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Title: Production Facility Prototype Blower 1000 Hour Test Results II

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Production Facility Prototype Blower 1000 Hour Test Results II

12/22/2017

Alexander Wass, Keith Woloshun, Greg Dale, Dale Dalmas, Frank Romero

Introduction

Long duration tests of the Aerzen GM 12.4 roots style blower in a closed loop configuration provides valuable data and lessons learned for long-term operation at the Mo-99 production facility. The blower was operated in a closed loop configuration with the flow conditions anticipated in plant operation with a Mo-100 target inline. The additional thermal energy generated from beam heating of the Mo-100 disks were not included in these tests. Five 1000 hour tests have been completed since the first test was performed in January of 2016. All five 1000 hour tests have proven successful in exposing preventable issues related to oil and helium leaks. All blower tests to this date have resulted in stable blower performance and consistency. A summary of the results for each test, including a review of the first and second tests, are included in this report.

First 1000 Hour Operations Test (Recap)[1]

The first 1000 hour test was performed from 12/9/15 to 1/31/16 at a helium pressure of 2.5 MPa (365 psig) and a blower speed of 1800 RPM. A throttling valve was used to mimic the flow pressure drop expected from the target in actual plant operation. The differential pressure across the blower was nominally 120 kPa (17.4 psi), the helium mass flow rate was roughly 325 g/s, the power measured from the VFD was about 25 kW, the blower torque was estimated at 130 N-m, and the helium temperature rise across the blower was 10°C. Complete details for this test is shown in the report, "Production Facility Prototype Blower 1000 Hour Test Results", and is included in Appendix A.

At the completion of this 1000 hour test, an oil leak was discovered near the shaft seal of the blower. A thinly distributed coating of oil was discovered over the majority of the tank interior. Figures 1 and 2 show traces of oil that have dripped from the shaft seal onto the blower and pressure vessel. After investigation, it was discovered that the sealing covers had not been removed. These are vent ports that allow for pressure equalization between the oiled bearing housing and atmospheric conditions, in this case, pressurized helium. The shaft seal was also replaced in preparation for the next 1000 hour test.

[1] K. Woloshun et. al., LA-UR-16-27971, Production Facility Prototype Blower 1000 Hour Test Results, 2016

Figure 1 – Oil drip trace at the shaft seal of the blower.

Figure 2 - Oil on the vessel bulkhead, and dripping to the platform below after opening the tank.

Second 1000 Hour Operations Test (Recap)[1]

The second 1000 hour test was performed from 4/21/16 to 6/9/16 at a helium pressure of 2.6 MPa (377 psig) and a blower speed of 1800 RPM. During this test, a six hour stoppage every six days was included to simulate the periodic change-out of a target. Just like the first test, a throttling valve was used to mimic the flow pressure drop expected from the target in actual plant operation. The differential pressure across the blower was nominally 120 kPa (17.4 psi), the helium mass flow rate was roughly 330 g/s, the power measured from the VFD was about 20 kW, and the helium temperature rise across the blower was about 9°C. Complete details for this test is also shown in the report, "Production Facility Prototype Blower 1000 Hour Test Results", and is also included in Appendix A.

At the completion of this second 1000 hour test, another oil leak was discovered at the shaft seal. After discussions with the vendor, a "gas tight" seal configuration was recommended and installed. The primary feature of this upgrade was a double seal arrangement at the shaft, with a grease packing between the seals. The blower was re-installed and operated with atmospheric air for 1000 hours to establish a performance baseline, described in the next section.

Third 1000 Hour Operations Test

The third 1000 hour test was performed from 11/28/16 to 1/17/17 using air at local atmospheric pressure (Los Alamos atmospheric pressure is 77.9 kPa or 11.3 psia) and a blower speed of 1800 RPM. During this test, a six hour stoppage every week was included to simulate the periodic change-out of a target. Just like the previous tests, a throttling valve was used to mimic the flow pressure drop expected from the target in actual plant operation. The differential pressure across the blower was about 31.8 kPa (4.6 psi), the air mass flow rate was roughly 76 g/s, the power measured from the VFD was about 5.4 kW, the air temperature rise across the blower was about 44°C, and the blower shaft torque was 29 N-m. The third 1000 hour test results beginning at 500 hours for one week can be seen in Figs. 3-8.

The new blower shaft-seals were inspected weekly and no oil leaks were found from the new high-pressure seals. After completing the long-duration tests with air, the system was pressurized with helium for another 6-week long test in high pressure helium, discussed in the next section.

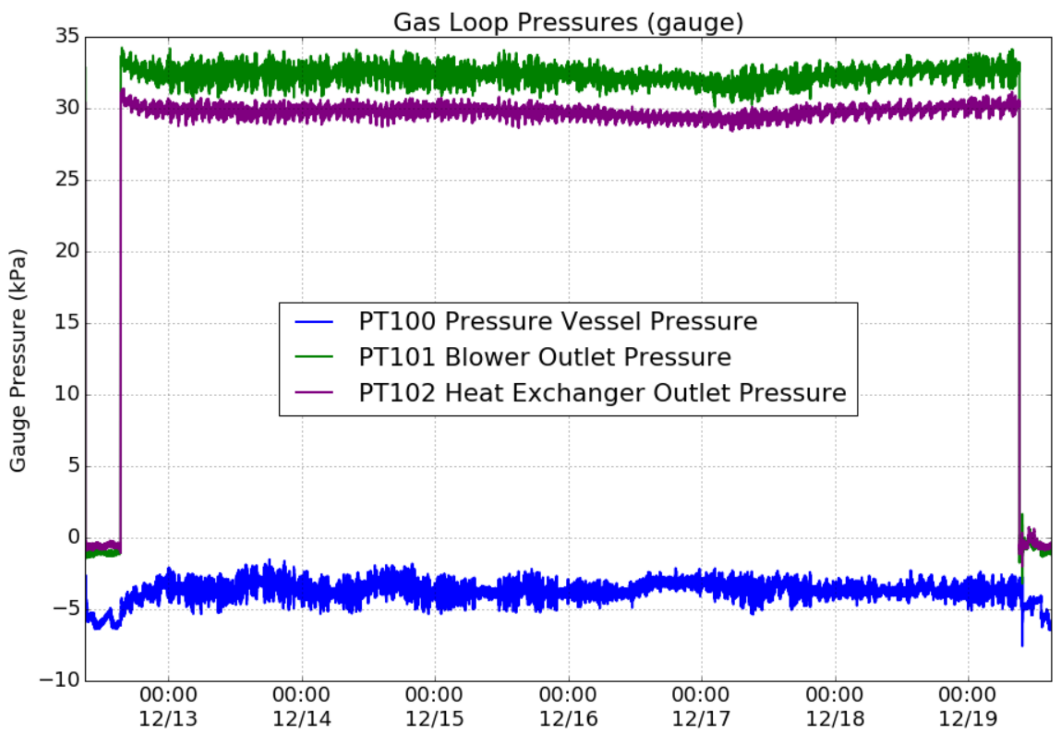

Figure 3 – Gas loop pressures for one week beginning at 500 hours for third 1000 hour test. The gas flow loop pressures is measured with three pressure transducers. The pressure vessel pressure, which is also the blower inlet pressure, is measured with PT100. The blower outlet pressure is measured with PT101. The heat exchanger outlet pressure, which would also be the target inlet pressure in a production system, is measured with PT102. There appears to be an issue with PT100, although the disagreement with the other pressure transducers when the blower is off is within the 0.25% full scale accuracy of the transducers, which is 8.62 kPa (1.25 psi) for these 34.5 kPa (500 psi) full scale transducers. This difference should not be an issue when running the system pressurized with helium.

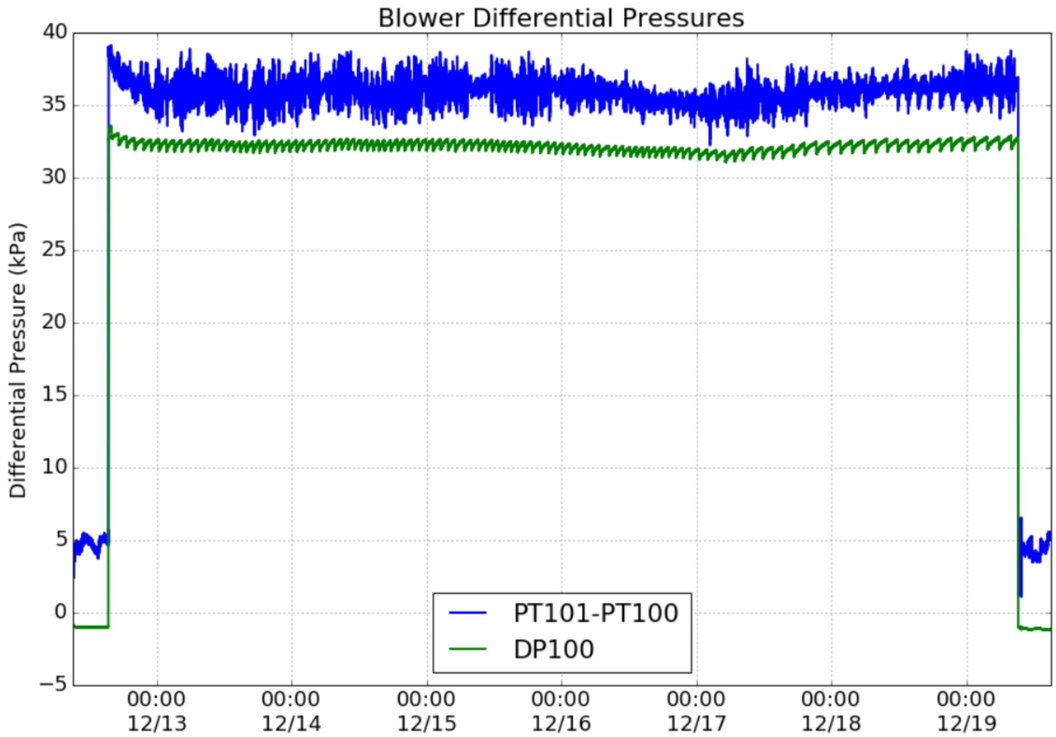

Figure 4 – Blower differential pressures for one week beginning at 500 hours for third 1000 hour test. The blower pressure head measured with the differential pressure transducer is compared with the blower head calculated by subtracting the pressure vessel pressure (PT100) from the blower outlet pressure measurement (PT101).

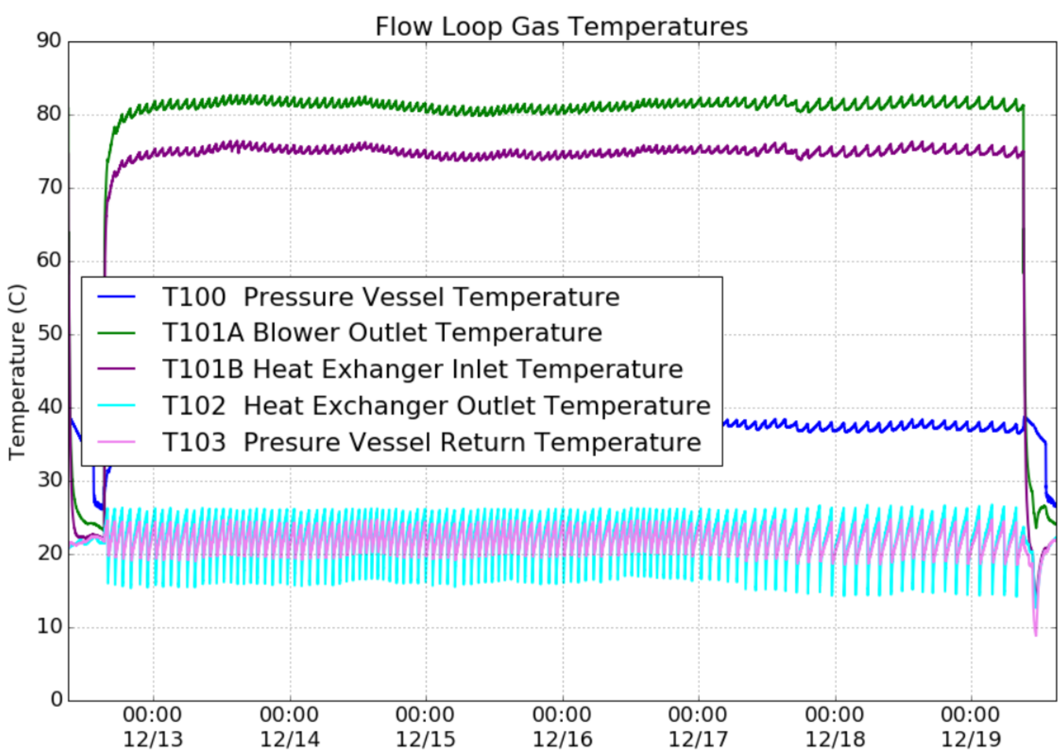

Figure 5 – System temperatures for one week beginning at 500 hours for third 1000 hour test. The temperature of the gas in the pressure vessel, which is also the blower gas inlet temperature, is measured with T100. The blower outlet temperature is measured with T101A. There is a fairly long pipe run between the blower outlet and the heat exchanger inlet. Therefore, a second thermocouple, T101B, is used to measure the gas inlet temperature to the heat exchanger to account for any heat loss to the room over this pipe run. The heat exchanger gas outlet temperature is measured with T102. This would also be the target inlet temperature in a production system. The temperature of the gas return to the pressure vessel is measured with T103.

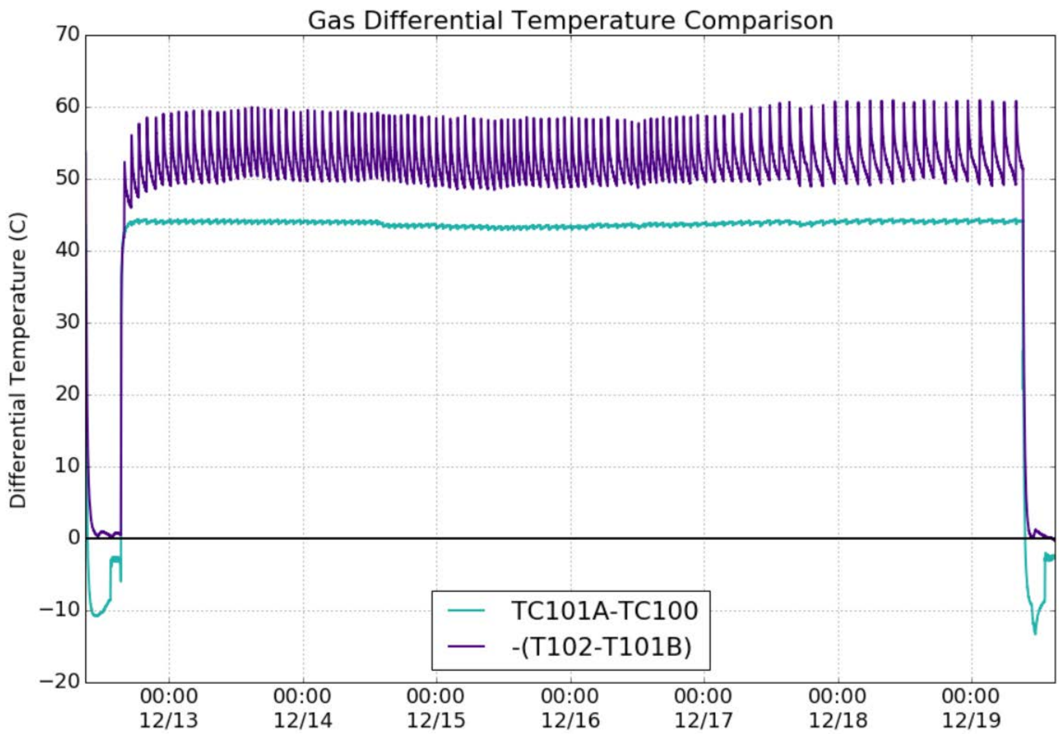

Figure 6 – Blower differential temperature for one week beginning at 500 hours for third 1000 hour test. The gas temperature rise from the blower is compared to the gas temperature rejected to the heat exchanger. The sign on the gas temperature rejected to the blower was inverted to compare the two curves. It's rather interesting that the gas temperature lost to the heat exchanger is higher than the temperature added to the gas from the blower. We would not normally expect this. But, in inspecting the raw thermocouple data above, we see that the gas return temp is less than the pressure vessel gas temperature. The reason the pressure vessel gas temperature is higher is because the motor and the blower case are both rejecting heat to the surrounding gas in the pressure vessel. So, the heat rejected to the heat exchanger is higher than the thermal energy added to the gas by the blower by the amount of heat loss from the motor and the outside case of the blower.

