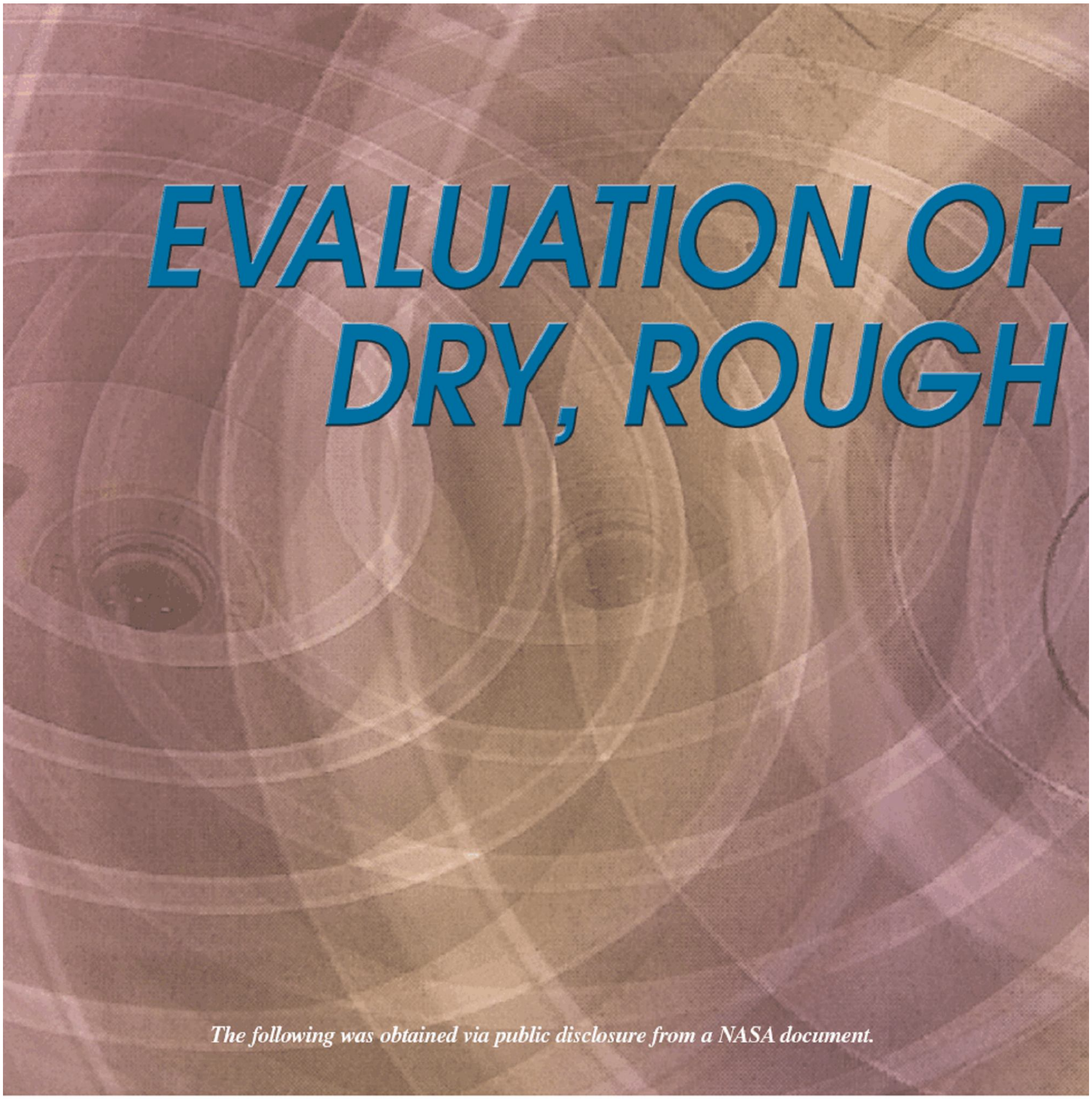
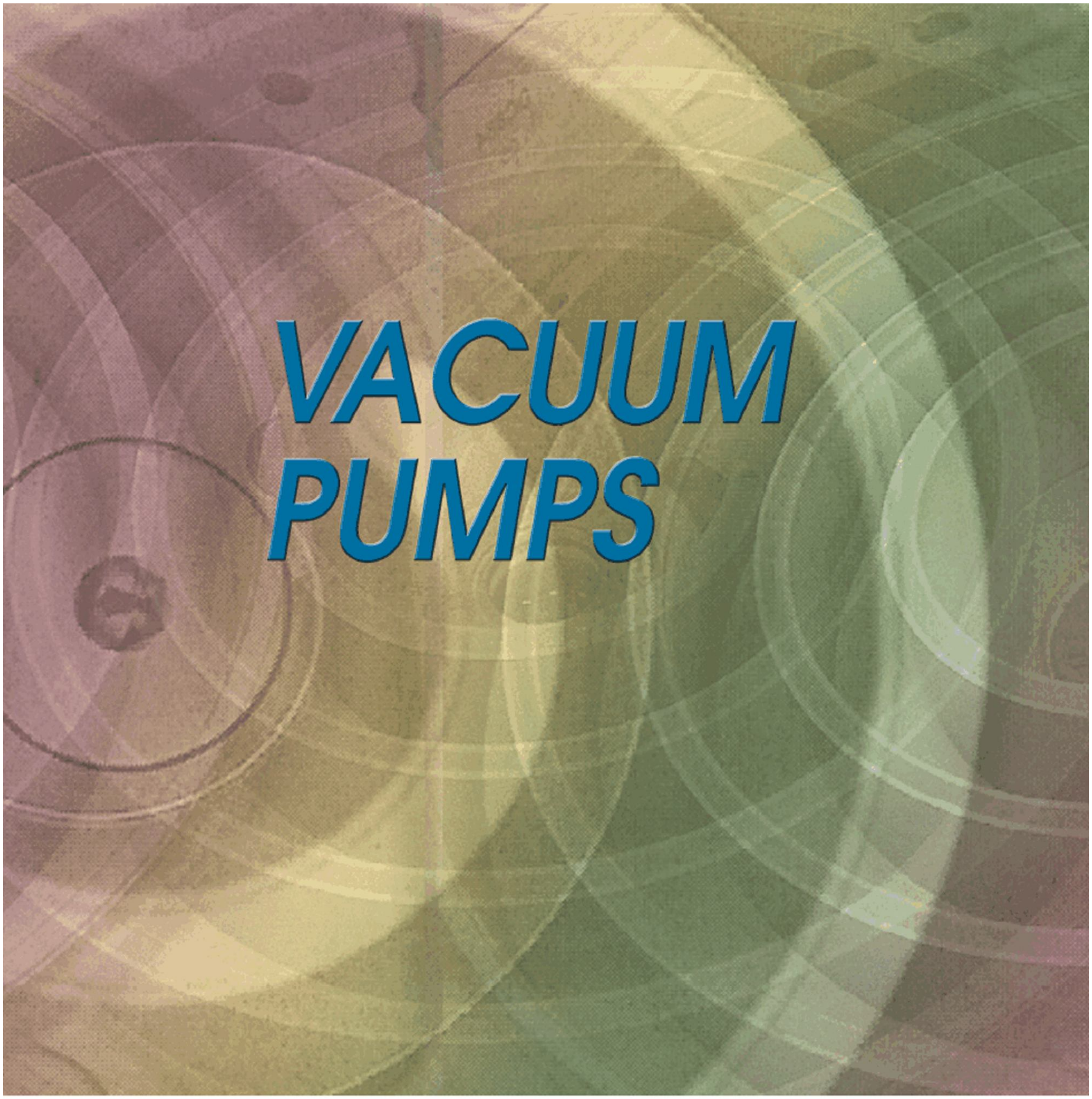


EVALUATION OF DRY, ROUGH

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

EDITOR'S NOTE:

This is the first 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.



