CONSIDERATIONS FOR SMALL TO MEDIUM LIQUEFACTION PLANTS

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ABSTRACT

The basic requirements for a user to size and design small to medium helium liquefaction systems are quite multilayer. The feed gas composition, for example, defines whether impurities can be removed by an internal adsorber system or if a purifier (internal or external) is required and if the purification operation is a continuous or batch process.

The liquefaction rate of the system furthermore is dependant on the running time, e.g. if the system is operated during the whole week or stopped on weekends and if a turn-down of the system is required. This will also determine the size of the liquid dewar and storage tank.

Another important issue is the availability of liquid nitrogen for pre-cooling purposes. In the US liquid nitrogen is a commodity with a liter price equal to the price for a kW hour of electricity, whereas in Europe LN_2 is more expensive and used only if necessary or easily available. In case LN_2 is used the components like the compressor and coldbox can be smaller with less consumption of electric power.

The presentation will cover a number of issues showing important considerations in specifying a helium liquefaction system.

KEYWORDS: Helium Liquefaction, Recovery, Purification.

INTRODUCTION

In order to size and specify the requirements of a helium liquefaction system, FIGURE 1, like a liquefaction centre at a university, or an institute or for a facility where superconducting components like MRI magnets are manufactured a number of different issues have to be considered. This paper describes some of the important issues to be looked at.

The foregoing recovery system is not part of the paper. It has therefore been assumed that the liquid helium distributed within the university, institute or facility after evaporation has been collected in a gas bag or other low pressure storage and further compressed to high pressure and stored at a pressure of typically 200 bar.

Additional assumptions are:

- Small to medium liquefaction systems with capacities from 20 to 400 l/h
- The air impurities contained in the recovered helium are in the range of a few hundred ppm up to 10%.

REQUIRED SIZE OF THE LIQUEFACTIN SYSTEM

The correct sizing and specification of the liquefaction system is dependant on a number of operating conditions such as:

- Continuous or intermittent operation
- Future increase of helium volume
- Availability/use of LN_2 for pre-cooling
- Level of air impurities in the recovered helium
- Type of purification system
- Loss of helium in the system and recovery rate
- Turn-down requirements (e.g. weekends)
- Available budget and anticipated operational cost
- Definition of liquefaction capacity

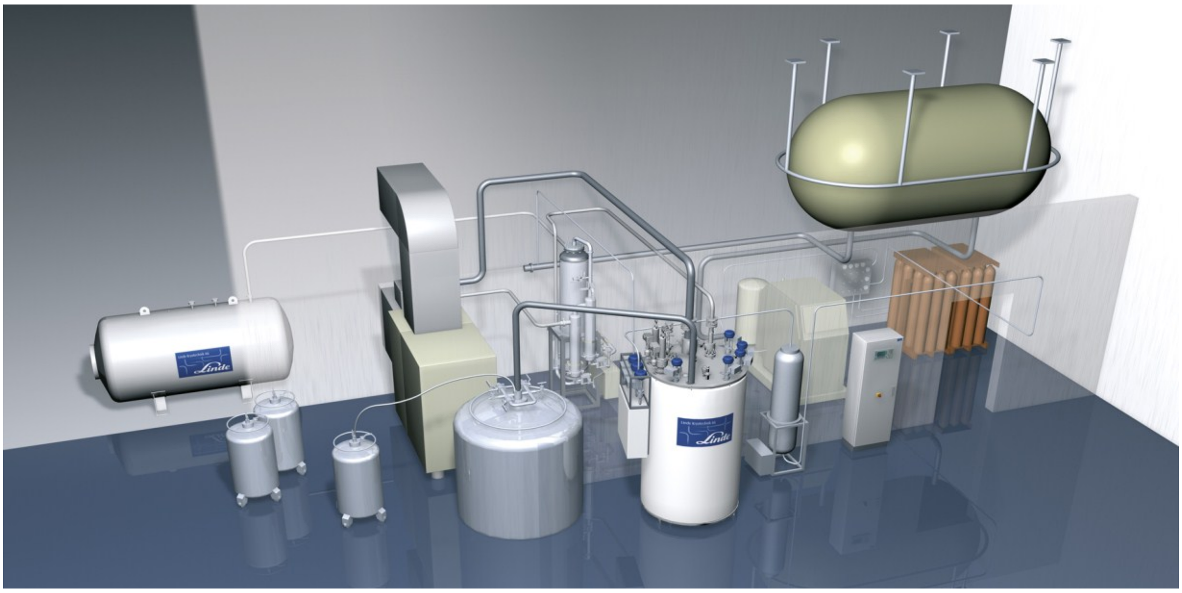

FIGURE 1. Liquefaction system

A liquefaction rate defined as rising level for example is measured as the increase of the liquid level in the LHe Dewar over time under the condition that the displaced cold vapour is re-condensed. This measured rate shows approximately 20% more capacity than the real feed rate to the liquefier.

