PERFORMING EVACUATIONS

PURPOSE

Evacuation and dehydration of a refrigeration system is necessary on all new halocarbon installations and when servicing existing halocarbon refrigeration systems. Evacuation may be applied to new ammonia systems as well; evacuation removes non-condensable gases which would adversely affect the system including water vapor which is extremely detrimental to halocarbon systems.

Achieving, maintaining, and measuring a system evacuation superficially appears easy. In actuality there are many pitfalls which can mislead the technician. It is the intent of this document to provide a uniformity of practice, identify problems, and provide a basic understanding of the evacuation and dehydration process.

DEFINITIONS

The following is a partial list of Vacuum Technology terms.

***Absolute Pressure*, a term used in engineering literature to indicate pressure above the absolute zero value corresponding to empty space, or the absolute zero of temperature as distinguished from gauge pressure. In vacuum technology pressure always corresponds to absolute pressure and not to gauge pressure; therefore, the term absolute pressure is not required.**

***Atmospheric Pressure*, the pressure of the atmosphere at a specified place and time. The normal atmosphere has been defined as the pressure exerted by a mercury column 760 mm in height at O°C under standard acceleration of gravity of 980.665 cm/sec^2.**

***Backstreaming* is a term used to indicate a process whereby oil from the vacuum pump moves in the direction of the vacuum chamber.**

***Blankoff Pressure* is the lowest achievable pressure obtainable by any particular vacuum pump.**

***Compression Ratio*, the ratio between the outlet pressure and the inlet pressure of a pump for a specific gas.**

***Conductance*, is a quantity describing the flow of gas in a channel. Conductance in a vacuum system can be limited by the diameter and geometry of vacuum lines. Conductance (Z) = Throughput / Pressure Drop, where Throughput = Pumping speed X Suction pressure at the pump.**

***Degassing*, the deliberate removal of gas from a material, usually by application of heat under high vacuum.**

***Foreline*, vacuum line connecting to the inlet of a vacuum pump.**

***Free Air Displacement*, the volume of air passed per unit of time through a mechanical pump when the pressure on the intake and exhaust sides is equal to atmospheric pressure. Also called displacement and free air capacity.**

***Gas Ballast*, the venting of the compression chamber of a mechanical pump to the atmosphere to prevent condensation of condensable vapor within the pump. Sometimes called vented exhaust.**

***Gas Flow*, within a vacuum system, the passage of gas through a duct. Gas flow behavior varies with pressure range as Viscous Flow from atmospheric pressure to 10-1 Torr, and Molecular Flow below 10-3 Torr, as well as with system design.**

***High Vacuum*, vacuum range from 10-2 to 10-6 Torr.**

***Isolation Valve*, device that seals off a vacuum system from its vacuum pump when the pump is not operating. Designed to maintain a vacuum for a period of time.**

***Low Vacuum*, vacuum range from atmospheric pressure to 1 Torr (760 mm Hg to 1 mm Hg).**

***Micron*, unit of pressure equal to 10-3 Torr. Millimeter of Hg, unit of pressure equal to 1 Torr.**

***Molecular Flow*, type of gas flow, which usually occurs at pressures below 10-3 Torr. In molecular flow gas molecules travel randomly, virtually without interaction.**

***Outgassing*, the description of gas from materials within a vacuum system. In ultra-high vacuum systems outgassing can be a limiting factor on the lowest ultimate pressure that can be achieved.**

***Partial Pressure*, pressure due to a gas or vapor component of a gaseous mixture.**

***Pumpdown Curve*, a graph representing the relationship between pressure and time. Used to determine the time required to achieve the desired operating pressure in a system with a given pump.**

***Pumping Speed*, the volume of gas per unit time which the vacuum pump is able to remove from the system. Pumping speed is often expressed in liters per minute (1-1m), liters per second (L/s), or cubic feet per minute (CFM).**

