PROCEEDINGS OF SCIENCE

Helium recapture and reliquefier system for Dynamic Nuclear Polarization at UNH

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A new helium recapture and reliquefaction system, consisting of a gas bag, recapture manifold, cooling chiller, cryogenic purifier and a gas storage cylinder bank has been installed in the dynamic nuclear polarized target lab at the University of New Hampshire. This new system has the capability to improve the efficiency of our capacity to do target polarization runs by recycling our cryogenic helium which would otherwise be lost during polarization operations. Our helium liquefier is rated upto 40 L/Day under normal full-capacity operations, and has a capacity of 500 liquid liters of helium. I explain the initial installation process followed by a discussion of the challenges with installation, including issues of impurities which appeared during the initial operation of the system. Then I discuss how we overcame these difficulties. Finally, I discuss the function of the system during normal operation and the present situation of the helium recapture and reliquefaction processing in the UNH Lab.

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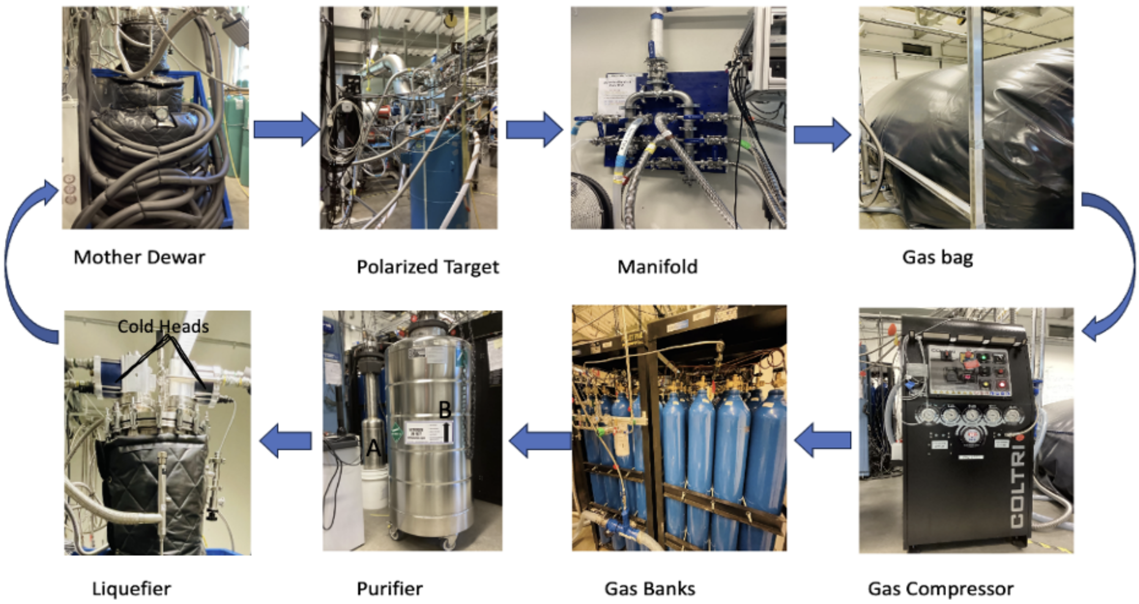

Figure 1: General set up and components of the Helium Reliquefier System for the cool-down in the Nuclear Dynamic Polarization Target group at the University of New Hampshire.