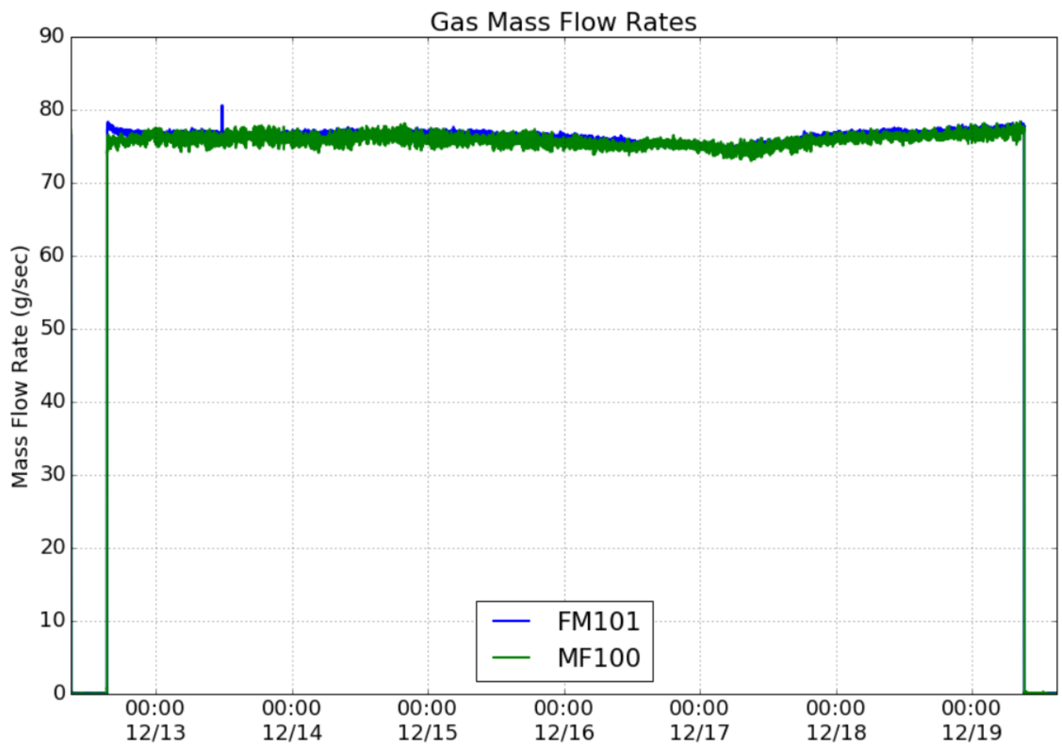

Figure 7 – Mass flow rates for one week beginning at 500 hours for third 1000 hour test. The mass flow rates from the vortex flow meter (FM101) and the mass flow rate calculated from the turbine flow meter (FM100 -> MF100) are compared.

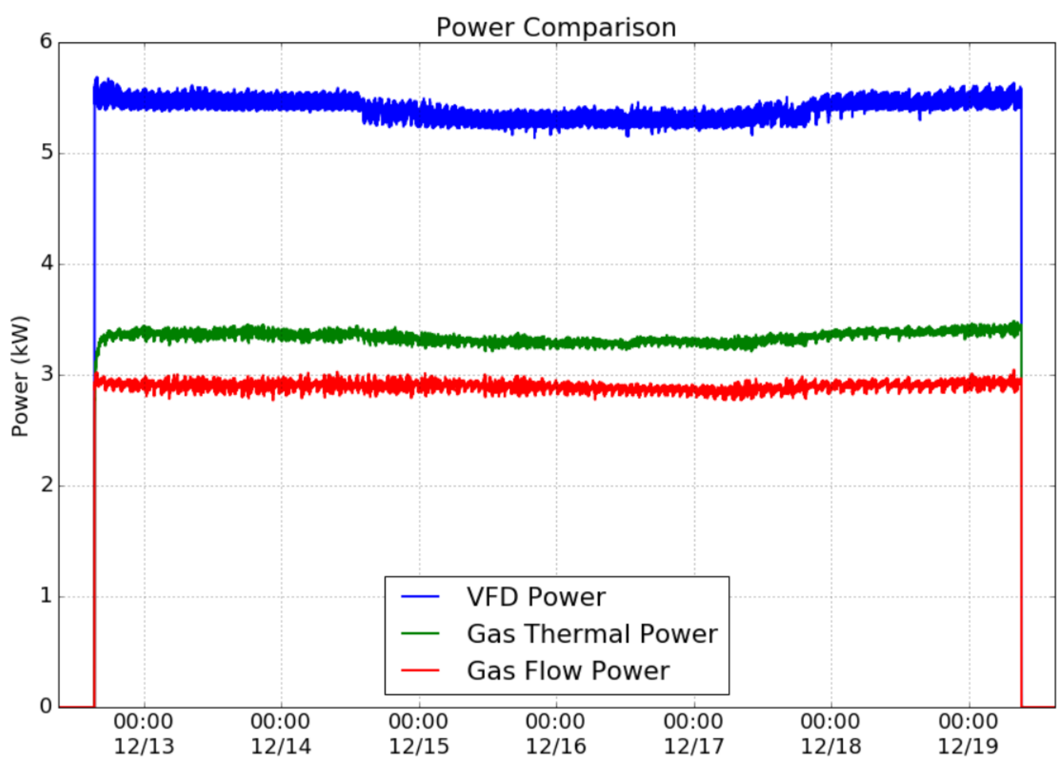

Figure 8 – System power comparison for one week beginning at 500 hours for third 1000 hour test. The gas thermal power is calculated by $q_T = \dot{m} C_p \Delta T$, where $\dot{m}$ is mass flow rate, C_p is specific heat at

constant pressure, and ΔT is the temperature difference. (Even though the blower "compression" is not a constant pressure process, the pressure change is such a small fraction of the absolute pressure that we can use this equation.) The gas flow or hydraulic power is determined from $q_h = \Delta P Q_{in}$, where ΔP is the pressure differential across the blower, and Q_{in} is the blower inlet volumetric flow rate.

Fourth 1000 Hour Operations Test

The fourth 1000 hour test was performed from 2/9/17 to 3/30/17 using high pressure helium at 2.28 MPa (330 psig) and a blower speed of 1800 RPM. The pressure vessel flange was sealed with a BLUE-GARD Style 3000 polymer type gasket with a bolt torque of 1600 ft-lb. During this test, a six hour stoppage every week was included to simulate the periodic change-out of a target. Just like the first test, a throttling valve was used to mimic the flow pressure drop expected from the target in actual plant operation. The differential pressure across the blower was nominally 124 kPa (18 psi), the helium mass flow rate was roughly 320 g/s, the power measured from the VFD was about 20 kW, the blower torque was 107 N-m, and the helium temperature rise across the blower was about 10°C. When one helium gas cylinder was open, the leak rate was roughly 5.6 ft^3/hr and lasted about two days. When both bottles were open, the leak rate increased to about 10.2 ft^3/hr. This resulted in almost double the helium loss when both bottles were open. The fourth 1000 hour test results beginning at 500 hours for one week can be seen in Figs. 9-15.

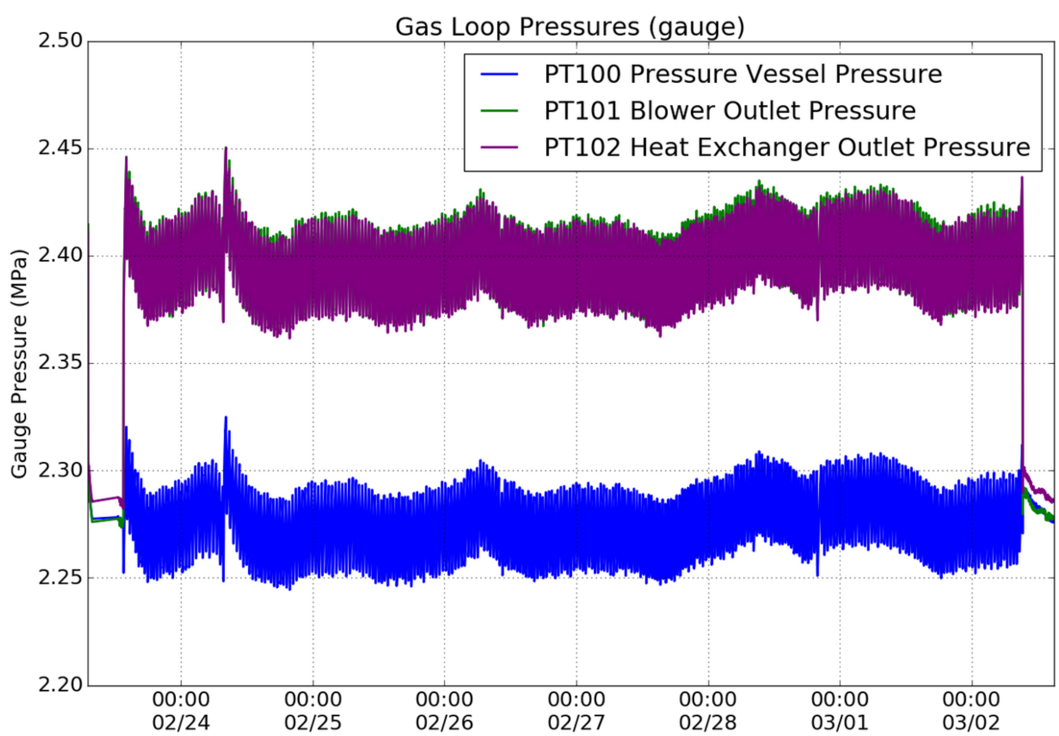

Figure 9 - Gas loop pressures for one week beginning at 500 hours for fourth 1000 hour test.

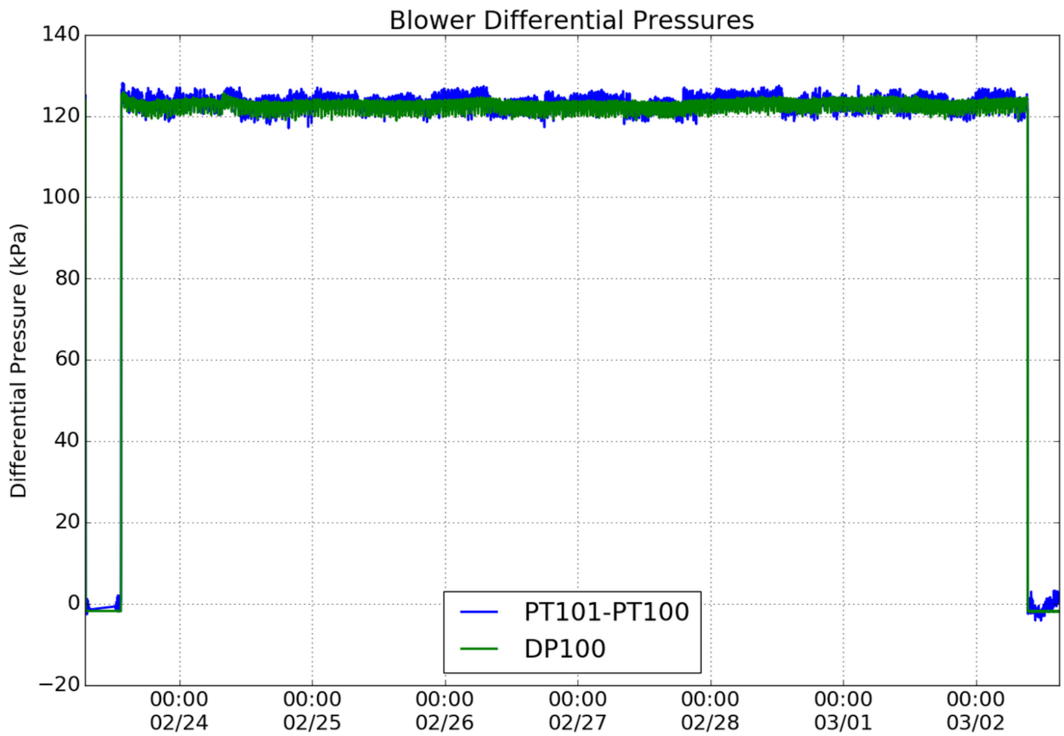

Figure 10 - Blower differential pressures for one week beginning at 500 hours for fourth 1000 hour test.

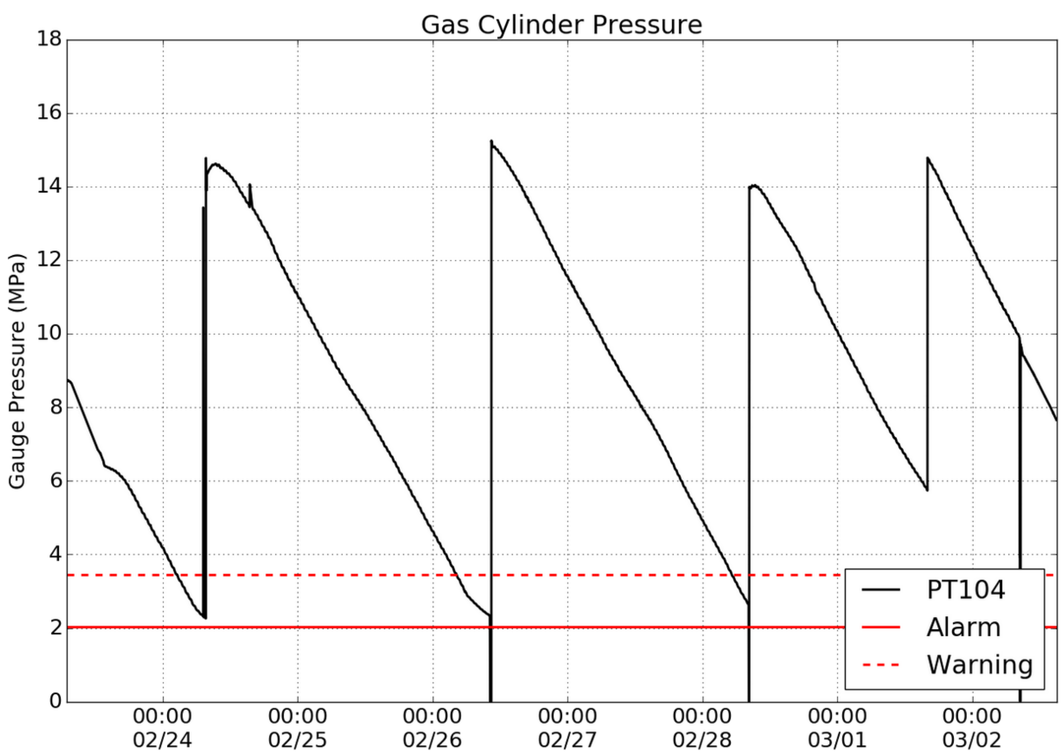

Figure 11 – Gas cylinder pressures for one week beginning at 500 hours for fourth 1000 hour test.