VACUUM PUMPS

This document provides information on the testing and evaluation of thirteen dry rough vacuum pumps of various designs and from various manufacturers. Several types of rough vacuum pumps were evaluated, including scroll, roots, and diaphragm pumps.

Tests included long term testing, speed curve generation, voltage variance, vibrations emissions and susceptibility, electromagnetic interference emissions and susceptibility, static leak rate, exhaust restriction, response/recovery time tests, and a contamination analysis for scroll pumps. Parameters were found for operation with helium, which often is not provided from the manufacturer.

Overview

Rough vacuum pumps are an integral part of vacuum systems in gas analysis systems. They are used to transport gas samples from the test article to the analyzer, move the gas sample throughout the analyzer, rough the high vacuum chamber of the analyzer, and back the turbo molecular pump used to generate high vacuum. The performance and reliability of these pumps strongly influences the performance and reliability of the system as a whole.

Types of Pumps

Rough vacuum pumps can be categorized as one of two varieties: oil-sealed and dry. Oil-sealed pumps are positive-displacement with one or more stages whose clearances (leak paths) are sealed with a low vapor pressure oil. As the pumping mechanism moves, the oil flows into new positions to seal against gas returning back through the pump. Oil pumps are highly reliable, but produce oil backstreaming that affects sensitive instrumentation. Also, pump oil is an oxygen hazard, a hazardous waste, and can be expensive. Dry pumps use various methods other than oil to seal the pumping mechanism. By eliminating the sealing oil, they attempt to produce no backstreaming, or hazardous waste stream. Because of the highly sensitive nature of analytical instrumentation used, the hazardous waste produced by oil pumps, and the oxygen hazard posed by the pump oil, dry pumps are desirable.

Several different types of dry pumps exist, but the three types evaluated here are scroll pumps, diaphragm pumps, and roots pumps. Scroll pumps use two or more concentric spirals, one inside the other, to move crescent shaped pockets of gas towards the outlet, which lies at the center of the spiral. Each of these crescent shaped pockets acts as a stage, compressing the gas as it moves towards the center until it is discharged from the outlet. Scroll pumps often have low ultimate pressures, and can also have high pumping speeds. Scroll pumps require a tip seal, which seals the spiral faces together. This restricts gas from traveling through any path other than through the spiral. Unfortunately, this material is prone to wearing, producing particles which can contaminate the vacuum system, plug exhaust lines, and cause failure of system components. The friction of the orbiting tip seal also generates substantial heat.

Diaphragm pumps use the reciprocating action of an elastomer diaphragm and valves to remove the gas in a system. As the diaphragm moves away from the head, gas flows through the intake valve to fill the void. When the diaphragm moves towards the head, the intake valve closes and the exhaust valve opens. The diaphragm then displaces the gas and the cycle repeats. Diaphragm pumps often have multiple pumping heads, referred to as stages. These stages can be arranged in parallel or in series depending on the application of the pump. Multiple stages in series help the diaphragm pump achieve low ultimate pressure but with the same pumping speed as a single head. Multiple stages in parallel provide higher pumping speed but no improvement in ultimate pressure. Often, the heads on a diaphragm pump can be arranged as required by the user, allowing for flexibility. Diaphragm pumps have very low contamination, but usually have higher ultimate pressures and lower flow rates than other types of dry pumps. In addition, the flow of gas through them often pulsates with the movement of the diaphragms, which can affect the stability of an instrument.

Roots pumps use two rotating, figure-eight shaped lobes that are always 90 degrees out of phase with one another. In current designs, there are no seals between the two lobes, so multiple stages must be used to achieve reasonable vacuum. Roots pumps are characterized by high flow rates and low ultimate pressure, but often do not function as well in helium environments than in nitrogen or air environments. Historically, roots pumps have not been able to start at atmospheric pressure, although recently such models have become commercially available.

Pump Functions

In many gas analysis applications, rough vacuum pumps are categorized by three distinct functions:

- Transport
- Sample
- backing

Transport pumps are intended to quickly flow large amounts of gas long distances from the test article to the system. These pumps require high flow rates at higher pressures (60 – 150 sLpm at 250 – 500 torr). High flow rates ensure a quick system response time because it reduces the residence time of the sample in the transport line. To effectively transport the sample to the analyzer, higher pressures are often used.

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, typically 10 -20 sLpm at 50 - 500 torr. Backing pumps rough the high vacuum chamber and provide the high vacuum pump with rough vacuum. Backing pumps require low ultimate pressure (<5 torr, but desire < 100 mTorr) to assist the compression of the turbo molecular pump and only small flow rates (<1 sLpm).

Description of Tests

Thirteen dry, rough pumps from various manufacturers and of various designs were evaluated in this study. **Table 1** outlines the various pumps, their possible uses, and some manufacturer specifications. Tests include

- long term testing,
- speed curve generation,
- voltage variance,
- vibrations emission and susceptibility,
- electromagnetic interference emission and susceptibility,
- static pressure test to determine leak rate,
- exhaust restriction,
- response/recovery time

The long term test attempts to asses the long term reliability of pumps, their steady state power requirements, and heat generation. Scroll pumps also were tested for particulate generation, which could contaminate the system causing performance issues or failure.

The speed test generated pumping speed curves. These curves describe how the effective pumping speed changes with inlet pressure. This function is never constant, often changes with the gas being pumped, and is sometimes highly non-linear. Although manufacturers supply this curve for nitrogen and air, it is rarely provided for helium. Because helium is commonly used by NASA, the helium pumping speed curve is desirable. Additionally, the current required at each operating pressure was determined.

The voltage variance test determined how the current demand and inlet pressure of the pump changed with input voltage. In addition, this test determined the minimum voltage to sustain operation once the pump was running. In a brown-out condition, this voltage determines when the pump, and therefore the system, fails. Current vs. voltage curves are often highly varied from pump to pump and can be non-linear. Inlet pressure vs. voltage curves are typically non-linear, and pressure rises exponentially as voltage drops.

Many pumps generate substantial vibration while in operation. This vibration emission can fatigue components, and impact sensitive analytical instruments. The translational acceleration associated with pump operation was measured both at the pump inlet and at a surface the pump was sitting on. When a pump is turned off, gas leaks back through it from the high pressure exhaust side to the low pressure vacuum. This gas leakage can bring contamination into the vacuum chamber. The faster the pump leaks back to atmospheric pressure, the more likely the contaminant will be pneumatically conveyed into the vacuum chamber. Static leak rates on the pumps were measured, and leak rates varied widely, even among pumps of the same type. Rough vacuum pumps are typically designed to exhaust at atmospheric pressure or slightly above. Tubing and fittings attached to the exhaust of the vacuum pump can easily cause exhaust pressure to rise above the manufacturer's exhaust pressure specification. A test was performed to quantify the effects of exhaust restriction.

Pump Descriptions

Table 1 contains some manufacturer specified data about the candidate rough pumps. Photographs of the pumps used in this study are provided in **Figures 1 – 13**.

Long Term Tests

The long term test assessed long term functionality and reliability of pumps, as well as steady state power requirements of pumps. It also assessed the particulate generated by scroll pumps during long term use. With a few exceptions, the test duration was approximately 30 days. Transport and sample pumps were run at 300 torr, and turbo backing pumps were run at ultimate pressure. Scroll pumps had their exhaust filtered with a 100 micrometer filter to collect particulate generated during operation. The 100 micrometer filter is of a size that is efficient at capturing particles, but still allows the exhaust to flow relatively freely. Diaphragm pumps and the roots pump did not have the exhaust filtered because past experience has shown these pumps to have minimal contamination. Current, exhaust temperature, and housing temperature were measured approximately once per day on turbo backing pumps.

For transport and sample delivery pumps, current, housing temperature, flow rate, and pressure were also measured daily.

Table 1.

