EVOLUTION OF THE STANDARD HELIUM LIQUEFIER AND REFRIGERATOR RANGE DESIGNED BY AIR LIQUIDE DTA, FRANCE

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The standard helium liquefier and refrigerator range, called HELIAL, designed by AIR LIQUIDE DTA, has been upgraded with significant improvement of efficiency as a result of technological development.. Indeed in the demanding high tech markets, (international laboratories, aerospace applications, synchrotrons, HTS applications...), cryogenic systems must provide increasingly high performances. The new HELIAL Evolution is equipped with AIR LIQUIDE DTA's expansion turbines, well known for their extremely high reliability and efficiency,. The results of this development endowing the HELIAL Evolution with twice liquefaction capacity, are presented in this paper.

INTRODUCTION

The AIR LIQUIDE DTA HELIAL was born in the 1980s. These machines were revolutionary in that they constituted the first helium liquefiers to be fully automatic and therefore easily operable. Nearly 30 years later, their refrigeration and liquefaction capacities have grown enormously, but helium liquefiers-refrigerators still operate on the same principle. With a 30-year wealth of experience, AIR LIQUIDE DTA decided to assess the situation, looking through all the HELIAL projects. This study led in 2007 to the launching of a new range named HELIAL Evolution. Indeed, in the demanding high-tech markets, cryogenic systems such as HELIAL must provide increasingly high performances with strong reliability.

CAPITALIZATION OF THE PAST SIX YEARS

In 2001, AIR LIQUIDE DTA upgraded its standard helium liquefiers range constituted by the HELIAL 7, HELIAL 20 and HELIAL 50. Three new liquefiers/refrigerators were created and called HELIAL 1000, HELIAL 2000 and HELIAL 3000. Their performances resulted from an evolution of the liquefaction market characterised by the arrival of third generation synchrotrons requiring dedicated cryogenic systems with refrigeration and mixed-mode operations. At the same time, small liquefiers were still required all over the world, particularly in Asia with the premises of helium liquefaction in new developed countries.

The design of the HELIAL 1000/2000/3000 range was therefore adapted to these specific requirements, trying to find a good compromise between refrigeration and liquefaction, in order to fulfil specifications requiring various modes of operation.

After six years of experience with the HELIAL 1000/2000/3000 range, past projects were analysed. First, AIR LIQUIDE DTA examined the field of applications for which HELIAL systems were installed. Figure 1 – upper left corner – shows the variety of customer applications for which the HELIAL systems provided a solution (see also next chapter). Two main fields appear: synchrotron centres and liquefaction centres. They constitute about 75% of the needs in terms of helium liquefaction and/or refrigeration. Nevertheless, the remaining 25% reveal new markets like cold and ultra-cold neutron sources, HTS applications or neutral beam injectors for fusion applications, which should develop in the near future for helium refrigeration. Therefore, HELIAL machines should constitute a solution for cryogenic needs within these new fields. On the upper right corner of Figure 1, the operation modes for past projects have been distinguished highlighting a quasi-perfect repartition between liquefaction, refrigeration and mixed modes. These two repartitions, i.e. final applications and operation mode required, convey the difficulty to design a standard machine able to cover the whole range of applications, satisfying the diversity of users.

Regarding the operating temperatures, Figure 1 – bottom left corner – shows that most of the projects work at liquid helium temperature. Nevertheless, in recent years, more and more projects at temperatures above 10 K were born in different fields such as HTS applications, cold neutron sources and space chambers. The HELIAL standard machines must remain flexible to allow, with minor modifications, operation at this temperature range.

Moreover, power consumption becoming a major topical concern, AIR LIQUIDE DTA decided at the same time to analyse the efficiencies of the HELIAL range and to improve them.

RECENT ACHIEVEMENTS

Through the following list of recent achieved projects, the variety of applications for HELIAL range is again pointed out:

- **SSRF (China):** Cooling down of superconductive cavities.

