

Helium recovery at the National High Magnetic Field Laboratory

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Abstract. Helium conservation is becoming increasingly important as helium availability is on the decline and prices are on the rise. The Florida State University National High Magnetic Field Laboratory has taken several steps over the past five years to increase the percentage of helium recovered. These include the installation of a standalone purifier, recovery flow meters, contamination meters, and a new piping system. The improvements to the recovery system have reduced the amount of helium purchased by the Mag Lab by 60% while helium usage has increased by roughly 40%. This article will provide details about the recovery system as a whole and describe some of the main components. There will also be some examples of the problems we've had to overcome, and some that we are still working on. Finally, there will be an update on the current status of the recovery system and a description of our plans for the future.

1. Introduction

The National High Magnetic Field Laboratory (Mag Lab) is the largest and highest powered magnet laboratory in the world. Every year, hundreds of scientists (internally referred to as "users") perform research at the Mag Lab for free, thanks to funding from the National Science Foundation, The Department of Energy and the State of Florida.

Next to electricity, one of the most significant costs associated with the research performed at the Mag Lab is liquid helium. The 45T Hybrid Magnet requires roughly 650 L/day of LHe to maintain its operating temperature between 1.55 K and 1.8 K. The 45T Hybrid is directly connected to our Linde LR280 helium liquefier through a Central Distribution Box. Using portable dewars, another roughly 1,200 L/day are distributed throughout the lab to cool other superconducting magnets and experiments.

With this level of demand for liquid helium, it is necessary to employ a helium recovery system in order to remain within our operating budget. Helium recovery systems for research facilities generally include piping networks, gas bags, compressors, liquid and gas storage systems, liquefiers, and portable dewars. This work will present an overview of the helium recovery system for the Mag Lab, including usage and recovery statistics, system layout, some specific components, and examples of the challenges we've faced while developing the system.



2. Facility Overview

The main helium refrigerator at the Mag Lab is a Linde model LR280. The LR280 is capable of providing 1000 W of refrigeration at 4 K, 200 L/hr of liquid helium, or some combination of the two. The addition of a Central Distribution Box (CDB) reduces the capacity of the LR280 by about 20%, but allows automated operation of many integral processes. The CDB allows us to supply supercritical or liquid helium to the 45T Hybrid, the upcoming 36 T Series Connected Hybrid, and a 3,000 L storage dewar. A 1,500 L dewar is also available for filling portable dewars when the LR280 is unavailable. The 1,500 L dewar is supplied by a CVI model 1600 liquefier. In addition to the stationary dewars, we have 100, 250, and 500 L portable dewars. There are currently 58 portable dewars in circulation with a maximum possible inventory of 14,800 L. In practice, helium users are in possession of 35-40 dewars at any given time.

Gas storage is divided into high, medium, and low pressure containers. The high pressure storage consists of a bank of high pressure cylinders with a total volume of 20 m³. In addition, we receive make up helium from an external vendor in high pressure tube trailers with volumes around 26 m³. There is always one vendor trailer present on site. Medium pressure storage consists of four 145 m³ tanks designed to hold 1.48 MPa (200 psig). Low pressure storage consists of three 70.8 m³ (2500 ft³) gas bags, which act as a buffer between compressor suction and the helium recovery network.

The helium recovery system begins with individual stations near magnets or research cryostats. These stations, located all around the Mag Lab, connect to copper piping to avoid problems with thermal cycling. The copper originally transitioned to PVC piping for the long runs across the lab. In recent years, many leaks have been found in the PVC piping. In response, the PVC piping is being replaced by high-density polyethylene (HDPE) piping, PE2406 SDR11, designed for use in the natural gas industry. The HDPE piping conveys the recovered helium from the individual lab to the main gas bags. Screw compressors pump the gas from the bags to our dedicated helium purifier. The purifier resupplies the medium pressure storage tanks with helium and less than 5 ppm contamination.

