

## STATE OF THE ART HELIUM LIQUEFACTION AND REFRIGERATION PLANTS

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A new design for small scale helium liquefiers with a liquefaction capacity between 20 l/h and 290 l/h LHe is presented. Compared to the old liquefier generation efficiencies and liquefaction rates could be enlarged, and shorter cool down times have been achieved. Improved components will be presented and their impact on the plant performance will be discussed.

The effect of different parameters, for instance compression power and LN<sub>2</sub> precooling on liquefaction rate and overall efficiency will be presented for different sizes of the newest helium liquefier generation. Results from the first operating plants will be presented and compared to the performance of liquefiers of the old generation.

### INTRODUCTION

High reliability, availability, low operational costs and short delivery times have become key requirements for small scale helium liquefiers. In addition, the demands concerning product design and user friendliness have risen. By using standardised high quality components, for instance heat exchangers, expansion turbines and control software, L-Series liquefiers can be designed according to the customer's requirements within short times. This paper shows the impact of these optimised plant components on liquefaction rate and specific power input.

### LIQUEFACTION PROCESS

L-series liquefiers are designed for liquefaction rates at 4.4 K from 20 l/h up to 290 l/h. The range is covered by three sizes of liquefiers - L70, L140 and L280, which are all based upon a Claude cycle. Figure 1 shows the process flow diagram of any L-Series plant.

High pressure (HP) helium gas, supplied by the compressor system, enters the coldbox. It is cooled down in heat exchanger E3110 and E3120 by low pressure (LP) helium gas in counter flow. At its cold end a liquid nitrogen (LN<sub>2</sub>)-evaporator is integrated so that precooling of the HP-stream with LN<sub>2</sub> becomes possible and the refrigeration or liquefaction capacity of the plant gets larger. The heat exchanger E3120 has two sections. Between these two sections the high pressure stream is split in two parts. The larger fraction gets expanded in turbine X3130. After a further cool-down in heat exchanger E3140 it enters turbine X3150. It is expanded to low pressure and finally joins the returning JT-stream. The smaller fraction, called Joule-Thomson stream continues to be cooled down in heat exchangers E3120 - E3160. After that it is throttled by the JT-control valve to dewar pressure and gets partially liquefied

in the dewar. The gaseous fraction is returning as LP stream to the coldbox. It is warmed in the heat exchangers before returning to the intake of the compressor.