***Thermocouple Gauge*, electronic pressure gauge measuring pressure-dependent heat flow.**

***Torr*, unit of pressure equal to 1 mm of mercury (1 atmosphere = 760 mm Hg).**

Total Pressure, **the sum of the partial pressures of all the components of a gaseous mixture.**

Ultimate Pressure, **lowest attainable pressure in a vacuum system. In a vacuum pump, the lowest pressure that can be attained with that pump. Ultimate pressure is limited by the pumping speed of the vacuum pump and the vapor pressure of the vacuum pump sealing fluid among other factors.**

Ultra-High Vacuum, **vacuum range with pressures of 10-1 Torr and below.**

Vacuum, **a space with gas pressure less than 1 atmosphere.**

Vapor, **a substance in gas phase which is condensable at the ambient temperature.**

Vapor Pressure, **partial pressure of a vapor.**

Viscous Flow, **type of gas flow which usually occurs at pressures from atmosphere to 10^{-1} Torr. In viscous flow, the preferred direction of gas molecules is in the direction of the streaming gas.**

VACUUM PUMPING

A conventional two-stage mechanical vane pump is generally used to obtain an acceptable refrigeration system evacuation. The essential purpose of the vacuum pump is to reduce the given pressure in a vessel or enclosed system. AS A RULE OF THUMB A TERMINAL VACUUM OF 500 MICRONS IS DESIRABLE ON LARGE CENTRAL SYSTEMS AND 50 MICRONS ON SMALL UNITARY SYSTEMS. The purpose of the evacuation is twofold. First, it is desirable to remove all non-condensable gases from a refrigeration system and second, evacuation removes water and water vapor from the system.

PRODUCTION OF LOW PRESSURES

The rotary vane vacuum pump operates similar to a mechanical refrigeration compressor. With each cycle of the pump the quantity of gas in the system is reduced. The remaining gas in the system must necessarily expand to fill the vessel, and, following Boyle's Law which states that the volume of a body of gas is inversely proportional to its pressure, provided the temperature remains constant, the system pressure will drop. As the pressure is reduced a successively smaller volume of gas is compressed by the pump as it must raise the pressure of the captured gas above atmospheric pressure in order to expel it.

In the beginning of an evacuation the compression ratio is very small. Gas enters the pump at atmospheric pressure and is expelled at atmospheric pressure. At blankoff pressure, on the other hand, the pump will draw in a volume of gas at, say, one millitorr and compress this volume to a pressure of 760,000 millitorr or atmospheric pressure. In order to expel the gas a pressure somewhat above atmospheric pressure is actually required to overcome the spring loaded exhaust valve. Therefore, at a guaranteed

blankoff pressure of 10 $^{-4}$ Torr, the compression ratio performed by the pump is in the order of 10,000,000 to 1.

THE ULTIMATE PRESSURE

With each cycle of the pump a quantity of gas is removed and the remaining gas expands to fill the volume. It is obvious that this method of evacuation cannot remove all the gas from a system. Additionally, the pump blankoff pressure limits the best obtainable vacuum and outgassing and leaks will contribute to system equilibrium where no further reduction in pressure can be accomplished by mechanical action.

EVACUATION TIME

There are three basic evacuation considerations.

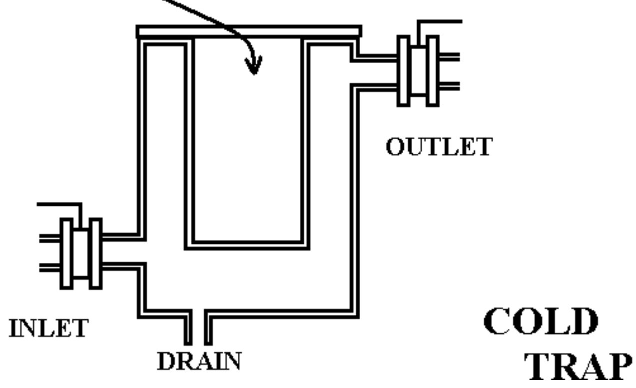
1. Pump speed. (CFM displacement)