3. Recovery System Components

3.1. Helium Recovery Stations

Modular helium recovery stations have been developed to meet the needs of users while providing a uniform interface to accommodate the portable dewars. Each station consists of a quick connect fitting, a flexible hose, a check valve, and copper piping leading to the HDPE recovery headers. The quick connect provides a connection point that's easy to use and isolates the recovery system when not connected. The hoses give users some flexibility for parking the portable dewars. The check valve prevents the recovery system from contaminating the individual experiments when the pressures fluctuate. The check valves are chosen for minimum relief pressure, 9 mbar (0.125 psig), to prevent unwanted pressure build up in the dewar or experiment. Previously, a larger check valve was used for groups of recovery stations. This led to pressure fluctuations when the valve would open and close. Having check valves on each station and eliminating the larger valve alleviates this effect.

3.2. Helium Piping Network

The piping network connects the helium recovery stations to the main gas bags and compressors. As mentioned above, the piping near the recovery stations is mainly copper. The copper helps to warm the helium before entering the recovery flow meters. The piping transitions from copper to HDPE for the main runs across the lab. The piping runs vary from 10 m to over 300 m, with one of the lines buried underground to recapture helium used at the Applied Superconductivity Center, located in a separate building across the street from the Mag Lab. 2" HDPE piping is used for the majority of the runs. 3" piping is used when higher flowrates (>12 m³/hr) are expected. Pieces of HDPE piping can be joined

