Focused Review

Very Efficient and Highly Reliable Standard Helium Liquefiers and Refrigerators In the service of Japanese science

Lutz DECKER^{*1,†} and Lars BLUM^{*1}

Synopsis: For many decades helium liquefaction had been a science for itself. With the raise of exotic scientific research at the universities in the 80's the need for affordable industrial liquefiers led to the development of standardized plants of type TCF. Further development in this field result in nowadays highly efficient and reliable standard liquefier and refrigerator product line of Linde Kryotechnik named L-series. This paper gives an overview of the latest different improvement steps that had been taken, including development work in turbo expander design and purifier performance. The specific impact on efficiency gets indicated by comparing the performances of the new L-series versus the former well-established TCF liquefiers. The main equipment and the infrastructure for a helium distribution center get shortly described. Performance data together with high reliability explain the strong market position of Linde Kryotechnik worldwide and together with its partner TNSC especially in Japan.

Keywords: helium liquefaction, standardization, turbo expanders, internal purifier

(Some figures in this article may appear in color only in the electronic version)

1. Introduction

In 1895 Carl von Linde invented a process for the liquefaction of air and various gases, thereby ushering in the era of the cryogenics industry. As early as 1932, Linde supplied the world's first industrial helium liquefaction plant to the University of Kharkov in the Ukraine.

In the following decades helium liquefaction came into reach only of few larger institutes that required reasonable but still small amounts of this rare gas in its exotic state of deep cryogenic liquid. Each plant was tailor-made even with components that underwent continuous development. In this period Linde Kryotechnik (formerly Sulzer) supplied a first helium liquefier to Japan for the University of Tokyo (1965).

With upcoming research at the universities in low temperature physics the demand for reliable but low cost helium liquefiers and refrigerators stepped up. At the same time the number of these institutions increased steadily in the 80's allowing the industry spending more effort on systematic engineering and design of cryogenic helium plants. Japan developed to a hotspot of intense research at renowned institutes and universities.

A first standardization took place at Linde Kryotechnik

in the late 80's resulting in the product line of the TCF helium liquefiers and refrigerators. The type number indicated the expected liquefaction capacity, e.g. TCF50 was initially designed for a capacity of 50 L/h of liquid helium. TCF10 and TCF20 were the smaller systems. Further improvements let the liquefaction capacity further increase (see Table 2). In 1992 Linde acquired all cryogenic business from Sulzer and merged the different units into the singular profit center Linde Kryotechnik based in Pfungen, Switzerland.

By the end of the 90's the TCF50 was capable to liquefy up to 190 L/h of helium. Japan became a major market for these well reputed plants.

2. Development of Standard Helium Liquefiers

In 1999 Linde Kryotechnik started a development program with the objective to raise the efficiency of their proven turbo expanders TGL focusing on small cooling capacities. The project was very successful, boosting the efficiency of a small expander unit from e.g. 61% to 77% (see Table 1). Coincidentally KAESER, the supplier of oil injected screw compressors, took a step of improvement in their portfolio in aspect of design and efficiency. Linde Kryotechnik decided to take this opportunity for an overall redesign of their standard helium liquefiers and refrigerators giving also new type nominations ensuring a clear communication of the successful work.

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^{*1} Linde Kryotechnik AG
8422 Pfungen, Switzerland

[†] E-mail: lutz.decker@linde-kryotechnik.ch
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Table 1 Influence of turbine efficiency on liquefaction capacity.¹⁾

Turbine design	Compressor input power [kW]	Turbine efficiency		Liquefier capacity [L/h]	Relative capacity
		Tu1	Tu2		
TGL	110	61%	67%	33.6	100%
TED	110	77%	77%	48.7	145%

The new liquefier product line is called L-series with the type number indicating the new maximum liquefaction capacity, i.e. L70, L140 and L280. The improved turbo expanders are identified as TED (Turbo Expander with Dynamic gas bearing).

The objectives included efficiency, reliability, cost and standardization by modularization. Merging the benefit of the improved turbines with the new compressor series allowed adapting process design and optimizing the heat exchangers. The overall efficiency of the liquefiers could be increased starting from more than 50% for largest up to almost 120% for the smallest liquefaction capacity (see **Table 2**).