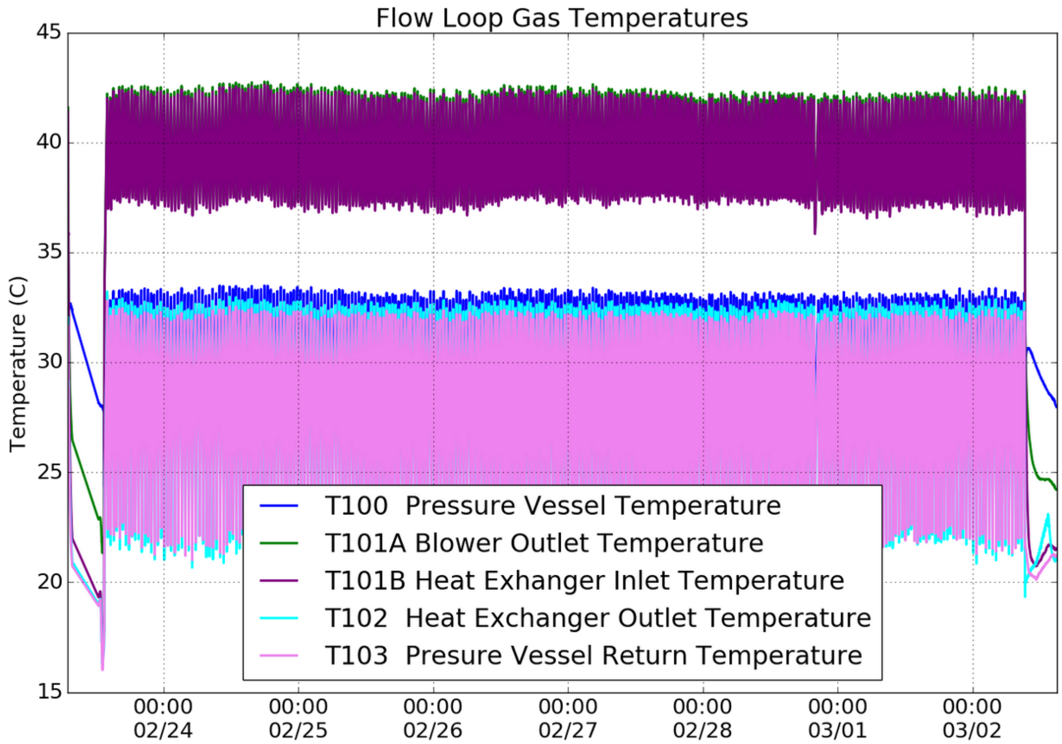

Figure 12 - System temperatures for one week beginning at 500 hours for fourth 1000 hour test.

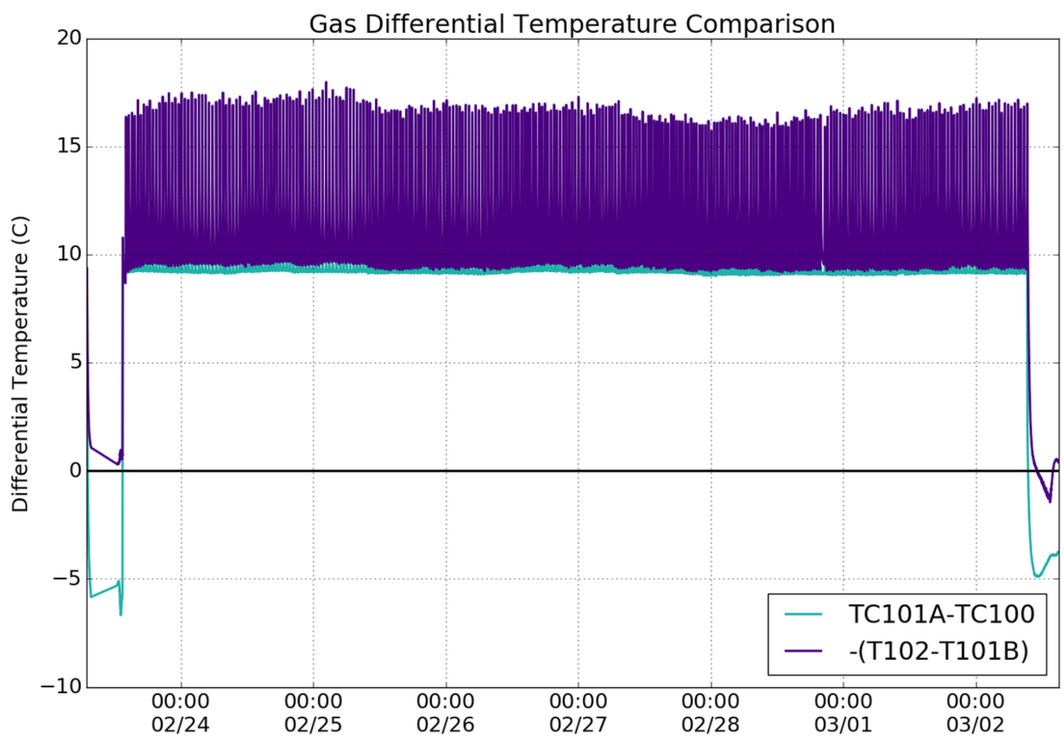

Figure 13 – Blower differential temperature for one week beginning at 500 hours for fourth 1000 hour test.

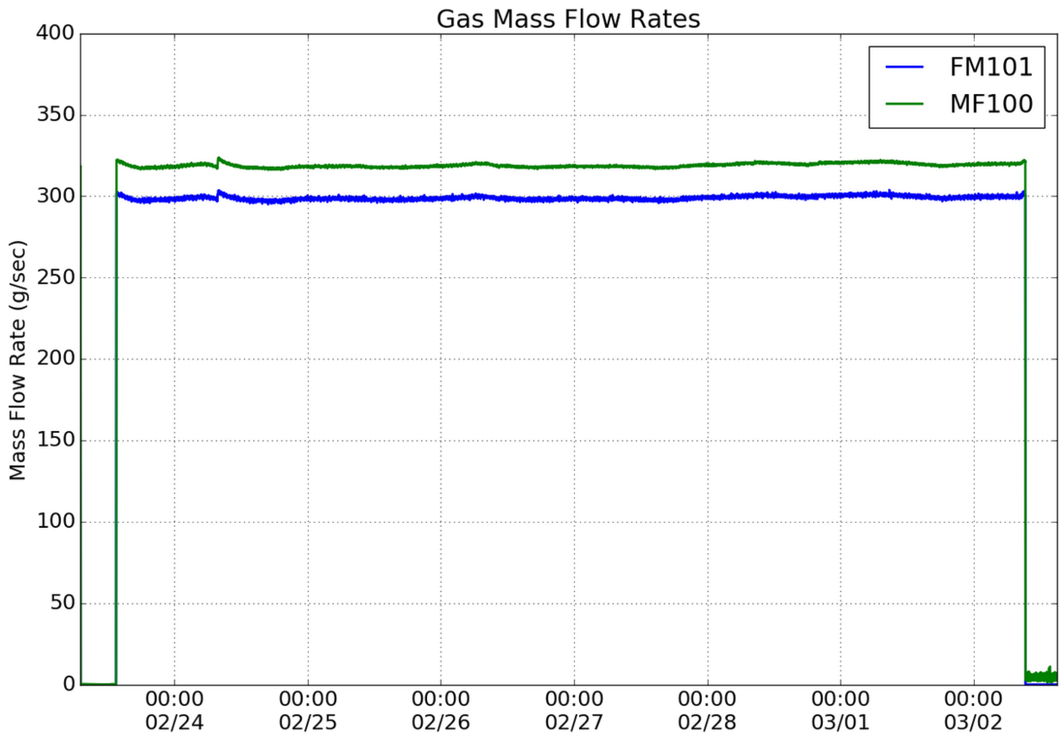

Figure 14 - Mass flow rates for one week beginning at 500 hours for fourth 1000 hour test.

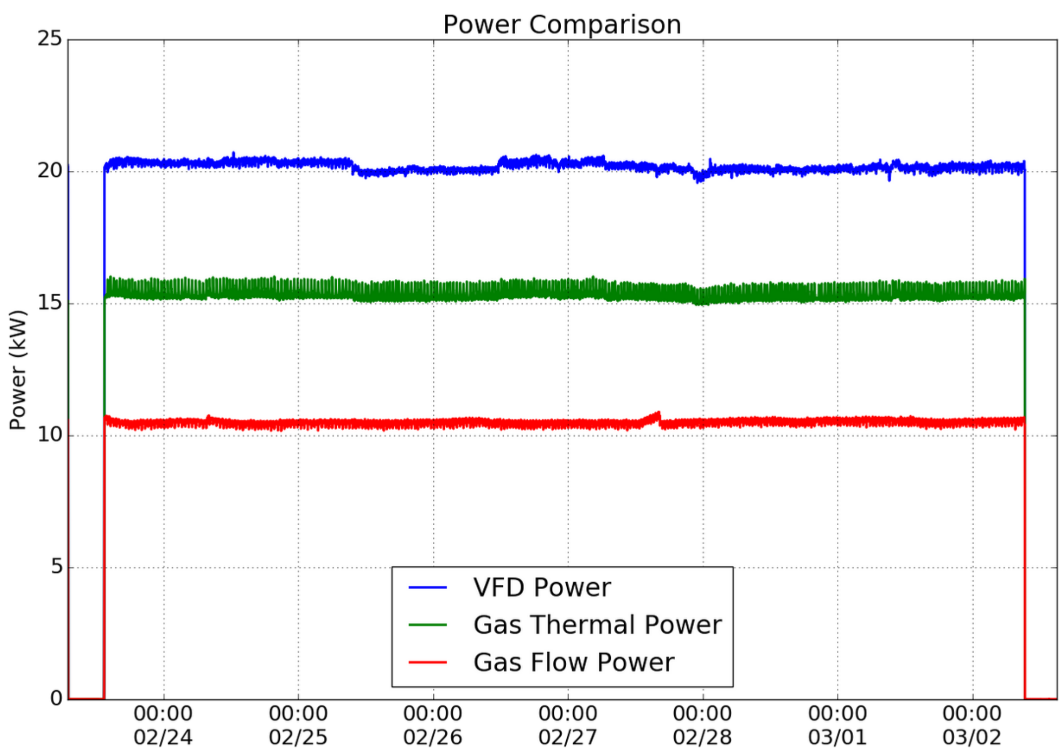

Figure 15 - System power comparison for one week beginning at 500 hours for fourth 1000 hour test.

Upon completion of this 1000 hour test, the pressure vessel was depressurized and opened. We found that the drive shaft on the blower was seized and wouldn't move. This shaft usually moves freely and was rotating fine during operation (there was no indication of increased power or torque required to turn the blower during the test). It was also found that some grease had squeezed out of the motor side shaft bearing. After consultation with the blower manufacturer, it was suspected that the new high-pressure shaft seals were still holding pressurized helium in the gearbox, which was compressing the bearings and preventing the shaft from rotating. The oil fill ports were removed from the blower and indeed, one of the blower gearboxes was holding pressure. After relieving this pressure, the blower shaft rotated freely. Pressure held-up in the gearbox by the high pressure shaft seals also likely caused the small grease leak that was observed.

A pressure relief system, shown in Figs. 16-17, was designed and installed to relieve the gas pressure in the blower gearbox which occurs during high pressure helium operation, and when pressurizing and depressurizing the pressure vessel for maintenance. The oil fill plugs were connected through a check valve to a coalescing oil filter. A manual valve, normally closed, was included to allow for pressure bleed in case the check valve or filter was clogged, and pressure needed to be released to the atmosphere. This system will allow any pressure buildup in the gearbox to be released into the pressure vessel and filtered of any residual oil.

Figure 16 – Installed pressure relief system to relieve pressure from the blower gear boxes.

Figure 17 - Installed pressure relief system to relieve pressure from the blower gear boxes.

Prior to the latest 1000 hour test with helium, a week-long test of the blower system in air was performed from 5/23/17 to 5/30/17 to test the new components and to verify that there was no damage to the bearings and oil seals during the last operation. The blower was operated at atmospheric pressure at 1800 RPM, a blower torque of 30 N-m, and a mass flow rate of 78 g/s air. Once complete, it was discovered that the current check valve was allowing oil to escape through the coalescing filter and into the pressure vessel. To resolve this issue, the pressure relief system was reconfigured with a 25 psi check valve so that the pressure is relieved only when the gear box pressure is 25 psi greater than vessel pressure. Once again, the blower was operated in air at atmosphere from 7/11/17 to 7/19/17 to confirm that the modifications were working. The blower speed was 1800 RPM, the blower torque was 27 N-m, the mass flow rate was 76 g/s air, and the blower differential pressure was 37 kPa.

After inspection, no oil leaks were identified and the pressure vessel was prepared for the next 1000 hour test with high pressure helium. A Garlock FLEXSEAL RW graphite impregnated spiral wound gasket was installed on the pressure vessel to replace the Garlock BLUE-GARD Style 3000 polymer type, hoping to reduce helium leak rate from the system. The next test contained helium at 300 psig and is described in the next section.

Fifth 1000 Hour Operations Test

The fifth 1000 hour test with helium was performed from 8/28/17 to 12/18/17 which included weekly six hour stoppages to simulate the periodic change-out of a target. Just like the previous tests, a throttling valve was used to induce a flow pressure drop, which is slightly lower than the production target. The pressure vessel on the production prototype helium flow system was pressurized with helium to 2068 kPa (300 psig). The helium mass flow rate was 272 g/s with a differential pressure of 108 kPa (15.7 psi). The blower torque was about 93 N-m, and the blower gas temperature rise was roughly 9°C.

On 9/21/17 at 559 hours, the blower was shut down to update operating permissions (IWD) and to plumb in the Watlow resistive heater test hardware. The blower was restarted on 11/27/17. Since the pressure drop of the new test hardware was larger than the throttling valve, the blower speed was reduced to 900 RPM. The blower torque was about 100 N-m, and the helium mass flow rate was 79 g/s with a differential pressure of 129 kPa (18.7 psi). The rise in gas temperature through the blower was about 17°C. The fifth 1000 hour test results beginning at about 500 hours for one week can be seen in Figs. 18-24. The pressure vessel will be opened prior to the next 1000 hour test to determine if we have a blower oil leak free system.

