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SNS Central Helium Liquefier spare Carbon Bed installation and commissioning

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Abstract. The Spallation Neutron Source (SNS) Central Helium Liquefier (CHL) at Oak Ridge National Laboratory (ORNL) has been without major operations downtime since operations were started back in 2006. This system utilizes a vessel filled with activated carbon as the final major component to remove oil vapor from the compressed helium circuit prior to insertion into the system's cryogenic cold box. The need for a spare carbon bed at SNS due to the variability of carbon media lifetime calculation to adsorption efficiency will be discussed. The fabrication, installation and commissioning of this spare carbon vessel will be presented. The novel plan for connecting the spare carbon vessel piping to the existing infrastructure will be presented.

1. Background

The Spallation Neutron Source (SNS) operates a Superconducting Linac (SCL) containing 81 Superconducting Radio-frequency (SRF) cavities housed in 11 medium-beta and 12 high-beta cryomodules. The SNS Central Helium Liquefier (CHL) provides cryogenic liquid helium bath cooling for these SRF cavities at 2.1 K [1]. This cooling is produced by the CHL facility through: a 4-K cold box, a 2-K cold box, three first stage warm compressors, three second stage warm compressors, liquid nitrogen (LN2) storage tank, warm gas helium storage tanks, a helium purifier, and all necessary cryogenic transfer lines and warm piping.

Both the first stage and second stage CHL compressors are oil flooded type screw compressor, making the oil removal system of vital importance to the long term reliable operation of the facility. Even small amounts of oil vapor passing the oil removal system and entering the 4-K cold box would have a negative effect on heat exchanger performance, turbine lifetime and pressure drop through the box.

The SNS CHL oil removal system is comprised of bulk oil separators on each compressor and then three liquid coalescers in series on the common high pressure header. After the final coalescer is a carbon bed designed to remove any aerosolized oil vapor. The carbon bed is a packed bed designed with helium flow going from the top of the vessel to the bottom to minimize carbon dust formation. The design of the filtration system uses a final filter to trap any carbon dust generated from flowing through the carbon media. After the final filter, the high pressure helium enters the 4-K cold box. Figure 1 is a simplified schematic to show the location of the oil removal system between the CHL compressors and the start of the 4-K cold box.

The first two coalescers are actively drained back into the suction of the second stage compressors. The third coalescer is checked weekly for any liquid oil accumulation. Due to daily monitoring of oil drainage flow, there is no concern about oil buildup over time in any of the coalescers. The final filter vessel has several replaceable filter elements, so it too is equipped for long term sustainable operation through procedurally changing the filter elements.

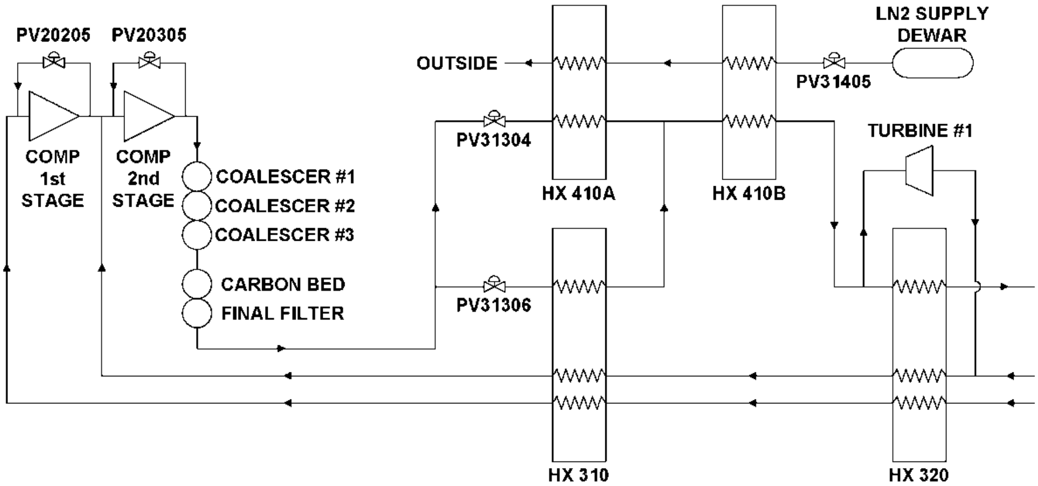

Figure 1. Simplified schematic showing oil removal components before 4-K cold box