1. Introduction

The study of spin polarization of deuterated material is necessary for the polarized targets for the upcoming A_{zz}[1] and b_1[2] experiments at Thomas Jefferson Lab. In order to develop the target system for these experiments we need to perform 'cool-downs' where around 500L Liquid Helium (LHe) is needed to cool the superconducting magnet and maintain 1K temperature for the target material[3][4] per cool-down. Recently we have installed a new Quantum Technology[5] helium recapture system with its components shown in Fig.1. Once the LHe is used to cool the polarized target, it boils off, and it is recaptured by the recaptured manifold. Then this recaptured boil off Helium accumulates inside our 10ft ×10ft ×15ft gas bag. Collected gaseous Helium (gHe) is compressed by a High Pressure Compressor and goes to our high pressure cylinder bank. Next, the compressed gas is fed for purification to one of two purifiers to remove impurities that the magnet collects in the helium during the cool-down. Finally, the helium is fed for liquefaction through two cold heads and the condensed liquid is collected in the 500L capacity Mother Dewar. So, the recovery pathway follows the path of Mother Dewar to the polarized target material, then to the gas bag through collection manifold followed by the compression to the cylinders bank by the high-pressure compressor. Then purified by purifiers and liquefied by cold heads. And this is a never-ending cycle.

2. Working Principle of Purifier

In order not to freeze atmospheric gases in the system, the purity of gHe output to the cold heads should be 99.995% or higher. The purifier consists of an inlet port where gaseous helium enters and is forced through approximately 19 liters of absorbent material in the bottom of the purifier. The absorbent material is held at 77K by submerging the purifier in a bath of liquid nitrogen. This causes

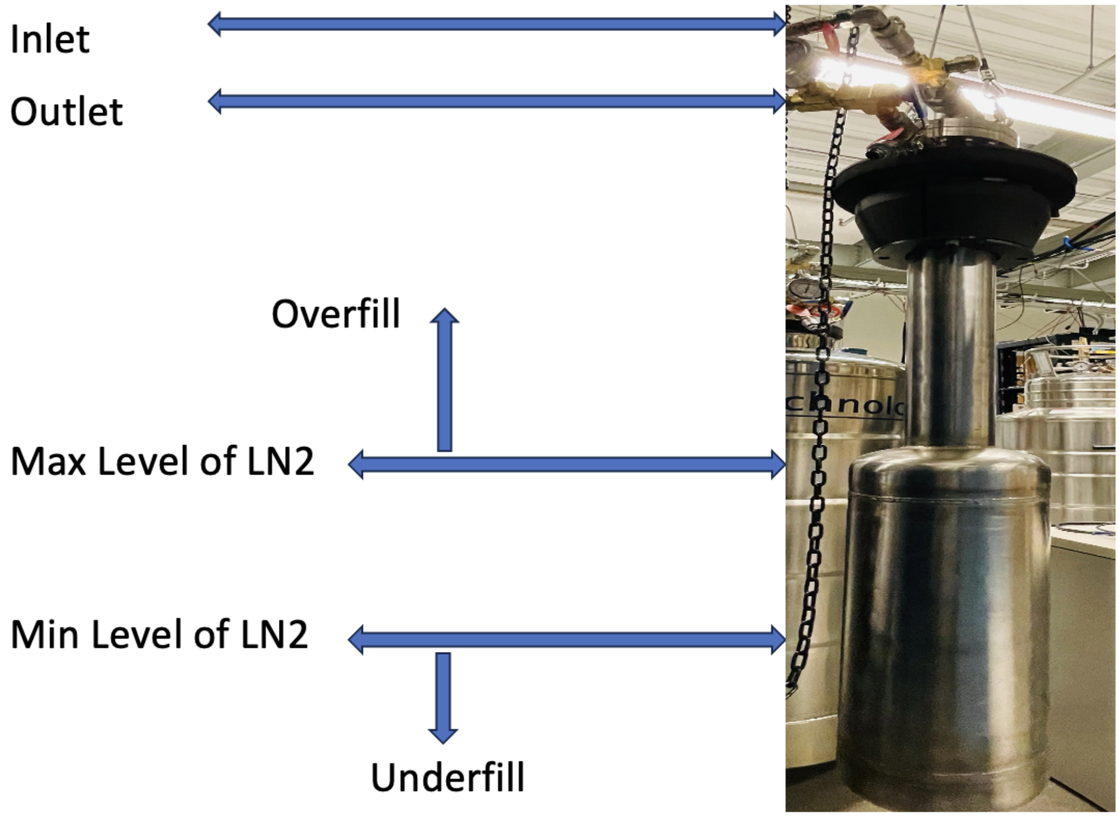

Figure 2: The level of LN2 needs to be in between Max and Min Level when purifier is submerged in LN2 dewar for proper working. Inlet is the helium gas coming from the cylinder to the purifier for purification and outlet is the helium flowing out to the cold heads after the purification.