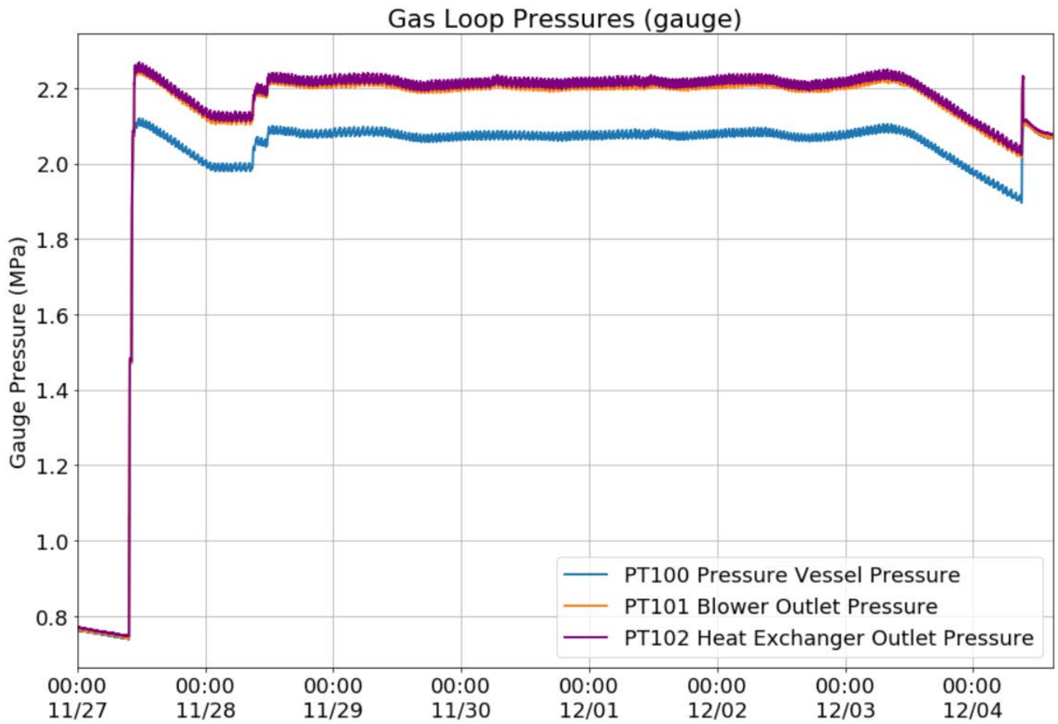

Figure 18 - Gas loop pressures for one week beginning at 500 hours for fifth 1000 hour test. Pressure loss at the beginning of this week was due to regulator adjustments. At the end of this week, the empty gas cylinders were not replaced in time, and the pressure vessel pressure dropped slightly.

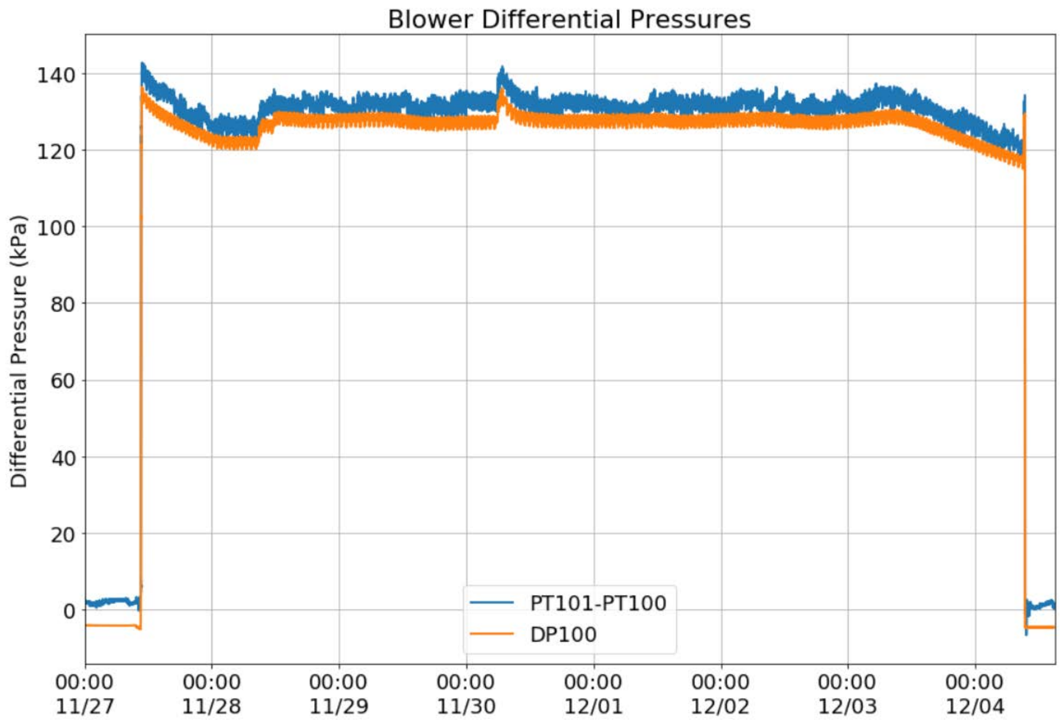

Figure 19 – Blower differential pressures for one week beginning at 500 hours for fifth 1000 hour test.

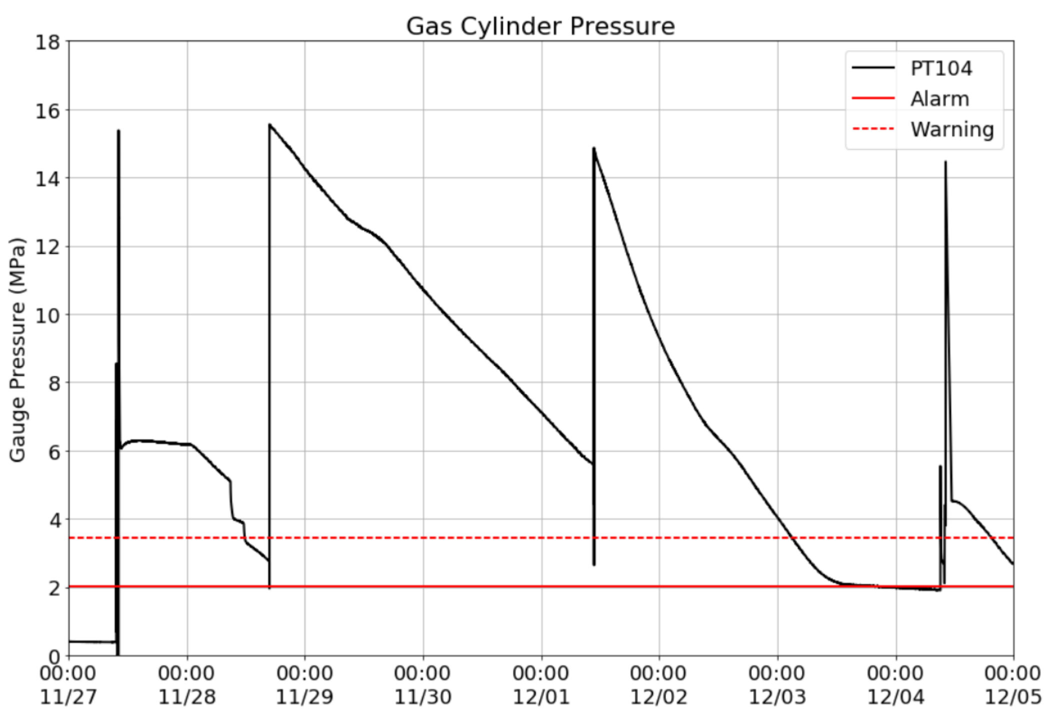

Figure 20 – Gas cylinder pressures for one week beginning at 500 hours for fifth 1000 hour test. A large leak at the gas cylinder outlet connection caused the gas cylinder to empty much quicker on Dec. 1.

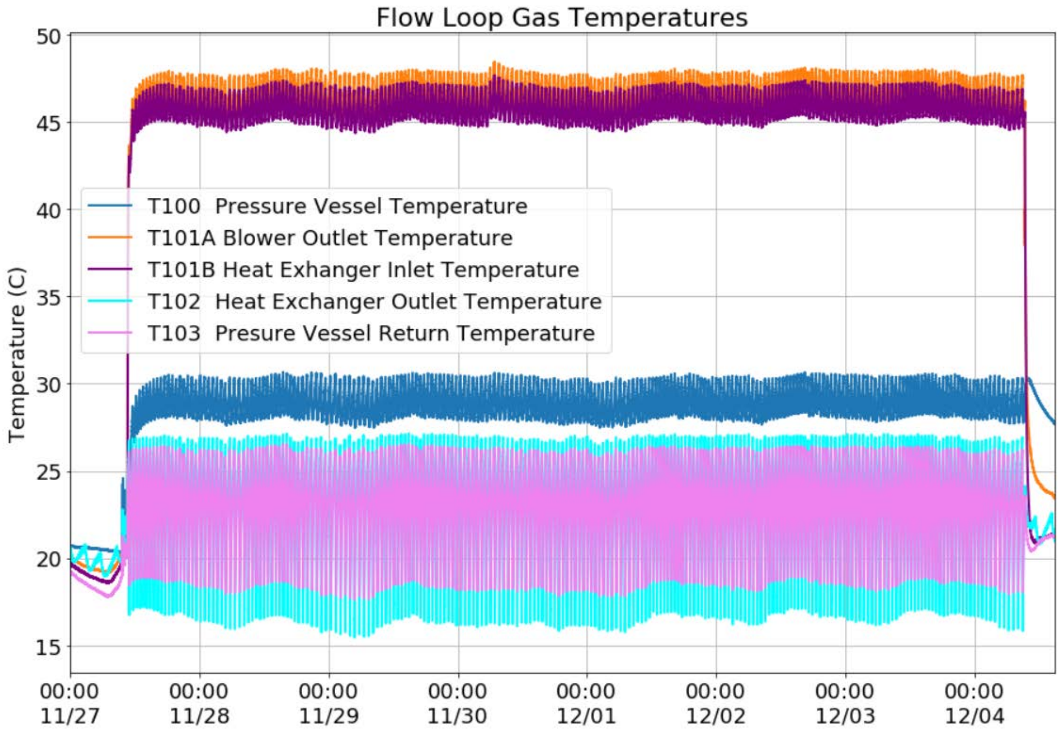

Figure 21 – System temperatures for one week beginning at 500 hours for fifth 1000 hour test.

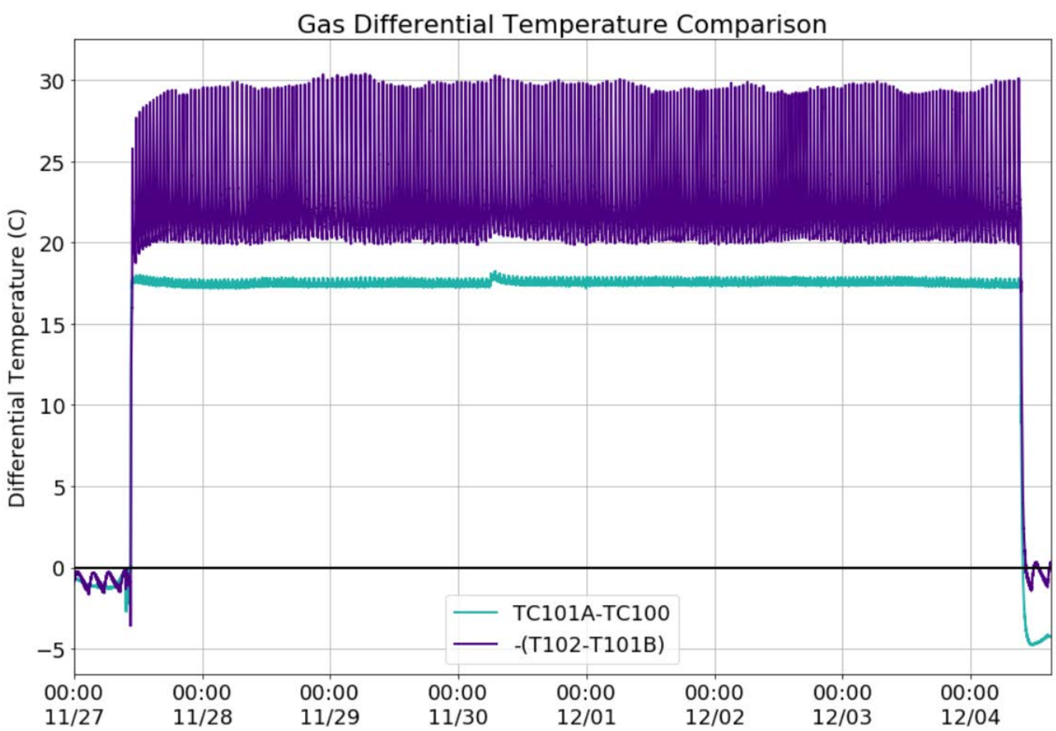

Figure 22 – Blower differential temperature for one week beginning at 500 hours for fifth 1000 hour test.

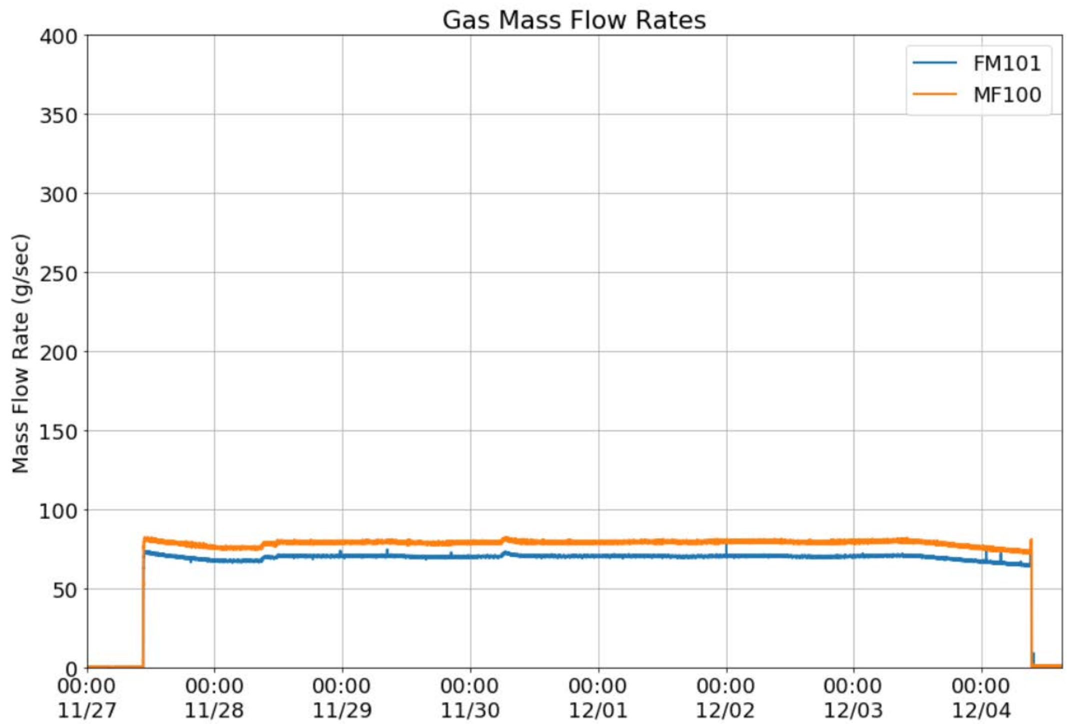

Figure 23 - Mass flow rates for one week beginning at 500 hours for fifth 1000 hour test.