2. Conductance. (Pressure drop and friction)

3. Leak rate and outgassing, (Internal and external vapor entering the system)

In practice water vapor presents the most serious impediment to obtaining a quick deep vacuum. Water vapor and other condensable vapors are usually present in a new refrigeration system. Occasionally substantial quantities of liquid water may also be present. When these vapors condense in the second (compression) stage of the vacuum pump they contaminate the oil and raise the pump's actual blankoff pressure. As in most mechanical pumps oil is used for lubrication and sealing. When contaminated oil enters the low pressure cavity of the pump the condensed contaminants in the oil vaporize again occupying a portion of the intake cavity and reducing the amount of system gas drawn in. When the oil is seriously contaminated, the pump will simply re-circulate the contaminants and no further reduction of system pressure is possible.

Oil contamination can be minimized in wet systems by utilizing a cold trap on the pump inlet and by using the gas ballast valve provided on larger pumps. If a cold trap is used on an existing refrigeration system caution should be used when draining as liquid refrigerant may be present. Periodic purging of the system with dry nitrogen and frequent oil changes are also necessary to reduce the total evacuation time.

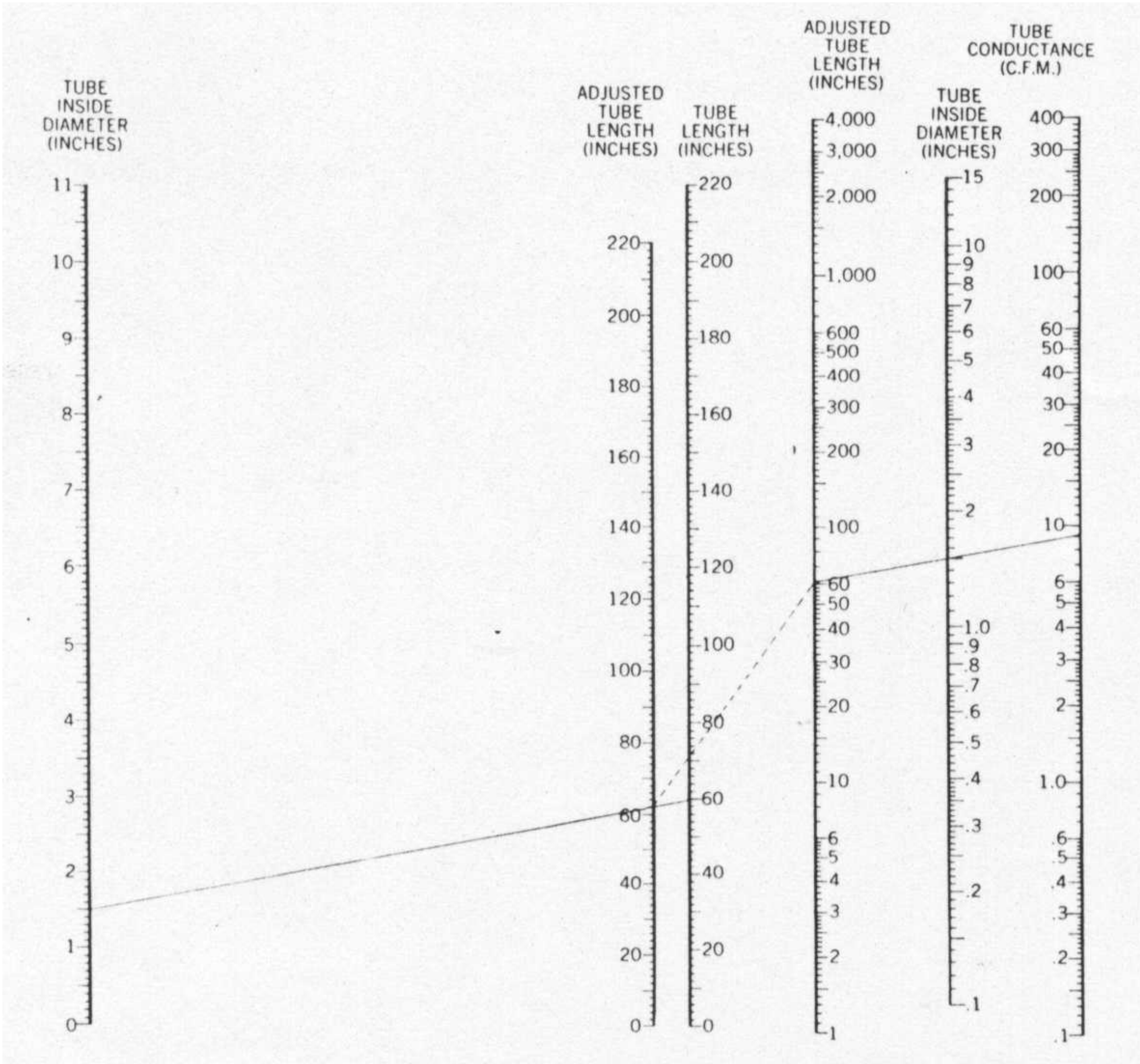


The frequency of oil changes necessary will vary system to system depending on the size of the system and the total volume of contaminants present. Experience and observation of oil quality will determine the required frequency.

The largest possible inlet line size should be used when connecting the vacuum pump to the system to be evacuated. Additionally, the shortest connection length possible is desirable to provide the minimum conductance losses between the system and the pump. The Tube Conductance Nomogram illustrates the reasoning behind these rules. A 1-1/2" ID tube 60" long can conduct 9 CFM. A 3/4" tube 60" long can conduct less than 1 CFM. Obviously a 3/8" hose of even 36" length seriously limits the ability of a 5 CFM two stage pump to evacuate even a small system in a reasonable period of time.

