# 30 K to subK vibration free remote cooling systems

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**Abstract**. Absolut System has built a 30K and a 10K remote Helium cooling loops used as vibration free cooling source, respectively for IR detectors electro-optical characterization test bench and two-stage optical cryostat. The circulation loops are based on a by-passed flowrate from either a two-stage Gifford–McMahon cryocooler or a two-stage Pulse Tube cryocooler. Dedicated compact and high efficiency tubes & shell heat exchangers have been designed and produced for the recuperators. The paper describes the design and the performances of the vibration free cooling system produced. The current work towards a 4K low vibration cooling source and its coupling with a subK stage will be introduced as well.

## 1. Introduction

A fluid cooling loop is an option to couple a cryocooler to the application that minimizes the integration issues when the vibrations are a limitation. Absolut System has developed several gaseous Helium cryocooling closed loops configurations that allow to provide a so-called remote cooling by using a flexible between a cold box containing the cryocooler and the application providing versatile remote distributed cooling capacity. Those remote Helium cooling loops are addressing electro-optical characterization test benches for very large wavelength IR (VLWIR) detectors in Mercury-Cadmium-Telluride (MCT) technology in the 50-60 K temperature range [1], or MgB2 based superconducting electro-technical equipment's in the 20-30 K temperature range such as motors or power cables [2, 3].

Spatial noise characterization of IR detectors requires systematic and repetitive measurements at variable temperatures over long periods of time. In this context, Absolut System extends the temperature range of remote Helium cooling loops to address 30-200 K characterization with extremely low vibration and a user-friendly press-button operation. Furthermore, remote Helium cooling loops system has been extended to closed cycle cryostats with optical access, dedicated to the study of magneto-optical properties of semiconductors in the 10 K region. Extremely low vibration is also a key requirements to interface with the optical table.

Those two realizations introduce the work done so far by Absolut System towards Advanced Cryogenic Equipment (ACE-CUBE), a versatile optical cryogenic plateform designed for low temperature scientific instrumentation.

## 2. 30 K remote Helium cooling loop for IR detectors characterization

The 30 K remote Helium cooling loop developed makes use of a two stage Gifford-McMahon (GM) cryocooler type Coolstar 6/30 cold head driven by a 3.0 kW Cryodrive Helium compressor from Oxford Cryosystem Ltd and two counterflow heat exhangers (recuperators) as presented in Figure 1. A small part of the flowrate (~20 mg/s) is by-passed from the compressor supply/return lines to supply the cooling loop. A 2 meters long super-insulated flexible line joins the cold box, which contains the cold head and the heat exchangers, to the cold finger providing cooling power to the customer application.

The flexible line and the cold box share the same vacuum insulation, while the cold finger vacuum is managed by the application (separated vacuum).

