Overview of different standard helium liquefiers / refrigerators for various applications

Caillaud A., Bonneton M., Delcayre F., Grabié V., Grillot D., Hilbert B., Praud A., Walter E.

Division des Techniques Avancées, Air Liquide, Rue de Clémencière, B.P.15, 38360 Sassenage, France

The design of Air Liquide DTA standard helium liquefaction / refrigeration systems was upgraded three years ago. Several of these systems were built and started up over the last years. Since then, these standard machines have been supplying different applications with either LHe or refrigeration power at 4.5 K. The standard design of this range of machines will be presented in relation with typical applications such as SRF cavities or SMES magnets operated at 4.5 K. This standard design can be modified to accommodate cryogenic power needs at temperatures ranging from 2 K to several tens of Kelvin. An overview of some design adaptations will be presented in relation with different applications such as superconducting magnet operated at 3 K or space simulation chamber.

EXAMPLES OF APPLICATIONS FOR HELIAL LIQUEFIERS/REFRIGERATORS

HELIAL machines are fully automatically controlled systems which can be used either as liquefiers, either as refrigerators, or both, depending on the final use of liquid helium.

Synchrotron light sources [1], with ranges from IR to hard X-rays, are produced by a beam of electrons circulating at high energies in a storage ring. The radio-frequency (RF) power and voltage required for storing the electron beam are provided by means of cryomodules containing superconducting RF cavities. The cavities made of Niobium deposited on Copper are bath-cooled with saturated liquid helium near the atmospheric pressure. Standard HELIAL are then used to supply with liquid helium the cryostats in which the cavities are installed.

HELIAL can also be used for SMES (Superconducting Magnetic Energy Storage) applications [2]. SMES devices store energy in magnetic fields. The devices consist of closed coils of superconducting wires. Superconductors are the only appropriate materials for SMES devices because they have no electrical resistance and thus can be operated in a persistent current mode without being connected to a power supply. A SMES device is the only method of storing electrical energy without first converting it into mechanical or chemical energy. SMES scale can be large (from a few Wh up to more than 1 GWh).

From materials to complete satellites, some equipment are sent into space and will have to face extreme conditions. Therefore, they are tested in space simulation chambers which are cooled in order to recreate space conditions. These chambers are maintained at a cold temperature thanks to cryopanels supplied with cold helium gas which can be produced by HELIAL adapted to temperatures above 10K.

In a NBI (Neutral Beam Injector) [3], the neutral beam is produced by charge exchange of ions extracted from plasma box and accelerated by an extractor. The pressure over the beam propagation has to be kept low so as to reduce the reionization losses. Cryocondensation pumps enable to maintain this low pressure, by freezing hydrogen or deuterium on Helium panels. The refrigerator HELIAL is then used to supply continuously these panels with LHe at 3.8K.

Basically, HELIAL are small-to-medium liquefiers. Some laboratories in physics or biotechnologies need permanently small quantities of liquid helium to perform experiments. They can recover helium gas from their users and liquefy it again to have their own production adapted to their needs.

STANDARD HELIAL RANGE

Air Liquide DTA have updated its range of the so-called HELIAL standard helium liquefiers /

refrigerators. Three machines have been defined : HELIAL 1000, HELIAL 2000 and HELIAL 3000.

The table 1 presents the performances guaranteed for each machine.

Table 1 HELIAL performances

	HELIAL 1000	HELIAL 2000	HELIAL 3000
Liquefaction capacity without LN2	30 l/h	85 l/h	180 l/h
Liquefaction capacity with LN2	65 l/h	175 l/h	300 l/h
Refrigeration capacity without LN2	130 W	415 W	560 W
Refrigeration capacity with LN2	160 W	500W	875 W

The turbines can be adapted to different operating modes.

