Demonstrating Pump Performance for Fusion Fuel Cycle Conditions

Cesar D. Camejo, David Dogruel, William L. Kubic, Victoria Hypes-Mayfield* and Joseph H. Dumont*

Los Alamos National Laboratory, Los Alamos NM 87545, USA
Correspondence: vhypes@lanl.gov, joseph.dumont@lanl.gov

Prepared for: IFE Science and Technology Strategic Planning Workshop
February 22-24, 2022

EXECUTIVE SUMMARY

Deuterium-tritium fusion reactors require specialized pumps for tritium operations due to hydrogen exchange possible with tritium. The Hydrogen Processing Laboratory (HPL) at Los Alamos National Laboratory, a flexible system dedicated to responding to experimental needs of the fusion community, has the capability to evaluate various pump technologies. These systems commonly considered for gas processing for the fusion fuel cycle from laboratory scale to glovebox scale. All-metal "dry" scroll and metal bellows pumps, which preclude the exchange of tritium and deuterium with oils and polymeric materials, are the primary pumping technologies utilized at the HPL. The system's flexibility permits comparative tests of different pumps and pump trains, as well as interfacing with permeators and catalyst beds for further fuel cycle research and development. Testing conditions, including the evacuation of gasses from tank volumes, and pumping flowing feed gasses and mixtures over a broad composition range are similar to those found in fusion fuel cycle environments. The variables of pressure, from high vacuum to approximately two atmospheres and flowrate, from single digit standard cubic centimeters to tens of liters per minute, are measured throughout the system.

Introduction

Deuterium-tritium fusion reactors require specialized pumps to produce a vacuum in the fuel processing systems. These pumps must produce a pressure differential which will cause the hydrogen (H_2) isotopes to diffuse through a membrane, separating it from other gasses in order to be captured and processed. Due to tritium's similarities in chemical properties with chemically bound H_2, the isotope is able to exchange with H_2 in polymers found in oils and plastics, thus the need for dry, all-metal pumps. [1] All-metal pumps prevent the exchange of H_2 isotopes, which reduces the amount of tritiated waste generated by the power plant. [2] All metal pumps also require less maintenance since oils or tip seals do not need to be replaced. [3] One of the challenges of manufacturing an all-metal scroll pump is the ability to keep tight tolerances throughout the pump. [2] The rotor and stator must be in extremely close proximity in order to be hermetically sealed, but they must not come into contact since the lack of lubrication will cause the surfaces to wear out and need replacement. These manufacturing requirements have led to a limited inventory worldwide, driven by the fact that only one commercial company has successfully met this challenge. [3-5]

Normetex, a French company which focused on developing pumps for tritium applications, developed the all-metal scroll pump which is constructed completely of stainless steel, hermetically sealed, uses no polymers, and can operate over 30000 hours between maintenance. [4,6] Since the closure of Normetex, several companies have focused on developing a proper replacement. Air-Squared is currently developing a dry all-metal scroll pump of similar dimensions, power, and volumetric flow as Normetex 15 pumps. So far, there is very little data that compares the performance of both units under conditions relevant to the fusion fuel cycle.

At Los Alamos National Laboratory, the Hydrogen Processing Laboratory (HPL), was assembled in order to do non-tritium testing for the fusion fuel cycle. The HPL is a flexible system that can respond to existing and emerging experimental needs for the US and international fusion program, including ITER. Some modifications to the HPL have been made to perform fusion relevant pumping experiments with non-tritium gasses. [7]

Experimental

The pump testing station of the HPL has been assembled to test the performance of several scroll pumps and pump train configurations under common fuel cycle conditions. The system pairs a scroll pump (Normetex or Air-Squared) backed by a metal bellows pump (MB601), a common configuration for tritium service. [8,9] The gas feed system utilizes several mass flow controllers, which allow for gas delivery from a large variety of flowrate ranges, as well as from different gasses and mixtures. Baratron-type transducers ranging from 0.05 Torr up to 2000 Torr measure the pressure of tank volumes, pump inlets and outlets. The 0.05 Torr pressure transducer allows for accurate low-pressure measurements at the scroll pump inlet. The HPL's pump assembly will provide data for a broad range of pumping environments, which can be used to develop and validate models for fusion fuel cycle development. The pump testing apparatus is shown in Figure 1.

