EVALUATION OF DRY, ROUGH VACUUM PUMPS

PART III

The following was obtained via public disclosure from a NASA document.

EDITOR'S NOTE:

This is the second in a series of articles based on an evaluation of dry roughing pumps performed by ASRC Aerospace Corporation for NASA. Thirteen pumps from various manufacturers were evaluated. The series will be roughly broken up into topics such as long term tests, pumps speed tests, voltage variance and vibration tests, static leak tests, exhaust restriction tests, and other performance tests; followed by a product summary. The test results found in this report, while unbiased, do not reflect the opinion of VT&C.

PUMP SPEED TEST

The purpose of the pump speed test is to determine and/or verify the pump speed curves provided by the pump manufacturer. Curves were also determined for helium, which are usually not provided by the manufacturer. Helium speed curves are essential because of the large number of applications which use helium. Additionally, the current drawn by the pump at each pressure was determined. This information is useful when determining breaker and power requirements of pumps and the systems that use them.

The data was generated using 3 mass flow meters, a 1000 torr pressure transducer, and throttling valves. Flow meters were of the 300, 10, and 1 sLpm ranges. Throttling valves were sized appropriately to the meter being used. The pressure transducer was connected to the inlet of the pump via 3-way tee. The test gas was attached to the inlet of each flow meter. By opening the valve, and observing both the mass flow and pressure, it was possible to generate pumping speed curves. When the flow meter was out of range, the valve was closed and next largest flow meter was then used. For every point, the current was measured with an inductive ammeter.

Dividing the mass flow rate in torr-L/min by the inlet pressure in torr yields the pumping speed in L/min at that pressure. Graphs of inlet pressure vs. pumping speed and inlet pressure vs. current were then developed. Pumping speed and current demand at notable pressures are listed in **Tables 2, 3,** and **4.** Curves themselves are presented in **Figures 36 – 55** in Appendix A. Note that curves for air and nitrogen are similar. This is because air is comprised mostly of nitrogen and oxygen, another diatomic gas with molecular weight similar to nitrogen.

Error in measurement becomes much greater near the ultimate pressure of any pump. This is due to many factors which influence the ultimate pressure of the pumping system, such as chamber cleanliness and preparation, commodity moisture content, error in measurement devices, and extra gas load due to small leaks.

Some helium speed curves exhibit strange behavior, such as rising exponentially at higher pressures when it is expected to remain constant. This occurs due a systematic error in measurement with thermal flow meters. Unlike nitrogen, which most thermal flow meters are calibrated for, helium has a negative Joule-Thompson coefficient at standard temperatures. This means that the temperature of helium increases as it expands (drops pressure). In this case, helium is flowing from a high pressure cylinder, through a throttling valve, through a flow meter, and into a vacuum pump, so expansion is dramatic. The pressure profile is such that significant expansion occurs within the flow meter, increasing temperature of the gas. This is registered by the flow meter as an increase in gas flow rate.This phenomenon occurs much more strongly at high flow rates than low flow rates. Therefore more error is seen at the higher pressure end of pumping speed curves.