Pump	Type	Possible Function	Maximum Speed (LPM)*	Ultimate Pressure (mTorr)*	Hour Meter	Other Features or Notes
Adixen ACP 28	Roots	Transport	450	23	Yes	RS 232
Vacuubrand ME 16	Diaphram	Transport	215	60 Torr	No	Start under Vacuum
Iwata ISP 250	Scroll	Transport, Sample	300	12	Yes	Gas Ballast
Edwards XDS 10	Scroll	Transport, Sample	185	50	Yes	Gas Ballast
Varian Triscroll 300	Scroll	Transport, Sample	250	10	No	
Vacuubrand MD 4 Vario	Diaphram	Sample	63	1.1 Torr	No	Variable Speed, RS 232
Vacuubrand MZ 2D	Diaphram	Sample, Backing	32	3.5 Torr	No	Start under Vacuum
Iwata ISP 90	Scroll	Sample, Backing	108	38	Yes	Gas Ballast
Edwards XDS 5	Scroll	Sample, Backing	100	50	Yes	Gas Ballast
Varian 100	Scroll	Sample, Backing	100	50	Yes	Solenoid Inlet Valve
Edwards XDD1	Diaphram	Backing	25	<1.5 Torr	No	Private Label Vacuubrand MD1, Start Under
KNF XDD1	Diaphram	Backing	4.8	1.5 Torr	No	Vacuum No Compact Size, 24 VDC
Vacuubrand MD 1 Vario	Diaphram	Backing	27	1.1 Torr	No	Variable Speed, RS 232, Start under Vacuum 24VDC

*Manufacturer's Claim

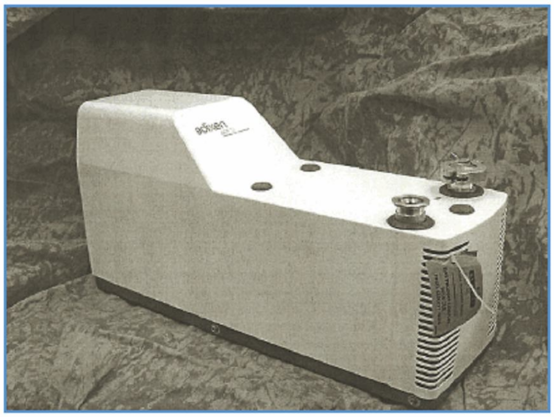


Figure 1. Adixen ACP 28 Roots Pump

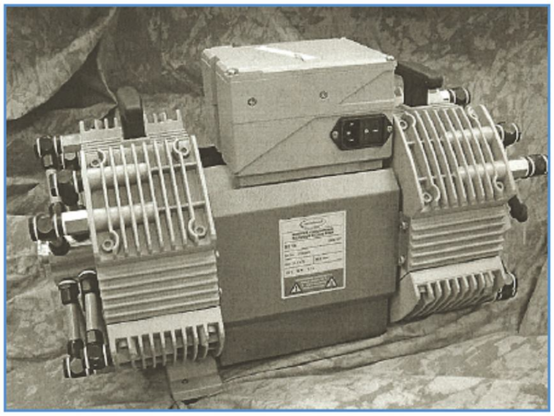


Figure 2. Vacuubrand ME 16 Diaphragm Pump

Figure 3. Iwata ISP 250 Scroll Pump

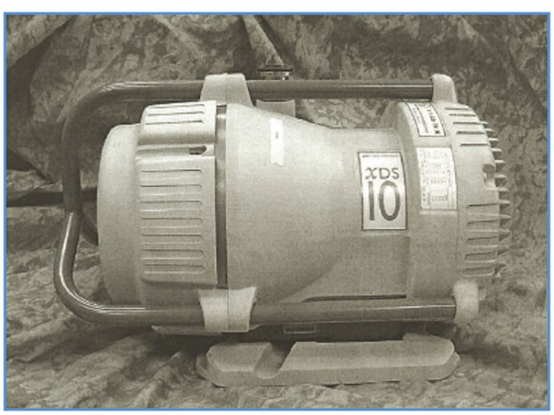


Figure 4. Edwards XDS 10 Scroll Pump

Any deviations from normal operation were noted. Significant changes in current, flow rate, and housing temperature often are indicators of impending failure. Increases in current or decreases in flow rate may indicate increased power demand due to increased friction and/or reduced efficiency. Increases in temperature at steady ambient temperature and flow rate suggest increases in friction within the pump. Most measurements were expected to have approximately 10% deviation from day to day. Beyond this, an anomaly was noted. Pump temperature, however, was expected to vary by more than 10% because ambient temperature varied substantially. At the conclusion of this test, rinse analysis was performed on the filters of scroll pumps to quantify the amount and size distribution of the particulate produced. In addition, non-volatile residue (NVR) analysis was performed to quantify the amount of grease and oil captured in the filters.

Dry pumps are not oil sealed, and NVR signatures were expected to be low; only grease and oils that migrate through seals should be found in the filters. To help verify the results of the rinse analysis, and better understand or predict failure mechanisms, the scroll pump housings were removed and visually inspected for particulate generation and overall condition.

Transport Pumps

Transport pumps are expected to quickly flow large amounts of gas long distances from the test articleto the system. These pumps require high flow rates at higher pressures (60 – 150 sLpm at 250 – 500 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. All transport pumps were run for approximately 30 days near 300 torr. Scroll pumps had their exhaust filtered with a 100 micrometer in-line filter.

Edwards XDS 10

The Edwards XDS 10 scroll pump was run at approximately 300 torr for 34 days as a transport pump. The exhaust was filtered with a 100 micrometer in-line filter to collect particulate generated. During the test, temperature, flow rate, and current remained within the expected 10% deviation. Housing temperature averaged 55°C and exhaust temperature averaged 52°C, while ambient temperature averaged 19°C. The XDS 10 required approximately 5.5 amps steady state current. After testing, the housing of the pump was removed and the scroll surfaces examined. The surfaces are shown in **Figures 14** and **15**. A light dusting of particulate was noted on the orbiting scroll, with slightly higher amounts of particulate noted on the fixed scroll. The particulate material was brown in color and seemed to adhere to surfaces with moderate strength. Tip seals appeared to be worn uniformly and evenly. The filter contents were analyzed for particulate count as well as size distribution. Results indicate that the Edwards XDS 10 discharges the least amount of particulate of any scroll pump tested. The majority of the particles recovered were less than 50 micrometers in size. Only 0.5

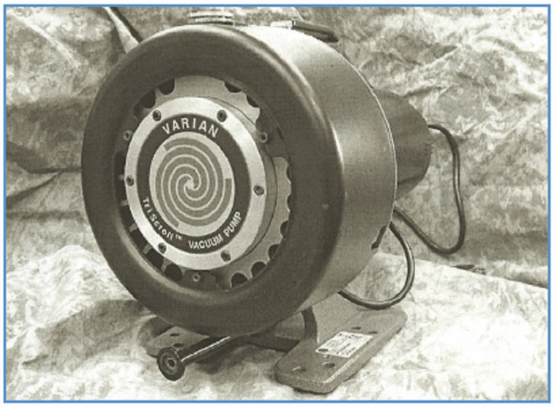


Figure 5. Varian TriScroll 300 Scroll Pump

Figure 6. Vacuubrand MD 4 Vario Diaphragm Pump

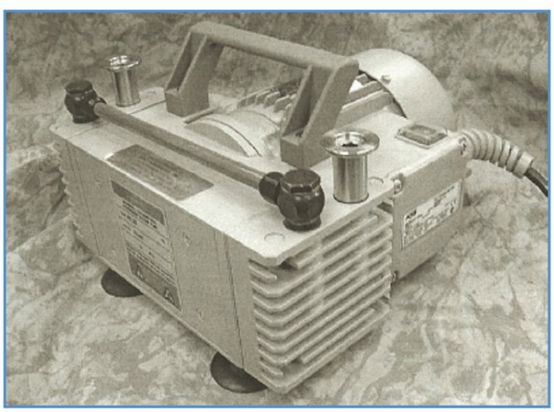


Figure 7. Vacuubrand MZ 2D Diaphragm Pump

mg of NVR was recovered from the filter, less than any other pump. A detailed contamination analysis will be presented at the conclusion of this article.