The design of the CHL carbon bed does not allow maintenance while continuing to operate. The SNS SCL has been cold since 2006, and there is concern that significant damage to the cryomodules could occur during a thermal cycle resulting from simply replacing the carbon in the existing carbon bed. The existing carbon bed represents a single point failure for the CHL system. If the carbon bed were to start showing contamination at its outlet, the entire CHL would have to be shut down and the Linac warmed to room temperature for a minimum of 4 months to facilitate removal of the current carbon adsorbent, filling with new carbon, and drying of the installed carbon.

Up until now, no liquid or vapor oil has been observed at the outlet of the carbon bed. The CHL uses a single LINDE multi-gas analyzer to monitor the CHL carbon bed. Figure 2 shows the contamination levels from this analyzer.

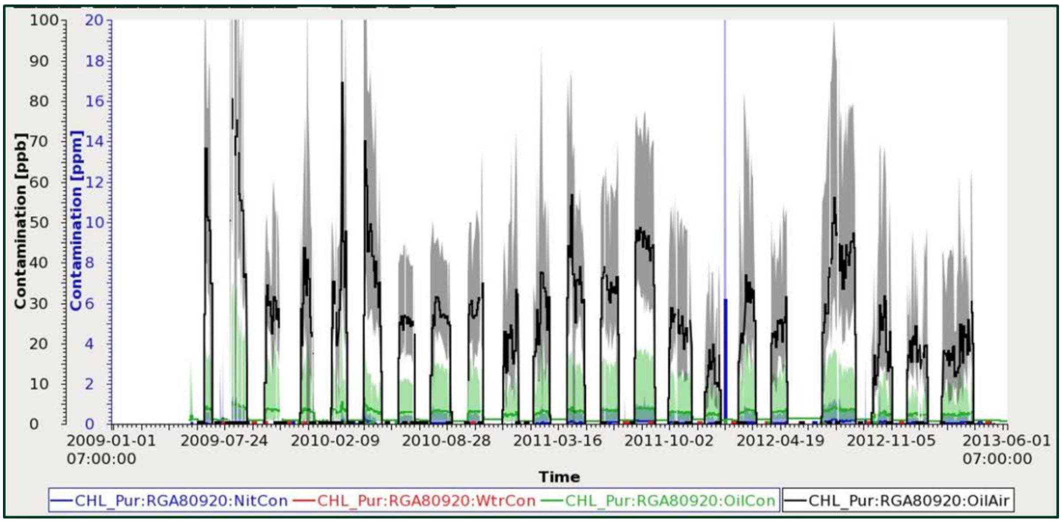

Figure 2. CHL oil aerosol contamination plot from 2010 to 2013

The alternating periods of high and low readings are from a period between 2009 and 2013 when the analyzer was regularly shifted between the inlet and outlet of the carbon bed. No contamination was recorded on the outlet and the inlet is dominated by a 30 to 100 ppb oil vapor reading. Since 2013, this analyzer has been kept on the carbon bed outlet with no sign of contamination.

The ability of the carbon material inside the carbon bed to remove oil vapor from the helium flow is dependent on several parameters, including the inlet contamination level. Equation 1 given by R. Ganni [2] allows the calculation of the carbon lifetime.

$$M = \frac{\dot{m}\cdot R\cdot t}{1000\cdot L\cdot E} \quad (1)$$

Using values of 1000 g/s for the mass flow rate ($\dot{m}$), 100 ppb for the oil contamination level (R), 4500 kg for the mass of the installed carbon (M), 0.75 for the effective length (L) and 0.01 for the adsorption efficiency of the carbon (E), the existing SNS carbon bed has a design lifetime of 11 years. SNS commissioning began in 2003 and full time operation started in 2006, meaning that according to the original design calculations, the SNS carbon bed has already reached the end of its expected lifetime. It should be noted that there is a high degree of uncertainty in the values used to calculate the bed's lifetime. The SNS contamination may be lower by ~50% than the design contamination level. The adsorption efficiency of the carbon for oil vapor in helium flow is not something highly studied by the carbon manufacturers. According to some estimates, the adsorption efficiency value of 0.01 may be off by a factor of two or three; however there is no data to validate this estimate.