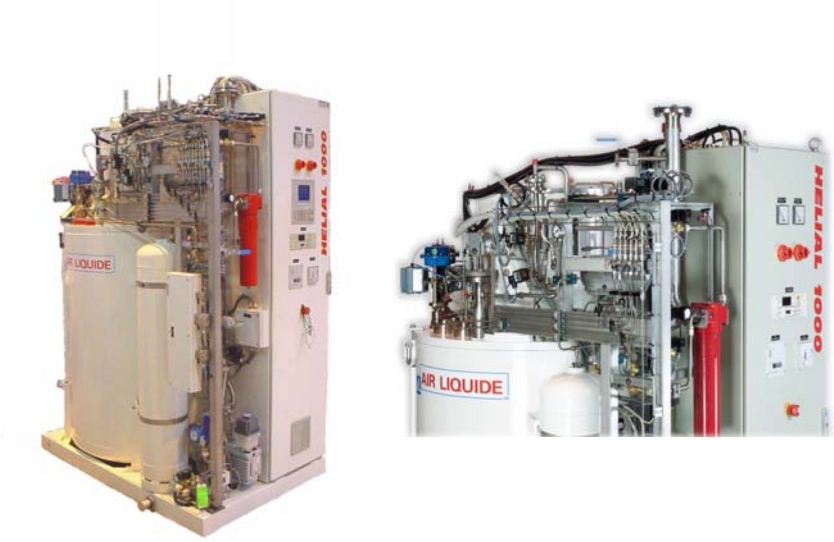


Figure 1 HELIAL 1000 cold box and warm panel

A standard HELIAL is basically composed of three modules :

- The screw compressor with a bulk oil separator, and coolers;
- The oil removal system;
- The cold box.

Additional equipment can be proposed in option such as variable frequency driver for compressor capacity adaptation, liquid helium dewar, HP or MP gas storage capacities, warm or cryogenic piping, internal or external helium purifier, recovery compressor, supervision control system…

CYCLE DESIGN

The HELIAL cycle is based on a Claude cycle which is the combination of a Brayton and a Joule-Thomson cycles. Two turbines associated in series compose the Brayton, and the Joule-Thomson function is ensured by the JT valve. The figure 1 presents a schematic view of the cycle associated to the corresponding T-S diagram.

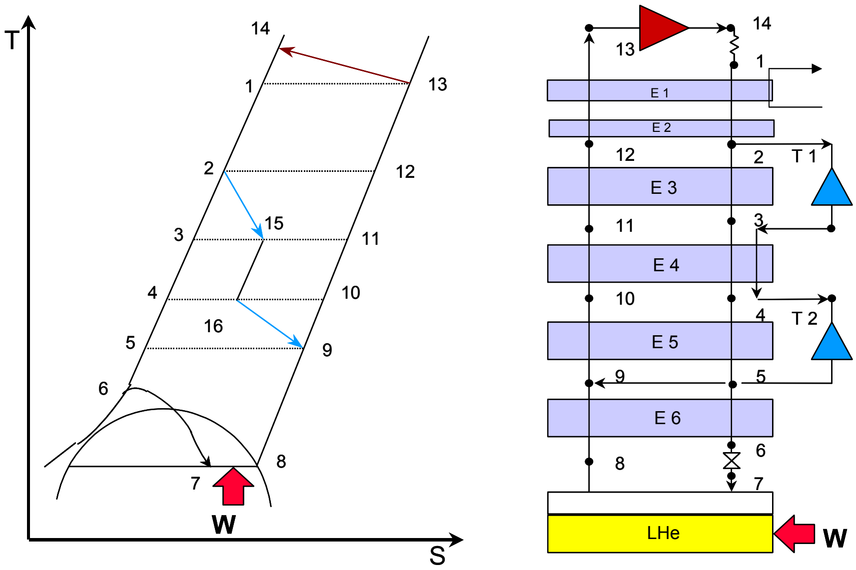


Figure 2 HELIAL T-S diagram and cycle design

Helium gas at ambient temperature and atmospheric pressure is compressed into the cycle compressor up to maximum 15 bar abs (see Figure 2, 13 to 14). After the compression, a first oil separation is then performed in the bulk oil separator integrated in the compressor casing, followed by a cooling of the helium gas (14 to 1). The helium stream is sent to the final oil removal module where the small quantity of remaining oil (either aerosols or vapours) is removed in two coalescing cartridges and a charcoal adsorber.