Iwata ISP 250

The Iwata ISP 250 scroll pump was run at approximately 300 torr for 30 days as a transport pump. The exhaust was filtered with a 100 micrometer in-line filter to collect particulate generated. During the test, current, flow rate, and temperature remained remarkably stable. Housing temperature averaged 50°C and exhaust temperature averaged 61°C while ambient temperature averaged 28°C. The ISP 250 required approximately 3.7 amps steady state current.

After testing, the housing of the pump was removed and the scroll surfaces examined. Some particulate was noted on both the orbiting and fixed scrolls. The particulate material was dark and tended to adhere to surfaces relatively strongly. The tip seals appeared to be worn in a non-uniform way on the orbiting scroll. White wear marks were observed with greater frequency towards the center of the scrolls. The fixed scroll appeared to be worn uniformly. The surfaces are shown in **Figures 16** and **17**. The filter contents were analyzed for particle size distribution and NVR. Results show that there are large numbers of particles less than 50 micrometers generated. Compared to the other scroll pumps, the second highest amount of NVR was recovered from the filter, 4.08 mg. The o-ring which seals the fixed and orbiting scroll was covered in what appeared to be fluorinated grease, and the presence of a front bearing on the ISP pumps is likely responsible for the higher NVR signature. Detailed contamination analysis will be presented in a future article.

Varian TriScroll 300

The Varian TriScroll 300 scroll pump was run at approximately 300 torr for 30 days. The exhaust was filtered with a 100 micrometer in-line filter to collect particulates generated. After 11 days, the pump experienced significantly higher current draw while flow rate decreased 33% from 71 sLpm to 48 sLpm. Soon after, the pump tripped the circuit breaker. The cause of this problem was determined to be a clogged exhaust filter. The filter was replaced with another 100 micrometer filter and after 11 more days the filter was again clogged. It was replaced a third time, which lasted the remaining 8 days until the long term test was concluded. Also, a loud squeaking sound began 28 days into the test. During the test, the highest recorded housing temperature was a staggering 104°C, and the highest recorded exhaust temperature was 69°C. Ambient temperature during these measurements was 30°C and 35°C, respectively. Current draw nearly doubled from approximately 7 amps to 12.6 amps while filter was clogged. Due to the wide variation of temperatures and currents, averages are not presented.

After testing was complete, the pump housing was removed and the scroll surfaces examined, which are shown in **Figures 18** and **19**. Large amounts of particulate were found in two forms. In one form, the particulate material is quite dense and adheres very strongly to the metal of the scroll. It was observed

Figure 8. Iwata ISP 90 Scroll Pump

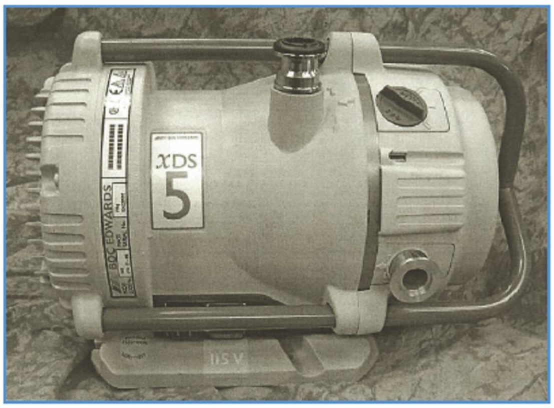


Figure 9. Edwards XDS 5 Scroll Pump

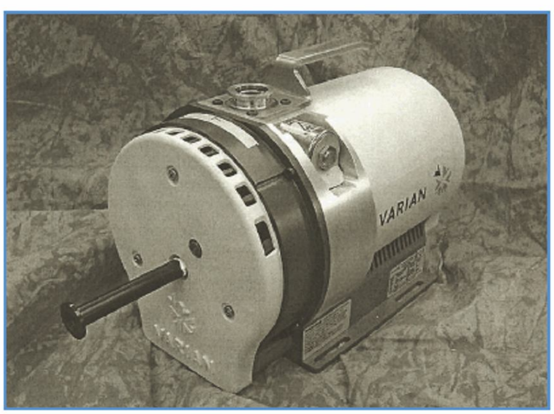


Figure 10. Varian SH 100 Scroll Pump

on the flat spaces between the spiral grooves, but not in the filter. It is likely caused by the tip seal being "smashed" against the opposing scroll. The second form of particulate is sawdust-like, being light and with little adherence to metal surfaces. This form was observed both insidethe pump housing and in the filter. The three filters were analyzed for particle size distribution and NVR. Particles in all size ranges and from all filters were too numerous to count, indicating large amounts of particulate. The TriScroll 300 had more particulate than any other pump tested. In addition, the TriScroll 300 had the highest NVR signature at 36.7 mg. The origin of this grease is unclear. See section 2.4 for a detailed contamination analysis.

Adixen ACP 28

The Adixen ACP 28 roots pump was run at 300 torr for 30 days as a transport pump. Since the pumping mechanism is non-contacting, no filtering was done on this pump as contamination was not expected. No material or oils were noticed on the exhaust or inlet fitting of the pump after the conclusion of the test. During the test, the pump shut down several times. Failure was determined to be caused by overheating and activation of the internal thermal protection circuit. The problem was reduced by placing an auxiliary fan near the cooling air intake, although the thermal protection was activated once after the auxiliary fan was installed. This experience suggests that the ACP 28 pump is likely to overheat when placed near thermal sources, such as other pumps in enclosed spaces. The ACP 28 required approximately 9 amps steady state current. Exhaust temperature averaged 66°C and rose as high as 71°C, while ambient temperature averaged 28°C.

Vacuubrand ME 16

The Vacuubrand ME 16 diaphragm pump was run at 300 torr for 30 days as a transport pump. No filtering was done on this pump as contamination was not expected from diaphragm pumps. Housing and exhaust temperature averaged 47°C, while ambient temperature averaged 28°C. The ME 16 required approximately 4.5 amps steady state current. During the test, current and temperature remained within deviation limits. However, large variation in measured flow rate was observed. This can be attributed to the restriction of the flow meter and associated tubing. Indeed, even slightly bending the flexible tubing connecting pump exhaust to the flow meter could reduce the indicated flow rate. A more detailed analysis of the exhaust characteristics will be presented in a future article.

Sample Pumps

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, typically 10 -20 sLpm at 50 - 500 torr. Sample pumps were run for 30 days near 300 torr. Scroll pumps had their exhaust filtered with a 100 micrometer in-line filter.