any non-helium impurities to liquify or solidify and become captured in the absorbent material, allowing purified gaseous helium to exist via an outlet port. The difference in the pressure between these two inlet and outlet port is called the differential pressure. The absorbent is considered saturated when the differential pressure reaches approximately 2psi , at which point the purifier is removed from liquid nitrogen and allowed to warm up to room temperature before being pumped down in a regeneration process [6]. Once regeneration is complete, the purification cycle can start again. There are two purifiers in the UNH system to minimize downtime from the regeneration process. When the purifier is submerged in the LN2 dewar, LN2 should be between the Max and Min level shown in Fig.2. If it is overfilled, as soon as the helium enters the purifier impurities start to freeze at the neck of the purifier which will clog the inlet port and artificially indicate that the purifier is saturate. If the purifier is underfilled, the impurities will not have low enough temperature to freeze which will give out the impure helium from the purifier. We make sure that purifier was within this level for at least three hours before bringing the system in the liquefy mode to improve its performance.

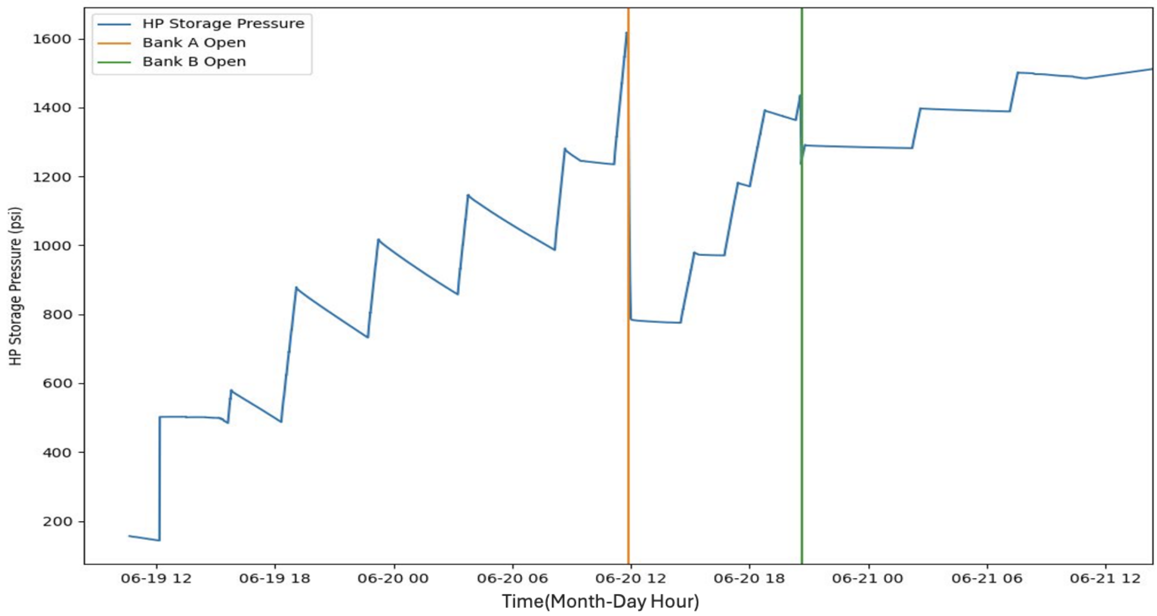

Figure 3: Even distribution of pressure when the Bank A was opened between Bank A and C and uneven distribution of gas when bank B was opened between Bank A, B and C.