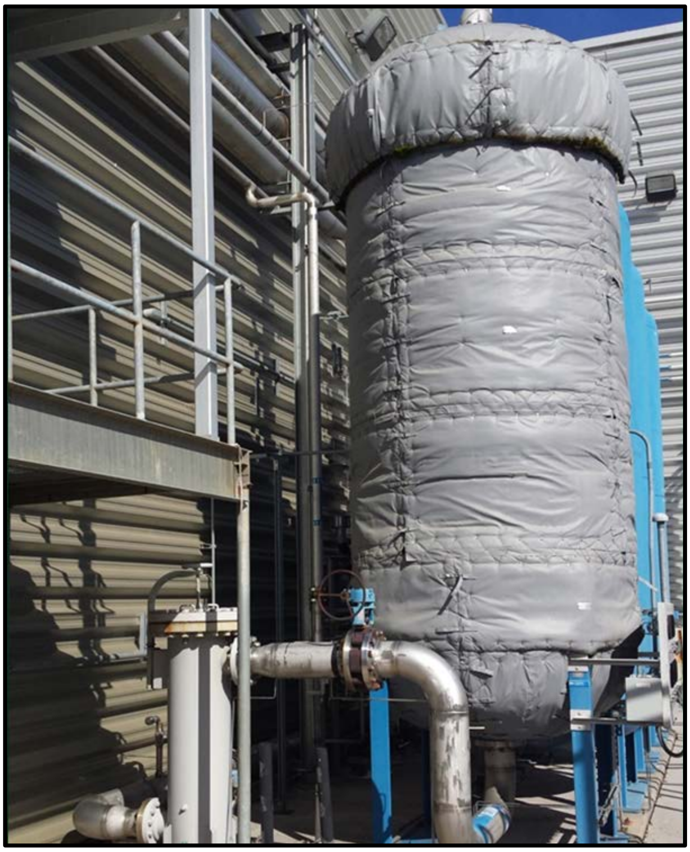

Figure 3. Existing CHL carbon bed vessel with heater blankets

The ability of carbon to adsorb oil is dependent on removing as much moisture as possible from the carbon. Two principle options are available for drying installed carbon: flowing dry nitrogen gas without heating the vessel or with heating the vessel. The existing carbon bed was dried with heaters covered by insulating blankets installed to assist in the moisture removal from the carbon. Figure 3 shows the original final filter and carbon bed with insulating blankets.

2. Installation Activities

Given the serious consequences of having the existing carbon bed fail, effort was started in 2015 to add a spare carbon bed with its own spare final filter to the CHL system. JLab was able to provide SNS with updated designs for both the carbon bed and the final filter. The spare carbon bed was manufactured by Hilliard and delivered in early 2016 [3]. The spare final filter vessel was manufactured by Riggins and delivered in early 2016 [4]. The maximum allowable working pressure (MAWP) of both vessels is 23.8 atm (350 psia), which is sufficiently higher than the normal operating pressure of the CHL high pressure circuit at 16 atm (235 psia). There is sufficient room between the first coalescer and the existing CHL compressed air tank to install both vessels.

With the arrival of the new vessels, SNS was faced with the decision of when to connect these two vessels with the CHL piping. The CHL piping installed during the original construction project did not include pipe taps for a second carbon bed to be connected in parallel with the current carbon bed and final filter. A parallel configuration would be ideal as this would allow for one carbon bed to be online with active helium flow, making the other one available for carbon replacement. However without taps being available, the installation of these new vessels would require the CHL to be taken offline for 4-6 weeks for the piping work, some of which must occur at elevation above the current carbon vessel and coalescers. Due to the potential harm that could occur to the Linac cryomodules during a complete thermal cycle, the decision was made to only install the spare carbon bed and final filter and defer the piping connection to the CHL system until a later date.