Figure 1. HPL Pump Test Assembly

Typically, pump performance is tested by filling a 20 L tank with a gas or gas mixture to pressures up to 1200 Torr. The metal bellows pump is started, and a valve at the pump inlet is then opened to allow gas flow. After the scroll pump inlet pressure, decreases appropriately, the scroll pump is started. In initial experiments, the metal bellows pump demonstrated the ability to reach pressures of 30 Torr, while the bellows-backed scroll pump has reached pressures as low as 2 mTorr. The metal bellows pump can drop pressures from 95 Torr down to 40 Torr in about 400 seconds from a 20 L tank filled with helium (He). Once the scroll pump is started, pressures begin to drop rapidly. Using He, pressures equilibrate at around 4 mTorr in about 750 seconds after the scroll pump is started. When using higher molecular weight gasses such as argon (Ar), the system takes about 2400 seconds to equilibrate once the scroll pump is initiated, but pressures of 2 mTorr were reached. Figure 2 shows an ultimate vacuum pumpdown test after filling the tanks with He, where the scroll pump was started once the diaphragm pump brought down pressures to 40 Torr.

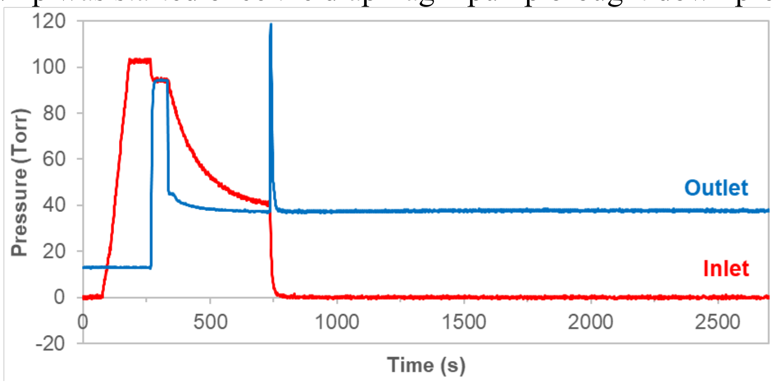

Figure 2. He ultimate vacuum test (scroll pump started at 40 Torr)

Scroll pump volumetric flow has also been tested by filling the tanks with gas, and initiating evacuation using a metal bellows pump. The scroll pump is started at inlet pressures between 40 Torr and 100 Torr, and outlet flow is measured using a flow meter. The tests conducted used He, nitrogen (N_2) and Ar separately. The flowrate was calculated using the data provided from a pressure transducer at the pump train inlet, as well as the tank volume, and time differential between pressures.

Results

The HPL's data acquisition system provides temperature, pressure, and flow data that give us an *in situ* description of the system. In order to calculate the volume of the manifold constructed for pump testing, the volume of one isolatable portion was accurately determined by gravimetric analysis, and a PV expansion gave the completed volume. The final pressure of the system was measured using two pressure transducers. Since the initial pressure and volume, and final pressure were known, we were able to calculate the total volume using equation (1):

$$P_1V_1 = P_2V_2 \quad (1)$$

Subsequent experiments involved filling the total tank volume with N_2 at varying pressures, and then closing all valves surround the two tanks. Then, a valve located between the diaphragm pump inlet and scroll pump outlet was opened slowly while the diaphragm pump was operating. The scroll pump was then started when sufficiently low pressures were reached. Tests were performed in triplicate. Using Baratron-type transducers at both the inlet and outlet of the scroll pump, data was acquired which was used to plot the system pressures at different starting parameters as shown in Figure 3.

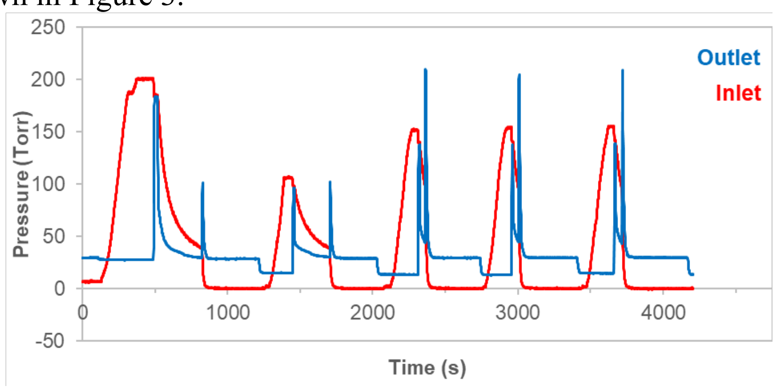

Figure 3. 40 Torr and 100 Torr N_2 scroll pump tests

These tests also provided data, which was used to measure the scroll pump's performance by plotting the volumetric flow rate (L/s) over pressure (Torr). This plot allows us to compare the pump's performance over a range of pressures, as shown on Figure 4. The initial flow rate (on right side of plot, above 100 Torr) is close to zero since only the diaphragm pump is operating, and the system has reached equilibrium. Once the scroll is initiated at 100 Torr, there is a large spike in flowrate with a peak of 2.53 L/s at 55 Torr. Peak outlet flows for the three gasses tested were 4.72 L/s for He, 3.63 L/s for N_2, and 2.31 L/s for Ar. These three tests demonstrate an inverse correlation between molecular weight and peak volumetric flow