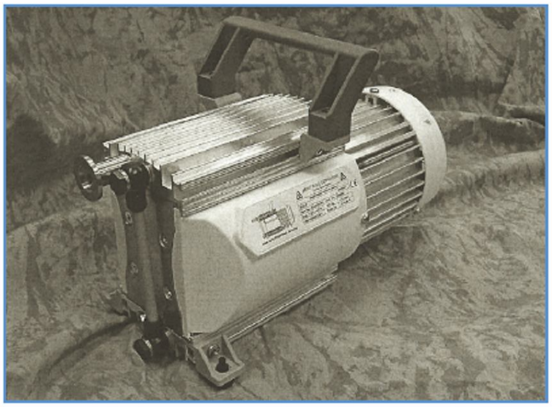


Figure 11. Edwards XDD1 Diaphragm Pump

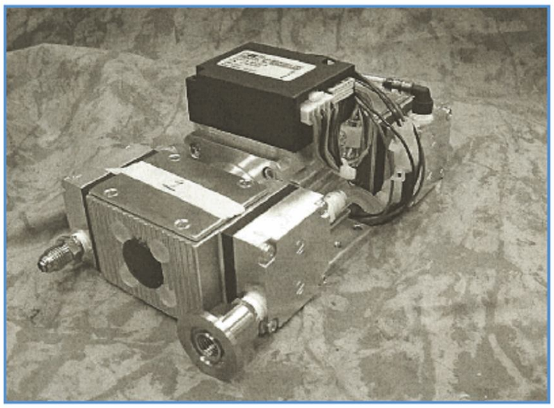


Figure 12. KNF Neuberger 84.4 Diaphragm Pump

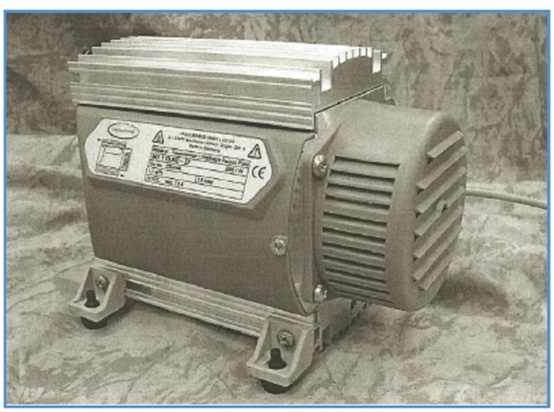


Figure 13. Vacuubrand MD 1 Vario Diaphragm Pump

Edwards XDS 10

The Edwards XDS 10 is a candidate sample pump, but was tested as a transport pump. It had the lowest amount of ejected particulate recovered from its exhaust filter, as well as the lowest NVR signature. A more detailed description of the long term test is provided above.

Edwards XDS 5

The Edwards XDS 5 scroll pump was run at 300 torr for 34 days as a sample pump. The exhaust was filtered with a 100 micrometer in-line filter to collect particulate generated. During the test, temperature, flow rate, and current remained within deviation limits. Housing temperature averaged 51°C and exhaust temperature averaged 40°C, while ambient temperature averaged 19°C. The XDS 5 required approximately 4.7 amps steady state current. After testing, the pump housing was removed and the scroll surfaces examined (**Figures 20** and **21**). Significantly more particulate was observed than inside the XDS 10. This observation is surprising, given that the XDS 5 and XDS 10 are the same general design and use the same tip seal material. The particulate material was brown in color and seemed adhered to surfaces with moderate strength. Tip seals were worn in a uniform manner. The filter contents were analyzed for relative particulate count as well as size distribution. Significantly more exhausted particulate was found in the filter of the Edwards XDS 5 than the Edwards XDS 10. NVR results show 2.4 mg of recoverable grease and oil.

Iwata ISP 250

The Iwata ISP 250 is a candidate sample pump, but was tested as a transport pump. Flow rate, temperature, and current were remarkably stable during the test.

Iwata ISP 90

The Iwata ISP 90 is a candidate sample pump, but was tested as a backing pump. Temperature and current were remarkably stable during the test. See section 2.4.1 for a more detailed description of the long term test performed.

Vacuubrand MD 4 Vario

The Vacuubrand MD 4 Vario diaphragm pump was run at 300 torr for 30 days as a candidate sample pump. No filtering was done on this pump as contamination was not expected from diaphragm pumps. Housing temperature averaged 55°C with a maximum of 65°C. Exhaust temperature averaged 80°C with a maximum of 91°C. Ambient temperature averaged 28°C. During the test, flow rate, temperature, and current remained within deviation limits. A slight "ticking" sound could be heard from inside the pump, but was attributed to shipping damage because the package the pump arrived in was heavily damaged. It did not seem to affect the performance of the pump because the pump met all manufacturer specifications. The MD 4 Vario required approximately 2.2 amps steady state current.

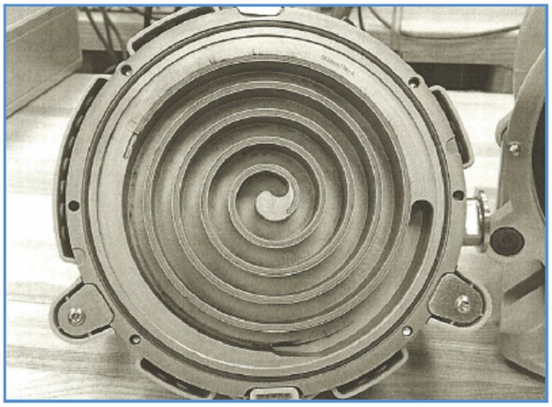


Figure 14. Edwards XDS 10 Fixed Scroll Showing Particulate and Wear

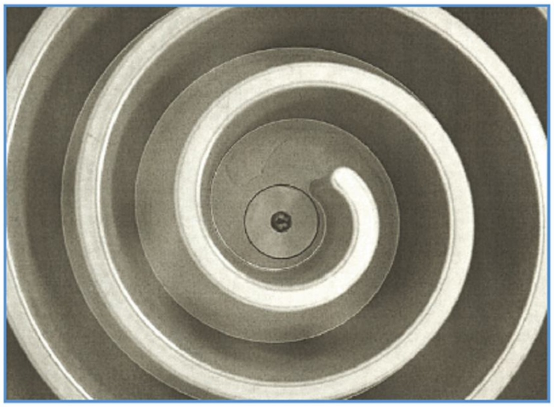


Figure 15. Close up of Edwards XDS 10 Orbiting Scroll Showing Particulate

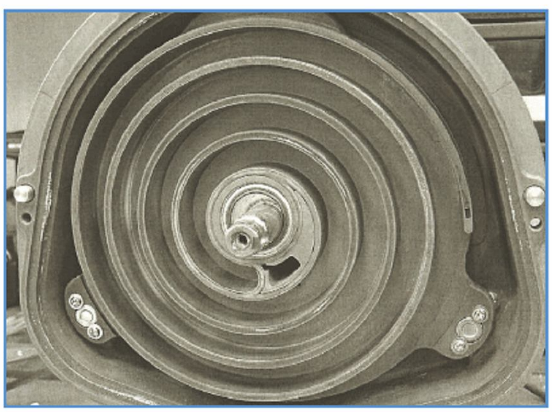


Figure 16. Iwata ISP 250 Orbiting Scroll Showing Wear and Particulate

Vacuubrand MZ 2D

The Vacuubrand MZ 2D diaphragm pump was run at 300 torr for 30 days as a sample pump. No filtering was done on this pump as contamination was not expected from the diaphragm pumps. Housing temperature averaged 68°C and exhaust temperature averaged 94°C, while ambient temperatureaveraged 28°C. During the test, flow rate, temperature, and current remained within deviation limits. The MZ 2D required approximately 1.9 amps steady state current.

Varian TriScoll 300

Although the Varian TriScroll 300 is a candidate sample pump, it was tested as a transport pump. By far, this pump produced and ejected the largest amount of particulate of any pump evaluated, as well as the greatest NVR signature. It filled 3 separate exhaust filters and tripped the circuit breaker twice. A more detailed description of this test was provided previously.

Varian SH 100

The Varian SH 100 is a candidate sample pump, but was tested as a backing pump. Measurements were within deviation limits during the test period. Some particulate was noted, especially inside the pump housing. A more detailed description of this test is provided in the next section.

Backing Pumps

Backing pumps rough the high vacuum chamber and provide the high vacuum pump, such as a turbo molecular pump, with the rough vacuum. Backing pumps require low ultimate pressure to assist the compression of the turbo molecular pump and only small flow rates (<1 sLpm). All backing pumps were tested at their ultimate pressure for approximately 30 days. Scroll pumps had their exhaust filtered with a 100 micrometer in-line filter.

Vacuubrand MD1 Vario

The Vacuubrand MD1 Vario diaphragm pump was run at ultimate pressure (~ 1 torr) for 30 days. No filtering was done on this pump as contamination was not expected. Housing temperature averaged 41°C while ambient temperature averaged 28°C.

During the test, no anomalies were reported. Note that the pump was run at 20VDC rather than 24VDC during the course of this test because a 24VDC power supply with sufficient current capacity could not be secured for the entire 30 day period. With the Vario technology, power demand was low at approximately 0.75 amps steady state current.