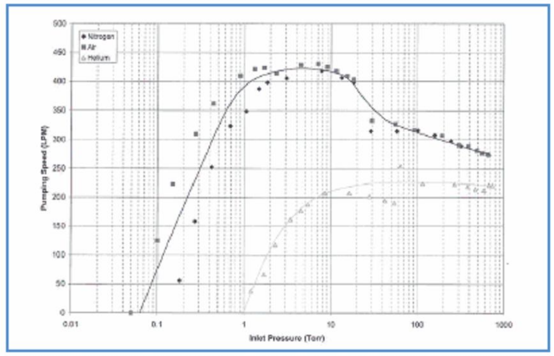

Figure 36. Adixen ACP 28 Pumping Speed Curves

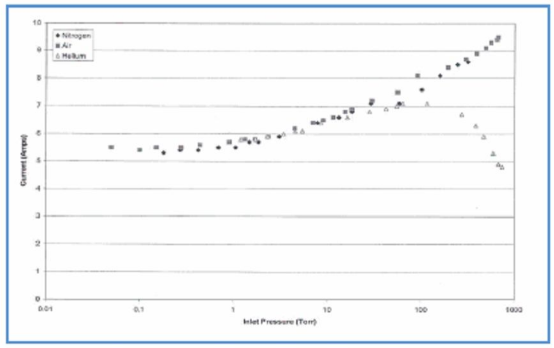

Figure 37. Adixen ACP 28 Current Curves

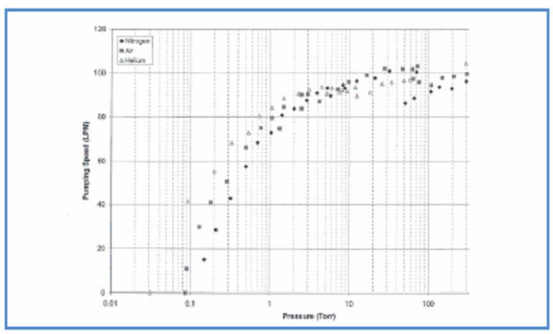

Figure 38. Edwards XDS 5 Pumping Speed Curves

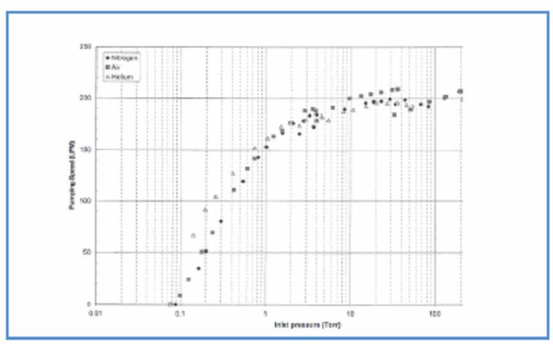

Figure 39. Edwards XDS 10 Pumping Speed Curves

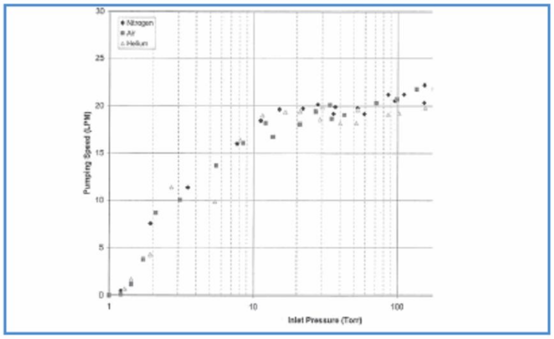

Figure 40. Edwards XDD1/Vacuubrand MDI Pumping Speed Curves

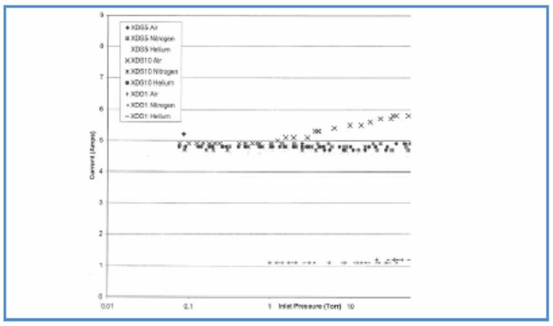

Figure 41. Edwards Pump Current Curves

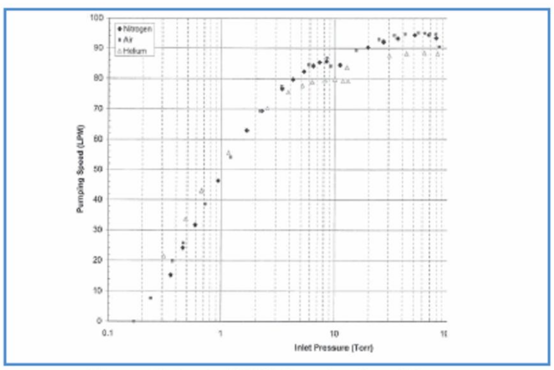

Figure 42. Iwata ISP 90 Pumping Speed Curves

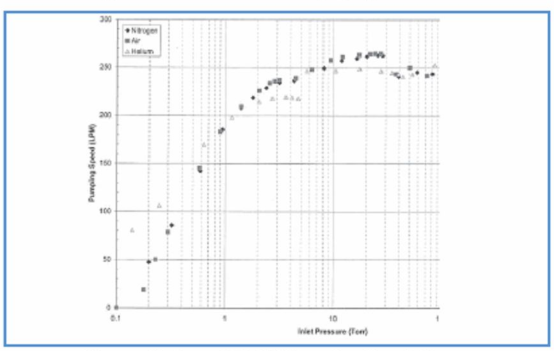

Figure 43. Iwata ISP 250 Pumping Speed Curves

Another error is a disjointed curve when switching between two different flow meters. The MZ 2D speed curve shows this behavior. This error is caused when two flow meters do not have the same zero, or one flow meter has large error relative to the other. In this case, a 300 sLpm with 1.5% full scale error was used with a 10 sLpm with 1.0% full scale error. The acceptable error for the largest flow meter is 4.5 sLpm, a full 45% of the full range of the 10 sLpm flow meter. This difference accounts for the disjointed nature seen in some graphs.

TRANSPORT PUMP SPEED TEST RESULTS AND DISCUSSION

Effective transport pumps transfer high flow rates at a few hundred torr. High flow rates ensure a quick system response time because it reduces the residence time of the sample in the transport line. Higher pressures are required so that the sample delivery system can effectively deliver the sample to the analyzer. The ideal transport pump has low power demand, a very high pumping speed, and pumps helium at the same rate as air or nitrogen. **Table 2** shows the speed and current at a typical transport pressure for nitrogen and helium.