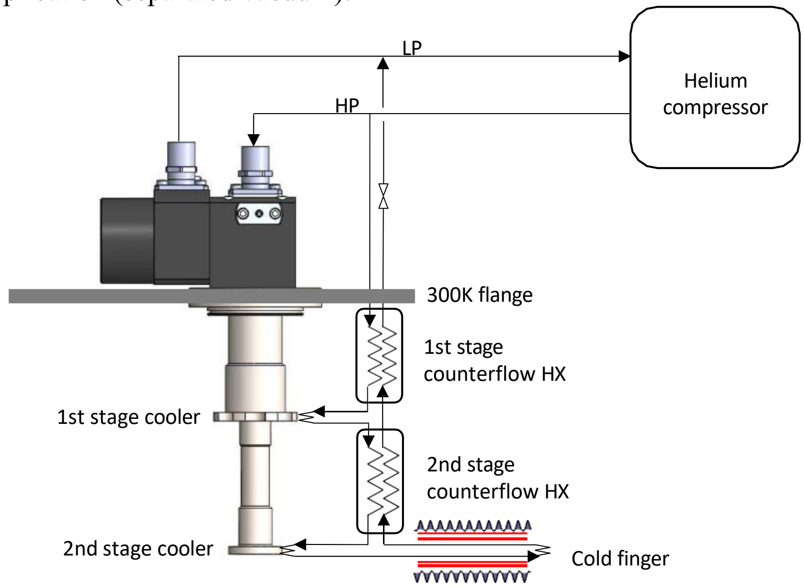


**Figure 1.** Schematic of the 30 K remote Helium cooling loop.

Illustrations of the 30 K remote Helium cooling loop are attached in Figure 2. A test cryostat from the laboratory was used at Absolut System during the factory test prior to on-site acceptance test performance. 30 K cryogenic temperature was achieved at the cold finger within 2 hours at 90 rpm maximum speed of the GM cold head stepper motor. For this speed, the cooling capacity available at the cold tip was 3.5 W @ 30 K. With the minimum speed set to 40 rpm to the stepper motor, the cooling power varies from 4.6 W @ 80 K to 16.6 W @ 200 K as reported in the mapping attached in Figure 3. The compressor input power was measured at 3.6 kW on 220V / 50Hz single phase electrical network.

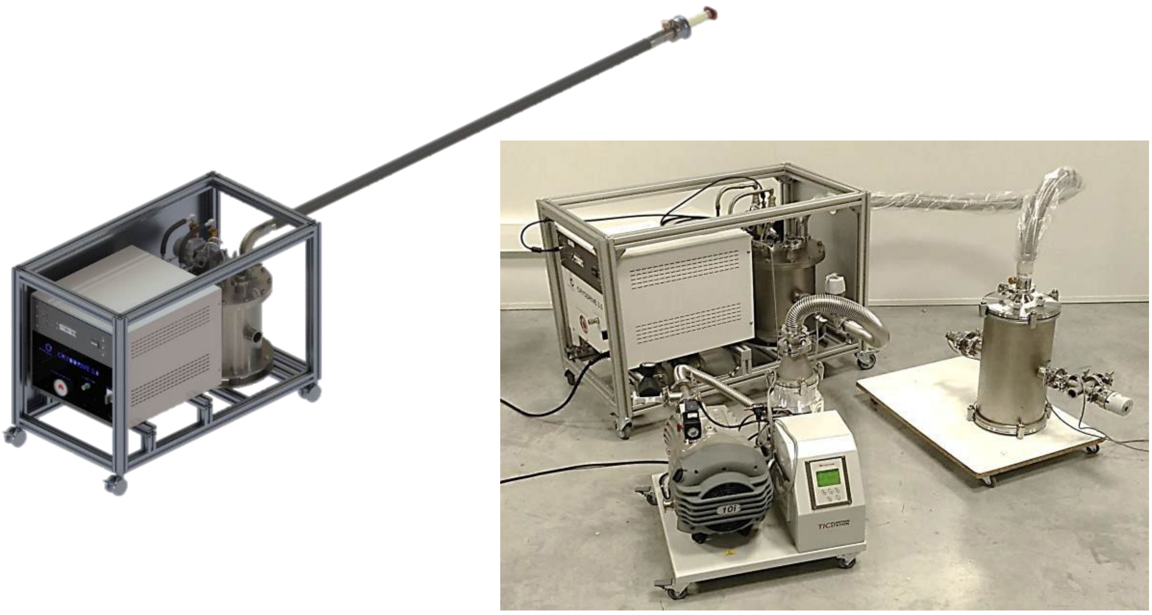

**Figure 2.** Illustrations of 30 K remote Helium cooling loop. Left: CAD view with the 2 meters flexible line unrolled. Right: test cryostat for factory performance test measurements at Absolut System.

