Implications and Methodology of Retrofits in Cryogenic Plants

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Abstract. Developments over the past few years allow Linde Kryotechnik to economically replace the turbines of a cryogenic plant with state-of-the-art technology leading to several advantages. Stand out among others are higher efficiency of the turbines, easier operation of the plant, increased reliability and an update of the design point regarding current customer demands which improve the overall performance and efficiency of an upgraded cryogenic system. While each retrofit is unique based on the customer demands and situation, it is still possible to follow a certain methodology. Several successful retrofits with conclusions are presented.

1. Introduction
Cryogenic liquefiers, refrigerators or mixed systems have a typical lifespan of 20 years [1]. According to the experience of Linde Kryotechnik it is an exception when the demands defined during the offer phase of a cryogenic project stay the same for the complete life cycle of said plant. The number of reasons for a change in operating conditions is vast, therefore only a few examples are listed below:

- Lower / higher refrigerator requirements owing to adjusted experimental setup
- Change of operation conditions due to external factors
- Economic interest in increasing the liquefaction rate
- Change of operation procedures (plant automatization, cooldown, warm-up)

While a new plant will always match new requirements, retrofits are often an interesting and worthwhile alternative to investigate. This paper elaborates further on the possibilities and opportunities of a retrofit. Each cryogenic plant consists of diverse components, parts and devices. While every component has a potential for retrofits, this paper focuses on turbo expanders, as they play a critical role in the cryogenic plant, have a fairly low specific cost and provide greater efficiency thanks to advances in technology.

A retrofit adds new technology or features to an older system. Typical benefits of a retrofit are:

- Saving on capital expenditure (CAPEX) and / or operating expenditure (OPEX) while benefiting from new technologies
- Optimisation of existing plant components
- Adaptation of the plant for new or changed products
- Guaranteed spare parts availability
- Reduced maintenance costs
- Increased reliability
Increased system efficiency and product output
Higher operational flexibility and efficiency (e.g. floating pressure [2])
Prolonged life time of the system

Specific for cryogenic plants and Linde Kryotechnik as a world leading plant manufacturer, the inhouse turbo expanders provides a large potential for retrofits. The replacement of oil-bearing turbines (OBT) or of older generations of dynamic gas bearing turbines (TGL) with modern dynamic gas bearing turbines (TED) respectively an upgrade to the latest turbine technology could be combined with a re-adjustment to current and future demands of the plant. Next to the turbo expanders modern control logic provide an improvement to the plant operator. Automated cooldown, warm-up and smart controlling of the plant is possible with modern state-of-the-art tools.

Linde Kryotechnik suggests to always contact the plant manufacturer for consultancy regarding possible retrofit upgrades before considering / planning / investing in a new plant. The expenses of a new plant are by default huge compared to a retrofit on selected components. A calculation of retrofit feasibility is typically done by having a new plant efficiency from the manufacturer and comparing the expected plant OPEX and retrofit CAPEX. Main driving forces are the power input vs refrigerator capacity, plant maintenance and operation costs.

2. Procedure of a retrofit
While each retrofit project is highly individual based on the plant, owner and operator, there are several common steps during the retrofit in most projects. Figure 1 displays the typical relationships of a retrofit project at Linde Kryotechnik.

For retrofit projects the emphasis on the requirements for the quotation are a lot higher than during regular projects. This is due to the many constraints of the existing plant and operation. Often a study is initialized to reduce the risk of all involved parties and to elaborate both the conception phase and basis design. The goal is to define the scope of the retrofit including the interests of both owner as well as the operator. An extensive exchange with the operator to gather poorly or undocumented plant specific know-how is essential for a successful retrofit. This goes hand in hand with an alignment of the operational and technical requirements of the owner and the operator and to match these with possibilities of the new technical equipment.

The work on the detailed and extended basic design is a close collaboration between customer and plant manufacturer. This is necessary due to the fact that the documentation of existing plants typically does not provide sufficient insight required for a retrofit. Furthermore, the conditions of components due to wear has to be evaluated as well as changes in codes, standards, safety requirements or working procedures. The detail design already considers project specific peculiarities. One example could be work packages which the customers could take over.