The nomogram below can be used to determine the conductance of common tubing to insure that the system performs optimally. For example, consider a system where the connecting tubing is 60 inches long and has an inside diameter of 1.5 inches. The tube conductance in CFM is required.

EXAMPLE: 1.) Draw a line from 1.5 on the tube ID line to 60 on the tube length line. The point where this line intercepts the intervening line is the adjusted tube length or 62 inches. 2.) On the adjusted tube length line (to the right of the tube length line) draw a line from 62 through 1.5 on the tube ID line and extend it to the tube conductance line. 3.) The tube conductance can be seen to be 9 CFM.



Tube Conductance Nomogram

Outgassing and leakage in the connection can further reduce pump out speed and raise the blankoff pressure significantly. For these reasons it is recommended that connections be hard piped in steel or copper with as few joints as possible. Charging hoses and other flexible hoses may contain high vapor pressure compounds or residues that can outgas at pressures higher than 5000 microns. Condensables present in the system to be evacuated can substantially increase evacuation time by contaminating the pump's oil charge. A similar problem can be encountered when evacuating a system which has been in service. Refrigerant vapors entrained in residual oil will outgas slowly.

In summary evacuation time depends on the following factors.

1. Pump capacity.
2. Inlet connection size and length.
3. Oil quality.

4. Condensables present in the system.

THE OIL CHARGE

Only high quality vacuum oil should be used in the vacuum pump. Vacuum oil has a very low vapor pressure and will not outgas substantially at even deep vacuums. Ordinary oils contain high vapor pressure "seconds" which would vaporize and expand in the first stage at low pressures.

When initially pumping down a system the pump throughput is high and the relative volume of condensables is also high. The oil charge will become contaminated very quickly in the beginning and require changing more frequently until all water has been vaporized. At pressures below 5000 microns oil should still be changed frequently as less contamination is necessary to reduce pump efficiency.