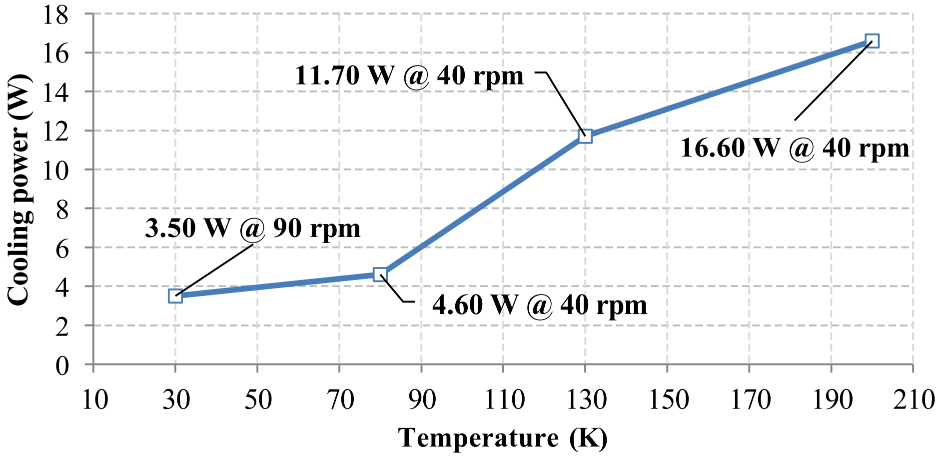


**Figure 3.** Performance mapping of the 30 K remote Helium cooling loop.

The performances of the cooling loop are limited by the heat losses into the cryogenic line and by the recuperative heat exchangers. We have designed optimized compact heat exchangers for cryogenic applications using a large number (500-1500) stainless steel micro-tubes accepting a maximum pressure of 2 MPa, compatible with the cryocooler compressors HP/LP pressure (0.5 to 2 MPa).

They are optimized for the specific temperature stage (first or second stage) and the mass flow. An example of such recuperator is shown in Figure 4.

The thermal characterization consists in measuring the efficiency of the recuperator considering the desired Helium mass flow (around 10-4 kg/s). The efficiency is measured for a given pressure (0.5 to 2 MPa) and within a wide range of temperature 30 to 300 K. The mean efficiency of the designed recuperator is measured in the range 97 – 98 %.

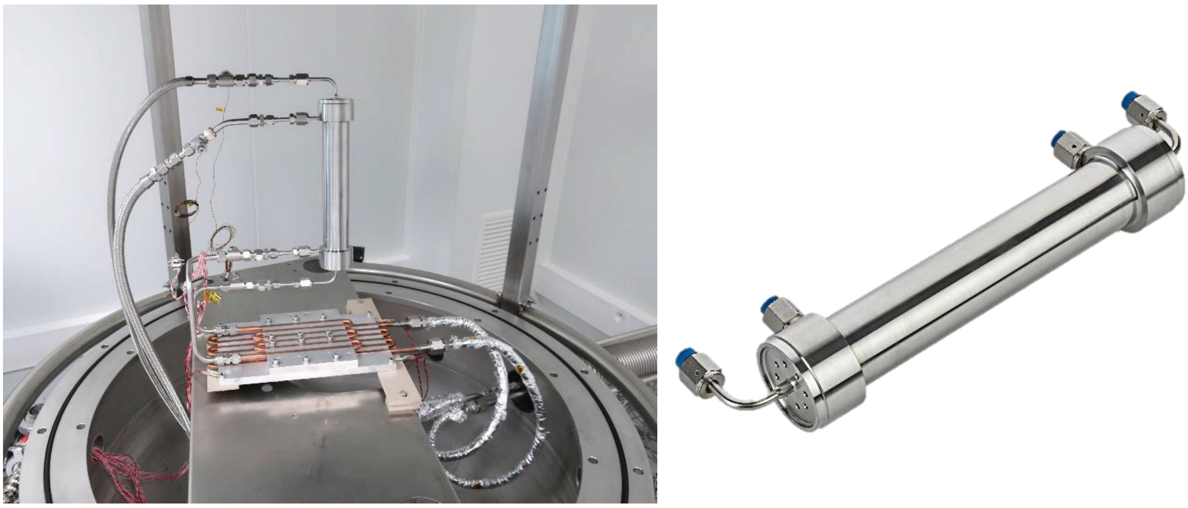

**Figure 4.** Performances test of a recuperative heat exchanger (example shown: diameter 50 mm, length 260 mm).

## 3. 10 K two-stage optical cryostat with remote helium cooling loop

A two stage remote Helium cooling loop system has been designed and produced for application to a 10 K closed cycle, two stage cryostat, with optical access, dedicated to the study of magneto-optical properties of semiconductors in the 10 K region. The system makes use of a two stage pulse tube cryocooler type PT807 from Cryomech Inc.

As per the previous example, a small part of the flow rate is by-passed from the compressor to supply the two-stage cooling loop. The schematic of the cooling loop is shown in Figure 5. The first stage provides cooling to the cryostat thermal shield in the 60-70K temperature range while the second stage provides cooling to the experimental cold plate in the 10-20K temperature range. In order to limit the impact on the optical table, a unique flexible line is used for the gas circulation from the cold box to the two stage cryostat, as illustrated in the Figure 6.