LIQUID NITROGEN PRE-COOLING

The use of liquid nitrogen (LN_2) as a pre-coolant provides advantages to the liquefaction system. Instead of using expansion machines to generate the required refrigeration, LN_2 is used to cool down the feed gas from ambient temperature to almost 80K and to cover heat transfer losses between the counter current flows in the heat exchangers. This reduces the size of the compressor, oil removal, heat exchanger, piping and valves as well as the power input. As a rule of thumb 1 litre/h of LN_2 is equivalent to a power input of 1.2 kW for the above mentioned liquefaction systems. Advantages of LN_2 Pre-cooling are:

- Smaller size of equipment such as the compressor & heat exchangers
- Less expansion machines
- Less investment cost
- Improved turndown possibility
- Less electrical power input
- Less space and installation cost
- Constant temperature profile in the heat exchangers
- Reduced cool-down time of coldbox

On the other hand the liquefaction system is dependant on the continuous supply of LN_2 and requires a LN_2 infrastructure including storage tanks and transfer lines. In case of an interruption of the LN_2 supply the liquefaction rate will drop drastically.

In many countries “e.g. North America and Japan” LN_2 is a commodity and widely used as a pre-coolant in cryogenic plants. However the operational cost of the system can be substantial higher if the price for LN_2 is much above the cost of electric power.

HELIUM PURIFICATION

The air impurities contained in the recovered helium of such liquefaction systems are ranging from a few hundred parts per million up to 10%. The goal for a helium recovery system should always be to minimize the level of contamination in order to reduce the consumption of electric power and LN_2.

Based on the impurity level different types of purification systems can be used. If the impurity level is in the percentage range either an external LN_2 cooled purifier or an internal freeze-out purifier can be used.

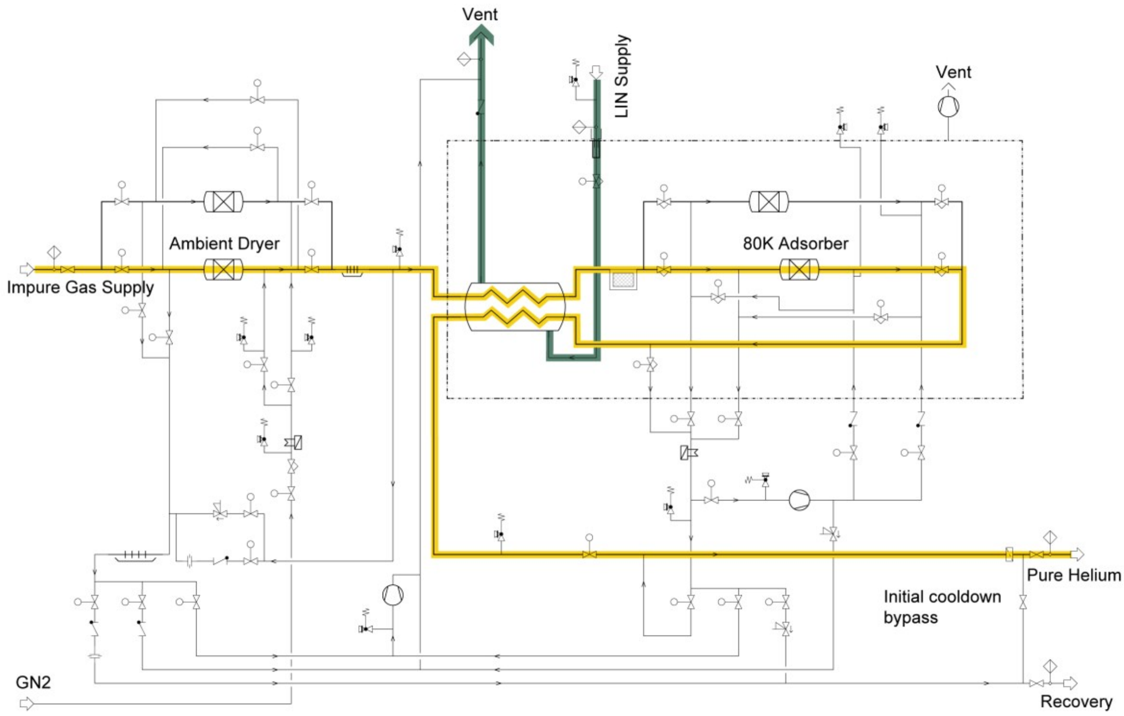

FIGURE 2. Process Flow Diagram External Purifier. Helium purification flow path is highlighted, other lines show adsorber switching and regeneration.