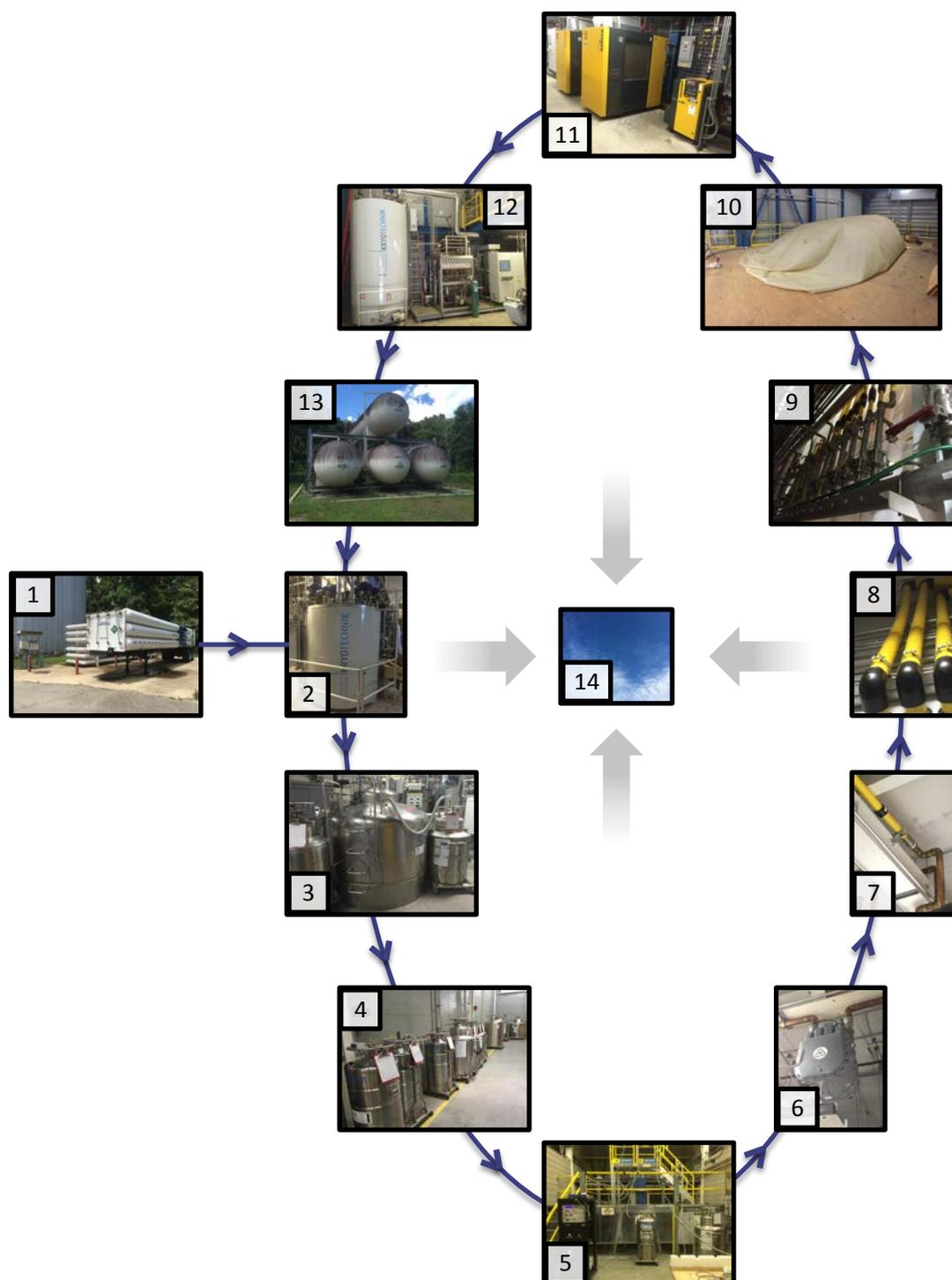


Figure 1. Typical life cycle for helium used for research at the Mag Lab: 1. High pressure storage trailers make up for helium losses, 2. LR280 liquefier, 3. 3,000 L dewar, 4. Helium retrieval station, 5. Magnet cell, 6. Gas meter, 7. Copper to HDPE transition, 8. HDPE piping, 9. HDPE to stainless transition, 10. Gas bag, 11. Compressors 12. Purifier, 13. Medium pressure storage tanks, 14. Losses to atmosphere can occur at any stage of the life cycle.

using a compression fitting or by fusing them together with heat. Otherwise, the HDPE pipes have reasonable bending radii (32" for the 3" pipes and 27" for the 2"), allowing them to turn corners without requiring additional joints. All of the HDPE runs end at a 6" stainless steel header that feeds the main gas bags.

3.3. Helium Recovery Compressors

Helium from the gas bags is pumped into the purifier using one of the dedicated screw compressors. We have two sizes of purifier compressors. The smaller compressor provides a flowrate of 2.5 g/s at a discharge pressure of 1.34 MPa (180 psig). The larger compressor can provide up to 18 g/s at 1.34 MPa (180 psig). If one gas bag outlet valve is open, the smaller compressor maintains its maximum flowrate to slowly empty the bag. If two or more gas bag outlet valves are open, one of the larger compressors can be started automatically to empty the bags much faster. When the bags are emptied, their outlet valves close automatically. The small compressor remains on to maintain flow through the purifier. Make up gas is provided from the medium pressure storage tanks when necessary.

3.4. Helium Purifier

The main purifier at the Mag Lab is a Linde PUR10 purifier. The purifier consists of two sections, an ambient temperature dryer and an 80 K adsorber. The dryer, designed to remove water from the helium, consists of two molecular sieve beds in parallel. The 80 K adsorber, designed to remove air from the helium, consists of a liquid nitrogen heat exchanger and two sets of silica gel adsorber beds. Having two sets of dryers and adsorbers in parallel allows for one set to regenerate while the other continues to process helium. The purifier is designed for 8 g/s, but can handle flows up to 18 g/s.