WATER

When evacuating a wet system care should be taken not to pull down below 5000 microns too quickly. Liquid water freezes below 5000 microns and large volumes of water inside insulated lines or vessels may freeze. While water vapor will still sublimate (turn from a solid to a vapor), the process is much slower and requires substantially more energy to remove. It is because water freezes at 32 °F that system dehydration becomes difficult to impossible below 60 °F. Energy is required to vaporize the water present and provide a driving force to help move air and water molecules toward the pump. One way of speeding up and achieving a bone dry system is to evacuate to 5000 microns and recharge the system to atmospheric pressure with dry nitrogen. Any residual moisture will be carried to the pump by the dry nitrogen. A common procedure for evacuating halocarbon systems is the Triple Evacuation Procedure. In a triple evacuation the system is evacuated to 5000 microns then repressurized to atmospheric pressure with dry nitrogen. This procedure is repeated two more times to insure moisture and contaminant gases have been removed from the system. In cases where an excessive amount of moisture is present it may be necessary to pull a hard vacuum over an extended period of time to effectively remove liquid water.

VACUUM MEASUREMENT

Instrument	Effective Operating Range
Bourdon Tube	760 – 10 Torr
Liquid Manometer	760 – 1 Torr
Force Balance Gauge	760 – 1 Torr
Mechanical Diaphragm	760 – 0.01 Torr
Capacitance Manometer	760 – 0.001 Torr
Thermocouple (Pirani)	1 – 0.0001 Torr
McLeod Gauge	50 – 0.00001 Torr

Vacuum measurement must be made using an appropriate electronic vacuum transducer. The accuracy of the transducer should be checked each time it is to be used by testing it on the freshly charged pump to verify the "blankoff pressure". If a blankoff reading of at least 50 microns cannot be achieved both the pump and the instrument should be checked out. Measurements must always be taken from a remote location from the vacuum pump inlet location. Under no circumstances should readings be taken from the vacuum pump inlet while the pump is running. If it is impossible to locate the transducer remotely, install the transducer between a stop valve and the system, Shut down the pump and allow the system several minutes to equilibrate. On large systems several hours may be required before a reasonably accurate reading can be obtained,

Once the pump has achieved 500 to 1000 microns the rate of rise can be measured. The rate of rise is a measurement reported in the number of microns increase over the period of time in which the measurement was taken. A certain amount of outgassing and leakage is to be expected. But, a rise of more than 50 microns in a one hour period indicates leakage, the presence of water, or some other problem which should be determined and addressed.

LOW AMBIENT EVACUATIONS

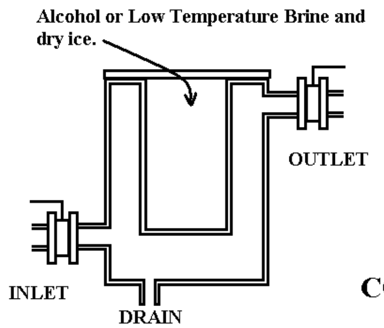
At temperatures below 60 °F, dehydration times become progressively longer. At temperatures below 32 °F, even the addition of heat to the bottoms of vessels helps little and dehydration becomes almost impossible as water vapor will crystallize on colder surfaces rather than travel to the pump. At temperatures near freezing it becomes necessary to either perform repeated evacuations with a dry nitrogen purge and the addition of heat or attempt to sublimate the moisture out over a period of days or weeks. The use of heat lamps can be an effective way of driving moisture toward the pump. Heat should be applied to the system components farthest from the pump and relocated closer to the pump daily. Periodic dry nitrogen purges will help. An alternative approach is to evacuate isolated sections of the system. This approach is useful in locating difficult to find leaks. If this approach is used it is recommended that on completion of dehydration on one part of the system a 5# holding charge be introduced to offset any inward leakage. When dehydration of the system is complete the system should be evacuated to 500 microns and the vacuum broken with refrigerant to a positive pressure,

EVACUATING AN OLD SYSTEM

Existing systems pose special problems to effective dehydration and evacuation. An existing system will usually contain a substantial quantity of refrigeration oil saturated with refrigerant and often moisture, particularly on the low side. Out gassing from these residues will often make it appear that a system leak is present. Under these circumstances a hard evacuation may be impossible. The most effective steps that can be taken to minimize outgassing is to drain as much oil as possible from the system and use repeated dry nitrogen purges. The addition of heat will also help.

