

High Vacuum with Mechanical Pumps

A Summary of Work Done by Bruce Kendall and Others

I. INTRODUCTION

It's common knowledge that even the best 2-stage rotary vane mechanical pump won't, in actual practice, achieve a pressure lower than about 10^{-3} Torr. To do better one has to add some sort of high vacuum pump i.e. diffusion, turbomolecular, ion, cryogenic, sorption, etc.

One reason for this that the gas that is being pumped transitions from viscous flow to molecular flow in the vicinity of 10^{-3} Torr and the mechanical pump, which ceases to work when the gas loses fluid-like behavior, simply stops pumping molecules. In order to achieve any practical pumping speed you have to introduce a pump (like the diffusion pump) that can pump gases that are in the molecular flow regime.

Another factor is what the pump is pumping. Let's say that the pump is connected to a 1 liter chamber. Assuming that the chamber, at the beginning of the evacuation cycle, is filled with room air, the pump will be drawing out nitrogen, oxygen, some water vapor, argon, carbon dioxide, argon and all of the other gases that make up room air. But there is more to the task than just removing 1 liter's worth of air.

Assuming that the system is pretty free of real leaks (i.e. no holes in the tubing or chamber) the pressure in the chamber will stop declining when we get to that apparent 10^{-3} Torr limit.

If we now look at what's in the chamber, we'll find that the composition of the "air" in the chamber is a lot different from what we started with. Instead of being mostly comprised of nitrogen and oxygen, the main gas that will be found is water vapor. Next there will be lots of hydrocarbon residuals. At some lower level will be the leftovers of the molecules that make up most of normal atmospheric pressure air.

Figure 1 shows what's happening. As the pump reaches its low pressure limit, it has actually removed most of the air that was in the chamber. What it has to contend with are the water molecules that are desorbing from the walls of the chamber and the oil molecules that are now backstreaming from the pump.

In principle, the water molecules will eventually be pumped away as there is a finite supply of them. However, we usually don't have hours or days to spare to wait for the water residuals to decline. Baking can speed things up a lot but it is a real complication and may not be compatible with some set ups. Finally, even if we can get rid of the water, the oil vapor is

available in essentially an unlimited quantity and will continue to keep us from getting a low ultimate pressure.

The answer to this dilemma is to insert something in the line between the pump and the chamber that can efficiently capture (pump) the oil and water molecules. This brings us to the topic of traps.

II. TRAPS

Traps of various types were discussed in Volume 4, Number 3 (Phil Danielson, *Backstreaming from Oil-Sealed Mechanical Pumps*). Here the main concern was the reduction of backstreamed oil vapor for the purpose of reducing contamination. Examples include keeping oil films from forming on optical surfaces or simply to keep backstreamed mechanical pump oil from contaminating the oil used in the diffusion pump.

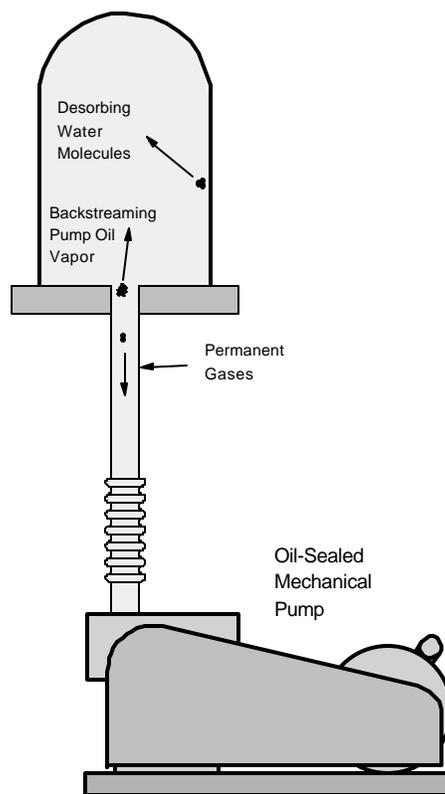


Figure 1 - Residual Gases at Base Pressure

Bruce Kendall, with the assistance of D.R. David [1] used traps to achieve a somewhat different end. They wanted to produce a fairly simple, student-proof high vacuum system for teaching topics such as electron physics. The goals included:

- Base pressure in low 10^{-4} range achievable in less than 2 minutes
- No tricky-to-operate or expensive high vacuum pump
- Using commonly available parts or parts that can be produced economically in a small machine shop
- Long life with low maintenance
- Clean, oil-free vacuum to avoid poisoning or contamination of electron emitters or electrodes
- No need for cryogenic liquids (liquid nitrogen)

The system that Kendall and David produced used a common 2-stage rotary vane vacuum pump in conjunction with a zeolite trap of original design. There are some special design requirements and these are discussed in the next section.

III. SYSTEM DESIGN SPECIFICS

Figure 2 is a schematic description of the system. One key aspect of the design is the minimization of elastomeric tubing which would act as a significant source of permeation leaks. The line to the pump is copper tubing with a length of metal bellows to isolate vibration.

In the original design, all of the major components were incorporated into a machined aluminum manifold. This included all of the valves. The innards of 3/4" brass bellows valves were used for the roughing and foreline valves, the innards of a 1-1/2" butterfly valve was used for the main valve and machine screws with adapted o-ring seals served as the vent and gas leak. The gauges were likewise attached directly to this manifold block. The use of the manifold came from the fact that multiple systems could be easily manufactured using a programmed milling machine. This entire assembly could be made from individual components provided that the connections are soldered, brazed or welded.

