Helium Reclamation System

---- White Paper ----

Farhad Memarzadeh, Ph.D., P.E.

The 2014 U.S. Geological Survey notes that helium used in the U.S. in large-volume applications is seldom recycled. Recovery would reduce vulnerability to shortages and possible supply disruptions. There is no substitute for helium to cool a superconducting magnet which generates enormous amounts of heat. Helium-3 becomes a liquid at the lowest temperature of any element in the universe. A temperature of -429 °F is required to cool an MRI making it essential to its operation.

Helium reclamation is a cost-effective option for large scientific facilities where it is used for superconducting magnets, probes and other instrumentation.

Helium reclamation systems should be as simple as possible. The pipe routing should minimize total length of the lines, amount of the helium kept inside the process lines, total volume of external vacuum insulation and the number of branches.[3]

Recycling cryogenic gas involves three steps and all the requisite equipment for facilitation of the steps:[1]

1) Gas capture in a closed system that collects the gas and pumps it to liquefier equipment.
2) Purification
3) Returning recovered gas into the process which requires re-liquefaction.

Depending on the type of system and the distance the cryogenic fluid has to travel, there are numerous factors and challenges that must be considered when planning and designing the installation of a Helium reclamation system.[2,3,4,5]

1) Total distance, routings, sectorization, modularization and available space.
   Sectorization splits a line into sections divided by vacuum barriers. Modularization facilitates the production, transportation and installation.[3]
2) Required mass flow rate and its time characteristic
3) Thermodynamic properties of the cryogenic fluid

4) Thermal loads
5) Mechanical stresses due to pressure difference between the vacuum insulation and the inner content of the pipes
6) Fatigue stresses due to cyclic temperature changes
7) Access to the cryogenic lines if underground can be limited
8) Mechanical properties of conduit material, insulation and sleeve welds
9) Contamination of the fluids
10) Integration of appropriate maintenance schedules, processes and monitoring systems.

Detailed guidance for these challenges and for the design of complex cryogenic transfer systems can be found in the 'Handbook of Cryogenic Engineering'.[6] Recommended steps in designing and analyzing the specifications for a cryogenic reclamation system, although not all inclusive include:[3]

1) Routing analysis of the individual cryogenic transfer lines for each facility that will incorporate cryogenic subsystems
2) Designing the process line arrangement including specification of the pipe internal cross section areas with respect to nominal mass flow rates and acceptable pressure drops, calculation of pipe wall thicknesses (accounting for nominal pressure, temperature and material properties). This step determines the relative positions of the lines inside a common vacuum envelope and accounts for the distribution of pipe weights and the radiation. The lines should be grouped according to their temperatures with some space available around each line for processing and welding tools for maintenance purpose.
3) At the NIH, the pipes shall be manufactured of 304L steel per the NIH Design Requirements Manual (DRM).[7] Since process lines are pressure equipment, they have to be designed and constructed according to ASME B31.[4] The radiation shield may be made of aluminum alloys of 6000 series [4] and equipped with longitudinal welded aluminum clamps.[3]
4) Account for thermal contraction of each process line so that each expansion joint will be able to compensate for the maximum total thermal contraction.
5) Conduct thermo-mechanical numerical analysis of the process lines and external vacuum envelope including the bends in the line, nominal operating conditions (ambient temperature and high vacuum pressure), and failure modes e.g. cold helium leakage to the vacuum space, external envelope temperature decrease to ensure that the supports will withstand all forces caused by weight, pressurization, and thermal contraction of the lines.

6) Conduct a detailed design analysis of fixed and sliding supports such that the process line fixed supports can transfer to the external envelope all the forces caused by both pressurizations of bellows (axial expansion joints) and pipe thermal contraction.
7) Estimate the total heat inleaks to the process lines and the temperature increase along the lines for nominal conditions. This can be accomplished using multilayer vacuum insulation mathematical models available in Polinski J. et.al. 2008.[8]

Although cryogenic systems are closed systems, contamination may occur during inspection or maintenance, if the superconductive magnet or cavity is warmed at the downstream side, the helium gas piping is modified, or there is a leakage event in the helium circuit. Oxygen, nitrogen, and moisture are the primary contaminants. Contaminants may remain in the system even after several cycles of pumping and purging the helium circuit. Oxygen and nitrogen contamination can be addressed by incorporating cryogenic adsorbers inside the cold box. Moisture, on the other hand, solidifies into a thin layer of ice that accumulates. The ice decreases the cross section of piping causing an increased pressure drop as helium gas passes through the heat exchanger thus decreasing the efficiency of the heat exchanger and degrading the cooling capacity of the cold box. The system designers must take this phenomenon into account by conducting proper analysis and incorporating precise (ppb) moisture analyzers and monitoring systems.[5]

Finally, once the system is properly designed and installed, an extensive commissioning process is necessary. This shall include at a minimum cold performance tests of the sub-cooler box, measured temperatures in the valve box process lines with rapid cool down close to the nominal operating conditions for an extended period and then abruptly warming up to ambient temperature.

REFERENCES

1. Royzman, Ed. (2013) Making Helium Worth the Cost of Recovery. Laboratory Equipment (NIST) Retrieved 11/1/18. Available at: https://www.laboratoryequipment.com/article/2013/12/making-helium-worth-cost-recovery

2. Jenkins, Gregory (2017) Laboratory Helium Recovery System Manual Rev.2.0. Retrieved 11/1/18. Available at: http://www.physics.umd.edu/drew/people/gjenkins/Summary%20of%20Helium%20recovery%20system%20v32.pdf

3. Fydrych J, Chorowski M, Polinski J, and. Skrzypacz J. (2010) Design methodology of long complex helium cryogenic transfer lines. AIP Conference Proceedings 1218, 1103. Retrieved 11/1/18. Available at: https://doi.org/10.1063/1.3422272.

4. Fydrych J. Cryogenic Transfer Lines; J.G. Weisend II (ed.) in Cryostat Design: Case Studies, Principles and Engineering Chapter 9 (2016) International Cryogenics Monograph Series.

5. Hsiao, FZ et.al. (2014) Investigation of Moisture Contamination In the Cryogenic System at NSRRC. 5th International Particle Accelerator Conference.

6. McIntosh, Vacuum-jacketed transfer line design, section 5-6, in Handbook of Cryogenic Engineering, ed. by J.G. Weisend II (Taylor & Francis Ltd, 1998), pp. 269–278

7. National Institutes of Health (NIH).Design Requirements Manual; NIH,Division of Technical Resources;Bethesda, MD, 2016. Retrieved 11/1/18 Available at: https://www.orf.od.nih.gov/PoliciesAndGuidelines/BiomedicalandAnimalResearchFacilitiesDesignPoliciesandGuidelines/Pages/DesignRequirementsManual2016.aspx

8. Polinski J., Chorowski M., Choudhury A., Datta T.S., “Synthesis of the Multilayer Cryogenic Vacuum Insulation Modeling and Measurements” in Advances in cryogenic engineering 53, edited by J. G. Weisend II et. al.. Melville, New York, (2008), pp. 1367-1374.