Vacuubrand MZ 2D

The Vacuubrand MZ 2D is a candidate backing pump, but was tested as a sample pump. Flow rate, pressure, and temperature all were within deviation limits, although the pump ran hotter than other pumps.

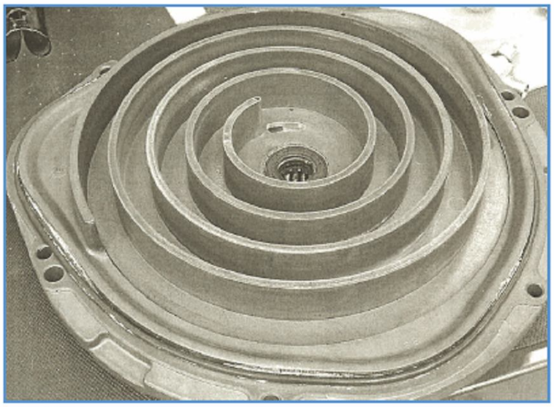


Figure 17. Iwata ISP 250 Fixed Scroll showing Particulate

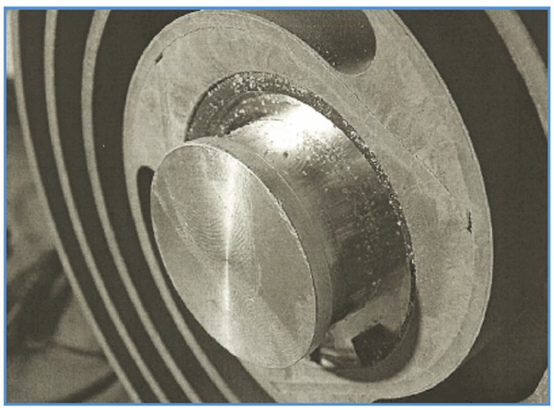


Figure 18. Close up of Varian TriScroll 300 Orbiting Scroll Showing Particulate

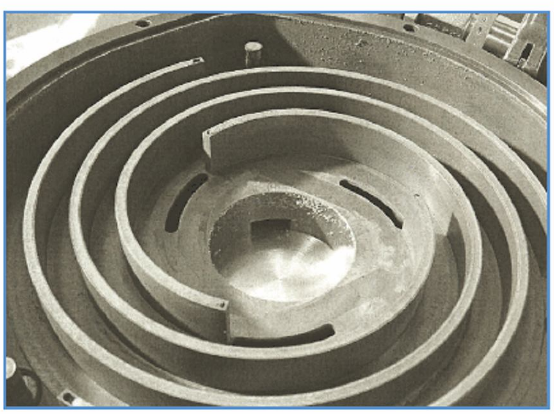


Figure 19. Varian TriScroll 300 Fixed Scroll Showing Particulate

KNF 84.4

The KNF Neuberger 84.4 24 VDC diaphragm pump was run at ultimate pressure (<0.5 torr) for 30 days. No filtering was done on this pump as contamination was not expected from diaphragm pumps. Housing temperature averaged 41°C while ambient temperature averaged 28°C. During the test, no significant anomalies were reported. The KNF 84.4 required approximately 0.5 amps DC steady state current.

Varian SH 100

The Varian SH 100 scroll pump was run at ultimate pressure (~50 mTorr) for 30 days as a backing pump. The exhaust was filtered with a 100 micrometer in-line filter to collect particulate generated. Current and temperature remained within deviation limits throughout the test. Housing temperature averaged 51°C while ambient temperature averaged 28°C. The SH 100 required approximately 3.5 amps steady state.

After testing was complete, the housing of the pump was removed and the scroll surfaces examined. These surfaces are shown in **Figures 22, 23,** and **24**. Two forms of particulate material were observed.

In one form, the particulate material was quite dense and adhered very strongly to the metal of the scroll. It is most commonly observed on the flat spaces between the spiral grooves, and was not observed in the filter. It is likely caused by the tip seal being "smashed" against the opposing scroll. The second form of particulate is sawdust-like. It is light and has little adherence to metal surfaces. This form was observed both in the filter and inside the pump housing. Tip seals were worn unevenly. On both scrolls, the material looks burnt or scorched near the outside of the scroll wrap, but relatively unscathed near the center. The filter was analyzed to determine particle size distribution and NVR. Some particulate was collected,the majority of which is less than 250 micrometer. NVR showed 1.97 mg of recoverable grease and oil.

Edwards XDD1

The Edwards XDD1 diaphragm pump was run at ultimate pressure (<1 torr) for 30 days as a backing pump. No filtering was done on this pump as contamination was not expected from diaphragmpumps. During the test, current and housing temperature remained within deviation limits. The XDD1 required approximately 1.1 amps. Housing temperature averaged 42°C while ambient temperature averaged 21°C.

Iwata ISP 90

The Iwata ISP 90 scroll pump was run at ultimate pressure (<60 mTorr) for 30 days as a backing pump. The exhaust was filtered with a 100 micrometer in-line filter to collect particulate generated. During the test, current and temperature were remarkably stable. The ISP 90 required approximately 1.7 amps steady state current. Housing temperature averaged 50°C while ambient temperature averaged 28°C. After testing, the housing of the pump was removed and the scroll surfaces examined. Some buildup of particulate was noted, primarily on the orbiting

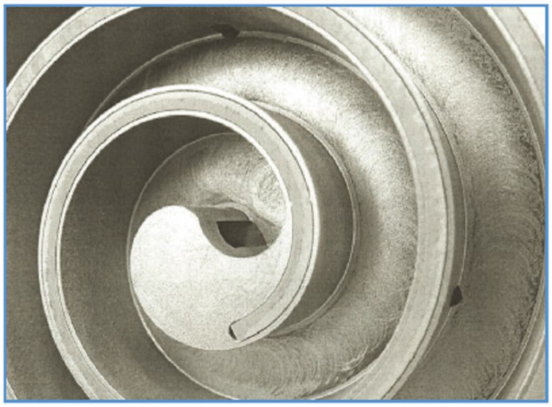


Figure 20. Close up of Edwards XDS 5 Fixed Scroll Showing Particulate

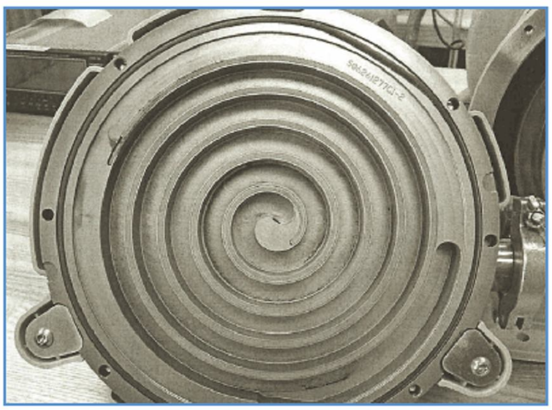


Figure 21. Edwards XDS 5 Fixed Scroll Showing Particulate

Figure 22. Close up of Varian SH 100 Orbiting Scroll Showing Particulate

scroll. The particulate is dark and tends to adhere to surfaces relatively strongly. The tip seals appear to be worn in a non-uniform way. White wear marks were observed with greater frequency towards the center of the scrolls. Surfaces are shown in **Figures 25** and **26**. A detailed contamination analysis is provided later in this article. Corrosion was noted on the exhaust fitting, shown in **Figure 27**. The stainless steel NW 16 centering ring was tarnished, and the coating on the NW 16 exhaust fitting was corroding.