After significant achievements in France (Soleil), UK (Diamond), Taiwan (NSRRC), AIR LIQUIDE DTA has

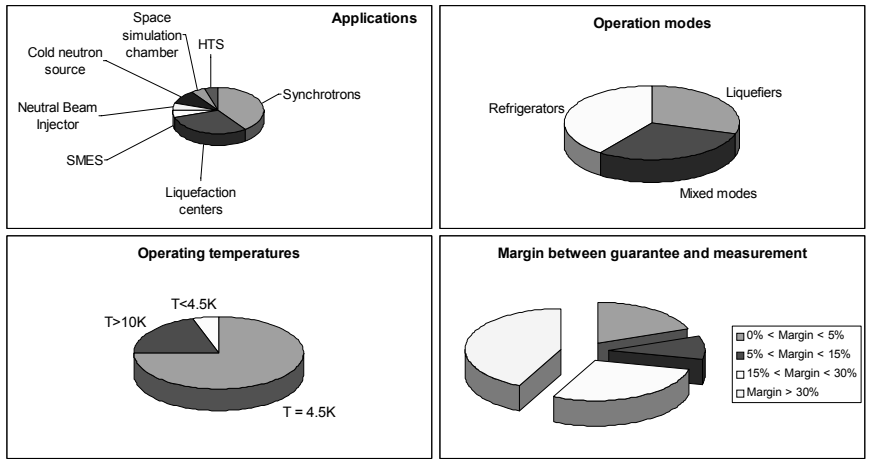

Figure 1: Characterisation of past HELIAL projects.

successfully started up a 650kW@4,5K HELIAL refrigerator for SSRF in China.

- **ISIS (UK):** Cooling down of combined moderators for Spallation Neutron Source ISIS.

The complete refrigeration system (two refrigerators (700W@13.5K), one H2 cold loop, multi-circuit cryogenic transfer lines and moderators) has been successfully tested in real operating conditions at AIR LIQUIDE DTA test area. The cryogenic equipment have now been installed at ISIS and the complete system is being started up on customer site.

- **NBI (India):** Subcooled helium loop for cryopump cold shields.

HELIAL 1000 and its Helium sub-atmospherical loop (110W@3.8K) was commissioned in March 2007 to supply cooling power to NBI project cryompump cold screens for IPR Tokamak.

- **Bristol University (UK):** Liquid helium production (15L/h)

A standard He liquefaction system was installed and started-up in Bristol University in July 2007. Integrated downstream of the He collection network of the university, the system is able to remove the air (about 0.5%) and water impurities and to recover Liquid Helium.

- **Kourou (French Guyana):** Recondensing of liquid helium storage boil off and distribution system (cryogenic lines).

AIR LIQUIDE DTA delivered a recondenser-liquefier to control the pressure in Liquid Helium tanks (about 170 000L) and limit the Helium losses on European Launch pad. The complete system including a complex cryogenic distribution network was started-up in April 2008.

NEW HELIAL EVOLUTION RANGE

Process Optimisation

HELIAL machines can operate in a liquefaction mode or in a refrigeration mode. For both modes, the basic cycle is the same, remaining a Claude cycle with two turbines installed in series. Nevertheless, the components of the cold box do not have the same contribution depending on the operating modes. The process studies were based on the differences between refrigeration and liquefaction modes.

In refrigeration, the power extracted by the turbines compensates only for the heat losses of the system, (i.e. non-reversibility of heat exchangers), heat-in leaks to internal components of the cold box and the heat load transferred by the customer's application to helium.

In liquefaction mode, no cold gas is returned through the heat exchangers except for the flash generated by the Joule-Thomson expansion. Therefore the turbines must balance not only the heat losses of the system but also must extract the power to cool down the helium to be liquefied.

In that way, one can easily understand that in a liquefaction mode, turbines have to extract more power than in a refrigeration mode, whereas in a refrigeration mode, the heat exchangers must provide the largest surface, particularly for the last heat exchanger, so as to recover the maximum cold enthalpy of the cold gas generated by the application.

Moreover, within the diversity of applications, the requirements for liquefaction and refrigeration modes are very different in terms of process specificities, scope of supply, control system, and system operating approach.

The HELIAL range was therefore split into two series: liquefiers and refrigerators. This separation permits one to obtain the maximum specific consumption with a given compressor for the operation mode chosen by the customer.