SERIOUSLY CONTAMINATED SYSTEMS

Seriously contaminated systems may contain more water than the vacuum pump can reasonably be expected to handle. The introduction of a cold trap between the system and the pump inlet can be used to condense much of the vapor. The trap can be made from a piece of 4" to 6" pipe capped and provided with an Inlet, outlet, vent, and drain. The trap must be packed in ice and salt or dry ice and alcohol. The trap should be drained each time the pump oil is changed. Care should be taken when draining a cold trap applied on an existing system, as condensed refrigerant may be present.



COLD TRAP

EVACUATION AND DEHYDRATION PROCEDURE

1. Before an evacuation can be performed, the refrigeration system must have been successfully pressure tested, properly leak checked, and free of leaks.

2. Prior to evacuation, verify that all system valves are open and backseated. All control valves and check valves with manual opening stems should be manually opened. Compressors should be isolated from the primary evacuation, as most compressor seals are not designed to hold deep vacuums. Compressors should be evacuated immediately prior to or after having broken the vacuum on the main system.

3. Isolate or disconnect any components of the system that may be damaged by low pressure.

4. The vacuum pump should be hooked up to a 1/2" or 3/4" drain valve on a vessel or large header. The use of 3/4" ID copper is recommended to connect the pump to the applicable service valve. The line should be as short as possible. If additional pumps are connected to the system they should be located as far apart as possible for best results. It should be remembered that when using multiple pumps the lowest obtainable blankoff pressure is usually that of the poorest performing pump.

5. The vacuum analyzer should be connected in a place remote from the pump(s),

6. All threaded connections should be made with Teflon tape. If a union is used it is recommended that the mating faces be lightly greased prior to assembly. If a union is not used a purge valve should be installed between the system and the pump to permit breaking the vacuum in this line before servicing the pump.

7. Start the pump. Initially, the large volume of gas moved will cause some oil carryover from the pump. Once the volume has dropped off the gas ballast valve should be opened 1 turn to assist in purging condensables. Once again some oil carryover may be observed. Care should be taken to insure oil from the pump does not drain onto the floor or otherwise damage property. Cardboard over sheet plastic can be used to absorb dripping oil.

8. Monitor oil quality. If the oil becomes dirty or cloudy in appearance it must be changed according to the following procedure.

- **a. Valve off the system access valve.**
- **b. Shut off the vacuum pump.**
- **c. Immediately break the vacuum in the connecting line.**
- **d. Drain the oil charge from the pump making sure to drain all oil or by flushing the sump with a pint of clear oil.**
- **e. Charge with new oil.**
- **f. Close the vent valve and start the pump to evacuate this line prior to opening the line to the system.**

9. Change oil frequently during the first 24 hours of evacuation based on how quickly the oil charge becomes contaminated.

10. When the system pressure has dropped to 5000 microns a more thorough dehydration can be achieved by recharging the system with dry nitrogen. Add dry nitrogen until the system pressure rises to 8" to 10" while the pump is running. The nitrogen will drive any residual moisture toward the pump.

11. At 500 to 1000 microns the vacuum analyzer should be monitored. The pump should be shut down and the connecting service valve closed. Monitor and record the rise in pressure over no less than a one hour period. Change the vacuum pump oil charge at this time. If the oil is clean and the rise is less than 50 microns terminate the evacuation and break the vacuum with refrigerant. If the oil is cloudy or evidences water continue dehydration and evacuation an additional 12 to 24 hours. If at the end of this period the pump oil evidences moisture a leak is probably the cause.