Scroll Pump Contamination Analysis

The largest downside of using scroll pumps is the particulate generated as the tip seal wears. This particulate can contaminate sensitive instrumentation present in the system, clog orifices and capillaries, or interfere with sensors in the sample delivery system. Any one of these events can cause performance issues or failure of the system. Filter contents collected during the long term test were analyzed for size distribution and NVR. Particulate results are presented based on the number of particles of a certain size range of the recovered particulate emissions. Filters removed from the pump exhaust were analyzed at a chemical analysis laboratory. A rinse analysis in both the forward and reverse direction was performed, as well as a nonvolatile residue analysis. Analysis could only be performed on the particles that were ejected from the pump, embedded in the filter, and were then removed from the filters. The analysis pads were sometimes silted with particles too numerous to count. This is represented with bars labeled "TNTC" in **Figure 28**. Nevertheless, the results are useful for qualitative comparisons when used in conjunction with other observations, such as visual inspection of the scroll surfaces.

Comparison of particulate count from pumps run at ultimate pressure (turbo backing) with those run at higher pressures is not a fair comparison. Higher gas flow rates transfer a higher percentage of the particles generated to the filter, causing them to appear to make more particulate. This also applies to the amount of NVR transferred to the filters.

Results of testing on transport and sample pumps indicate that the Edwards XDS 10 produced the least amount of recoverable particulate, followed by the Iwata ISP 250. The Edwards XDS 5 produced a significant amount of particulate. This is unexpected because it uses the same tip seal material as the XDS 10, however visual inspection of the exhausts shows significantly more particulate within the exhaust fittings of the XDS 5, confirming the result. The TriScroll 300, by far, produces the largest amount of particulate.

Figure 29 shows the results of particulate testing on scroll pumps for backing duty. The SH 100 had less particulate in the filter than the ISP 90. As previously mentioned, this does not necessarily mean that the ISP 90 produces more net particulate, only that more was found in its filter. Due to the low gas flow rates of the backing pumps, only a small amount of the particulate generated inside the pumps actually made it to the filter. Therefore, it is possible that the ISP 90 produces less particulate than the SH-100, but a higher percentage was transferred. A visual inspection of scroll surfaces supports this result.

Figure 23. Varian SH100 Fixed Scroll showing Particulate and Uneven Wear

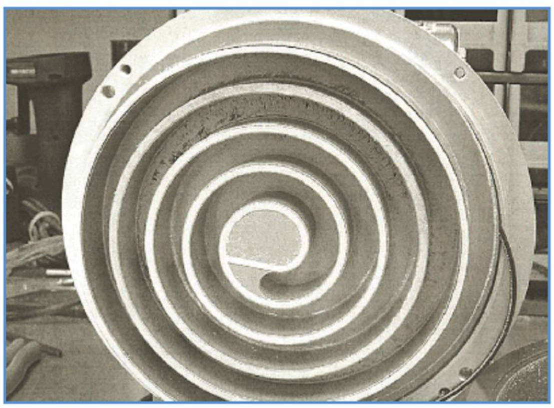


Figure 24. Varian SH 100 Orbiting Scroll showing Particulate and Uneven Wear

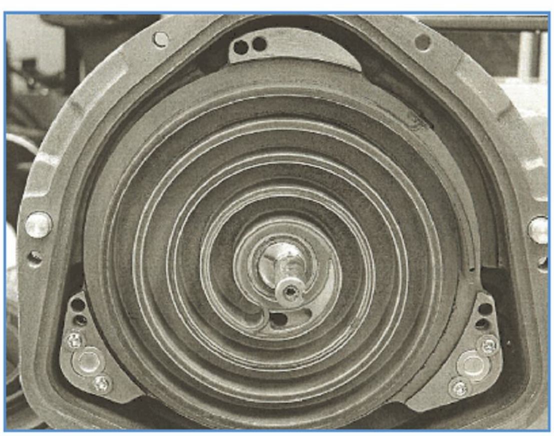


Figure 25. Iwata ISP 90 Orbiting Scroll showing Particulate

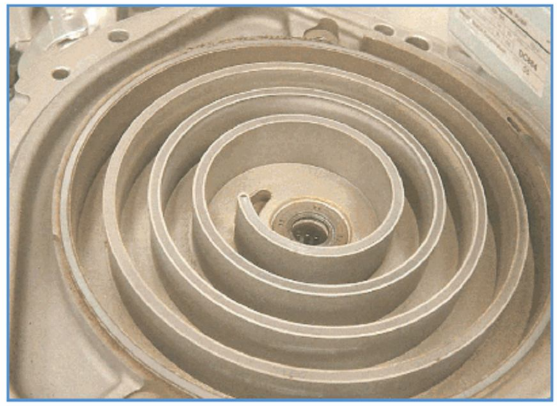


Figure 26. Iwata ISP 90 Fixed Scroll showing Particulate

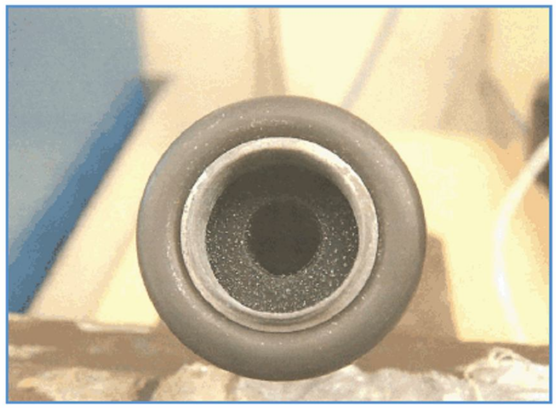


Figure 27. Iwata ISP 90 Filter Inlet Showing Corrosion

Filters were also analyzed for NVR, which consists of deposits of greases and oils. **Figure 30** shows the results of the analysis. Results are presented as mg of NVR per 100 mL of solvent. Since all filters were washed with 100 mL of solvent, results can be directly compared. All filters had some level of contamination. Because they were run near ultimate pressure, the low flow rates of the ISP 90 and SH 100 probably did not carry much NVR into the filters. Therefore they are a good idea of the baseline contamination of the filters, indicating that 0-2 mg can be regarded as a baseline contamination level.

The Varian TriScroll 300 had much greater NVR signatures than the other scroll pumps. This partly could be because it required three separate exhaust filters, tripling the amount of contamination, but this cannot fully explain the extremely high readings.

The Iwata ISP 250 had significant NVR signature, indicating that some grease was recovered. Inthis pump, the scrolls are sealed with an o-ring covered in fluorinated grease, and the pump has onemore bearing than usual for the fan. This is likely responsible for its higher NVR signature. The Edwards XDS 10 had the least amount of NVR of any pump at 0.5 mg, although it cannot be said with certainty that the XDS 10 produces less NVR than the SH 100 or ISP 90 or XDS 5.

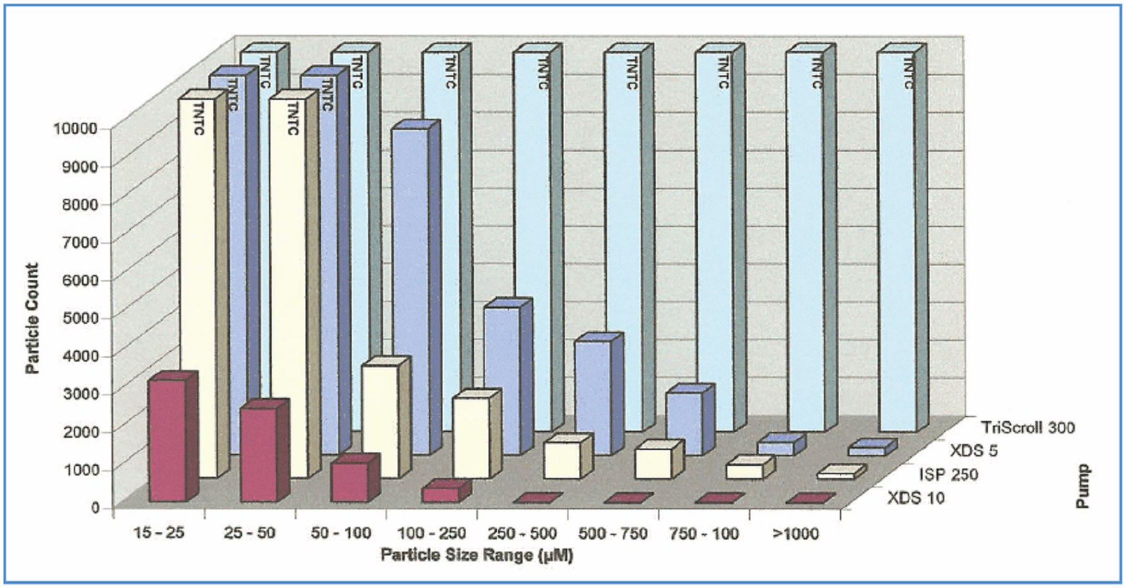


Figure 28 . Particulate Generation of Candidate Transport and Sample Scroll Pumps