3. When it fails

If we are not able to feed 99.995% input purity of gHe to the cold heads, the system goes to idle mode and cannot liquefy the helium, it means our cold heads are so sensitive that they need high purity gas to convert into the liquid form. The reason behind the low outlet purity is due to the high differential pressure above 2psi (Purifier saturation limit) or we have not workable LN2 level in Purifier LN2 Dewar. So, these are the two things that we need to maintain in our workable limit. Additionally, during the cool-down ballast valve must be closed.

4. Trouble Shooting

When the gaseous Helium (gHe) storage banks were delivered they were expected to be under vacuum, but one of the banks was already filled with some unknown gas, which is verified from Fig.3. Our system has three sets of gaseous helium storage banks labelled A, B, and C with each consisting of 16 high pressure cylinders. In initial operation, only Bank C was initially opened and was filled with gaseous helium until it reached approximately 1600psi, at which point Bank A was opened and the two banks equalized. This led to a combined pressure across banks A and C of approximately 800psi, as expected. Once the pressure in banks A and C reached approximately 1400psi, bank B was opened. Once the pressure between all 3 banks had equalized, we expected a pressure of approximately 925psi but instead measured a pressure of 1250psi. This implies that bank B was already partially filled with an unknown gas, which is one of the possible causes of impurities in commissioning of the system. This was one of the possible causes of the impurities. A second, much larger source of impurities was due to the ballast valve from the roots pumps having been left open, as shown in Fig.4. The roots pumps are used to cool the target material down to 1K, and the ballast valve allows atmospheric air to mix with the outlet gas. We found that the flow rate

Figure 4: Zero'0' pointed up is closed and '1' pointing upward is open.

from the roots pumps can be used to determine whether the ballast is open, as shown in Fig.5. In the plot, when the ballast valve was closed (blue), the flow clearly pointed towards zero standard liter per minute (slm) as the Manometer pressure reading fell from 100 Torr to 0 Torr. When the ballast valve was open(red), there was always a flow rate of more than 75 slm even when the manometer pressure was zero Torr. This indicates that when the ballast valve was open, the flow rate was reading not only the flow from the fridge, but also the atmospheric gas that enters our system. This was a major cause of impurities causing the purity of helium to drop to 70%. Multiple attempts to purify the purity 70% helium were made, but the cryogenic purifiers could not remove that level of impurity without losing significant amounts of helium in the process. So, the lesson learned from the commissioning of our system is to close the ballast valve during every cool-down, maintain the purity level, and start the cool-down after a pump and purge with gHe to avoid such trouble.

5. Analysis of Normal Working Conditions

In normal operations we will have continuous liquefaction, periodic magnetic fill, periodic turning on of compressor, and so on. Fig.6. shows the level of Liquid Helium in the Mother Dewar(in Litre) in blue and the gas pressure in the gas banks(in psi) in green. Here, some periodic drop in the liquid level is due to the transfer of liquid helium to the polarized target, we called a magnet fill. The steady increase indicates continuous liquefaction occurring at the same time. Inverse to this,