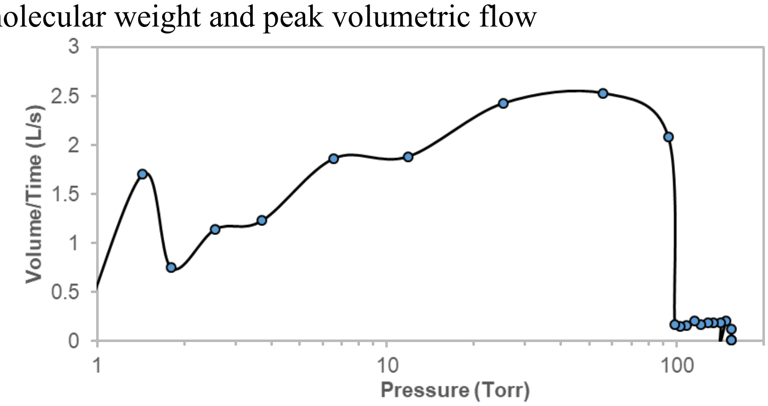

Figure 4. Flowrate *vs*. Pressure (N_2)

Three additional N_2 pump tests were performed for total pumpdown, where the pumps operated on the tanks until the system-pressure no longer changed significantly. These tests lasted between 35 minutes and 40 minutes, and a pressure of 0.002 Torr was reached on the scroll pump inlet for all three tests. These replicate ultimate vacuum plots were plotted together in order to compare consistency as shown below in Figure 5a. A standard deviation plot was created using Excel for each data point as shown on Figure 5b to confirm that the pressure had equilibrated.

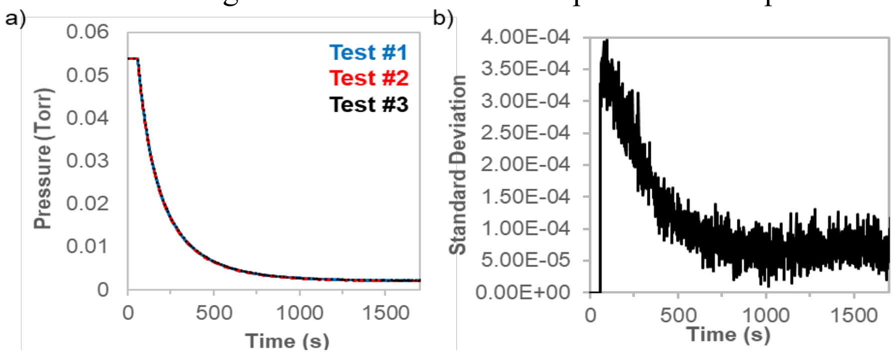

Figure 5. a) Comparison of N_2 ultimate vacuum tests and b) corresponding standard deviation (3-test average)

Ultimate vacuum and pumping speed tests were also performed three times with Ar and He. Future work will include repeating these tests with different gasses to allow us to measure pump performance under varying conditions, and also the effects of the gasses' molecular weight and conductivity on pumping speed and ultimate vacuum. These results were plotted in order to compare the effects of gasses on pumping speed.

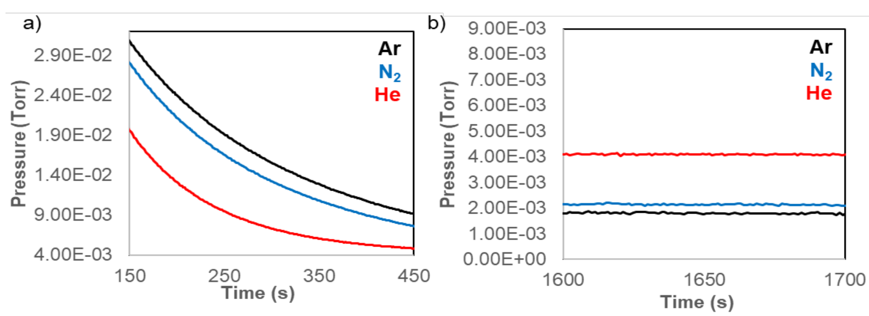

Figure 6. a) Ar / N_2 / He Pump Test Slope Comparison; b) Ar / N_2 / He Ultimate Vacuum Comparison. All curves show an average of three tests.

Figure 6a shows that gasses of lower molecular weight (He) are pumped faster with the slope of the plot for He decreasing more rapidly in comparison to the other gases. On the other hand, Figure 6b shows that even though He was pumped out of the system at the greatest rate, the ultimate vacuum performance was better for gasses of higher molecular weight.