Scroll pumps typically have constant pumping speeds from approximately 1 torr to atmospheric pressure. They pump helium at a rate slightly less than that of nitrogen or air, and the helium speed curve is similar in shape to the nitrogen and air speed curve. Below 1 torr pumping speed drops dramatically until it reaches zero at ultimate pressure. All Edwards and Iwata scroll pumps follow this trend. The exception is the Varian TriScroll 300, shown in **Figure 51**. It has a highly non-linear pumping speed curve which peaks with a speed of 225 Lpm at approximately 10 torr. Below 10 torr the pumping speed falls off rapidly. There is a substantial drop in pumping speed between 100 and 600 torr, reaching less than 150 Lpm near 350 torr. The pumping speed rises again to near 200 Lpm at atmospheric pressure.

The roots pump also exhibited highly non-linear pumping speed curves. When operating in air or nitrogen, the Adixen ACP 28 has peak pumping speed near 425 Lpm between 1 and 10 torr. This curve is shown in **Figure 36**. Above 10 torr the pumping speed gradually falls off until it reaches 275 Lpm at

Table 2 – Speed and Power Consumption of Candidate Transport Pumps at 350 torr

Transport Pump Comparison: Speed (Lpm) at 350 Torr				
Pump	N_2	He	N_2 Current (Amps)	He Current (Amps)
Edwards XDS 10	220	195	6.8†	5.1
Iwata ISP 250	250	230	3.2	3.1
Adixen ACP 28	290	220	8.8†	6.5
Vacuubrand ME 16	205	225	5.0	4.4
Varian TriScroll 300	145	125	4.4	3.6

† Nitrogen current unavailable. Value is air current at 350 torr.