The high pressure gas enters the cold box (1). The flow is fed to the heat exchangers to be cooled by the low pressure returning stream. Liquid nitrogen can be used in the first heat exchanger E1 to help cooling the high pressure stream down to 80K. At 80K, the flow is then supplied to the 80K adsorber filled with charcoal in order to remove air impurities. The stream exits the adsorber (2) and is split into two parts :

- the gas which is expanded in the turbines in the so-called Brayton cycle;
- the gas which leads to the production of liquid helium in the so-called Joule-Thomson cycle.

<u>The Brayton cycle flow</u>

The power extracted by the turbines compensates for :

- the power which is necessary to compensate the liquefaction/refrigeration load;
- the power dissipated by the temperature difference at the warm end of the heat exchanger (warm end heat exchanger pinch);
- the power corresponding to the heat-in leaks into the cold box and eventual associated equipment (dewar, cryogenic interconnecting pipes…).

In between the turbines 1 and 2, the medium pressure stream is cooled in a heat exchanger to about 20K (3 to 4), and finally expanded in the cold turbine from which it exits at about 12K (4 to 9).

<u>The Joule-Thomson cycle</u>

The stream exiting the 80K adsorber and not sent to the turbines is cooled against the low pressure cold stream in the heat exchangers E3 and E4 (2 to 4). It is then purified in the 20K adsorber to remove low levels of air contamination. It is fed to the heat exchangers E5 and E6 (4 to 6), the so-called Joule-Thomson exchanger, and finally expanded from the cycle high pressure to 1.2 bar abs in the JT valve (6 to 7). The expansion produces a mixture of liquid and gas at 4.5K. The liquid is stored in the dewar whereas the cold gas is returned to the cold box low pressure stream (8).

<u>The cold box low pressure stream</u>

The low pressure gas returning from the dewar is mixed to the gas which was expanded through the turbines. This stream flows through LP channels of the heat exchangers where it cools down the HP counter flow. It finally exits the cold box at ambient temperature (13) and then returns back to the compressor suction side.

ADAPTATIONS OF STANDARD HELIAL FOR SPECIFIC APPLICATIONS

The standard HELIAL can be adapted for specific applications at temperature below or above 4.5 K..

<u>Temperatures below 4.5K</u>

HELIAL 1000, for NBI-IPR project, has been used to provide cold power at 3.8K. To achieve such a low temperature, the liquid helium bath must be pumped below atmospheric pressure. This is performed thanks to a warm vacuum screw compressor which enables to pump liquid helium down to 660 mbar abs. The technical solution presented here is specific to this project. Other technical solutions can be proposed for refrigeration at temperature below 4.5K.

The cycle is kept identical to a standard liquefier. Liquid helium is withdrawn from the main dewar towards a phase separator, connected to the suction of the vacuum screw compressor. The vapour phase is pumped and flows through a recuperator heat exchanger in order to warm the cold gas up to 300K before entering the vacuum screw compressor. The cold enthalpy of the gas is recovered inside this heat exchanger by HP gas coming from the inlet of the cold box. This HP flow is cooled down and expanded in a second JT valve at the outlet of the main JT valve, producing additional gas/liquid mixture at 4.5K.

The liquid at 3.8K is withdrawn to the customer's cryopumps and evaporated inside, producing cold gas which goes back to the phase separator. The circulation from the phase separator towards the cryopumps is performed thanks to thermosiphon effect.

The vacuum screw compressor enables to compress helium from 600 mbar abs up to 1.2 bar abs. Oil is removed from helium in an additional oil removal system. Finally helium gas is sent back to the main compressor suction.