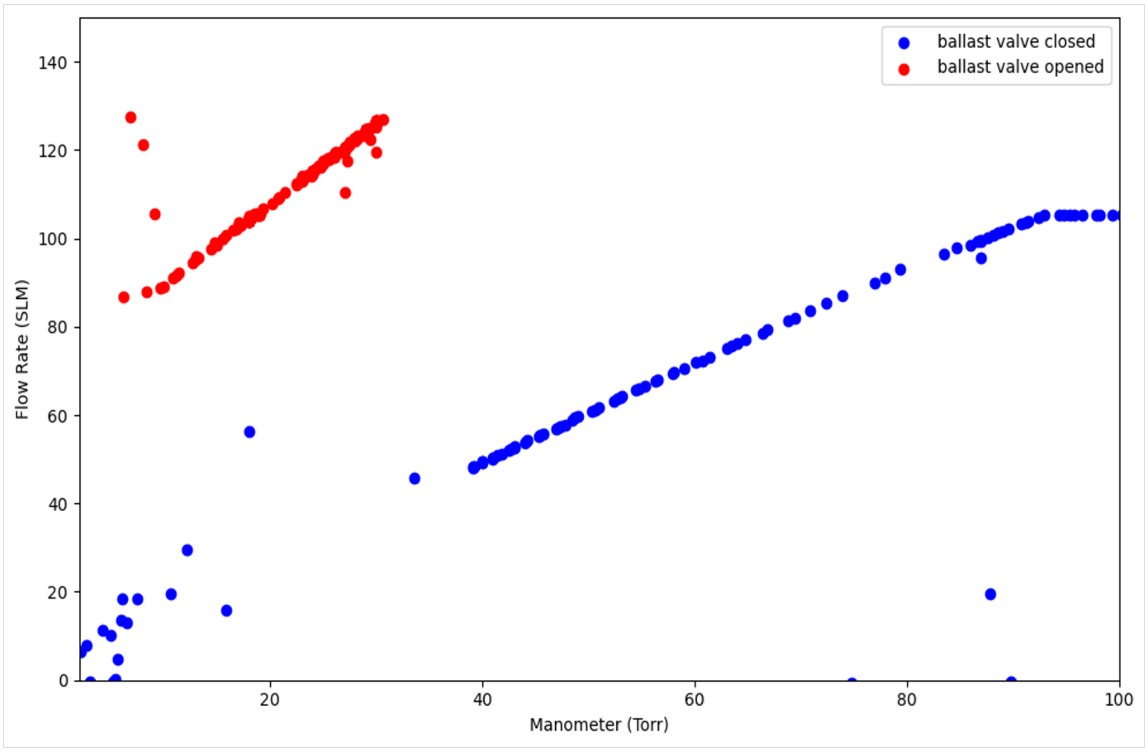

Figure 5: Fit(in blue in color) is showing that flow rate is pointing down towards zero slm when the ballast valve was closed. Fit (in red), when the ballast valve is open the flow rate is more than 75slm even the pressure drops below zero torrs.

the green data line shows the amount of gas in the gas bank(in psi). Similarly, the sudden sharp increase in the pressure is due to the sudden boil off collected from the gas bag to the bank after the magnet fill. The small continuous decrease in pressure is due to continuous purification and liquefaction. We typically have a cool-down of 4 to 5 days followed by 11-12 days of continuous liquefaction. This is clearly shown in Fig.6. We see that after 4 and half days there is continuous liquidity happening, so the liquid level is increasing and the gas level is continuously decreasing. Fig.7 is the liquid helium production rate for each day, measured between 35LL/day to 45LL/day with our this system. So we were able to reliquefy 400LL of Helium in approximately 12 days. Once liquefied, it is stored in the Mother Dewar for future use.

6. Result

After the first mistake during the commissioning of our system, we maintained the 99.995% input purity level (checked ballast valve status, started the system with Pump and Purge), and we were able to liquefy 35LL / day to 45LL / day on average of helium at standard pressure of 6psi as Quantum Technology suggested. We were able to liquefy 392LL in approximately two weeks and we were able to utilize it to run the polarized target for a week. Thus we can observe physics for more than 15 weeks in a year with almost the same amount of cost to do a single cool-down previously.