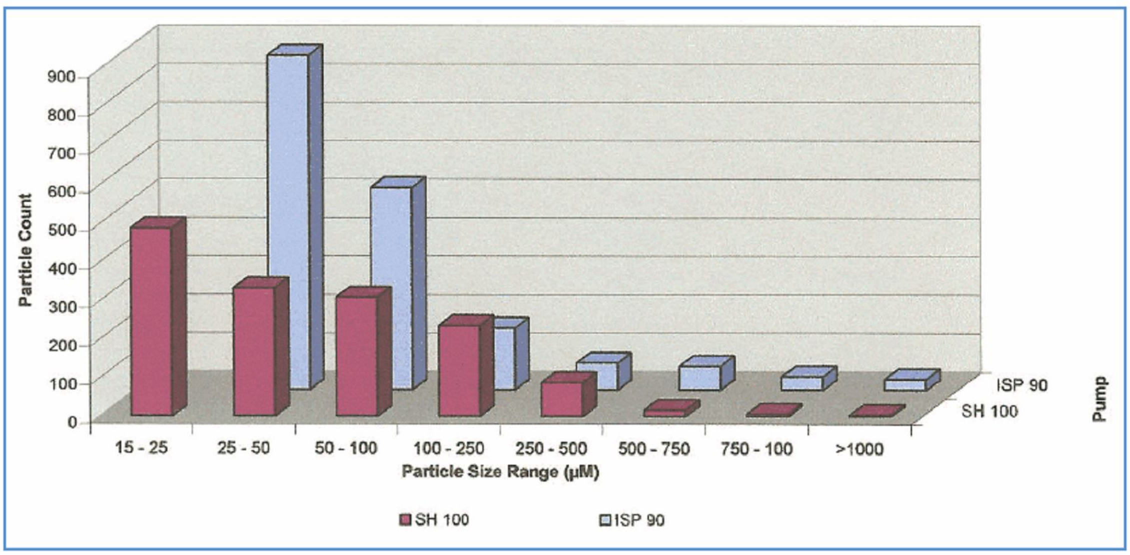


Figure 29. Particulate Generation of Candidate Backing Scroll Pumps

Long Term Test Discussion

Long term testing of scroll pumps reiterates that all scroll pumps create particulate. The quantity and qualities of the particulate material vary by pump and manufacturer. The TriScroll 300 produced the largest amount of particulate. The Edwards XDS 10 was found to eject the least amount of particulate, and comparatively little was observed within the pump. The Iwata ISP 250 also produced little particulate compared to the Varian TriScroll 300. Scroll pumps produce moderate amounts of heat, and are moderately power efficient, in terms of pumping speed per unit power.

All diaphragm pumps performed as expected, with no significant anomalies. They typically have low or moderate power demands, although they are less efficient than scroll pumps in terms of pumping speed. As a whole, they are clean and dry pumps with reliable, consistent performance. The Adixen ACP 28 roots pump has high pumping speed but large power requirements and produces large amounts of heat. In enclosed spaces and near other pumps, heat generation may cause the thermal protection circuit to trip, shutting the pump off for at least several minutes, causing temporary failure of a pumping system.

This concludes the first section of the report. Pump speed tests will be addressed next month.

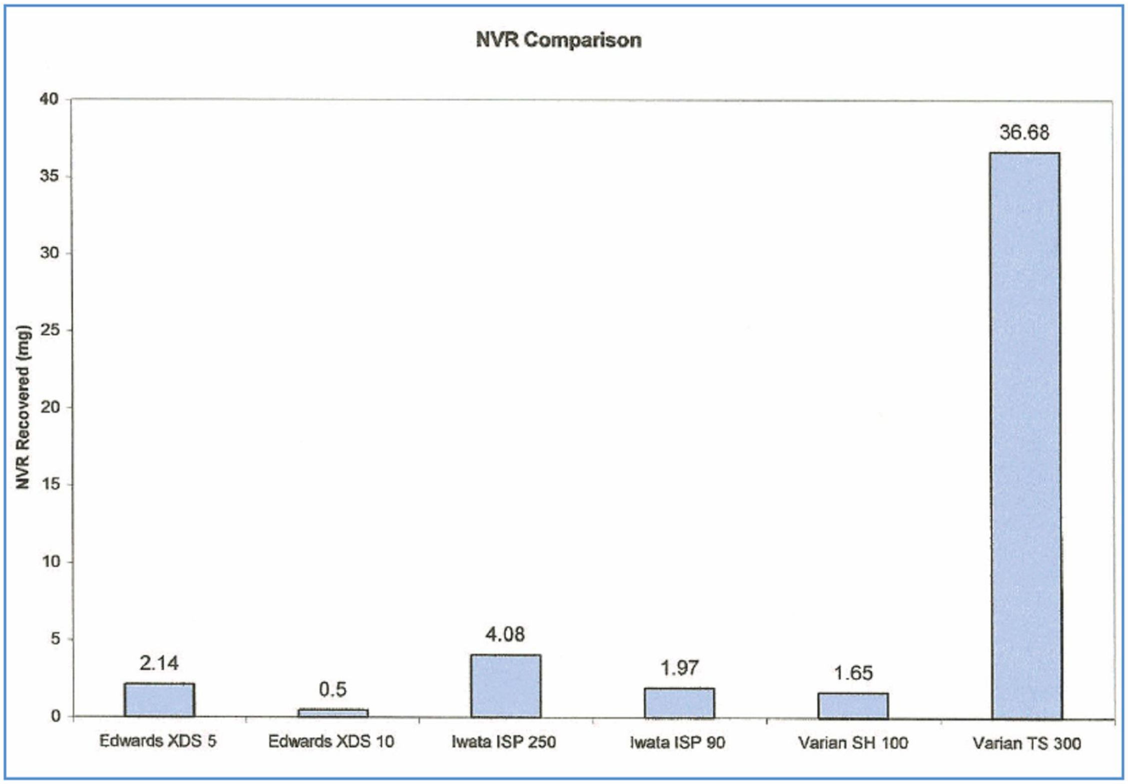


Figure 30. NVR Recovered from Scroll Pump Filters

ABBREVIATIONS AND ACRONYMS

AC: alternating current
Ar: argon
c.: circa
CE: conducted emissions
Ccm: cubic centimeter per minute
CDR: cleaning and decontamination request
CM: capacitance manometer
CS: conducted susceptibility
dBμV: decibel microvolt
DC: direct current
DVM: digital volt meter
G: acceleration, relative to Earth's acceleration due to gravity
Grms: root mean square acceleration, relative to Earth's acceleration due to gravity
H2: hydrogen
He: helium
Hz: Hertz
ID: inside diameter
LPM: liters per minute
MFM: mass flow meter
MHz : megahertz
Min: minute
mTorr: milliTorr
NASA: National Aeronautics and Space Administration
N2: nitrogen
N/A: not applicabale
N/T: not tested
NVR: non-volatile residue
O2: oxygen
OD: outside diameter
RE: radiated emissions
RGA: residual gas analyzer
RS: radiated susceptiblility
Sccm: standard cubic centimeter per minute
SDS: sample delivery system
sLpm: standard liters per minute