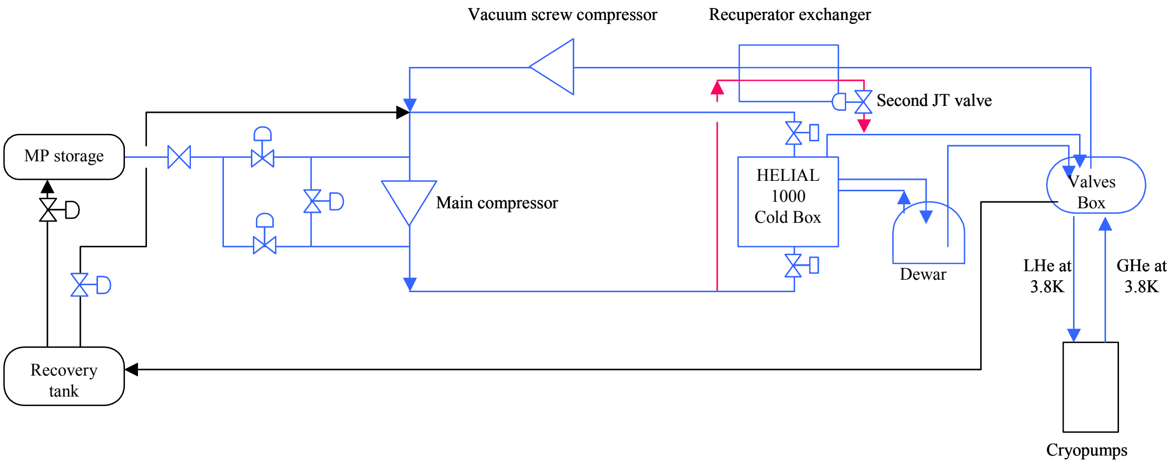
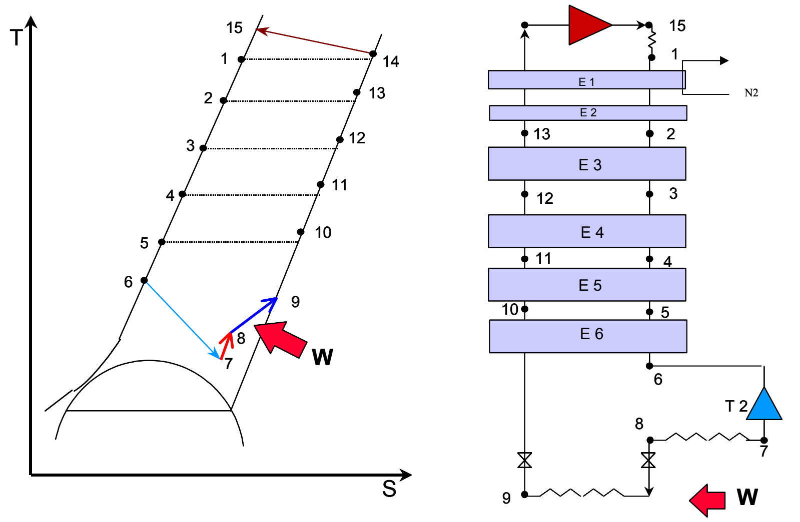


Figure 3 Standard HELIAL refrigerator adapted for 3.8K refrigeration system

Temperatures above 10K

For a space simulation chamber in China, the design of HELIAL 1000 has been adapted in order to provide cold helium gas at 13.5 K to cool cryopanels.



The Joule-Thomson circuit has been removed (see figure 4), keeping only the Brayton cycle composed of a single turbine. The warm helium gas is compressed in the compressor station up to 15 bar abs and sent to the oil removal system before entering the cold box. It is cooled down inside the heat exchangers E1 to E6 thanks to the cold LP counter flow. The turbine is connected at the end of the heat exchanger E6 and expands at 1.6 bar abs the gas which is directly sent to the customer's cryopanels.

Figure 4 HELIAL adaptation for refrigeration power @13.5K

The delivered temperature can be controlled thanks to an electrical heater which has been added inside the cold box. The gas is warmed in the cryopanels and sent back to the cold box heat exchangers to cool down the HP flow. The heat exchangers are kept identical compared to the standard ones. This HELIAL 1000 is able to provide 600 W between 13.5K and 18K.

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REFERENCES

1. Technical Specifications for the Engineering, Design, Manufacturing, Testing and Delivery of the cryogenic plant of the SOLEIL superconducting RF system, Same volume, Gif-Sur-Yvette, France (2003) 5.
2. Committee on the Impact of Selling the Federal Helium Reserve, Board on Physics and Astronomy, Commission on Physical Sciences, Mathematics, and Applications, National Materials Advisory Board, Commission on Engineering and Technical Systems, National Research Council, The Impact of Selling the Federal Helium Reserve, National Academy Press, Washington D.C., U.S.A. (2000) 26-39.
3. Design, Fabrication, Testing and Supply, Installation and Commissioning of 110 W at 3.8K Helium Refrigerator System at IPR, SST/ENQ/F/001, Gandhinagar, India (2001).