The modification is typically bound to a short time span to reduce downtime of the plant. A certain flexibility for unexpected events is necessary. For example, when opening the cold box and the piping is different than what is documented and planned for. In anticipation of any findings, the availabilities of appropriate time / manhours / resources are required.

The procedure during commissioning of the system is not different at a retrofit. Documentation on the other hand needs to include an update of the plant documentation and the description of the procedures of the plant. Possible examples of new procedures are new features concerning the cooldown, filling of Dewar or warm-up.
3. Retrofit success stories and lessons learned

3.1. Large industrial liquefier
The large industrial liquefier described in this section consists of two cold boxes (two trains) and has a capacity of two times 7.5 tons per day liquid helium. The original intention of the customer was to increase the plant liquefaction rate. The discussion with the operator yielded highly valuable information, leading to the conclusion that the liquefier was not operated according to its original design. It also added the additional emphasis on the plant automatization achieving a more stable operation and less manual input by the operator. Linde Kryotechnik did evaluate possible improvements with retrofits based on the actual situation.
At the start of the project the liquefaction performance of the existing plant was measured and documented. Based on these findings the guaranteed plant performance after the retrofit was defined. Additionally, the plant documentation was compared to the actual installation on site. It is common to have inconsistencies from equipment changes over the years. A comparison of the norms, codes and standards at the time of building the liquefier compared with the actual ones is essential to define the scope of the retrofit. From the start the time windows for maintenance were considered, planning the retrofit within the planned production stops time frame.

Further things to consider are:

- The conditions at the liquefier building – how is the accessibility, safety regulations, can the equipment be moved freely?
- Compatibility of old and new technology. Confirm the interoperability of signals between instruments, equipment and the control system.
- Plan spare parts early during the retrofit project and review the spare parts list regularly.
- Always consider safety relevant topics. For example, the new turbine technology lead to a higher efficiency and a change in the process. Therefore, a hazard and operability study (HAZOP) and new safety valves were necessary.
- The availability and quality of the utilities (cooling water, supply air)
- The feasibility with the operator requests regarding automatization of the cryogenic plant, which are related to the cycle compressor operation and compressor load adjustment, turbine operation, Dewar swap in and swap out and sustainability against high amount of trailer return gas.
- Due to the tight time frame of this project a step-by-step installation plan is necessary. This does not only include the effective work of the retrofit but also include the deinstallation work and purge processes.

Each cold box was equipped with two OBT’s (depict in Figure 2 and Figure 3) and five dynamic gas bearing turbines of the older Linde Kryotechnik generation (TGL). To achieve higher liquefaction
rate, the OBT’s were replaced with two TED turbines for each train. Figure 4 depicts the two TED turbines installed in the in previous OBT positions of the first train. In addition to the increased liquefaction rate the plant was/is also automated, reducing the amount of manual operation input.

![Figure 4](image)

**Figure 4.** The latest TED turbine technology instead of the OBT’s on top of the cold box valve plate.

It is important to realise the scope of retrofit projects is highly influenced by the pre-existing conditions on site and not just the predefined process parameters. For example, within this project a local contamination of oil was found. Therefore, a unique method and tools (to connect to existing equipment) for solvent flushing to locally remove said oil contamination was required.

Concluding the retrofit the customer gained:
- Full automatization of the liquefaction plant, increasing the plant operation stability and highly reducing the turbines and plant trips. It further enables a redistribution of the work power due to the automatization.
- Removal of the turbine oil supply and therefore no more oil contamination of the plant.

3.2. **Small mixed liquefaction / refrigeration plant**

In this example a small helium refrigerator plant with 300 Watts at 4.4 Kelvin rated cooling capacity consisting of two TGL turbines is upgraded by exchanging one turbine to TED and upgrading the cycle compressor. The refrigerator plant is used for an accelerator facility. The incentive to upgrade the existing plant originates from the demands of the experiment. In this retrofit project the customer managed several work packages and provided excellent support on site.