Before starting the installation of the spare carbon vessel, the lower screen was installed with the vessel resting on its side in the construction lay-down area. This lower screen consists of mechanical supports to take the load of the weight of the carbon media, two sheets of perforated plates and a fiberglass blanket. Once the lower screen was installed, the vessel was transported to the CHL. Two cranes were used to both remove the spare carbon vessel from the truck and to rotate the vessel to the vertical position. Then a large crane was used to lift the spare carbon vessel over the CHL gas helium storage tanks onto a newly poured concrete pad. Figure 4 shows the spare carbon vessel being flown into position over the CHL gas helium storage tanks.

Since it requires 10,000 lbs of carbon to fill the spare carbon vessel, SNS procured 56 drums of OVC 4x8 coconut granular activated carbon media from Calgon [5]. While not identical to the carbon media in use on the existing CHL carbon bed, this replacement media was chosen to have the same absorption properties. This carbon media has a maximum ash weight of 3%, a maximum moisture content of 5%, a density of 0.45 g/cc, a hardness number of 97, a carbon tetrachloride weight of 60%.

In order to minimize dust generation during filling the spare carbon vessel, a transport hopper was used with a fabric chute attached to the bottom. The carbon drums were emptied into the hopper on the ground and then the hopper was lifted into position above the open head of the spare carbon vessel. The carbon was then released slowly as to minimize the generation of carbon dust. Even with proceeding slowly, the entire process took less than one shift for the general contractor’s personnel. Figure 5 shows the hopper in use for filling the spare carbon vessel.

An upper screen, similar in design to the lower screen, was then installed to capture the carbon media and prevent carryover into the final filter and 4-K cold box. The elliptical head of the vessel was then re-installed with new bolt hardware and torqued appropriately. The final filter was then installed behind the spare carbon bed and the pipe joining the two vessels was also installed.

Figure 4. Spare carbon bed being lifted over CHL gas storage tanks for installation

Figure 5. Crane lifted bucket for filling carbon media into vessel

The cleaning of the carbon media was accomplished by flowing gaseous nitrogen through the carbon media. The CHL LN2 dewar was used to supply LN2 through an ambient vaporizer to produce a gaseous flowrate of between 15 to 18 cfm. The dew point of the exhaust nitrogen gas coming off the spare carbon bed is measured by a Shaw Automatic Dewpoint Meter (SADM) with a range of 0 to -80 ^{o}C. The SADM is in calibration and was tested on the LN2 boiloff gas to confirm the quality of the dry nitrogen at -80 ^{o}C.

In contrast to the original CHL carbon bed, the spare bed did not have heaters or insulating blankets installed as it was suggested that the same dry conditions could be achieved with simply flowing gaseous nitrogen for a longer period of time. Nitrogen flow was started into the spare carbon bed on December 5th, 2016 with initial reading of the dew point at -3 ^{o}C. Readings were taken once a day by CHL personnel and figure 6 shows the cleanup progress over time. While initially the gas flow showed a steady rate of dew point decline, eventually the progress seemed to stall. On May 5th, the meter was checked for calibration and found to be only slightly off. After recalibration however, a similar flat trend continued. Shortly after, a 1500 watt inline heater was added to the gaseous nitrogen flow immediately before entering the spare carbon bed. It does not appear that this heater had much positive effect. The rising dew point numbers observed in the past few weeks are likely due to the high ambient temperatures.

The cause for this stall is still unknown. It was observed that the cold weather experienced in January and February is not conducive to removing moisture from carbon with only nitrogen gas flow. It is possible that only in the last few months, as the weather has gotten warmer, that the majority of the water is being expelled from the carbon. It is likely that in the near future, heaters and blankets will be added to this vessel to complete the purification process.