The foundation for the homebuilt zeolite trap was a lipless stainless steel kitchenware beaker 3 inches in diameter and 4-1/2 inches deep. The zeolite, Linde 13X, was crushed and then bonded using a high temperature silicone adhesive (Columbine Formulation No. 6, probably no longer available). An important characteristic of the adhesive is to be able to withstand bakeout temperatures of 300° C. As shown in the figure there are several concentric surfaces that are coated with

the zeolite. The surfaces that aren't part of the beaker should be made from copper in order to enhance thermal conductivity if the trap is operated cold. The trap was sealed to the aluminum manifold block with a neoprene gasket. Mechanical clamps held the beaker in place.

The chamber used was a piece of 6" diameter T-shaped Corning glass process pipe with beaded ends. The T configuration permits two in-line access ports plus the evacuation port.

IV. OPERATION

The operating procedure is similar to that of any high vacuum system. The valves are sequenced to keep the trap under vacuum at all times, bypassing the trap when initially evacuating the chamber.

An interesting point involves the proper use of the foreline valve. Kendall found that the lowest base pressures would be achieved with this valve partially closed. This is because the pump backstreams vapors that the zeolite has to handle. By reducing the backstreaming, the zeolite performs more efficiently. The valve adjustment is performed when the system reaches base pressure with the valve opened. When the pressure stabilizes, the foreline valve is closed to the point where the pressure, as indicated by the ion gauge, reaches its lowest value.

The trap requires a 300° C, 1 hour bakeout initially and whenever the pumping performance falls off. They found that, in normal lab use with proper operation, that the bakeout interval would be many weeks.

Kendall and David evaluated the system with and without liquid nitrogen cooling of the trap. Performance with and without cryogenic cooling were reported as follows (chamber volume of 0.4 liters):

1. No cooling:
 - Pressure after 2 min. - 2×10^{-4} Torr
 - Ultimate vacuum - 5×10^{-5} Torr
2. Trap chilled:
 - Pressure after 2 min. - 4×10^{-5} Torr
 - Ultimate vacuum - 4×10^{-6} Torr

V. SUMMARY

Kendall and David built a number of the systems as described above. The systems worked well in the school lab environment and Bruce has a couple of systems that are still running on a regular basis.

Kendall also did some other research toward improving the base pressure capabilities of mechanical pumps. This work is reported in Reference 2. The work included degassing the oil under vacuum, evacuating the

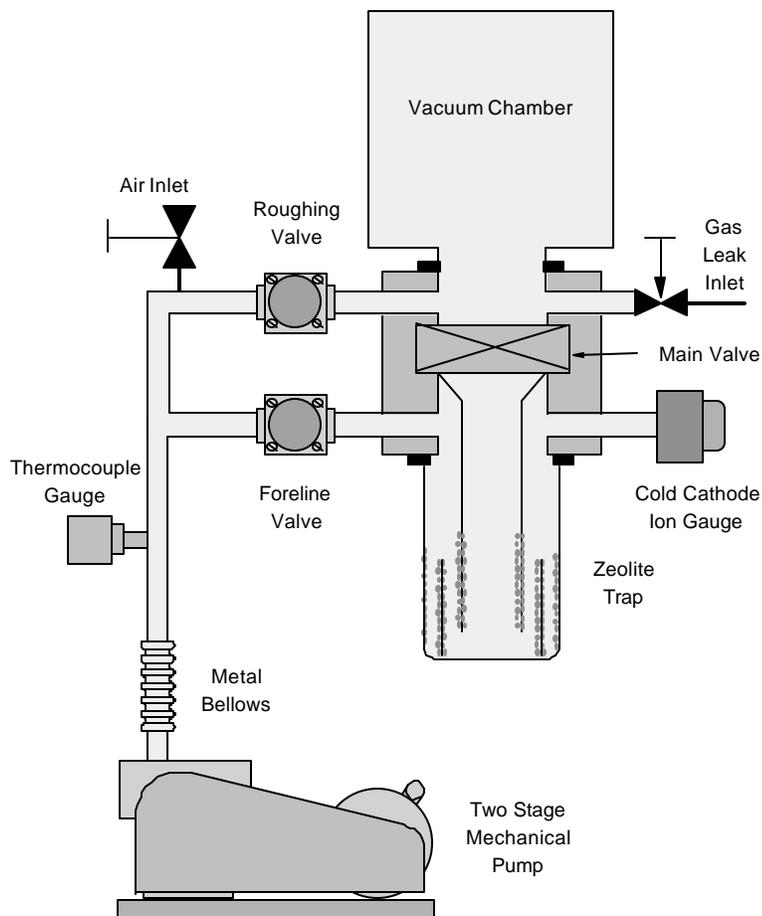


Figure 2 - Vacuum System Schematic

exhaust line (careful, this impairs the pump's lubrication) and using gases that are less soluble in oil (e.g. helium).

References 3 and 4 cover some of the associated teaching apparatus that were used with these systems.

CITED REFERENCES

[1] B.R.F. Kendall and D.R. David, *High-Vacuum System for Teaching and Research*, Am. J. Phys. **36**(3), 234, March 1968.

[2] B.R.F. Kendall, *Obtaining pressures in the 10^{-5} Pa Range with Oil-sealed Rotary Vacuum Pumps*, J. Vac. Sci. Technol. **21**(3), Sept./Oct. 1982.

[3] B.R.F. Kendall and H.M. Luther, *Apparatus for Teaching and Research in Electron Physics*, Am. J. Phys. **34**(9), 580, July 1966.

[4] B.R.F. Kendall, H.M. Luther and D.R. David, *Apparatus for Studying the Principles of Electron Physics*, Am. J. Phys. **37**(9), 855, September 1969.