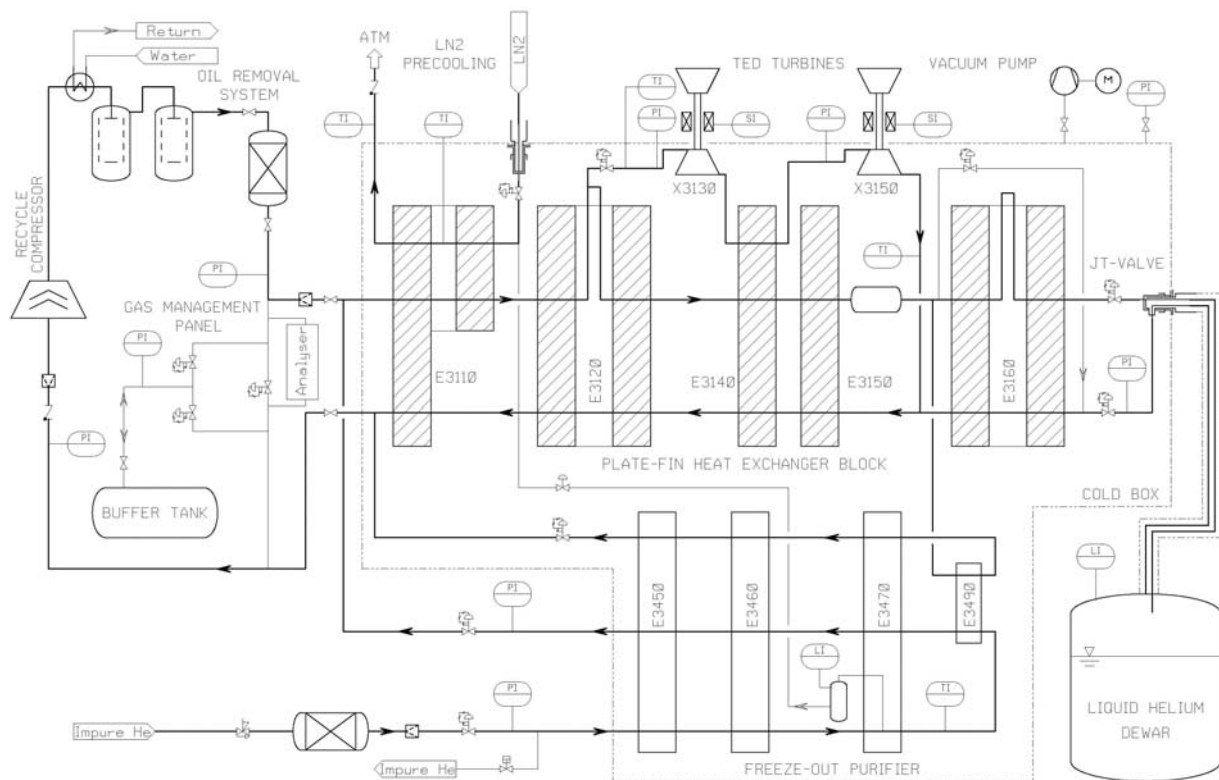


Figure 1 Process Flow Diagram of an L-Series helium liquefier by Linde Kryotechnik AG

Impure helium is fed to the integrated purifier unit. By cooling down the impure gas in counter current with cold HP gas impurities, nitrogen and traces of other gases condensate and/or freeze out. The purified gas is fed into the coldbox HP-inlet side. By warming up the purifier will be regenerated, whereby the removed undesirable gases are discharged.

## DESIGN FEATURES AND IMPROVEMENTS

Based on the proven TGL turbine technology, the new TED (TurboExpanderDynamic) turbines have been further developed. A TED 16 turbine is shown in Figure 2. Schoenfeld H. et al. [1] showed that efficiencies could be increased between 13 to 20% per turbine. Improved bearing design allows higher thrust capacities and wider operation range and leads to dramatically reduced cool down times. The robustness of the turbine could be increased by changed bearing material. TED turbines are absolutely maintenance free. Thus highest availability and reliability are ensured.

L-series liquefiers are equipped with a heat exchanger block, consisting five counter flow brazed aluminium plate-fin heat exchangers. The heat exchangers all have identical block length and identical plate fin design concept. Heat exchanger surface has been increased compared to TCF plants and pressure drop could be reduced. The L-Series heat exchanger blocks can be used both for liquefaction and refrigeration, which ensures high operation flexibility in case of multi purpose plants.

Outer piping has been minimised. The liquefaction and purification process has been designed such, that no icing on outer pipework occurs. L70, L140 and L280 have the same design layout. They only differ by cold box diameter. Figure 3 shows a L140 liquefier.

For all L-Series plants the same control strategy and the same software (PLC) with high grade of automatisisation has been applied. State-of-the-art visualisation is available for L70, L140 as well as L280 plants. The control panel is separated from the coldbox. Plant components are operated with a decentred control system and are connected by PROFIBUS DA. Field wiring is minimised and maximum flexibility concerning placement is ensured.



Figure 2 TED 16 turbine with cooler



Figure 3 State of the art helium liquefier L140

### COMPARISON OF L-SERIES PERFORMANCE DATA WITH TCF LIQUEFIERS

Table 1 Performance data of L-Series plants with and without LIN precooling compared to TCF plants

Compressor massflow [g/s]	with LIN m_liq [l/h]	with LIN m_liq [l/h]	Performance increase [%]	average P. increase [%]	wo LIN m_liq [l/h]	wo LIN m_liq [l/h]	Performance increase [%]	average P. increase [%]
79.5	293	190	54	52	153	90	70	67
61.6	226	150	51		115	70	64	
54.2	197	130	52		101	60	68	
40.8	140	78	80	95	70	37	89	91
34.3	116	57	104		59	30	97	
27.5	91	45	102		46	25	86	
21.1	68	39	74	98	34	23	47	74
17.7	54	27	102		28	15	86	
14.5	41	19	117		21	11	88	