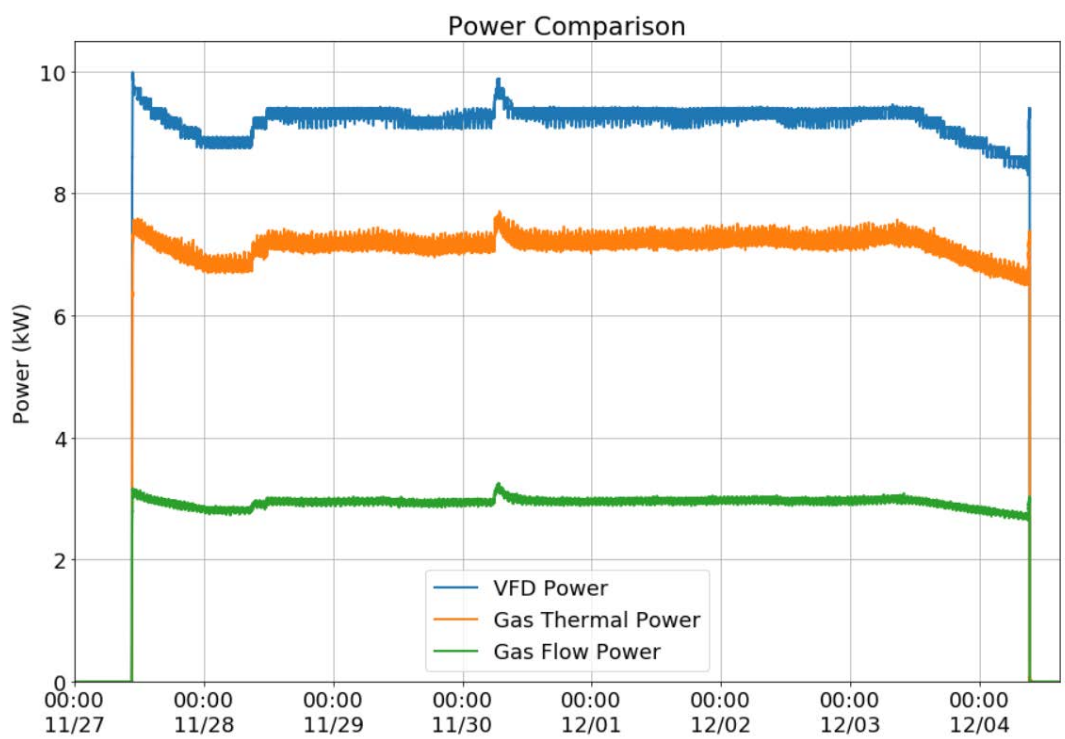

Figure 24 - System power comparison for one week beginning at 500 hours for fifth 1000 hour test.

The helium leak rate was being monitored to check the performance of the graphite spiral wound gasket for the pressure vessel large flange. Initial indications were that the leak rate was substantially less with the new gasket, although we are not yet at the full system pressure of 385 psi, so it's hard to draw definitive conclusions at this time. However, the leak rate was much less than would be attributable to the pressure difference alone, so the results are encouraging. When one gas cylinder was open, the leak rate was roughly 3.0 ft^3/hr (previously 5.6 ft^3/hr) and lasted just over three days. When both bottles were open, the leak rate slightly increased to about 3.5 ft^3/hr (previously 10.2 ft^3/hr). When applying a soapy solution to the gas cylinder manifold and regulator, it was found that the regulator had a slight leak around the pressure relief valve. Also, some gas cylinder bottles had leaks around the valve outlet connection. This seemed to contribute to quite a bit of helium loss. Figure 20 shows the gas cylinder pressure with time. On December 1, when a larger leak was found on a full bottle, the gas cylinder pressure decreased much faster than the previous cylinder change (which also had a small leak). Minor gas cylinder leaks have been found since, but the pressure losses weren't as drastic.

Conclusion

The Aerzen GM 12.4 blower has been performing consistently and as expected. A few modifications have been made to prevent the blower from leaking oil out of the shaft seal and pressure relief system. Prior to this last 1000 hour test, all blower oil leaks have been resolved. A blower inspection from test five will provide us details about whether or not the blower is officially leak free. The helium leak rate seemed to be improving since the pressure vessel gasket was upgraded from a compressed fiber gasket to a spiral wound graphite gasket. However, more accurate testing needs to be performed to verify their performance. Overall, these were very successful long-duration tests, and important operational items continue to be learned.

Future Studies

Another 1000 hour test with helium at 385 psig will be performed to better compare helium leak rate to the previous tests at that pressure. However, in order to determine if the new spiral wound graphite gasket provides more helium sealing capability, a more accurate test must be performed. A systematic cross check between gaskets is required. The blower should remain off while the pressure vessel is pressurized with helium. Also, the gas supply manifold should be closed off from the pressure vessel to avoid unnecessary losses. This should provide an exact measurement of helium leak rate due to the pressure vessel gasket (and minimal loss to the rest of the flow loop).

Appendix A

Production Facility Prototype Blower 1000 Hour Test Results

9/29/2015

Keith Woloshun, Greg Dale, Dale Dalmas, Frank Romero

LA-UR-16-27971

Introduction

The roots blower in use at ANL for in-beam experiments and also at LANL for flow tests was sized for 12 mm diameter disks and significantly less beam heating. Currently, the disks are 29 mm in diameter, with a 12 mm FWHM Gaussian beam spot at 42 MeV and 2.86 μA on each side of the target, 5.72 μA total. The target design itself is reported elsewhere. With the increased beam heating, the helium flow requirement increased so that a larger blower was need for a mass flow rate of 400 g/s at 2.76 MPa (400 psig). An Aerzen GM 12.4 blower was selected, and is now installed at the LANL facility for target and component flow testing. Two extended test of >1000 hr operation have been completed. Those results and discussion thereof are reported herein.

Also included in Appendix A is the detailed description of the blower and its installation, while Appendix B documents the pressure vessel design analysis.

The blower has been operated for 1000 hours as a preliminary investigation of long term performance, operation and possible maintenance issues. The blower performed well, with no significant change in blower head or mass flow rate developed under the operating conditions. Upon inspection, some oil had leaked out of the shaft seal of the blower. The shaft seal and bearing race have been replaced. Test results and conclusions are in Appendix B.

First 1000 Hour Operations Test

The goal of the 1000 hr. test was to operate the blower in a closed loop configuration with the flow conditions anticipated in plant operation with a target in line. Neglecting temperature effects that will be experienced in actual plant operation, a throttling valve was used to mimic the flow pressure drop expected from a target.

The procedure for initiating the test and setting the operating conditions was as follows:

1. Starting with a closed pressure vessel and closed loop, consisting of 2" pipe, a heat exchanger, a throttle valve and instrumentation, eliminate air by vacuum pump and purging.
2. Set fill with helium to the desired pressure, 2.5 MPa (365 psig).
3. Ramp up blower speed to maximum (1800 rpm).
4. Adjust throttling valve to achieve a pressure drop consistent with the plant target design at the desired flow rate.

In practice, ramping up the blower and adjusting the throttle valve for flow and pressure drop, steps 2 through 4, was an iterative process. The key independent variables of loop pressure, differential pressure and mass flow rate set during this process are shown in Figures 1 through 3 for the test duration.

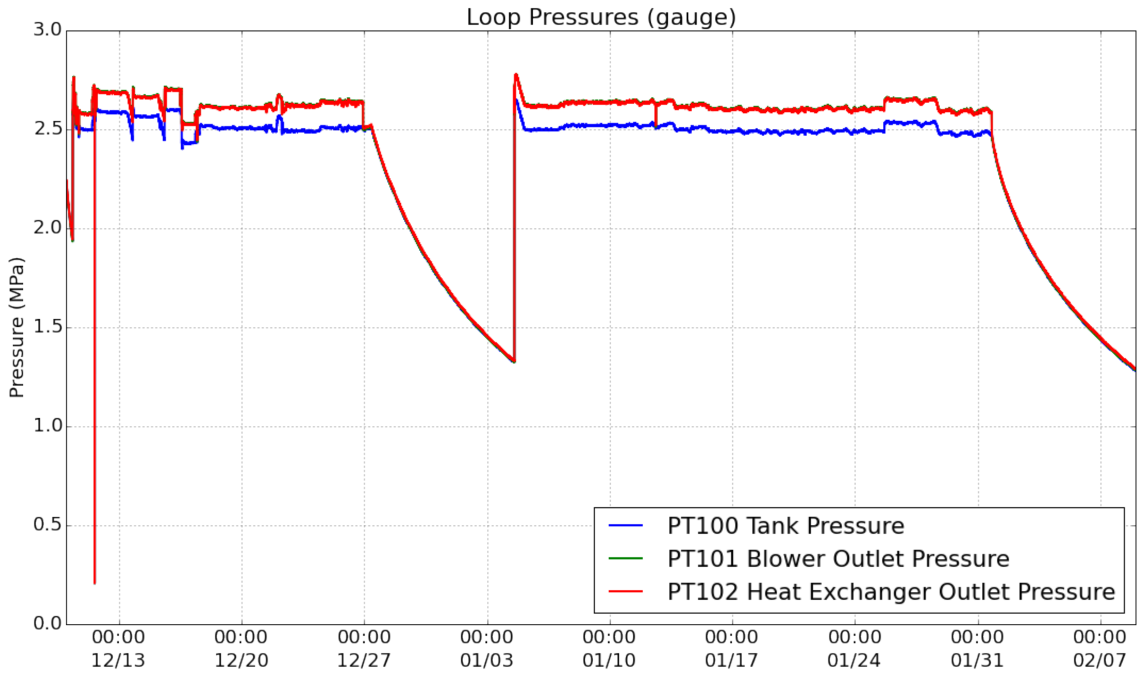

Figure 1. System pressures. The lines for PT 101 and PT 102 overlap. Inlet pressure is nominally 2.5 MPA for the test, or 365 psig or 26 bar.

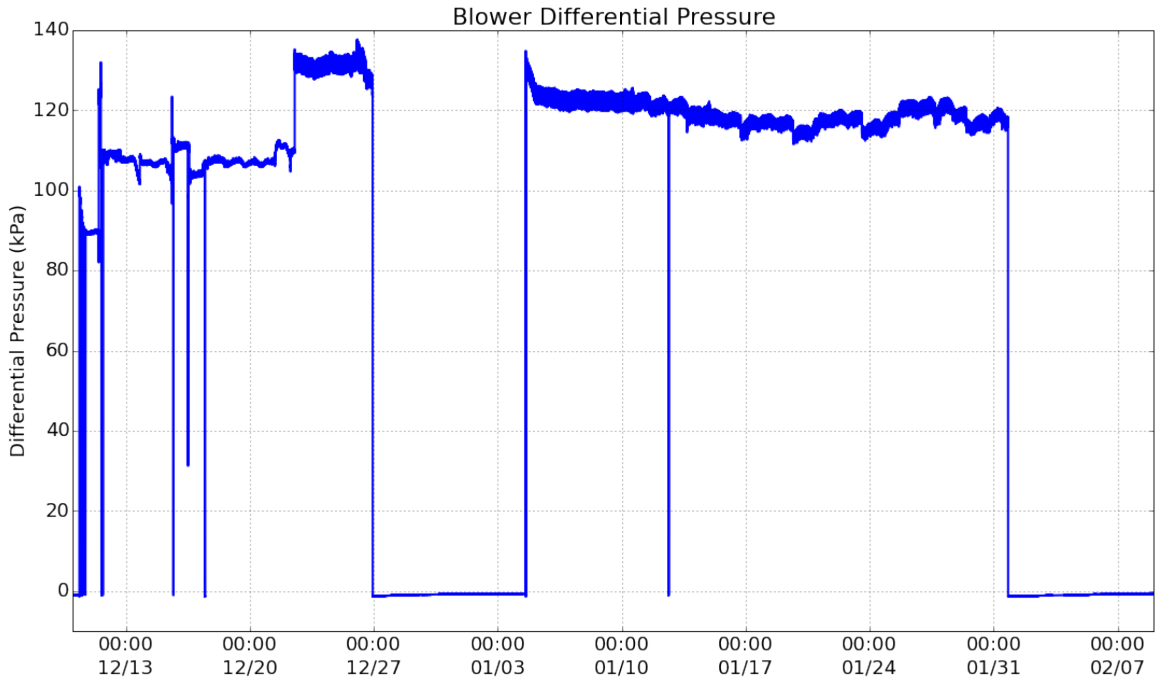

Figure 2. Pressure head developed by the blower. Differential pressure was nominally 120 kPa (17.4 psi).

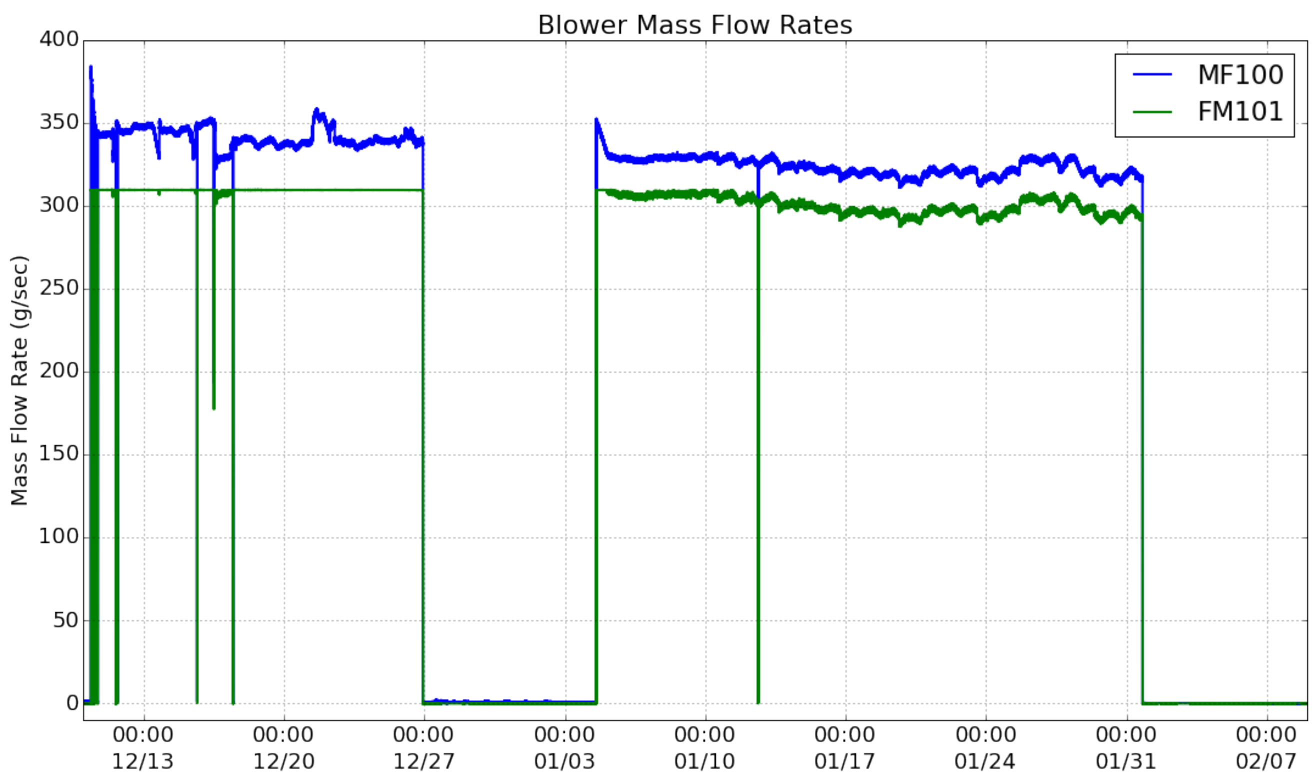

Figure 3. Mass flow rate of helium during the test.

The Aerzen performance calculations for this blower under these conditions is shown in Figure 4. The operating conditions for this test correspond well to the first column in the chart below, with a mass flow rate of 340 g/s and inlet pressure of 26.7 bar. However, the head developed by the blower, as measured, is significantly lower than expected.