Table 1. Purifier design conditions

Description	Unit	Design (with LN ₂)
Purifier supply		
- Crude helium supply pressure	[bar a]	18
- Crude helium supply temperature	[K]	313
- Crude helium massflow	[g/s]	8.3
- Oil content	[ppm]	< 0.1
- Impurities	N ₂ [ppm]	8000
	O ₂ [ppm]	2000
	H ₂ O [ppm]	500

4. Helium Consumption

Liquid helium usage (portable dewars only) at the Mag Lab has increased by about 7% per year over the past 5 years, from 311 m³ to 443 m³ annually (815 L to 1215 L daily). Over the same period, the amount of helium purchased by the Mag Lab has decreased from 226 to 84 equivalent liquid m³ annually. The improvements in helium recovery are a direct result of the implementation of the new purifier and modifications to the recovery system. The data does not take into account increases in the overall system inventory, which has a very minor effect on an annual scale.

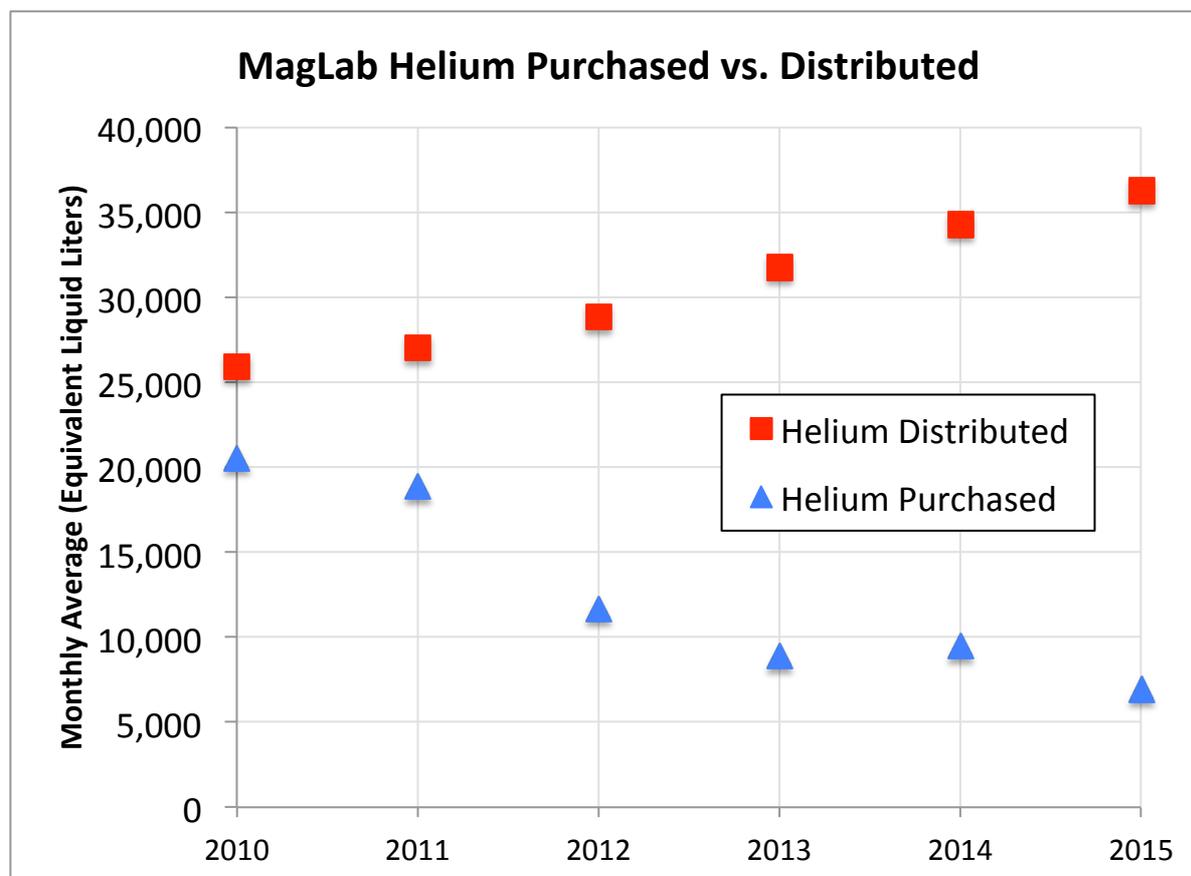


Figure 2. Mag Lab helium usage (portable dewars only) versus make up helium purchased from 2010 to present

