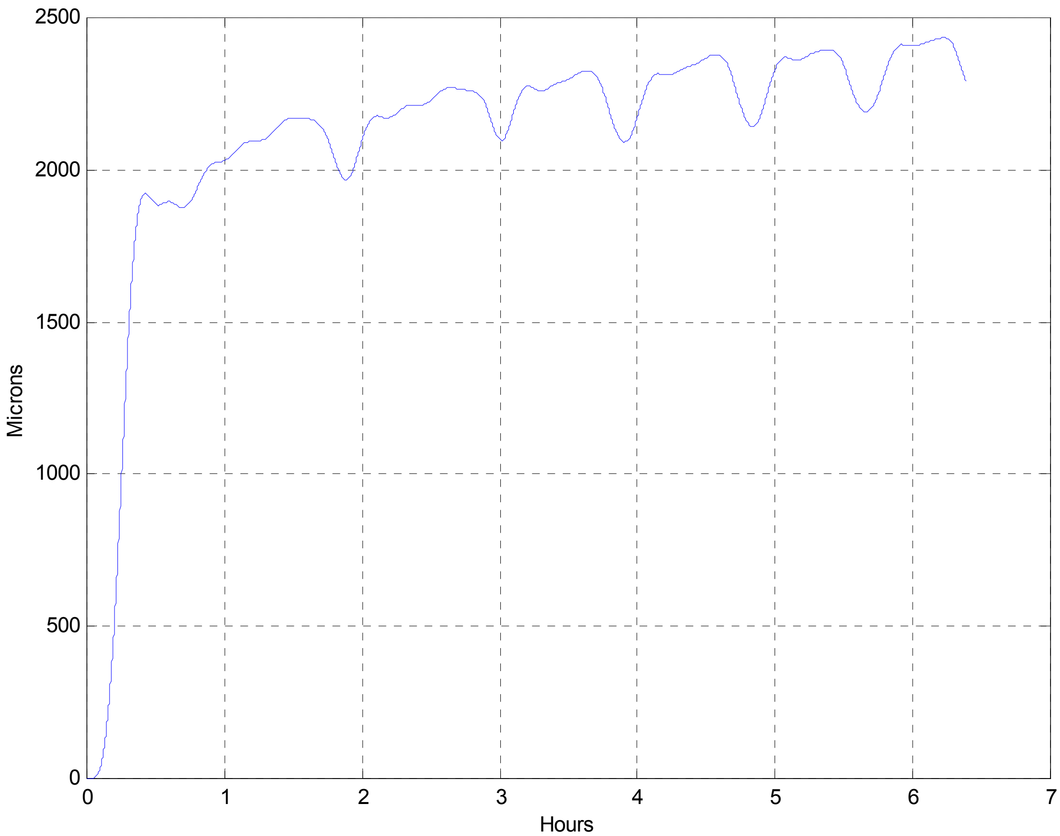

Figure 3: Pressure Rise in a System that Uses Charging Hoses

The final graph shows the system with a 4 micron diameter leak. Note first that the lowest vacuum reading that was obtained was about 2000 microns. We were using a 10 CFM pump. Second, once the pump is removed from the system, the pressure rise is extremely quick. In a refrigeration system a 4 micron leak is fairly big.

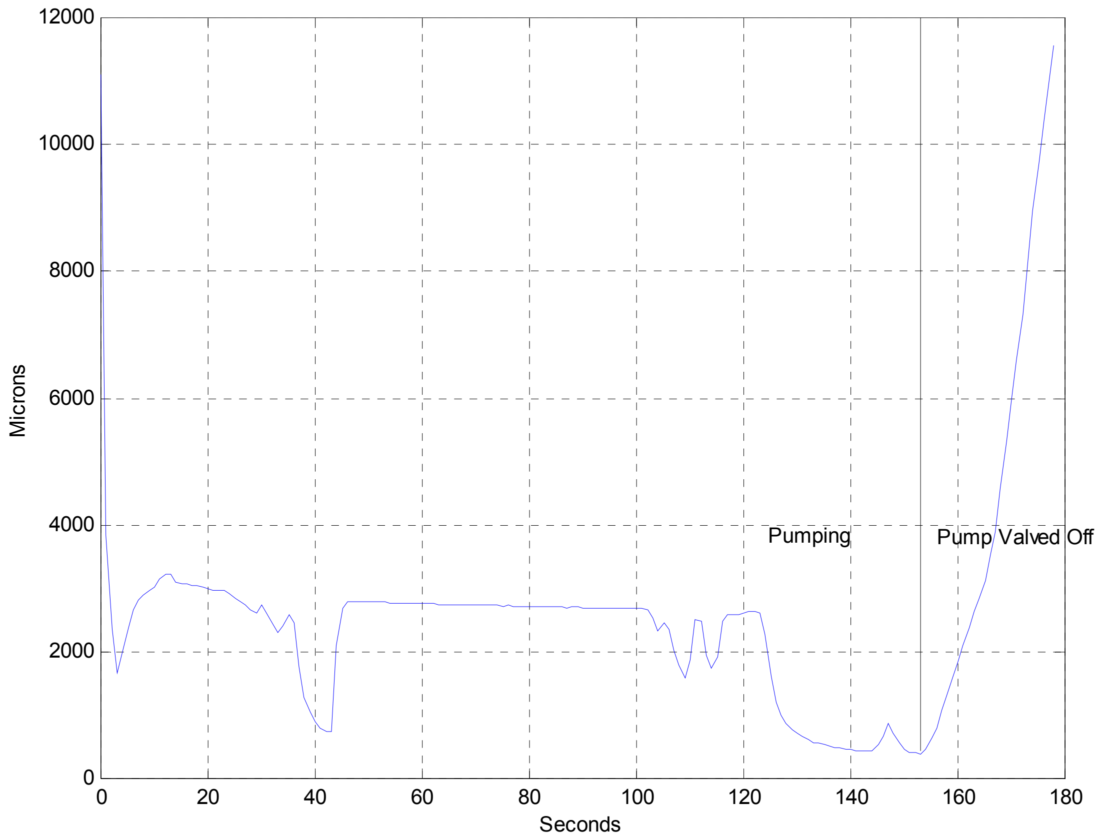

Figure 4: Pressure Rise in a System With a 4 Micron Leak

The graphs above can only be used as a reference. Real world systems are generally much bigger in volume than 0.05 cubic feet, and thus will behave differently.

As you can see from the above, testing for leaks using vacuum is not an exact science. You can have unclear results even under laboratory conditions.However, if this method is selected, one can take a few precautions to increase the chances of success.

- Always use copper tubing to connect your system to the vacuum pump. Avoid using outgassing materials such as refrigeration charging hoses and Teflon tape.
- Use a good quality ball valve. Never use the vacuum pump's blank off valve. The ball valve can trap small pockets of air, so close and open the valve at least once while pumping to remove these pockets.
- Remember that manifold gauges are slow and not sensitive to small pressure variations. High resolution, fast electronic vacuum gauges (such as the SUPCO VG64) will always show a pressure increase when the vacuum pump is valved off.
- The amount of pressure rise depends on how much volume there is in your system and how clean the system is inside.
- Evacuate the system to as low a reading as time allows. If you are running your pump for a day and the vacuum reading does not fall below 1000 – 2000 microns, then you may have a leak or the system

may contain moisture or other contaminants that are boiling away. If you are able to evacuate your system to about 300 – 500 microns, chances are the system has no leaks and all the contaminants are removed. Beware, though, refrigeration charging hoses outgass the greatest in this vacuum range.