WARNINGS

NEVER ALLOW THE PUMP TO DRAW IN PARTICULATE OR LIQUIDS. THE INGESTION OF PARTICULATES CAN CAUSE SCORING THAT WILL REDUCE THE PUMPS ABILITY TO MAINTAIN VERY LOW PRESSURES. THE USE OF A FORELINE TRAP OR COLD TRAP IS RECOMMENDED.

ALWAYS DISCONNECT THE VACUUM PUMP ELECTRICALLY BEFORE SERVICING.

NEVER OPEN THE PUMP SUCTION TO PRESSURES ABOVE ATMOSPHERIC.

NEVER CLOSE OFF THE PUMP EXHAUST AS THE PUMP CASING CAN RUPTURE VIOLENTLY.

NEVER EVACUATE FLAMMABLE GASES OR LIQUIDS AS FIRE OR EXPLOSION MAY RESULT.

USE HAZARDOUS WASTE PROCEDURES WHEN HANDLING USED VACUUM PUMP OIL OR COLD TRAP RESIDUES.

NEVER CLOSE OFF THE PUMP SUCTION WITH YOUR HAND AS INJURY WILL RESULT.

PRESSURE CONVERSIONS

ABSOLUTE PRESSURE(1)									Gage Pressure(2)	
Cm Of HG	Torr or mm of HG	Micron	Atmos-phere	Lb./In^2	Ton/ft^2	Gram/ Cm^2	Ft. / H_20	In of HG	Lb./in^2	In of HG
76	760	760000	1.0	14.70	1.06	1033	33.9	29.9	0	0
70	700	700000	.921	13.53	.975	952	31.2	27.6	1.16	2.36
60	600	600000	.790	11.60	.835	816	26.8	23.6	3.10	6.30
50	500	500000	.659	9.67	.696	680	22.3	19.7	5.03	10.2
40	400	400000	.526	7.74	.557	545	17.8	15.7	6.97	14.2
30	300	300000	.395	5.80	.417	408	13.4	11.8	8.90	18.1
20	200	200000	.263	3.87	.278	272	8.92	7.87	10.8	22.0
10	100	100000	.132	1.94	.139	136	4.46	3.94	12.8	26.0
5	50	50000	.066	.967	.070	68.0	2.23	1.97	13.7	27.9
1	10	10000	.013	.194	.014	13.6	.446	.394	14.5	29.5
0.1	1	1000	.001	.019	.001	1.36	.045	.039	14.68	28.88
0	0	0	0	0	0	0	0	0	14.70	29.92

(1) Positive pressure measured from absolute 0.
(2) Negative pressure (or vacuum) measured from atmospheric pressure.

PRESSURE EQUIVALENTS

Millitorr or Micron		Torr or mm of HG
1000	= 1.0	= 10^0
100	= 0.1	= 10^{-1}
10	= 0.01	= 10^{-2}
1.0	= 0.001	= 10^{-3}
0.5	= 0.0005	= .5 X 10^{-4}
0.1	= 0.0001	= 1 X 10^{-4} or 10^{-4}
0.01	= 0.00001	= 10^{-5}
0.001	= 0.000001	= 10^{-6}