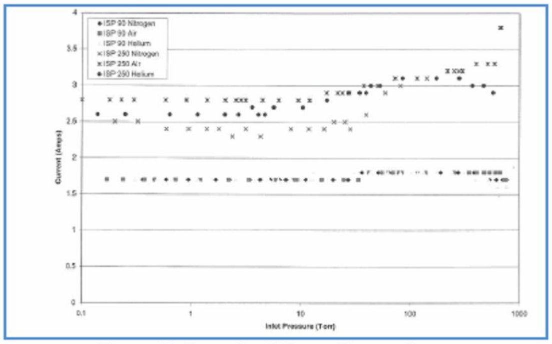

Figure 44. Iwata Scroll Pump Current Curves

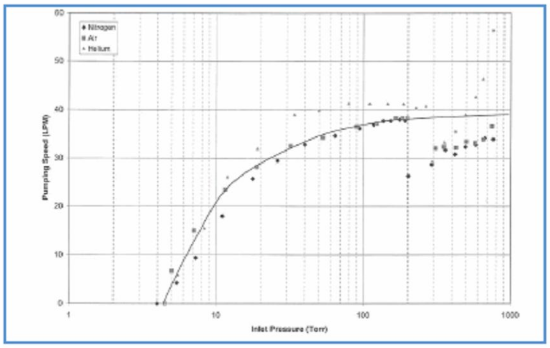

Figure 45. Vacuubrand MZ 2D Pumping Speed Curves

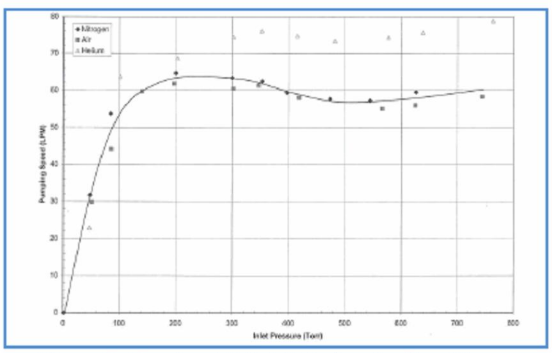

Figure 46. Vacuubrand MD 4 Vario Pumping Speed Curves

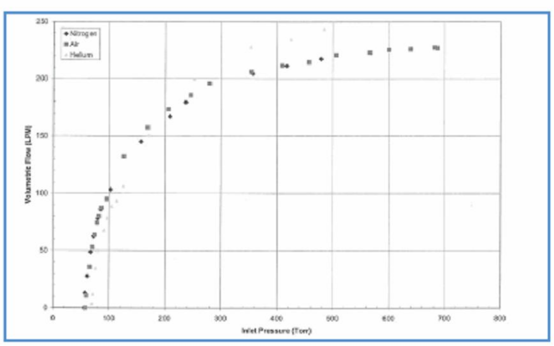

Figure 47. Vacuubrand ME 16 Pumping Speed Curves

atmospheric pressure. The helium speed curve for the ACP 28, however, has a very different shape. Pumping speed for helium is always significantly less than for air or nitrogen, and is essentially constant at 220 Lpm from atmosphere to approximately 10 torr. Below 10 torr, the pumping speed falls off rapidly until it reaches zero at an ultimate pressure of ~1 torr. The significantly lower helium pumping speed is attributed to the clearances between non-contacting lobes, which allow fast moving helium atoms to travel backwards through the pump.

The Vacuubrand ME 16 exhibited a typical diaphragm pump speed curve, shown in **Figure 47**. Helium is pumped at a rate similar to that of air and nitrogen. Pumping speed is relatively constant at 230 Lpm above 500 torr, and begins to decline slowly, reaching 205 Lpm at 350 torr. Pumping speed drops off very rapidly near the ultimate pressure of 60 torr. The helium flow rate curve shows the helium pumping speed surpassing that of air and nitrogen at pressures above 200 torr. This is attributed to measurement error. Helium pumping probably occurs at a rate slightly less than that of nitrogen and air, as seen in the lower pressure end of the curve.

At transport pressures, current demand varied widely between pumps and amongst gases. Helium typically requires less current at a given pressure than nitrogen or air does, and the shape of the current curve is rarely similar to that of nitrogen or air. Most pumps have a smaller helium flow rate at a given pressure, and this may account for some of the difference. The Iwata ISP 250 requires the least current of all candidate transport pumps, requiring slightly above 3 amps for both nitrogen and helium. The Adixen ACP 28 requires the most at 8.8 amps for nitrogen/air and 6.5 amps for helium. Note from **Figure 52** that the TriScroll 300 had rather scattered current curves.