External Stand-alone Purifier

The external purifier would be located upstream of the liquefier coldbox in a separate insulated coldbox whereas the internal purifier is an integral part of the liquefier coldbox.

The process of an external purifier, FIGURE 2, uses LN_2 as coolant to cool down the impure helium and the main quantity of the air will be liquefied followed by an adsorber system to take out the remaining air impurities. The pure helium is warmed up again to ambient temperature by the impure helium entering the purifier coldbox and combined with the recycle stream discharged by the recycle compressor.

Advantages of the external purifier are:

- Stand alone system with no impact on the liquefaction rate
- Helium with high percentage of air can be processed
- Only the contaminated helium stream is processed
- Continuous purification with redundant systems is possible
- Purified helium can be supplied at compressor discharge pressure

The downside is:

- Separate coldbox needed plus additional space & installation
- High investment cost
- LN_2 infrastructure required with separate LN_2 connection

Integrated Freeze-out Purifier

The integrated freeze-out purifier, FIGURE 3, uses cold helium supplied from the refrigeration process instead of LN_2 for the purification process. Impure helium entering the coldbox is cooled by a 30K helium stream and the main part of the contained air is liquefied in a heat exchanger. Within these heat exchangers the remaining air impurities are removed. The pure helium is warmed up again to ambient temperature and combined upstream of the coldbox with the helium discharged from the recycle compressor. Advantages of the internal purifier are:

- Less cost, integral part of the liquefaction coldbox
- Operation without LN_2 possible at reduced liquefaction rate
- Same LN_2 supply / return connection used as for coldbox
- Continuous operation due to regeneration cycle
- Only the impure helium stream is processed
- Freeze out of air impurities up to 10%
- Continuous liquefaction due to pure helium storage buffer
- Purified helium is returned at compressor discharge pressure

The disadvantages are:

- Reduction of liquefaction rate
- Pure helium buffer required

The purification / liquefaction system as shown allows continuous liquefaction operation. The cycle starts with the purification of impure helium. At the beginning the pure helium is distributed partially to the pure helium storage buffer and partially liquefied into the LHe dewar until a certain pressure in the buffer is reached. From that point on all purified helium is liquefied into the dewar. At the time the pressure drop in the purifier has reached a certain level the regeneration cycle starts with a warm-up of the purifier followed by a purge procedure.

During the regeneration period pure helium will be drawn from the storage tank and liquefied into the dewar. At the end of the regeneration the purifier is cooled down again by a cold stream supplied from the liquefaction process and the purification cycle starts again.