AERZEN

Rotary Lobe Blower Performance Data: SI Units

Project :	Helium Blower
Proposal- / Job-No :	PG-130
Customer :	Los Alamos National Labs
Date / User :	11/02/2015 Grady

Operating Case :			180 kPa	147 kPa	113 kPa	80 kPa
Name of Process Gas :			Helium	Helium	Helium	Helium
AERZEN Rotary Lobe Blower Size :			**GM 12.4**	**GM 12.4**	**GM 12.4**	**GM 12.4**
Mole Weight	R :	kg/kgM	4.0	4.0	4.0	4.0
Isentropic Exponent, K = Cp/Cv	κ :	./.	1.66	1.66	1.66	1.66
Intake Volume Flow (actual)	Q_{1act} :	m^3/min	4.64	4.87	5.13	5.44
Standard Volume Flow	V_N :	Nm^3/min	114.31	120.05	126.48	133.96
Standard Volume Flow	V_N :	Nm^3/h	6,859	7,203	7,589	8,038
Specific Weight at Intake Conditions	ρ_1 :	kg/m^3	4.40	4.40	4.40	4.40
Mass Flow	$\dot{m}$:	g/sec	340	357	376	398
Intake Pressure (absolute)	p_{1abs} :	bar	26.70	26.70	26.70	26.70
Discharge Pressure (absolute)	p_{2abs} :	bar	28.50	28.17	27.83	27.50
Differential Pressure	Δp :	kPa	180	147	113	80
Intake Temperature	t_1 :	°C	19.0	19.0	19.0	19.0
Discharge Temperature	t_2 :	°C	31	28	26	24
Blower Speed	n_R :	rpm	1,775	1,775	1,775	1,775
Motor Speed	n_{Mot} :	rpm	1,775	1,775	1,775	1,775
Power at Blower Shaft	P_k :	BkW	22	18	14	10
Motor Rating		kW	27	22	17	12

Tolerances:
for Intake Volume Flow ± 10 %
for Power at Blower Shaft ± 10 %

Standard Conditions:
Temperature = 0° C
Pressure = 101.325 kPa

Figure 4. Expected blower performance.

Gas temperatures are shown in Figure 5. Because of problems controlling the cooling water temperature as low as desired, the run was at a considerably higher temperature than that used in the Aerzen calculations.

Motor power and blower torque are shown in Figures 6 and 7. The temperature rise of the helium across the blower is shown in Figure 8. The total power taken up by heating the gas is Q_{th} = mass flow rate X specific heat X temperature rise, or Q_{th} = 0.325 X 5200 X 10 = 16900 W. The useful work performed on the gas is Qw = pressure rise X mass flow rate / density, or Qw = 118000 X 0.325 / 4 =

9750 W. Total power into the helium is then 26.7 kW. This compares well with the power as shown in Figure 6.

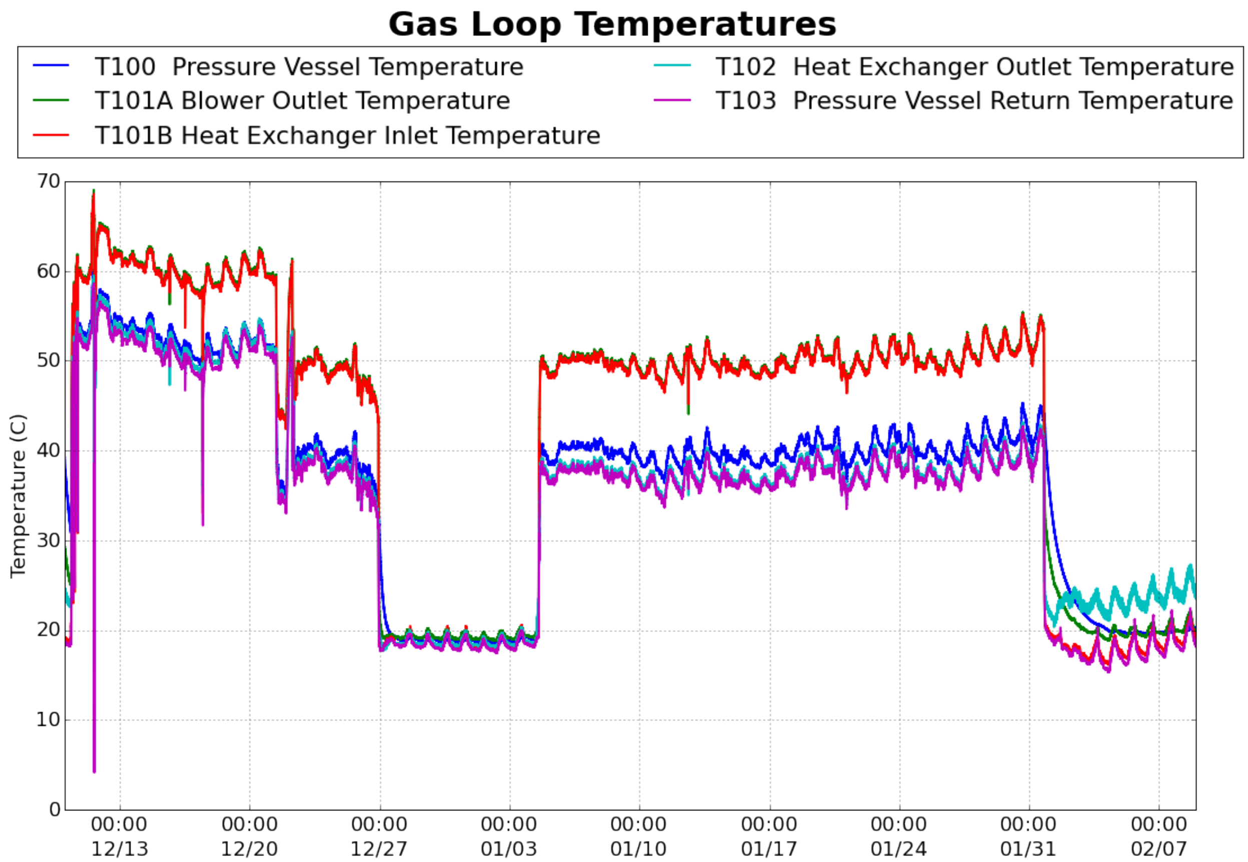

Figure 5. Helium temperatures during the test.

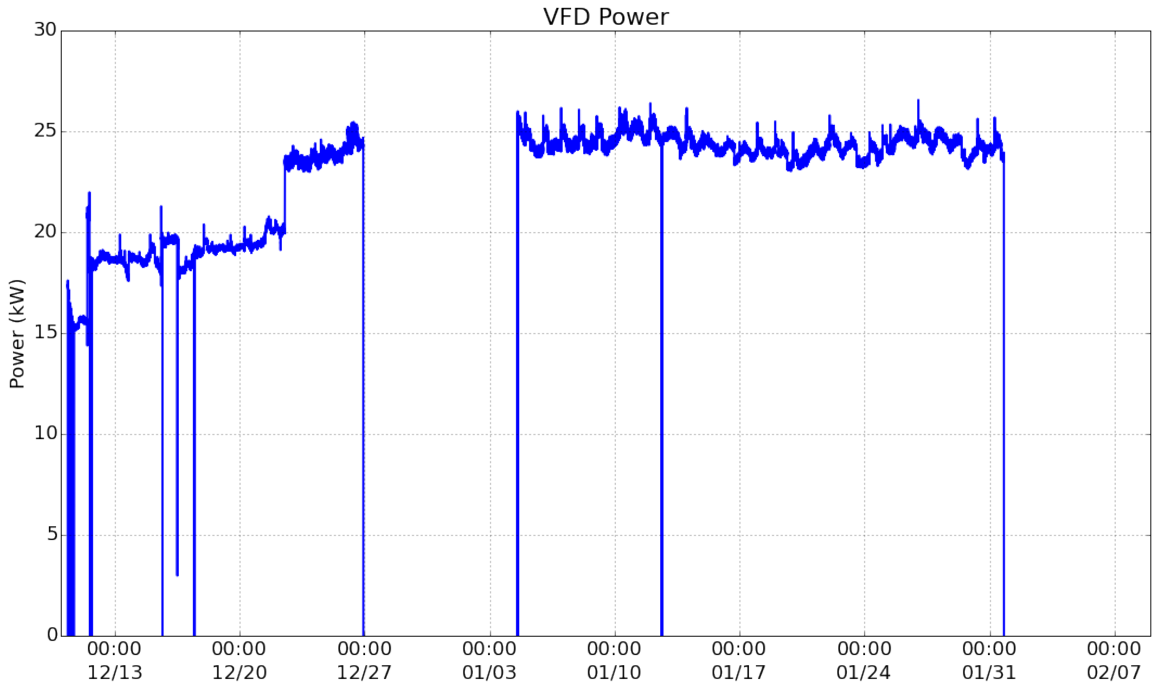

Figure B6. Power to the motor, as measured at the Variable Frequency Drive (VFD).

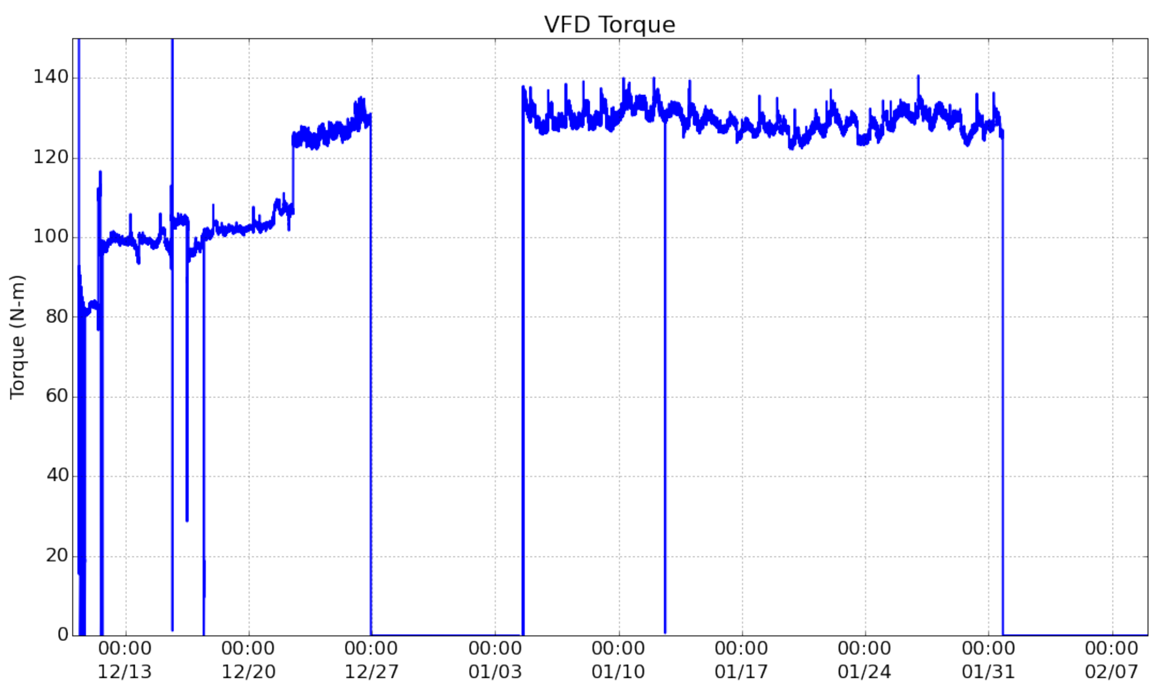

Figure B7. Blower torque.

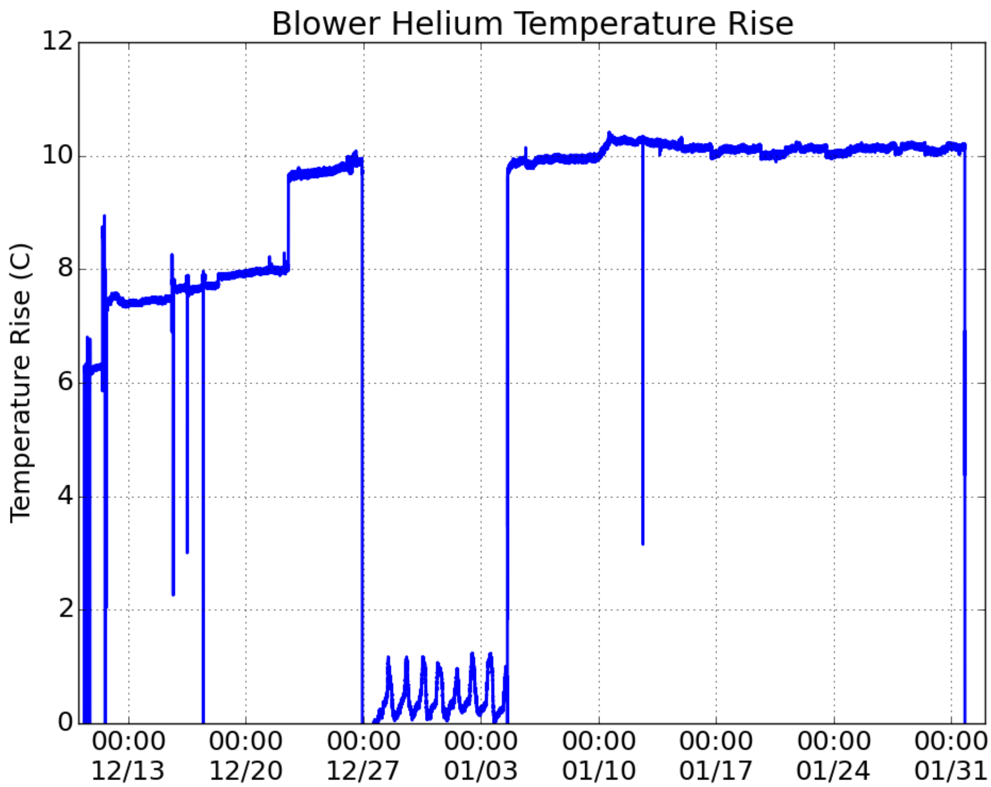

Figure 8. Helium temperature rise across the blower.

Oil Leak

Upon opening the tank, some oil leakage from the shaft seal was evident. Fig 9 shows the reduced oil level in the sight glass and Figures 10 and 11 show some of the escaped oil. The oil was a thinly distributed coating over much of the interior of the tank. After investigation, it was discovered that the sealing covers had not been removed. These are vent ports that allow for pressure equalization between the oiled bearing housing and atmospheric conditions, in this case pressurized helium.

Figure 9. Oil level sight glass, showing some loss.