Summary and future work

A pump testing apparatus has been developed at the HPL in order to perform fusion relevant testing. The pumping station is able to mimic the conditions of a fusion reactor, as well as collect pressure and flow data. The system also allows for the rapid exchange of components, such as the scroll and diaphragm pumps, pressure transducers, and flow controllers. Initial experiments have been performed using a Normetex scroll pump (Normetex 15) backed by a diaphragm pump (MB601). The first set of tests used Ar, He, and N_2 individually in order to fill the two tanks and were performed in triplicate to confirm consistency. So far, results have shown the effects of gas properties on pumping speed and ultimate vacuum on. The data gathered by the pressure transducers has also permitted the calculation of maximum pumping speed over a range of pressures.

This configuration will be used to do additional fusion-relevant tests such as H_2, compressed air, and carbon dioxide pumpdowns. These gasses will first be tested individually, but will then be tested as mixtures with similar compositions as those found in fusion facilities. The station will also be used to test more pumps, such as the Air-Squared scroll pump and other pump train configurations that will be essential for the community. Finally, the experimental results will be used to develop models to be used for systems design. The HPL will gather pump performance data under fusion related conditions which is critical for the development of fusion facilities. Out tests will provide insight on maximum flow rate, ultimate vacuum, and performance under various gas mixtures and configurations.

Fusion-relevant pumping experiments have been conducted to characterize the performance of a Normetex scroll pump under varying conditions: the scroll pump has operated with He, N_2, and Ar and various feed pressures. The systems pump-down time has also been measured under the same three gasses using a 20 L tank to simulate a large volume. Experimental results show the proportional relationship between molecular weight and pump-down time, and also show that the pump produces a higher vacuum when the tanks are filled with higher molecular weight gasses. Ongoing work will expand upon the same experiments, but using carbon dioxide, compressed air, and H_2 in order to determine these gasses' effects on pump performance. After tests with the Normetex to characterize the pump and establish the baseline performance of the Normetex/metal bellows pump configuration, an Air-Squared scroll pump will replace the Normetex pump, and this pump's performance will be measured under the same conditions. These pumping experiments will provide a better understanding of the performance of the Air Squared all-metal scroll for fusion fuel cycle applications. Additionally, pump configurations will be applied to a range of permeation scenarios which will be used as input to refine and validate permeation models. These models will be used to develop and refine system designs.

Acknowledgements

Los Alamos National Laboratory is operated by Triad National Security, LLC, for the National Nuclear Security Administration of the US Department of Energy under Contract No. 89233218CNA000001. This work was funded by Los Alamos National Laboratory Chemistry Division office. Mr. Camejo was supported by the NNSA Minority Serving Institutes (MSIPP) Partnership for Research and Education Consortium in Ceramics and Polymers (PRE-CCAP); grant DE-NA0003947. The authors wish to thank Dr. Chandra Marsden and Dr. John Kline for their support and insightful discussions as well as Dr. Guinevere Shaw from U.S. Department of Energy's (DOE) Office of Science, Fusion Energy Sciences for her continuous support.

References

1. Dorfman, L.M.; Mattraw, H. The exchange reaction of hydrogen and tritium. *The Journal of Physical Chemistry* **1953**, *57*, 723-725.
2. Coffin, D.O. A tritium-compatible high-vacuum pumping system. *Journal of Vacuum Science and Technology* **1982**, *20*, 1126-1131, doi:10.1116/1.571586.
3. Morgan, G.A. Performance Testing of a Potential Replacement for Normetex Pump. *Fusion Science and Technology* **2017**, *71*, 478-484, doi:10.1080/15361055.2017.1293454.
4. Boone, L.; Foster, P.J. *Normatex Pump Replacement*; 2013.
5. Priester, F.; Bornschein, B. TriToP – A compatibility experiment with turbomolecular pumps under tritium atmosphere. *Vacuum* **2013**, *98*, 22-28, doi:https://doi.org/10.1016/j.vacuum.2012.09.006.
6. Clark, E.A. *Normatex Pump Alternatives Study*; Savannah River National Laboratory: 2013.
7. Dogruel, D.; Hollis, W.K. *LANL Hydrogen Processing Laboratory (HPL), Data acquisition and control system upgrade*; United States: United States.
8. Nicholas, N.; Shaffer, B. All-Metal Scroll Vacuum Pumps for Tritium Processing Systems. *Fusion Science and Technology* **2020**, *76*, 366-372, doi:10.1080/15361055.2020.1712988.
9. Chang, M.H.; Cho, S.; Lim, J.Y.; Kang, S.B.; Lee, M.K.; Yun, S.-H.; Kang, H.-G.; Song, K.-M.; Kim, D.; Chung, H. Performance Test of Pump Combination Between Normetex 15 Scroll and MB 601 Pumps. *Fusion Science and Technology* **2011**, *60*, 918-921, doi:10.13182/FST11-A12566.