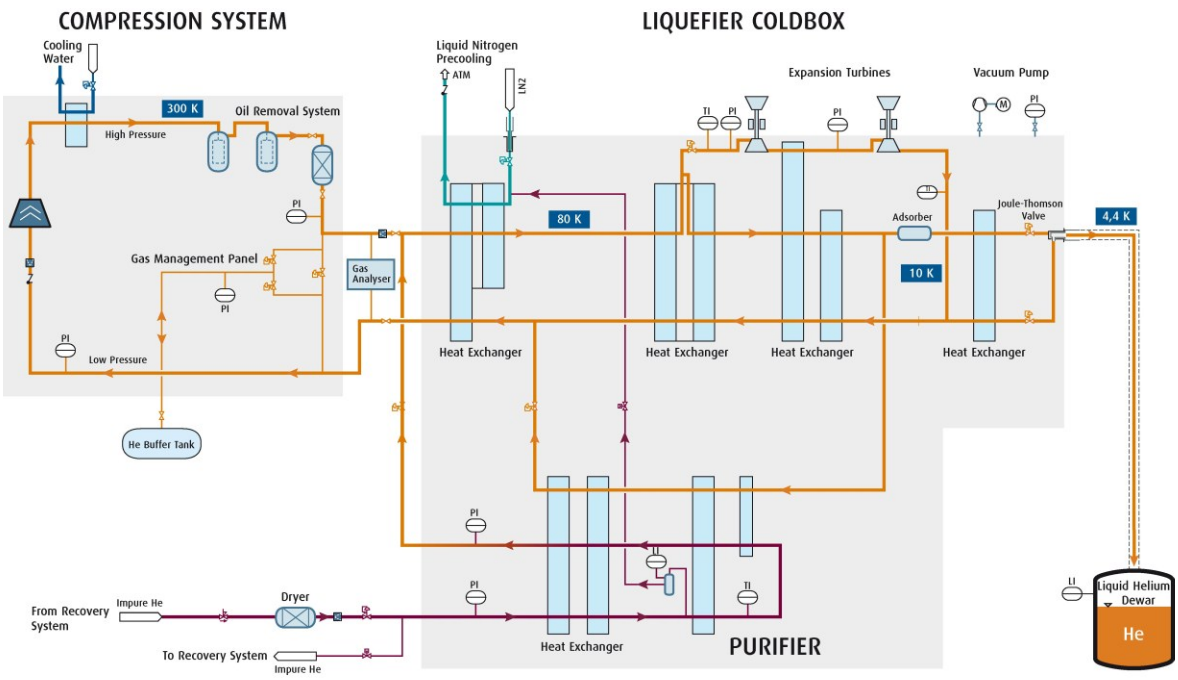

FIGURE 3. Internal Purifier Process Flow Diagram

Adsorber at 80K Level

A different way of integrated helium purification is to use an adsorber filled with charcoal or molsieve located at the 80 K level inside the liquefier coldbox, FIGURE 4.

Continuous operation is possible by using a system of two 80K adsorbers whereas one adsorber is in operation while the second one is regenerated. LN_2 is used for pre-cooling and keeps the adsorber system at a constant temperature to adsorb air impurities.

The advantages of an 80K adsorber are as follows:

- No or only little impact on liquefaction rate
- Continuous purification with redundant adsorbers
- Internal part of coldbox
- Located upstream of turbines
- Purification possible with and without use of LN_2

The disadvantages are:

- Air impurities limited up to a few hundred of ppm
- Full helium flow is processed through adsorber
- Special provisions needed in case of LN_2 loss
- External regeneration equipment needed with some He losses