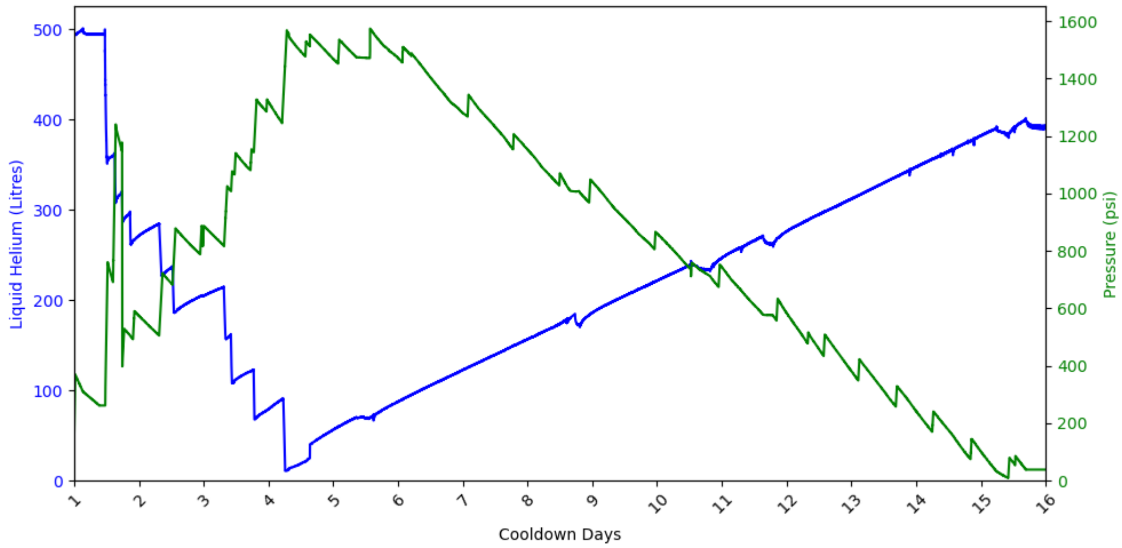

Figure 6: Liquid Helium in the mother Dewar(in litre), blue in color, and compressed gas in the gas bank(in psi), green in color at the time when magnet fill up and liquefaction happening simultaneously.

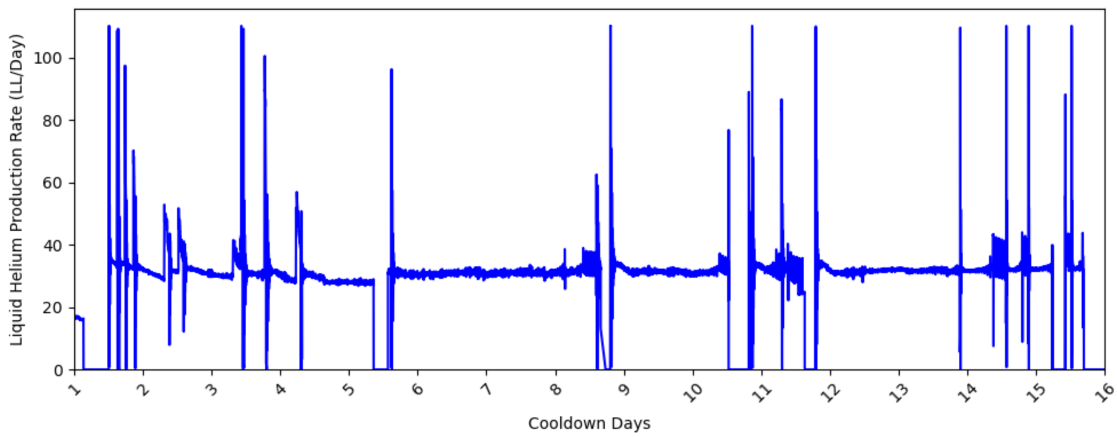

Figure 7: Helium liquefaction rate (LL/day) calculated for throughout the cooldown period.

7. Conclusion

With taking all the precautions, the system works as expected. The most important thing is that we need to avoid mixing impurities into the system, like the ballast valve must be closed and always start with a pump and purge of the system which will give us a clean system to use LHe. With these we can do 15+ cool-down per year for what used to cost one cool-down. In our total of five cool-downs we were able to recapture 80 % - 95% of helium used.

8. Acknowledgement

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