SAMPLE PUMP SPEED TEST RESULTS AND DISCUSSION

Sample pumps move a small amount of gas from the transport pump stream throughout the system, ultimately leading to the analyzer. The sample pump requires neither high flow rates nor low ultimate pressure, but a balance of the two. The ideal sample transport pump has a moderate flow rate at 1 to 10 torr, low power demand, pumps helium, nitrogen, and air at the same speed, and has a very smooth gas flow. **Table 3** shows the speed and power consumption of candidate sample pumps at atypically sample delivery pressure.

The scroll pumps evaluated here typically have constant pumping speeds from approximately 1 torr to atmospheric pressure. They pump helium at a rate slightly less than that of nitrogen or air, and the helium speed curve is similar in shape to the nitrogen and air speed curve. Below 1 torr, pumping speed drops dramatically until it reaches zero at ultimate pressure. All Edwards and Iwata scroll pumps follow this trend. The exception is the Varian TriScroll 300, which has a highly non-linear pumping speed curve which peaks with a speed of 225 Lpm at approximately 10 torr. Below 10 torr the pumping speed falls off rapidly. There is a substantial drop in pumping speed between 100 and 600 torr, reaching less than 150 Lpm near 350 torr. The

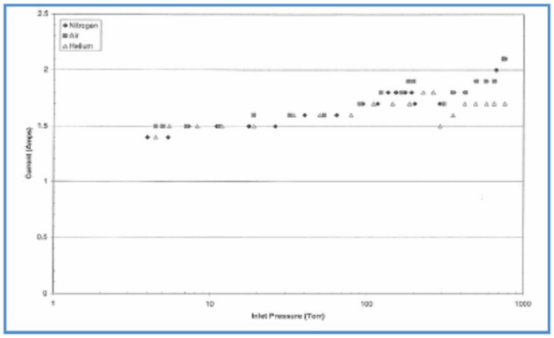

Figure 48. Vacuubrand MZ 2D Current Curves

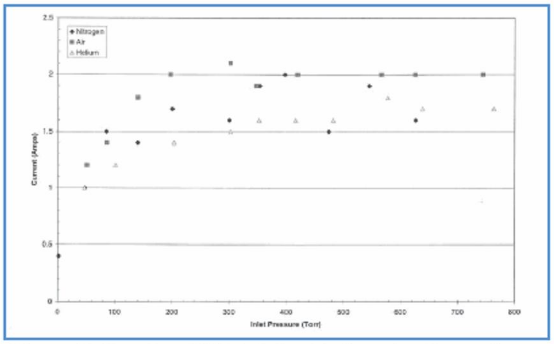

Figure 49. Vacuubrand MD 4 Vario with Controller Current Curves

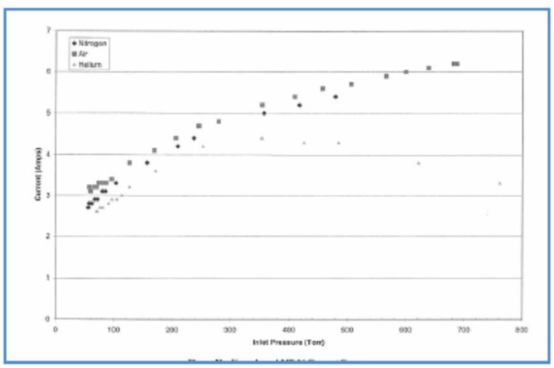

Figure 50. Vacuubrand ME 16 Current Curves

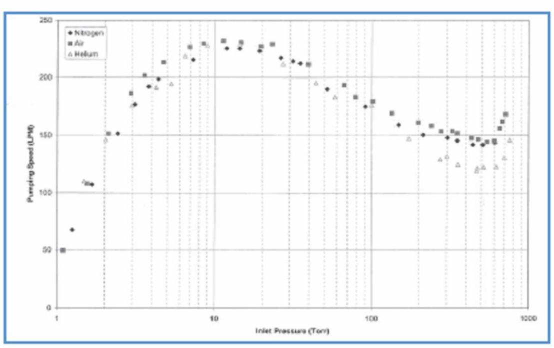

Figure 51. Varian TriScroll 300 Pumbping Speed Curves

Table 3. Speed and Power Consumption of Candidate Transport Pumps at 350 torr

Sample Pump Comparison: Speed (Lpm) at 10 Torr				
Pump	N_2	He	N_2 Current (Amps)	He Current (Amps)
Edwards XDS 5	95	90	4.8	4.6
Edwards XDS 10	200	190	5.5	4.7
Iwata ISP 90	85	80	1.7	1.8
Vacuubrand MD4 Vario	15	15	0.5	0.5
Vacuubrand MZ 2D	15	20*	1.5	1.5