Table 1 shows performance data of L-series liquefier compared to helium liquefiers of the old generation (TCF-plants). Liquefaction rates of TED equipped L-Series plants are based on constant isentropic efficiencies of 75% for turbine 1 and 80% for turbine 2, according to the measurements of Schoenfeld et al. [1]. Cold box inlet state is 13.0 bar and 313K for L-Series and TCF plants. Dewar pressure is 1.20 bar (4.4 K) for L-Series plants and 1.25 bar (4.45 K) for TCF plants. Assumed heat leak into dewar and transfer line are 10 Watt for both types. Using the same mass flow and thus compression power, liquefaction rates could be increased between 47 and 97% for operation without LN<sub>2</sub>. For operation with LN<sub>2</sub>, the increase of liquefaction rates is between 51 and 117%. In [1] a TCF20 was equipped with TED turbines. The increase of the liquefaction rate was 52% compared to a TGL-equipped TCF20. The

combination of TED turbines and improved heat exchangers in L140 lead to a increase of 102% compared to a TCF with the same compressor mass flow.

Consequently, the specific compression power input per liquefied helium

$$p = P_{Comp} / \dot{m}_{liq} \text{ [kW/l LHe @4.4K]}$$

could be reduced.  $P_{comp}$  is the shaft power of the helium recycle compressor. In Table 2 data for L-Series and TCF plants are presented. The liquefaction work for the consumed  $LN_2$  is not considered for the specific compression power.

For liquefaction of one litre liquid helium at 4.4 K without  $LN_2$ , between 1.54 and 2.22 kW of compression power is required for a L-Series plant. For TCF plants, between 2.62 and 4.06 kW are necessary (Table 2). This means, that a L280 requires a third less compression input power per produced litre LHe than a TCF50. Table 2 shows p for liquefaction with  $LN_2$  precooling as well. L-series plants require between 33% and 50% less specific compression power at operation with  $LN_2$  precooling.

Table 2 Specific compression power for L-Series plants compared to TCF plants

Compressor massflow [g/s]		with LIN p_spec [kW/l Lhe]	with LIN p_spec [kW/l Lhe]	p_spec decrease [%]	av. p_spec decrease [%]		wo LIN p_spec [kW/l Lhe]	wo LIN p_spec [kW/l Lhe]	p_spec decrease [%]	av. p_spec decrease [%]
79.5	L280	0.81	1.24	35	34	L280	1.54	2.62	41	40
61.6		0.90	1.36	34			1.78	2.91	39	
54.2		0.87	1.32	34			1.70	2.85	40	
40.8	L140	0.92	1.66	44	49	L140	1.85	3.50	47	47
34.3		0.92	1.87	51			1.81	3.55	49	
27.5		0.99	2.01	51			1.95	3.62	46	
21.1	L70	1.02	1.77	43	49	L70	2.04	3.00	32	42
17.7		1.03	2.08	50			2.01	3.75	46	
14.5		1.11	2.42	54			2.22	4.17	47	

### Results from first operating plants

More than ten plants have been ordered until now. The first four plants are already in operation. The L280 at Ibaraki, Japan is operating with 9.6 bar and 313K high pressure inlet state. Liquefaction capacities of 220l/h without purifier operation have been achieved. Cool down time from ambient to operation temperature is below 2.5 hours. To cool down a similar TCF50, approximately 4 hours were necessary.

### CONCLUSION

By using high efficient TED turbines and optimised heat exchangers, liquefaction rate could be increased by 50% to 100% compared to the old liquefier generation. The power input per litre LHe produced could be decreased by 33% to 50%. The L-Series helium liquefiers from Linde Kryotechnik AG establishes thus the new benchmark for small scale helium liquefiers.

### REFERENCES

1. Schoenfeld H., Creteigny D. and Loehlein K., "Standard liquefier-test results with improved turbines", ICEC – 20 Beijing, China (2004) 119-122