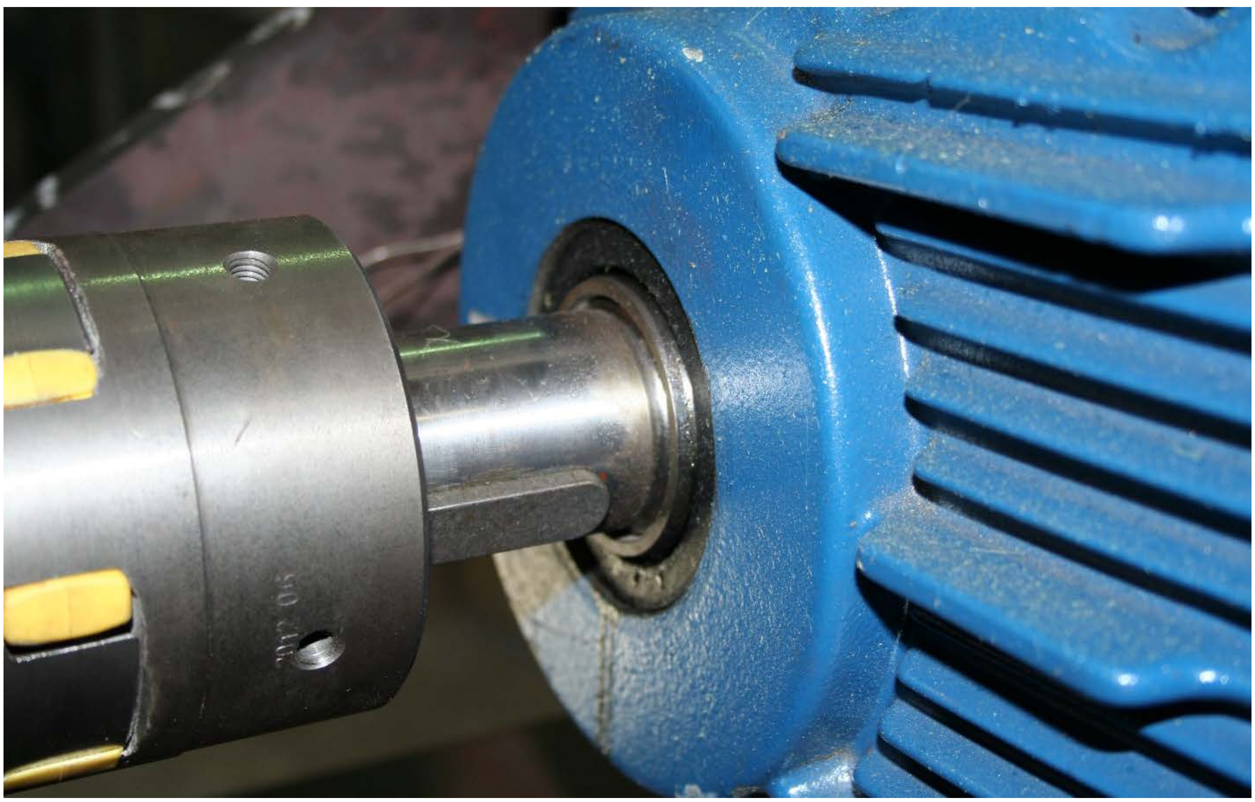

Figure 10. Oil drip trace at the shaft seal.

Figure 11. Oil on the vessel bulkhead, and dripping to the platform below after opening the tank.

Conclusions

The blower has performed well, and should be sufficient to the task of providing the required helium flow to the target. The apparent underperformance of the blower head generated, as compared with the vendor calculated numbers, needs to be investigated and understood. This will be systematically studied in the next test. The 4 calculated run points will be replicated as closely as possible and discussed with the vendor.

Second 1000 hr. Performance Test

After replacing the shaft seal a second 1000 hour performance test was conducted. Pressure conditions, shown in Figure 12, were unchanged from the previous test, nominally 2.6 MPa (377 psig), with a blower differential pressure of 120 kPa (17.4 psi). Helium flow rate was 330 g/s average over the test duration. During this test a 6 hr stoppage every 6 days was included to simulate the periodic change-out of a target.

Figures 13 through 16 are plots of the data recorded for this test: Differential pressure, mass flow rate, temperatures and power, in that order. The performance matched very well with the previous 1000 hr test.

However, once again oil leakage was evident. The problem was reviewed and discussed with the vendor. The result of the discussions and evaluation of possible causes was a decision to upgrade to what the vendor referred to as a "gas tight" seal configuration. The primary feature of this upgrade is a double seal arrangement at the shaft, with a grease packing between the seals. This upgrade is complete. The blower will be re-installed and operated with atmospheric air for 1000 hrs. to establish a performance baseline. Subsequently a third 1000 hr. test with pressurized helium will be performed.

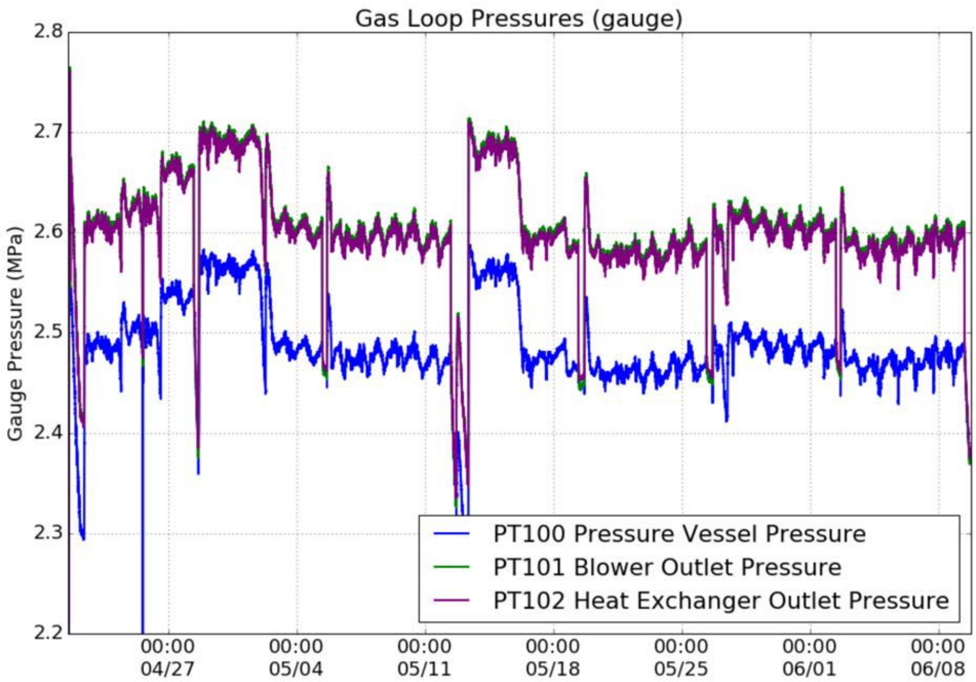

Figure 12. Blower test operating pressure.

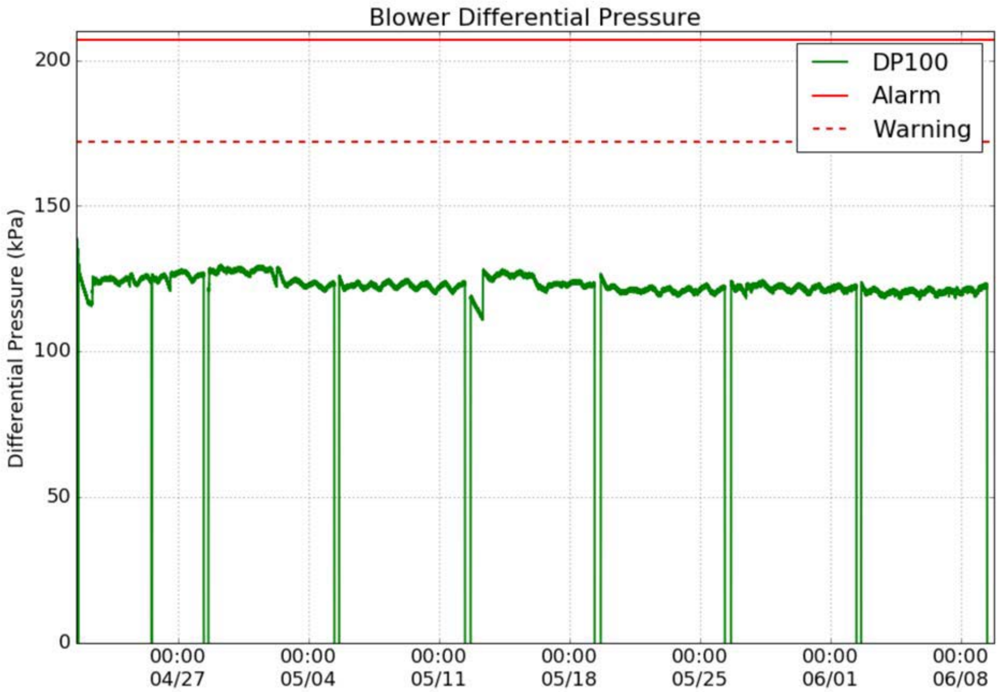

Figure 13. Pressure head developed by the blower, nominally 120 kPa (17.4 psi).

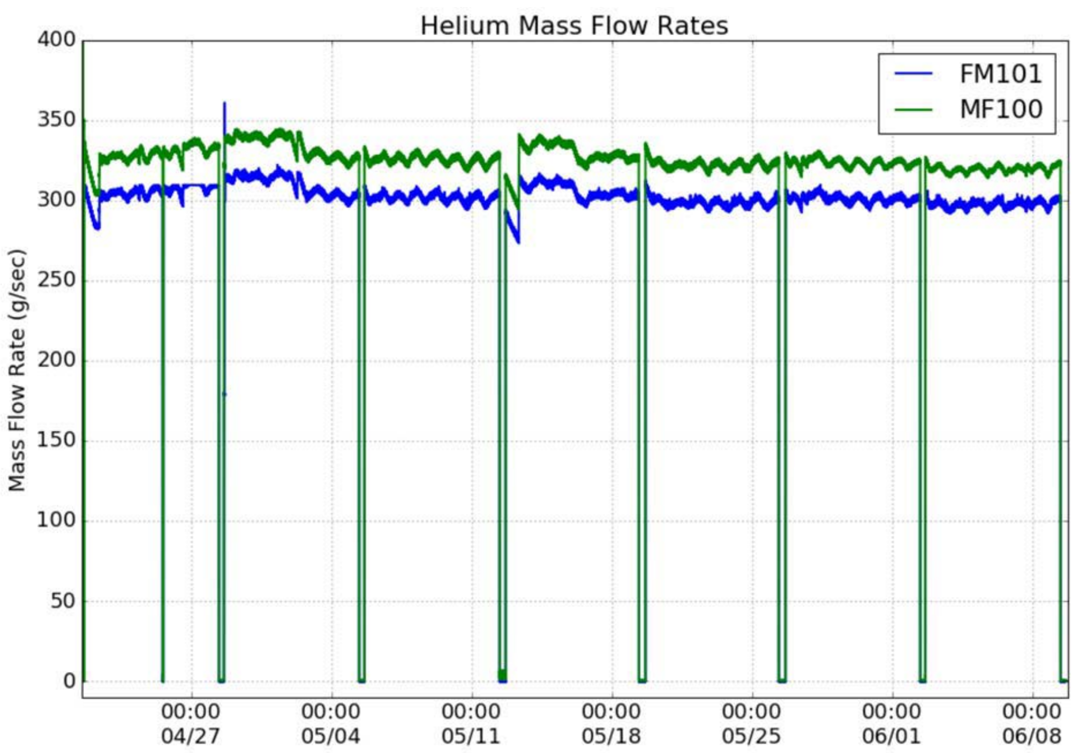

Figure 14. Helium flow rate.

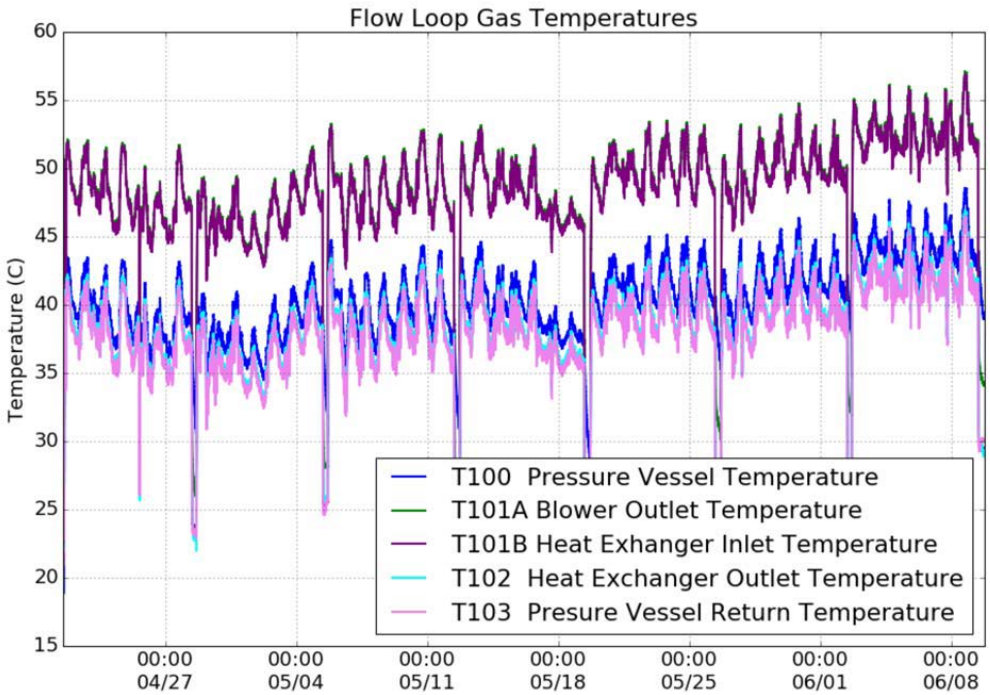

Figure 15. Helium temperature at various locations around the loop.

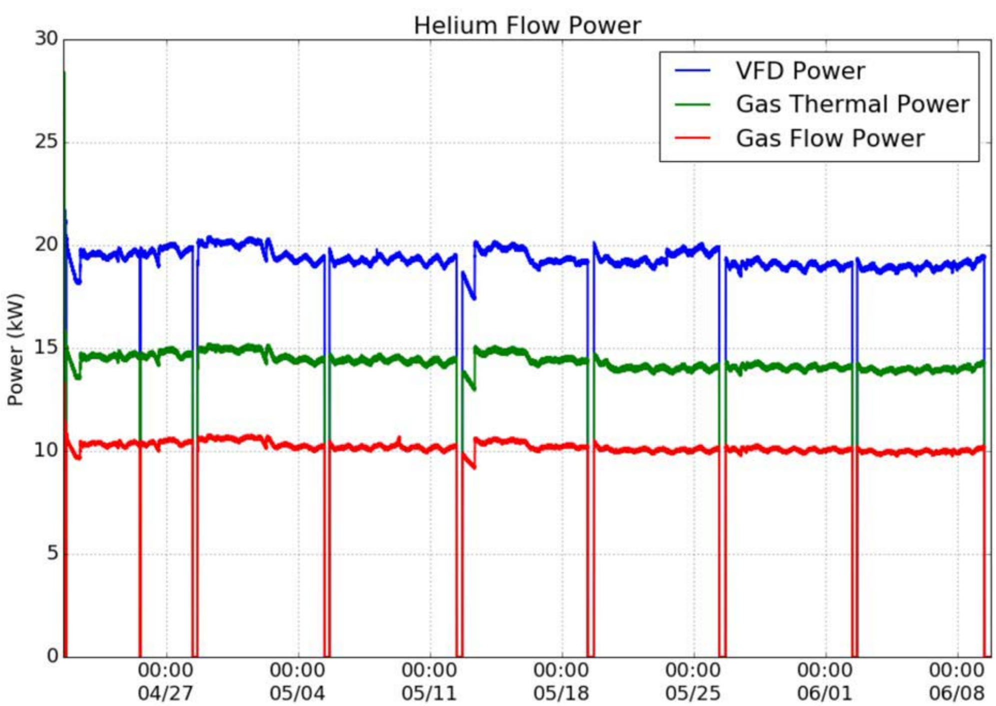

Figure 16. VFD power (power to the motor) along with calculated thermal power (heat load to the helium) and the calculated useful work, mass flow rate X pressure rise / density.