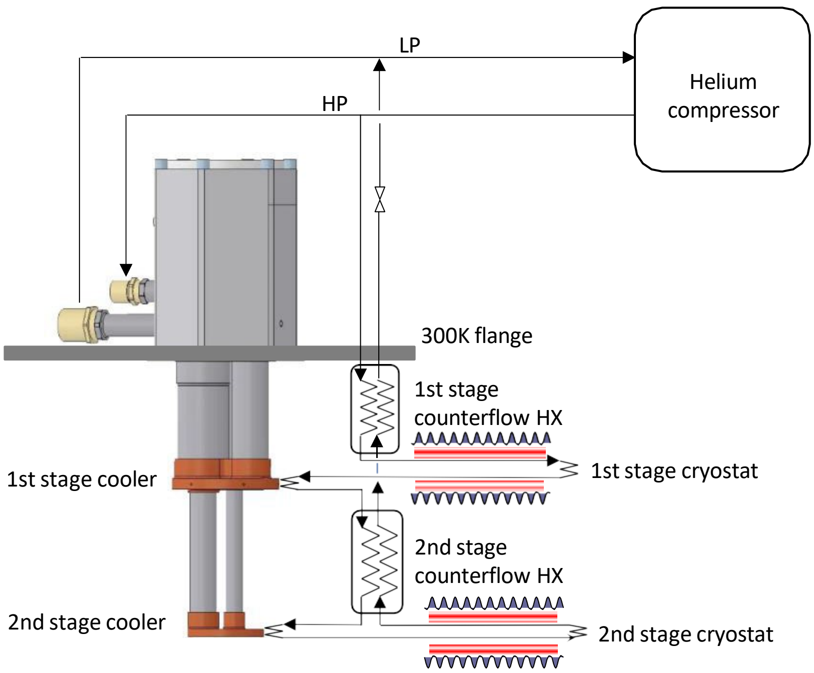


**Figure 5.** Two-stage helium cooling loop with by-passed flow from the cryocooler compressor.

**Figure 6.** Left: 10 K two stage remote Helium cooling loop and cryostat produced. Right: Illustration example of the cryostat configuration on the optical table.

The two stages of the cooling loop are illustrated on Figure 7. First and second stage recuperators are placed inside the cold box after dedicated performance characterization described previously. The cold head heat exchangers are composed with copper capillary wounded and silver brazed on copper blocks thermally anchored to the cold head stages. All the components, including piping mostly composed of stainless steel flexible lines, are finally wrapped in to MLI. A table-top style cryostat is produced. The experimental volume is specified as a cube with 100x100x100 mm dimensions. The gold coated cold plate is equipped with M3 holes on 12.5 mm centers. The thermal screen is equipped with five 2” BK-7 optical glass windows from ESCO Optics. MLI is also used on the thermal screen. Above 5 optical access ports with >40mm opening, the present cryostat offers 4 micro-coaxial cables and 15 DC lines routed from room temperature electrical hermetic feedthroughs to the cryogenic cold plate. The table-top cryostat and the flexible line share the same vacuum insulation, which is different from the cold box vacuum insulation.

**Figure 7.** View of the interior of the cold box prior to MLI wrapping (left) and two stage table –top cryostat coupled to the 10 K remote helium cooling loop (right).

The 10K two stage remote Helium cooling loop and cryostat produced as presented in Figure 5 has been tested. The cold plate reaches the minimal temperature (about 12.2 K) within 4 hours. The load curve of the system with 100 mg/s by-passed mass flow from the CP970 compressor is reported in the Figure 8. As shown, a cooling capacity of 500 mW is available on the cold plate at 13.1 K. Dedicated vibration measurements will be reported by the end user (Laboratoire de Physique de la Matière Condensée, Ecole Polytechnique, Paris, France) during the second semester of 2019.