Turbine Improvement

In order to increase the overall efficiency of their processes, AIR LIQUIDE DTA works on the efficiency of the turbines, trying to improve them especially on their smallest machines that only extract several hundreds of watts. This has been managed thanks to the micro-manufacturing of 3D-open wheels (see Figure 2) as it was already done on larger turbines. About ten efficiency points have been gained and demonstrated on our specific test bench in DTA, which permits testing the turbines

Table 1: HELIAL Evolution of liquefier performances

	HELIAL SL	HELIAL ML	HELIAL LL
Max. Liquefaction capacity without LN2	25 L/h	70 L/h	145 L/h
Max. Liquefaction capacity with LN2	50 L/h	150 L/h	330 L/h
Compressor electrical motor	55 kW	132 kW	250 kW
Improvement compared to previous range	**New**	**100%**	**80%**
Specific consumption for liquefaction w/o LN2	645 W/W	552 W/W	505 W/W

under real cold conditions. These good results, in addition to the optimisation resulting from the choice of operating mode, also contributed to the improvement of the performances (as shown in Table 1).

Figure 2: Examples of 3D wheels for few hundred watts and few hundred Kwatts turbines.

New Range of Performances

The liquefier optimisation performance results are summarised in Table 1. The specific consumptions of the new liquefiers when compared to the former range are much lower. In terms of performances, the HELIAL ML anticipates a doubled capacity with the same cycle compressor and size than the HELIAL 1000. The HELIAL LL offers 78% more capacity than the HELIAL 2000 when both use the same compressor, and a small adapted machine for low capacity requirements, the HELIAL SL, is born.

Thanks to similar developments, the refrigerator range (HELIAL SF / MF / LF) is now also able to provide increased performances: **from 100 W to 1 kW at 4,5 K with electrical consumption from 50 kW to 250 kW.**

All these improvements mean lower operation costs thanks to a better adaptation to the customer's needs, process optimisation and better use of the main components.

HELIAL EVOLUTION SOLUTION

The standard HELIAL units are dedicated to be used for a maximum range of applications, from liquefaction centers to refrigeration applications. Hence, this product must fulfil a lot of different requirements and should remain flexible.

For liquefaction applications, AIR LIQUIDE DTA proposed very standard and already-defined solutions (see Figure 3). For other applications (refrigeration @4.5K, @20K …) where the needs can be very specific (in terms of performance and interfaces), even if AIR LIQUIDE DTA can propose reference products, the final solutions are defined in detail with the customer.

Anyway, design optimization for customer preferred mode takes other running modes into account (either refrigeration or liquefaction) to allow a wide range of operation for the machine.

In any case, HELIAL range remains based on following main assets:

- **Turbines**: Industrial product, high reliability (MTBF >150 000h), optimized and tested in real running conditions (temperature, pressure and flowrate)
- **Heat exchangers**: High efficiency, compactness
- **Compressors**: Very standard and reliable product (KAESER)
- **Automation**: Simplicity of use, higher performance (optimal tuning)
- **Supervision**: Intuitive, straightforward and user-friendly communication interface
- **Turn-key system**: a complete cryogenic solution from design to on-site installation and tests (including performance test at AIR LIQUIDE DTA's if requested)

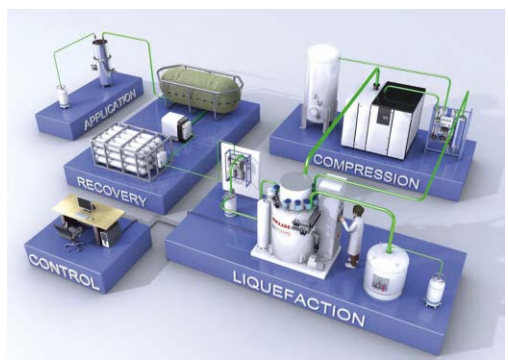

Figure 3: Scheme of a standard liquefaction solution

CONCLUSION

The HELIAL Evolution range constitutes a standard product line providing high performances with high reliability and efficiency. Performances have been considerably increased for the new HELIAL Evolution range. This product is the answer to a multi-range markets and remains adaptable to specific requirements.