Appendix A. Blower Selection and Installation

Blower Selection

The blower currently being used for the accelerator experiments at ANL and the flow visualization loop at LANL is a Tuthill 3206 PDplus. At 2.07 MPa (300 psi) and, we are limited to 100 g/s with about 138 kPa (20 psi) head. In order to achieve the heat transfer requirement of the new target, we need 400 g/s at 2.76 MPa (400 psig) as stated above. Tuthill has no blower that can achieve this. Aerzen offered 2 blower options, the performance of which is summarized in Figure A1. The GM 12.4 was chosen because it is physically smaller, fitting into a smaller pressure vessel. The 180 icfm in the 3rd column corresponds to 400 g/s, at blower speed 1737 rpm. Blower displacement is 0.14 ft^3/rev. The drive motor is a 30 hp WEG with maximum speed 1800 rpm.

Pressure Vessel

The motor and blower are mounted inside a pressure vessel rated for the 2.76 MPa. The vessel is designed to ASME BPVC. Appendix A below shows the code calculations for the pressure vessel, as well as the calculations for the loop piping and the pressure rating of the instruments. The vessel fabricated by AA Tanks. AA Tanks makes their own drawings from LANL drawings and requirements. They then make their own ASME code validation calculations, fabricate the vessel, and pressure test to ASME required load (1.3 times design pressure).

As with the earlier designs, the pressure vessel made of essentially 2 parts: A bell that rides on a rail to expose the blower and motor inside, and a fixed flange with all the penetrations for power, instrumentation, and helium inlet and outlet.

Aerzen USA Corporation Quotation nº: PG-130

09/26/2013

Aerzen Rotary Lobe Blower

Performance data:

		GM 13.6	GM 13.6	GM 12.4	GM 12.4
medium		Helium	Helium	Helium	Helium
operating case		Given	Current dP	Given	Current dP
MW	lb/lbM	4.00	4.00	4.00	4.00
K = Cp/Cv	./.	1.660	1.660	1.660	1.660
volumetric flow at intake conditions	icfm	180	150	180	150
volumetric flow at standard conditions	MMscfd	7.225	6.021	7.225	6.021
volumetric flow at standard conditions	scfm	5,017	4,181	5,017	4,181
specific weight at intake conditions	lb/ft³	0.294	0.294	0.294	0.294
intake pressure (absolute)	psia	414.5	414.50	414.50	414.50
discharge pressure (absolute)	psia	436.3	432.50	436.25	432.50
differential pressure	psi	21.8	18.0	21.8	18.0
intake temperature	°F	66.2	66.2	66.2	66.2
discharge temperature	°F	83	81	81	79
blower speed	rpm	1,019	877	1,737	1,482
motor speed	rpm	1,019	877	1,737	1,482
power required at blower shaft	BHP	28	20	24	18
motor rating	HP	40	25	30	20

Tolerances:

for volume handled at intake conditions	± 5 %
for power consumption at blower shaft	± 5 %

Machine noise:

sound pressure level without hood approx.	dB(A)				
sound pressure level with hood approx.	dB(A)				

Figure A1. Performance Table for the Aerzen blowers.

Blower/Motor/Pressure Vessel Assembly

The assembly is best described with the drawing and photographs in Figures A2 through A5. Not shown, but waiting for install, is a sound-proofing box procured from Industrial Noise Control to reduce the blower noise from the 90 dB range to closer to 70 dB.

Additional Loop Components

Blower heating of the helium will be removed with a plate type heat exchanger from GEA, part number FP10X20L-90. This is sized to keep the helium pressure drop to less than 1 psi in the exchanger. This is shown in Figure A6 along with connected helium and water piping and some instruments.

Helium flow rate will be measured using a turbine type meter, Omega PN FTB-939. Also installed for flow measurement is a vortex flow meter from Sierra Instruments. This flow meter has been used unsuccessfully on an earlier loop but has been reinstalled here for more cross-comparison with the turbine type under different conditions.

Temperature is measured at numerous locations around the loop with Type K thermocouples. Pressure is measured by gages and transducers acquired from Omega. A motor driven ball valve will be used to characterize the blower output curve mass flow rate vs pressure drop, as a function of motor speed. Although the blower is intended to run at full speed in the plant, this test facility has the motor on a variable frequency drive for flexibility and adaptability to a variety of test and experiment conditions. A P&ID is shown in Figure A7.

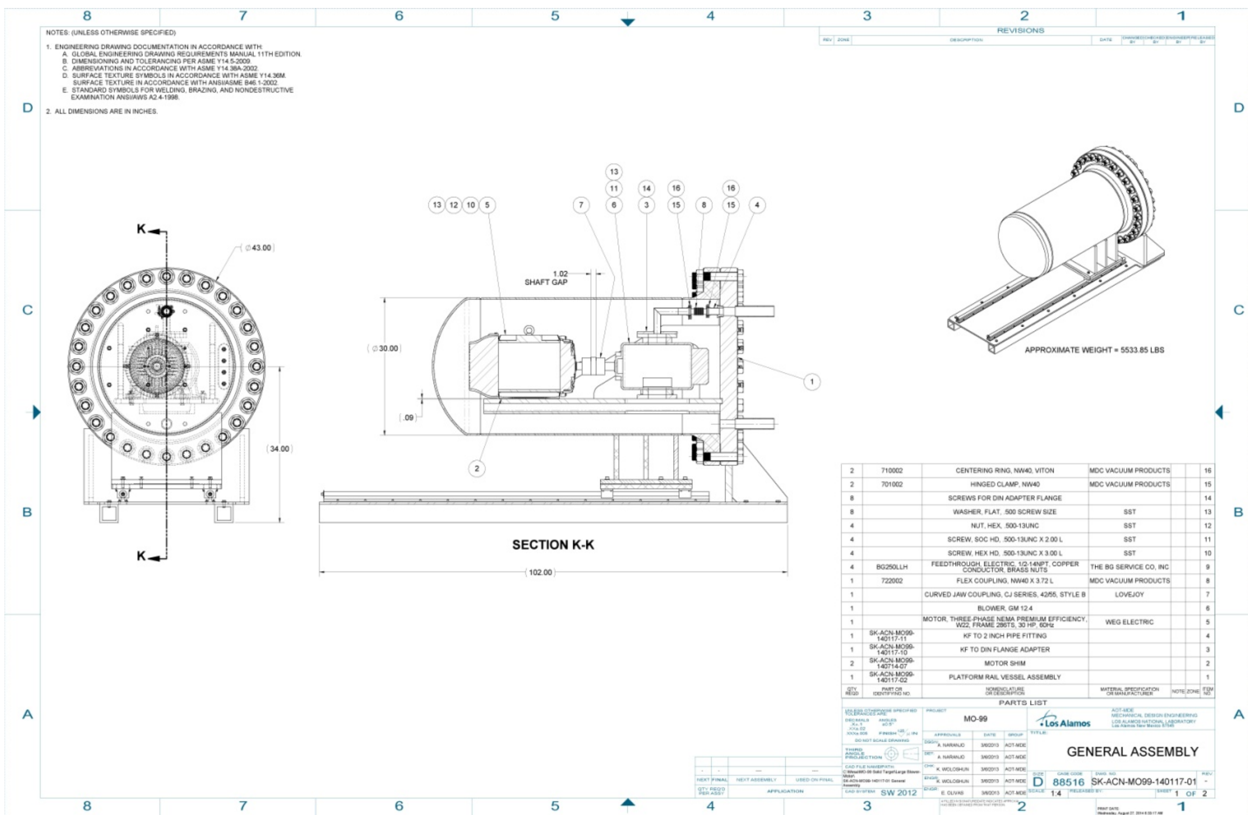

Figure A2. Drawing of the blower and motor in the pressure vessel, indicating overall dimensions.

Figure A3. Vessel open, showing blower and motor.

Figure A4. Close-up view of the blower, on the left, with motor. Motor is wired and blower exit piping is installed. (top left).

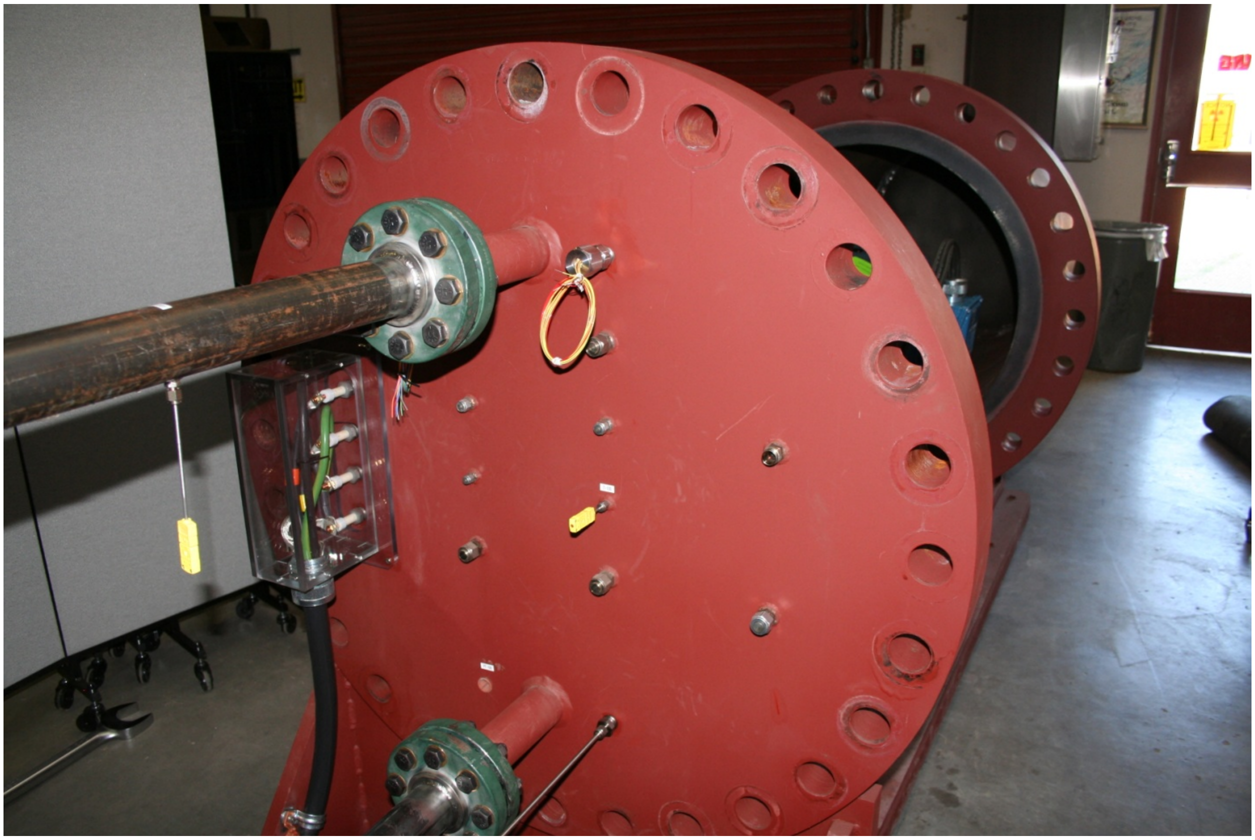

Figure A5. Fixed flange. Motor power inlet feed-throughs at center left. helium discharge pipe at the top, and return helium pipe at the bottom. Some instruments for temperature and accelerometers installed.

Figure A6. Heat exchanger (bottom of photo) along with piping and instruments. A water filter is mounted on the wall near the top.

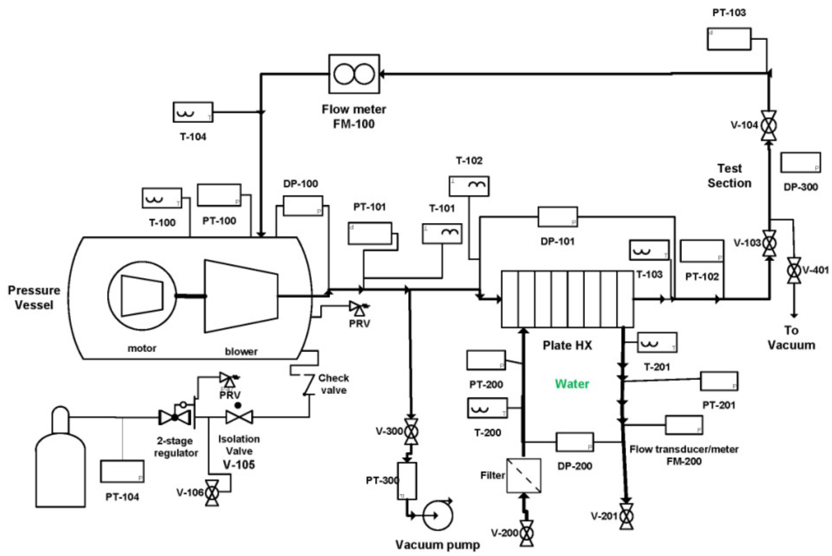

Figure A7. Flow loop Piping and Instrumentation Drawing.

Status and Conclusions

The blower/motor/pressure vessel set-up is installed and ready. After final instrumentation install is complete the sound enclosure can be assembled. The first test section is straight pipe with a motor controlled ball valve for blower characterization. This is ready to install. Final data acquisition software and hook-ups are now being readied. With the exception of a second heat exchanger to remove target heat, and a tritium removal slip stream, this loop is nearly identical to that envisioned for the Northstar production plant.

Appendix B. Pressure Vessel Calculations for Blower/Motor Enclosure.

Cylindrical Shell
$t \geq PR/(2SE+0.4P)$
P = 400 psi
SA515-70 steel (or equivalent, 70 ksi UTS or greater), S = 20000 psi
E = 0.6, butt welds
R = 14.625 "
t ≥ 0.242"
Sch 10 pipe, t = 0.375"

Domed Elliptical Head
$t \geq PD/(2SE-0.2P)$
E= 1, no welds on head
t ≥ 0.293"
t = 0.375"

Unstayed Flat Head
$t \geq d*\mathrm{sqrt}(CP/SE + 1.9Wh_G/SEd^3)$
C = .3 (from UG-34)
$W = W_{m1} = 0.785G^2P+2b3.14GmP$, bolt load
h_g = distance from gasket center to bolt circle = 4
b = gasket width = 2.5
G = gasket OD - 2b = 33.75-2*2.5 = 28.75
m = gasket factor = 2.00 (Appx 2)
W = 620640
t ≥ 3.63
t = 3.63

Pressure Rating of Instruments and Piping

Flow meter MAWP 500 psi

Heat exchanger MAWP 450 psi

Piping is sch 40 SA-53 carbon steel with allowable stress S = 16000 psi.

Allowable pressure $P = SEt/(R+0.6t)$

E = weld allowance, taken as 0.5. Flange welds are slip on flanges welded both sides. Other weldments are small Swagelok fittings for pressure and temperature measurements, fillet welds.

Sch 40 pipe has R = 1.03", t = 0.155"

Allowable P = 1104 psi.

Pressure stress calculations are for design guidance but the ultimate qualification is the pressure test. The vessel was factory tested and stamped. The piping, with instruments, was tested 1/22/14, as per attached record. System design pressure is 400 psig, with pressure relief valve set at 400 psig. Pressure test was conducted at 530 psig, greater than the required 130% of MAWP.