The L-series liquefiers entered the market in 2005. Since then 77 helium liquefiers have been sold worldwide, 30 out of this in Japan. 27 units of helium refrigerators, based on the L-series and named LR-series, got sold so far, 6 of them in Japan.

3. Improvement of the Internal Purifier

The optionally available internal purifier allows the recovery of impure helium prior to reliquefaction. It consists of an upstream dryer and a coldbox internal module of heat exchangers, condensation stage, freeze-out stage and related valves and accessories. The old 2 gr and 5 gr units did not quite fit to the TCF liquefiers, not being able to serve the bigger liquefaction capacity of the new L-series.

Table 3 Summary of test results P280.³⁾

Performance data	unit	5gr-purifier	P280
max. flow in purifier	[g/s]	13.5	> 17.5 ^{a)}
max. liquefaction rate (@ 2 vol% nitrogen)	[L/h]	180	> 230 ^{a)}
optimum impurity level	[vol%]	≤ 2	full range
max. impurity level, long term	[vol%]	5	> 10 ^{b)}
purifier parameter settings		optimized to predefined impurity level	fully automatic

^{a)} limited by size of tested liquefier (280 L/h)

^{b)} limited by infrastructure of manufacturer's test bench

In 2014 Linde Kryotechnik finished the redesign of the new internal purifier line to the larger capacities of the L-series consequently naming them P70, P140 and P280. Simultaneously the maximum impurity level for continuous purification operation got lifted from 5 vol% to above 10 vol% (see **Table 3**). The control parameters do not need to be set anymore by the operator but get adjusted automatically. In addition a small adsorber at below 40 K takes out traces of hydrogen and neon.

As a new feature Linde Kryotechnik offers also an additional catalyst stage for removal of higher hydrogen impurity content. This feature would be integrated upstream of the dryer.

4. Plant Design

This process is a Claude cycle with two pressure levels, one liquid nitrogen (LIN) pre-cooling stage and two expansion stages. The helium liquefier/refrigerator consists of the following major sub-systems (see **Fig. 1**):

- Helium compression system
- ORS (Oil Removal System)
- GMP (Gas Management Panel)

Table 2 Liquefaction capacity of L-Series plants with and without liquid nitrogen (LIN) precooling compared to TCF plants.²⁾

Compressor massflow [g/s]	Liquefaction capacity with LIN ^{c)} [L/h]				Performance increase [%]	Liquefaction capacity without LIN ^{c)} [L/h]				Performance increase [%]
79.5	L280	293	TCF50	190	54	L280	153	TCF50	90	70
61.6		226		150	51		115		70	64
54.2		197		130	52		101		60	68
40.8	L140	140	TCF20	78	80	L140	70	TCF20	37	89
34.3		116		57	104		59		30	97
27.5		91		45	102		46		25	86
21.1	L70	68	TCF10	39	74	L70	34	TCF10	23	47
17.7		54		27	102		28		15	86
14.5		41		19	117		21		11	88

^{c)} Note: capacities of TCF series are those at the end of the 90's after latest improvement

Fig. 1 Process flow diagram of Linde's helium liquefier.

- Coldbox system
- Liquid helium storage dewar

The screw compressors used for recycling the helium stream from the coldbox are standard KAESER compressors with oil injection that are modified according to Linde's standards for helium use. The compressor discharge pressure is reduced for part load operation. An optional VFD (Variable Frequency Drive) allows adaptation of the massflow rate to the discharge pressure maintaining the overall plant efficiency on a high level during part load operation. The compressor can be equipped for water or air cooling.

The PAO (Poly Alpha Olefin) type oil used by Linde Kryotechnik used for efficient helium compression is suitable for operation with KAESER compressors. In a first step the oil is removed from the helium at the first coalescer located in the bulk oil separator of the compressor. Downstream the bulk oil separator the oil content in the helium is below 30 ppm by weight.

A second and third coalescer vessel is located on the separate ORS/GMP skid. The final removal of oil and oil vapor takes place in the charcoal adsorber vessel. A dust filter is integrated into the adsorber downstream of the charcoal bed. Within the adsorber remaining oil impurities are removed to a final concentration of less than 10 ppb by weight.