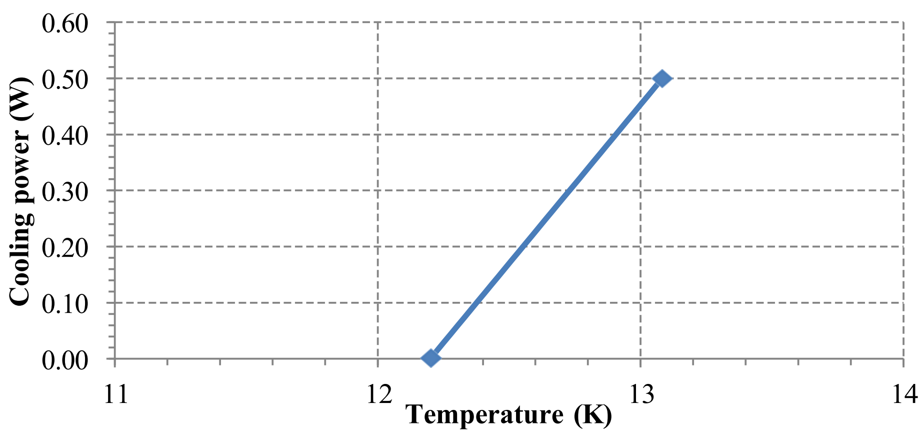


**Figure 8.** Heat load trial on the experimental cold plate.

## 4. Two-stage cooling loops with cryogenic circulation fan

The temperature difference between the cryocooler and the application depends on the Helium mass flow. If we neglect the losses in the line, it is estimated by the following formula giving the equivalent thermal conductance of the thermal link (T > 50 K, P < 2 MPa):

$$P = \dot{m} \cdot c_p \cdot \Delta T \sim 5.2 \cdot \left(\frac{\dot{m}}{10^{-3}\,kg/s}\right) \cdot \Delta T \;\; [W/K]$$

The by-pass mass flow acceptable on the compressor of small Pulse Tube or Gifford-McMahon cryocoolers has been investigated experimentally. The upper limit to avoid any performance impact on the cold head is ~$10^{-4}$ kg/s. For more demanding applications, we need to have a forced circulation flow by another mean. In order to support the optimization of its custom-made cryogenic circulation loops, Absolut System has developed, optimized and industrialized high reliability and high performance cryogenic circulation fans. A standard configuration is proposed covering a large range of applications: remote cooling loops, low temperature vibration free cryostats, HTS cable cooling etc.. In addition to the laboratory applications, this product also extends the AFCryo product range for the integration of high cooling capacity cryocoolers (~1 kW) in industrial applications (www.af-cryo.com). The schematic of a two-stage circulation loop with a cryogenic circulation fan is shown on Figure 11.