Varian TriScroll 300	225	225	3.4	3.4
Varian SH 100	115	115	3.8	3.9

* Value high due to error in flow meter.

pumping speed rises again to near 200 Lpm at atmospheric pressure. The Varian SH 100 does not have the shape of the TriScroll; its curves are similar to that of the Iwata and Edwards scroll pumps, which remain roughly constant from 1 torr to atmosphere.

For the Vacuubrand MD4 and MZ 2D, pumping speed is relatively constant at higher pressures, and begins a gradual decline which accelerates rapidly as ultimate pressure is approached. Near 10 torr, the speed for both is approximately 15 Lpm. Some flow meter error was experienced in generating the helium flow rate curve, showing helium pumping speed surpassing that of air and nitrogen.

At sample pressures, current demand varied greatly amongst pumps, but not amongst gases. Helium required only slightly less current than nitrogen or air. This is because the gas flow rates at this pressure are small, and therefore the difference in flow rates between nitrogen/air and helium are also small. The power required to compress the gas is less significant compared to the power required for mechanical operation of the pump itself. This statement becomes less true for pumps with larger flow rates, such as the Edwards XDS 10.

Vario is a variable speed technology developed by Vacuubrand. Near ultimate pressure, the pump slows down in speed to reduce wear and power consumption. The Vario technology reduced current demand of the MD4 Vario to only 0.5 amps, one-third of the current required by the MZ 2D. However, note the large variation in current demand from the MD 4 Vario, shown in **Figure 49**.

BACKING PUMP SPEED TEST RESULTS AND DISCUSSION

Backing pumps rough the high vacuum chamber and provide the high vacuum pump, often a turbo molecular pump in gas analysis applications, with rough vacuum. Backing pumps require low ultimate pressure to assist the compression of the turbo molecular pump and small flow rates. The ideal backing