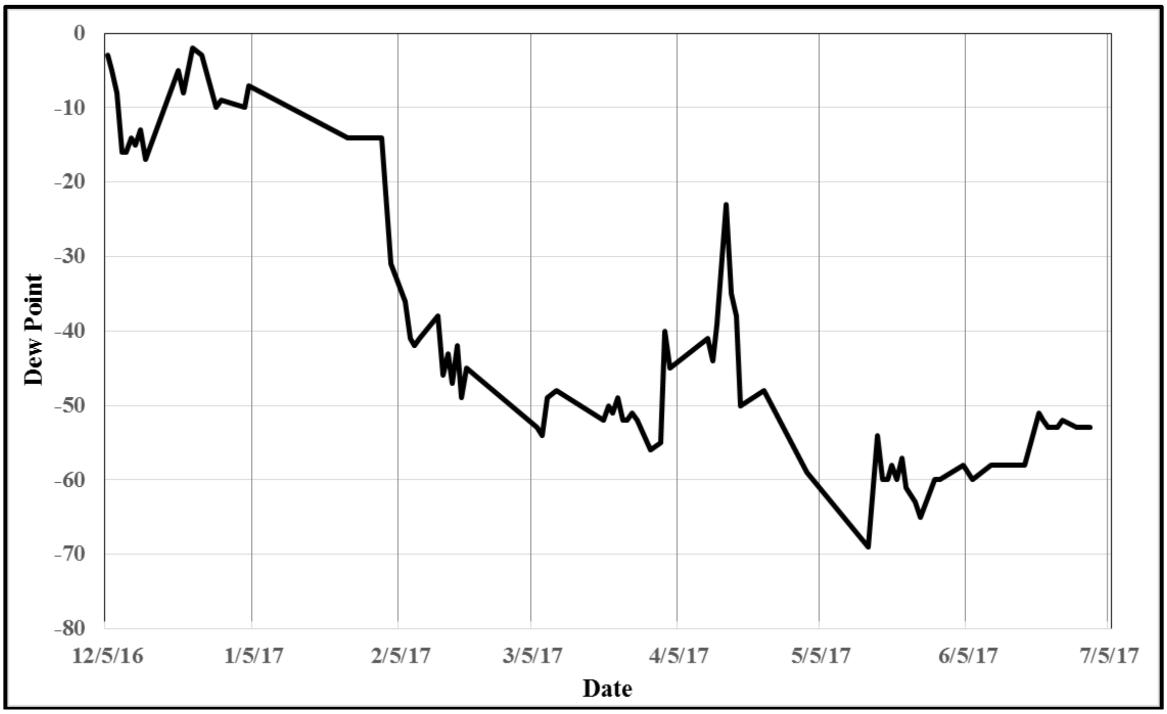

Figure 6. Dew point measurement showing cleanup of spare carbon vessel over time

3. Integration Plans

In early 2018, the beam at SNS will be off for 4 months for replacement of the Inner Reflector Plug (IRP) which surrounds the liquid mercury target. This timeframe was chosen to integrate the spare carbon bed piping with the existing CHL piping. Several potential solutions were considered that would keep the SCL at 80 K without having the 4-K cold box or CHL compressors online during this integration project. However, for various cost, schedule and technical reasons, each one of these solutions was not desirable.

In order to avoid a significant CHL outage and to avoid having to connect the spare carbon bed after the failure of the existing carbon bed, a novel solution was devised for the installation of the spare carbon bed in 2018. The space carbon bed will be connected in series to the existing carbon bed by means of a single 8 hour shutdowns of the CHL cold box and compressors. This type of successful short shutdown has been accomplished on three other occasions for necessary maintenance such as compressors switchgear cleaning and controls hardware upgrades.

The plan is to fabricate one pipe spool. It will be installed downstream of the current final filter. It will have a tee with three valves for additional piping connections. If successful, this new spool will allow connection to the spare carbon bed and final filter while the CHL remains fully operational.

Ideally, the tap to supply the spare carbon bed would come from the piping at the inlet of the existing carbon bed, however no spool piece exists at this location. In order to perform this work, cutting and welding at elevation would be required. It was determined that this is too much work to reasonably accomplish in a single 8 hour shutdown.