**Figure 9.** Cost effective cryogenic circulation fans developed by Absolut System.

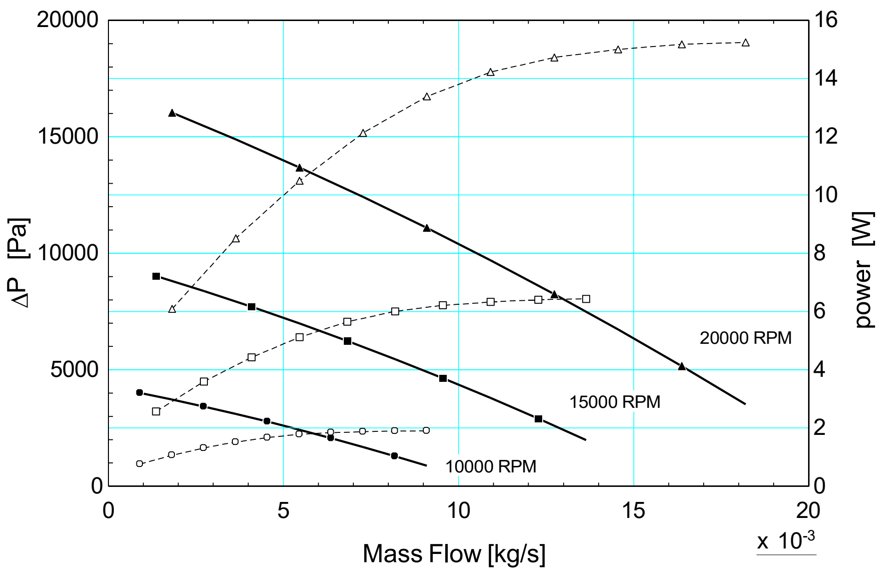


**Figure 10.** Fan performance with helium at 2 MPa, 50 K (45 mm diameter model).

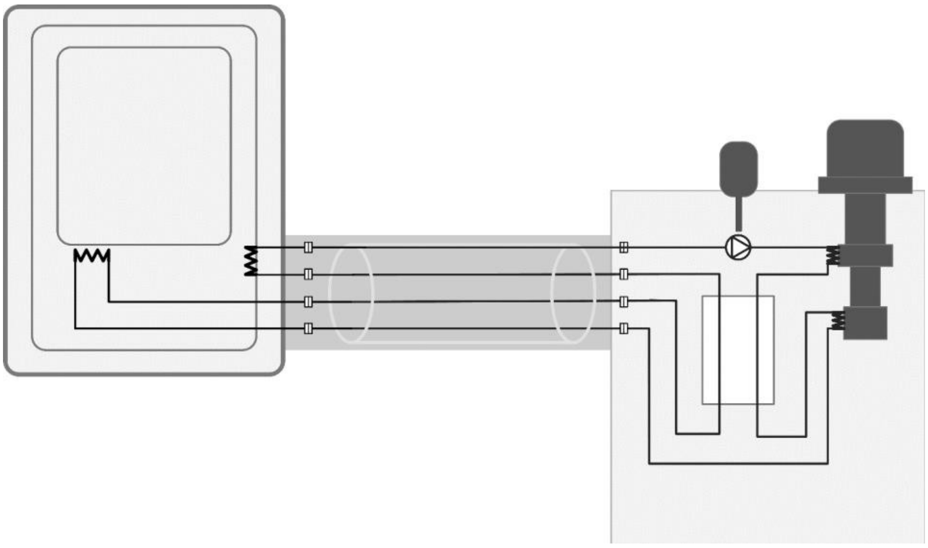

**Figure 11.** Two-stage cooling loop with a cryogenic circulator.

## 5. Perspectives

The use of a cryogenic fan in cooling loops has the advantage to suppress the first stage recuperative heat exchanger (Figure 11). By mastering the design of the cryogenic fan, we can build cost-effective solutions, even with small power cryocoolers (< 10 W).

As the mass flow can be matched by optimizing the cryogenic fan, this architecture is adapted to high power applications (up to ~1 kW) and currently applied to several projects.

For vibration sensitive applications in instrumentation (optics, low temperature detectors, …), the flexible helium loop is effective to limit the vibrations induced by the cryocoolers.

In order to reach temperatures lower than 4 K and keeping the advantages of flexible loop design, we are currently investigating the coupling of a Gifford McMahon or a Pulse Tube cryocooler to a Joule-Thomson cryocooler [4,5] (Figure 12). This is a classical architecture proposed in the 90's to reach 4 K with a 8 K cooler. It is still the preferred solution for 4 K cryocoolers in space applications.

Our objective is to have a complete range of solutions based on the flexible helium loop design for the range of applications between 2 – 30 K.

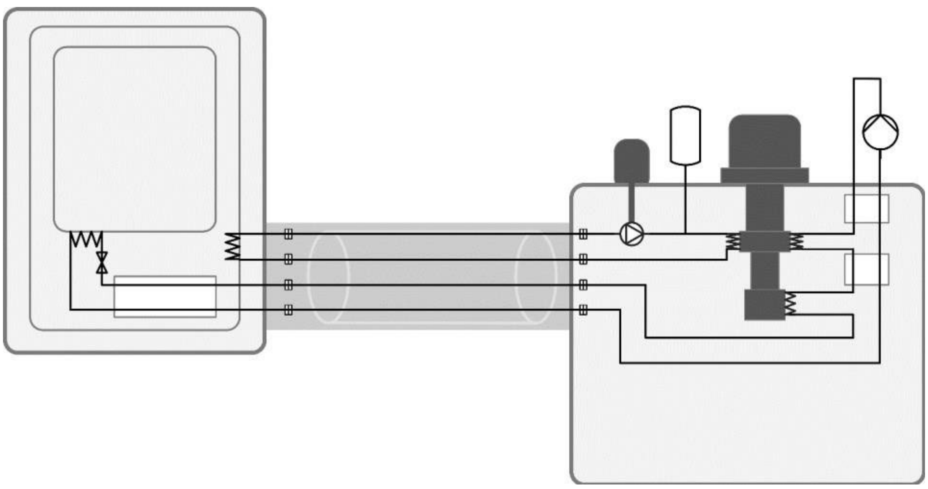

**Figure 12.** Joule Thompson cooler pre-cooled by a two-stage cryocooler for 2 - 4 K applications.

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