To carry out the modification, the existing low temperature housing of the TGL turbine must be removed. This requires the removal of the super isolation and the detachment of the inlet and outlet pipes. The cold box has to be lifted outside of the vacuum hull. Fully removing the inside of the cold...
box out of the vacuum hull, required a custom crane (short head) due to height constraints at the site. A support stand to hold the top flange during the retrofit operations also was made at site. Figure 5 depicts the separation of the valve plate and the vacuum shell.

![Figure 5. Separation of valve plate and vacuum shell.](image)

The old TGL low temperature housing must be removed and the prepared for the new housing of the TED turbine. Figure 6 depicts the valve plate after removal of TGL low temperature housing.

![Figure 6. Removed TGL low temperature housing on valve plate.](image)

Challenges during the retrofit which were not envisioned during the planning phase:

- The original weld detail on the top flange of the TGL low temperature housing was not adequately described. Therefore, the cut procedure of the low temperature housing had to be adjusted on site.
- The envisioned new internal piping had to be adjusted in order to weld the piping to achieve the requested quality.
- Moving the old compressor out and moving in the new compressor was also very tricky due to site constraints. The oil used in the new compressor is of a different grade, hence the charcoal bed had to be emptied and refilled. The heating and drying of the charcoal was a difficult and demanding task.
Besides the mechanical installation of the new turbine and cycle compressor, comprehensive changes were made to the control program. The reworking tasks were performed by highly trained and qualified local personnel provided by the plant owner with support and supervision given by Linde Kryotechnik.

The customer concludes the retrofit as follows: “The entire retrofit was a calculated risk, which was executed excellently, and we now have a plant which provides a very stable operating environment for our accelerator facility”. The upgraded compressor provides one third larger mass flow. Together with the TGL to TED turbine upgrade the plant capability was increased by 50%. Thanks to the upgrade extra capacity is available during the experimental cooldown and during any runaway situation.

3.3. Large hydrogen liquefier #1

The large hydrogen liquefier depicted in Figure 7 consisted of three OBT’s and has a liquefaction capacity of 5.0 tons per day. During the retrofit the first oil bearing turbine was replaced with a TED turbine.

![Large hydrogen liquefier](image)

**Figure 7.** Large hydrogen liquefier.

Benefit of this smaller retrofit is:
- Higher reliability of the TED turbine.
- Lower maintenance compared to the OBT.
- Higher liquefaction capacity of 3.5%
- Ensured spare part availability for the upgraded turbine

3.4. Large hydrogen liquefier #2

The here described large hydrogen liquefier also has 5.0 tons per day liquefaction capacity. The plant was equipped with three TED turbines instead of three OBT’s. Figure 8 depicts the difference between oil bearing and dynamic gas bearing turbines with the most obvious difference being the lack of an oil supply system (OSS). The plant operation was be further improved using the TED turbines. In addition, the operation system was fully automated.
The change from OBT to TED simplified the technical system and the operational procedures. The TED turbines are more flexible in terms of part load operation and cold start behaviour. Due to the higher turbine efficiency the OPEX costs were reduced. Furthermore, the plant is more reliable because of the removed risk of process contamination by oil.

4. Conclusion
An attempt to describe a generic workflow for retrofit projects is presented. Several possibilities, benefits and pitfalls are described. Typical retrofit modifications are the change of turbine technology, the automatization of the plant or a combination of compressor size and turbine size to increase the plant performance. The listed measures typically lead to higher reliability, less maintenance, easier to operate plant, a redistribution of man power or more plant capacity.

Four successful retrofit stories with retrofit scope, benefits and lessons learned are described:

- Large helium liquefier with upgrade from OBT to TED
- Small helium mixed liquefier / refrigerator with upgrade of compressor and TGL to TED turbines
- Two large hydrogen liquefiers with upgrade from OBT to TED

5. References
[1] Cardella U, Decker L and Klein H 2017 Final design of a cost-optimized 100 tpd H2 liquefier Cryogenic Engineering Conference and International Cryogenic Materials Conference
[2] Ganni V and Knudsen P 2009 Optimal design and operation of helium refrigeration systems using Ganni cycle Cryogenic Engineering Conference and International Cryogenic Materials Conference