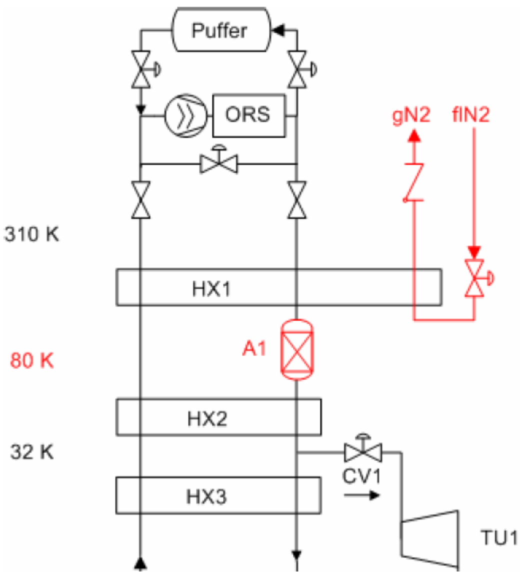

FIGURE 4. Adsorber at 80K level

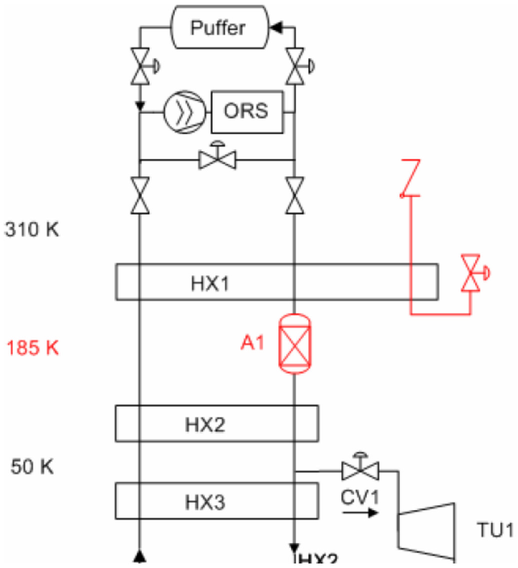

FIGURE 5. Adsorber temperature after loss of LN_2

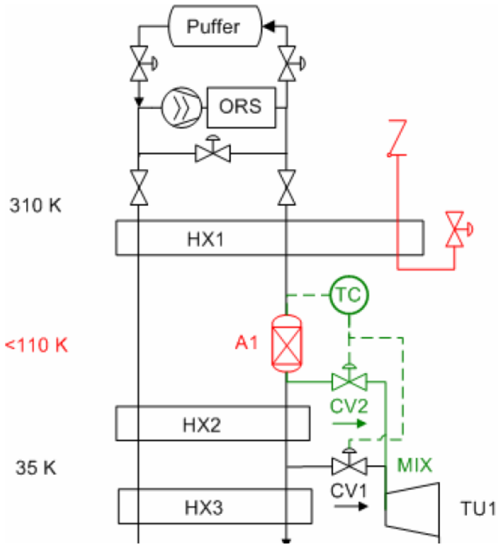

FIGURE 6. Adsorber temperature with activated control valve CV2

Special provision has to be taken in case of loss of LN_2 which will result in a warm-up of the adsorber, refer to FIGURES 5 & 6.

The loss of LN_2 will result in an increase of the temperature within the adsorber bed and release air impurities into the liquefaction cycle. The contaminated helium is moving to lower temperatures with the possibility of blocking the heat exchangers or damage to the expansion machine. This can be avoided by temperature control and a special arrangement of control valves upstream of the turbine, see FIGURE 6. If the temperature TC increases control valve CV2 will open and bypass a part or the whole helium flow around HX2. Bypassing HX2 forces a temperature drop downstream of HX3 and lower temperature of the adsorber to avoid desorption of air impurities.

PERFORMANCE INCREASE

Besides choosing LN_2 for pre-cooling or the correct purification system there are other issues to increase the performance or to optimize the liquefaction system. Transfer losses during liquid transfer due to the pressure difference between the stationary dewar and a mobile dewar are a major loss of liquid product. Transfer losses can be decreased by reducing the pressure difference with the disadvantage of a longer filling time of mobile dewars.

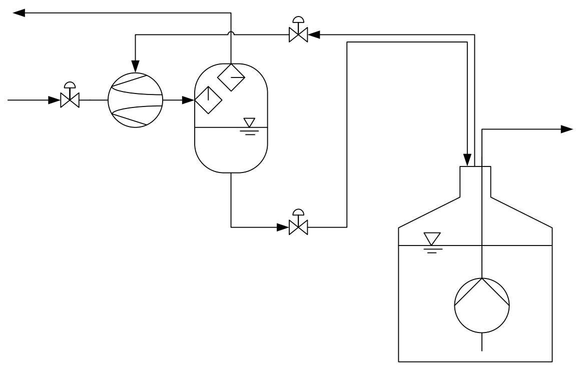

FIGURE 7. Cold Ejector & LHe Pump

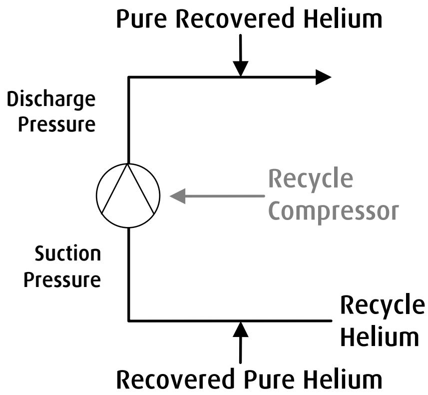

FIGURE 8. Feed supply pressure

Cold Ejector & LHe Pump

A more sophisticated but also more costly way to reduce transfer losses is the use of a cold ejector in the coldbox and an immersed liquid helium pump in the stationary dewar, refer to FIGURE 7.

The cold gas in the LHe dewar is recovered by a cold ejector, located in the coldbox, by reducing the pressure at the same time. An immersed liquid helium pump transfers the liquid helium to a mobile dewar at almost the same pressure without losses. This arrangement requires also a special transfer line and the use of a scissor lift to adjust and connect the mobile dewar to the rigid transfer line.

Feed Supply Pressure

Also the supply pressure of the pure feed to the liquefaction system has an impact on the efficiency. If the feed is supplied to the suction line of the recycle compressor this flow has to be compressed to the discharge pressure, refer to FIGURE 8.

This reduces the helium stream available by the compressor and turbines for generating the required refrigeration with the result of a lower liquefaction rate at the same power input

CONCLUSION

Besides the basic considerations like operation periods, future increase of capacity, and use of LN_2 pre-cooling there a number of conditions to be defined and specified for a liquefaction system. Based on the results it will be possible to customize a liquefaction system with the best performance, lowest investment and operation costs.