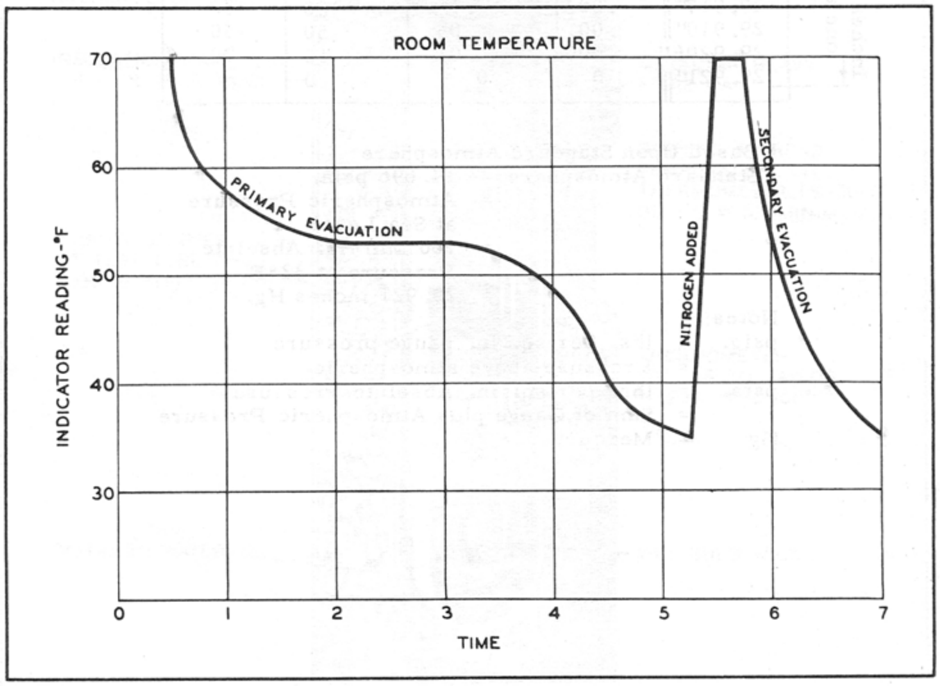
Corresponding dew point temperatures with water.

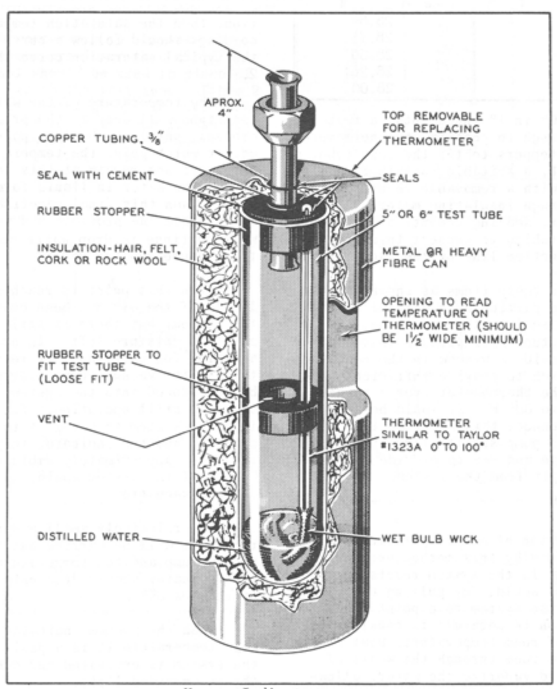
°F	Vacuum in inches of Mercury
35 °	29.72
40 °	29.67
45 °	29.62
50 °	29.56
55 °	29.48
60 °	29.40
65 °	29.30
70 °	29.18
75 °	29.05
80 °	28.89
85 °	28.71
90 °	28.50
95 °	28.26
100°	28.00

Corresponding dew point temperatures with methyl alcohol.

°F	Vacuum in inches of Mercury	Corresponding Dew Point of Water Vapor (Ice) °F
-55 °	29.90	-10°
-35 °	29.85	12°
-23 °	29.80	23°
-16 °	29.75	31°
-11 °	29.70	37°
-6 °	29.65	42°
-3 °	29.60	
1°	29.55	
4°	29.50	
10°	29.40	
14°	29.30	
19°	29.20	
23°	29.10	
26°	29.00	
29°	28.90	
31°	28.80	
33°	28.70	

Typical Dehydration Curve





Vacuum Indicator

Courtesy of York Refrigeration