In this proposed configuration, the existing carbon bed and final filter would flow directly into the spare carbon bed. While this solution has not been tried before at SNS, it allows the existing carbon bed to be operated until failure without any consequence to the facility. This has the benefit of verifying the design calculations and possibly providing valuable design information for future projects. Figure 7 shows a simplified flow diagram of this series flow path. Included in this design would be taps to potentially add a third carbon bed in parallel with the spare carbon bed. It is unknown if the CHL will operate for another 11 plus years without any need for an extended shutdown and warmup of the SCL, but adding these taps allows for an easy solution in that unlikely scenario.

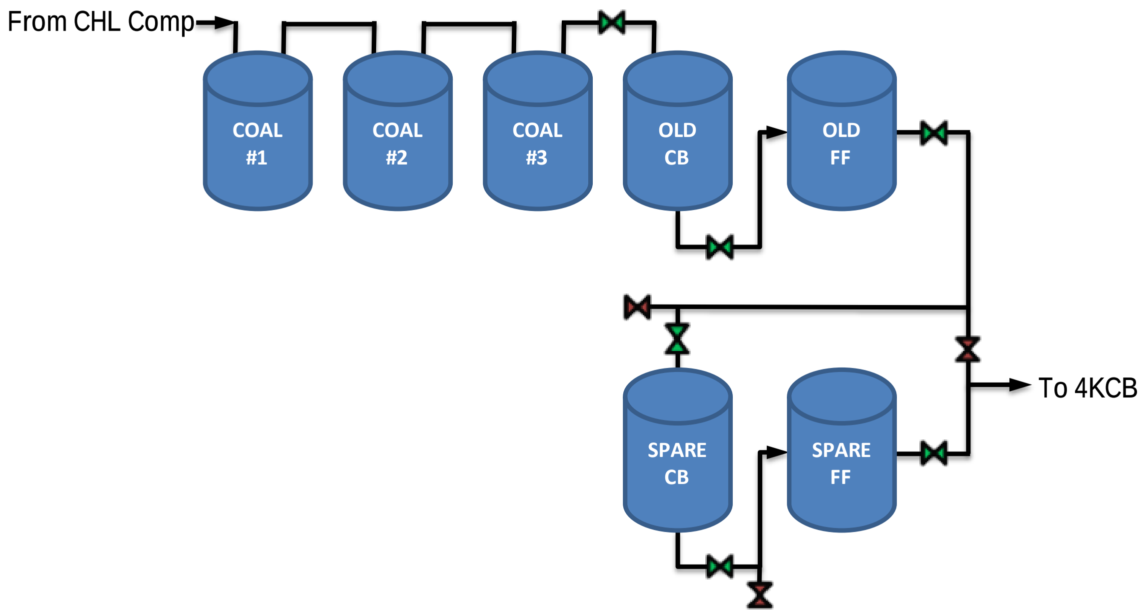

Figure 7. Future CHL carbon bed series flow configuration

4. Summary

The spare carbon bed represents a vital component in reducing the operating risk for the SNS CHL. The desire for SNS is to continue to operate without warming the Linac for the next several years. With an additional carbon bed installed in series with the current carbon bed, the CHL should gain an additional 15 plus years before further effort is required. At that time, it is hopeful that using the taps installed during the upcoming piping project will provide sufficient flexibility that no further outage is required to establish parallel operations with two carbon beds. It is also hoped that the end of life carbon data gained from operating the current carbon bed to failure will provide valuable information in support of future cryogenic installations.

References

[1] White M 2002 *Advances in Cryogenic Engineering*, AIP Conf. Proc. **613**, p 15
[2] Ganni V, 2019 Design of Optimal Helium Refrigeration and Liquefaction Systems, Short Course Symposium (Tucson, CSA Short Course) pp. 8-10
[3] http://www.hilliardcorp.com/
[4] http://www.rigginscompany.com/
[5] http://www.calgoncarbon.com/

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