The coldbox comes as a fully shop-assembled vertical type vacuum insulated coldbox with integrated purge

panel and junction/control box (see **Fig. 2**). It contains all equipment for helium liquefaction that runs below ambient temperature including highly efficient counter flow plate fin heat exchangers. All related equipment for liquid nitrogen precooling is pre-installed. The customer's preference for operation with or without LIN is taken into account.

Fig. 2 Coldbox L280.

Two turbo expanders in series form the heart of the helium liquefier as they generate the cooling power below 80 K that is needed. Linde Kryotechnik has their own and unique design of turbo expanders with fully dynamic axial and radial gas bearings (TED) (see **Fig. 3**). The rotor runs contact-free on a self-sustaining helium cushion ensuring wear-free operation and thus outstanding lifetime. The dynamic gas bearings maintain their function even in case of a power failure and without supply of any external backup gas. An internal filter protecting the turbine could be easily accessed without breaking the coldbox vacuum. The energy extracted from the process by the turbines gets dissipated to the cooling water cycle at ambient temperature. Energy recovery is not applied at systems of this size because of a negative cost-benefit ratio.

The option of a cryogenic ejector allows the customer to keep the liquid helium dewar pressure low. This decreases the flash losses when transfilling into mobile dewars and thus increases the amount of liquid helium being available at the scattered consumer sites by 6% if dewar pressure gets lowered from 125 kPa to 105 kPa.

The L-series helium liquefiers and refrigerators of Linde Kryotechnik are designed according to PED (Pressure Equipment Directive), ASME (American Society of Mechanical Engineers) and JHPGSL (Japanese High Pressure Gas Safety Law). Operation below 1.0

MPaG ensures easier approval by Japanese authorities.

Fig. 3 Turbo expander TED.

Fig. 4 Helium distribution center.

Table 4 Performance data of L- and LR-series.

	Liquefaction capacity @ ≤ 4.4 K			Refrigeration capacity @ ≤ 4.4 K		Compressor power rating
	with LIN [L/h]	without LIN [L/h]		with LIN [W]	without LIN [W]	[kW]
L70	40	20	LR70	130	d)	45
	55	27		160	d)	55
	70	35		190	130	75
L140	90	45	LR140	225	210	90
	120	60		325	250	110
	140	70		400	290	132
L280	200	100	LR280	560	445	160
	225	112		640	510	200
	290	145		900	640	250

d) on request

The standard control system consists of a PLC Siemens S7-300 and local HMI (operator panel TP 1200 touch). On request the customer can also use his own control system by integrating the Linde controls into it.

A helium recovery system completes the helium distribution center (see **Fig. 4**). It includes a gasbag, a high pressure piston compressor with condensate trap and gas bottles. All mentioned equipment can be obtained from Linde Kryotechnik, respectively from our partner Taiyo Nippon Sanso Corporation (TNSC) parenting customer care, infrastructure, equipment integration, commissioning and after sales services, in Japan.

5. Performance

The high efficiencies of screw compressor, TED turbo expanders and process design result in the highest overall efficiency for helium liquefaction available. The time to cooldown the plant with LIN from ambient to liquefaction service is as short as 4 hours (expected).

The L- and LR-series reach the performances as shown in **Table 4**.

6. Conclusions

Continuous development and longtime experience are the keys to highest efficiency in helium liquefaction and refrigeration. Standardization and modularization ensure high quality of the system at low cost. Together they guarantee highest availability and reliability of Linde Kryotechnik's products.

The L-series helium liquefiers and LR-series helium refrigerators define the state-of-the-art in cryogenics. They have reached an unsurpassed number of industrial plants coming into operation since 2005.

Linde Kryotechnik together with TNSC continue to serve Japanese universities and institutes, hotspots of scientific research, today and in future.

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Lutz DECKER

Lutz Decker holds a Master in engineering from the Swiss Federal Institute of Technology in Zurich. He joined Linde Kryotechnik in 1991 as a member of the process department. In 1999 he became the leader of the machinery department signing responsible for the redesign of the turbo expanders. In 2008 he became head of development. In 2013 he was awarded the title *Linde Technologist*. The current work area focusses on cold compressor development and large scale hydrogen liquefaction.

Lars BLUM

Dr. Lars Blum graduated at the Swiss Federal Institute of Technology in Zurich and joined Linde Kryotechnik AG in 2007. After having headed the process engineering department for four years, he became head business development and sales in 2012.