5. Monitoring Recovery

In order to assist with our recovery effort, we have installed flow meters and contamination meters. We have three types of flow meters installed. The first are natural gas type flow meters. These are bellows type meters, similar to those used by many utilities providers. These are located at each research station using liquid helium. The meters provide a totalized volume of gas, which is relayed to our distributed control system. The other meters we employ are rotary and thermal dispersion type meters. These meters are used when high flow rates are expected, normally due to pump exhaust or very fast helium transfers. In general, if transfers are expected to occur at less than 300 liquid liters per hour, the bellows type meters are sufficient. The meters give us an idea of where improvements need to be made in the recovery system. Our liquid helium ordering system keeps track of where the dewars are being used. When a large discrepancy is seen between the amount of helium being used, and the amount coming back through the gas meters, we can investigate the area for problems.

As a compliment to the gas meters, we have installed helium contamination sensors. These sensors sample the gas returning from the users to determine the concentration of air and water in the recovered helium. These sensors are very useful in finding problem areas. Since the recovery system is designed to be at a slightly positive pressure throughout, contamination spikes normally indicate either misuse of the recovery system or problems with external equipment, such as vacuum pumps.

6. Problems and Solutions

6.1. Compressor shaft seal leak

The suction side of our compressors runs continuously at sub atmospheric pressure. This is necessary to keep the recovery pressure low enough for users. Unfortunately, the sub atmospheric condition causes a potential for contamination to enter the process. The most notable instance we've found is the shaft seals of our recovery compressors. Since the installation of our contamination meters, we had noticed that the contamination levels at the suction and discharge of our recovery compressors were quite high. Most notably, the hygrometers were reading up to 5,000 ppm water in the helium, ten times the design condition for our purifier. Leak checking revealed that the recovery compressor shaft seals all had significant leaks from atmosphere. The shaft seals have been replaced with new seals, which force a small amount of oil out of the seal during operation, minimizing the amount of air allowed into the process. Since the new seals have been installed, the water contamination at the discharge of the pumps has already been reduced to less than half of the previous level. We have not yet had the opportunity to fully purge the system and find a baseline for the contamination rate of the new shaft seals.

6.2. Gas bag leaks

Gas bags are one of the main culprits for helium contamination. The seals around penetrations in the bags are the main locations where leaks occur. This combined with sub atmospheric pressures due to pump suction draws air into the helium. We have had several bags serviced to reinforce the seals around the penetrations. This has reduced, but not eliminated the contamination from the bags. Greg Labbe (University of Florida) suggests silicone caulk to seal the penetrations.

6.3. Safety

It is very important to make users aware that the recovery system is not to be used as a relief path. The recovery system is not designed for the high pressures or flow rates associated with a magnet quench or sudden loss of vacuum event. Separate relief paths are required on all cryogenic vessels. It is necessary to stress this point to users, as many researchers do not have experience in cryogenic vessel design.

7. Future Efforts

7.1. Vacuum pump connections

Currently, there are several pumping stations at the Mag Lab for users who need temperatures below 4.2 K. Some of these are not connected to the helium recovery network due to lack of plumbing or the risk of introducing pump oil into the recovery system. Over the next few years we plan to improve the piping network where necessary and provide the required oil removal techniques to allow the pumps' discharge to be recovered.

7.2. Full HDPE replacement

Some areas of the Mag Lab continue to use the original PVC piping. Over the next year, we plan to completely replace the PVC with the HDPE piping, eliminating many potential leaks.

7.3. Increased user involvement

Although our current focus is mainly on getting the recovery system as leak free and easy to use as possible, we also have to involve the helium users in the recovery effort. Our plan is increase the users' awareness and knowledge of our recovery system, and to encourage as close to 100% recovery as possible through efficient transfers and enlisting users' help in finding potential helium losses.

Acknowledgements

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