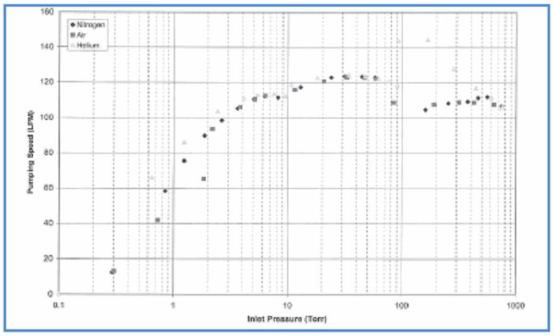

Figure 52. Varian SH 100 Pumping Speed Curves

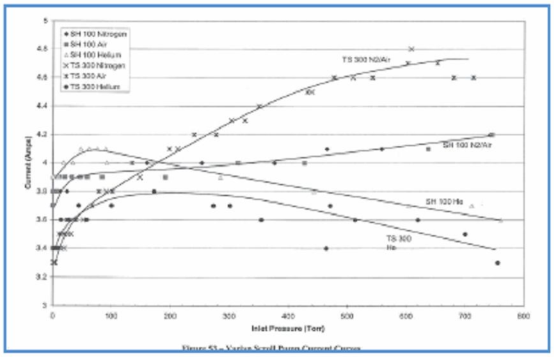

Figure 53. Varian Scroll Pump Current Curves

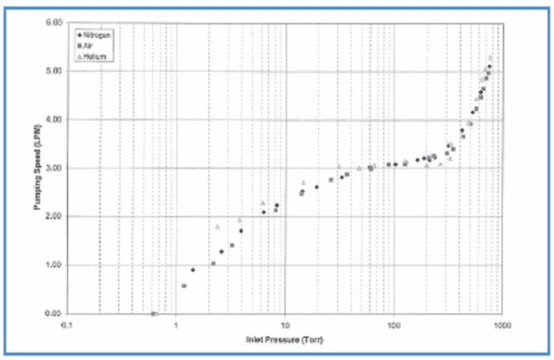

Figure 54. KNF 84.4 Pumping Speed Curve

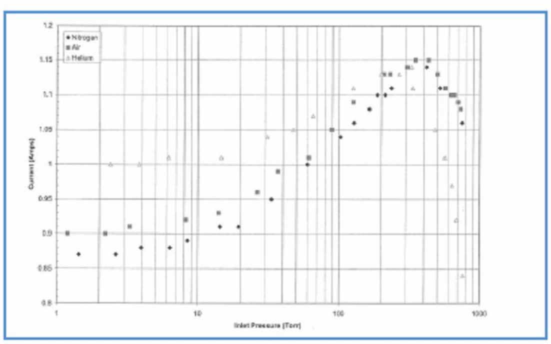

Figure 55. KNF 84.4 Current Curves

Table 4. Speed and Power Consumption of Candidate Backing Pumps at 5 torr

Backing Pump Comparison: Ultimate Pressure and Speed (Lpm) at 10 Torr					
Pump	N_2	He	N_2 Current (Amps)	He Current (Amps)	Ultimate Pressure (Torr)*
Edwards XDS 5	90	90	4.9	4.6	0.031
Edwards XDD1	13	10	1.1	1.1	0.945
Iwata ISP 90	80	80	1.7	1.7	0.060
Vacuubrand MZ 2D	4	5	1.5	1.5	3.00
Vacuubrand MZ 1 Vario	11	10	1.8 (DC)	1.6 (DC)	1.08
KNF 84.4	2	2	0.88 (DC)	1.00 (DC)	0.25
Varian SH 100	110	110	3.8	3.9	0.058

* Represents lowest pressure measured during testing.
Actual ultimate pressure may be lower, and vary with wear.

pump has low ultimate pressure, pumps helium at a rate similar to that of air or nitrogen, a modest pumping speed which rises rapidly with inlet pressure, and low power demand. **Table 4** shows the speed, power consumption, and ultimate pressure of candidate backing pumps at a maximum acceptable backing pressure.

All pumping speed curves decrease near the ultimate pressure of the pump. A steeper pumping speed curve is desirable, given a certain ultimate pressure. This steeper curve indicates a rapid increase in pumping speed as pressure rises, and if a small leak were to occur, a pump with a steeper curve will maintain a lower pressure.

The Edwards XDS 5, Varian SH 100 and Iwata ISP 90 have similar speed curves, with the XDS 5 having slightly higher pumping speed. Helium, air, and nitrogen are pumped at similar speeds. Al42 though they have the lowest ultimate pressure and highest pumping speeds, scroll pumps also require the most power, and are often physically larger.

Diaphragm pumps have higher ultimate pressures, lower pumping speeds, and less steep pumping speed curves. Pumping speeds range from 13 Lpm for the Edwards XDD1 to 2 Lpm for the KNF 84.4. The diaphragm pumps tested, however, require less power than scroll pumps. The Vario technology from Vacuubrand reduces the power required by the MD1 Vario to 43 Watts at 5 torr. The KNF 84.4, a significantly smaller pump, requires only 21 Watts.