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Characterisation and optimisation of flexible transfer lines for liquid helium. Part I: Experimental results

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ABSTRACT

The transfer of liquid helium (LHe) into mobile dewars or transport vessels is a common and unavoidable process at LHe decant stations. During this transfer reasonable amounts of LHe evaporate due to heat leak and pressure drop. Thus generated helium gas needs to be collected and reliquefied which requires a huge amount of electrical energy. Therefore, the design of transfer lines used at LHe decant stations has been optimised to establish a LHe transfer with minor evaporation losses which increases the overall efficiency and capacity of LHe decant stations. This paper presents the experimental results achieved during the thermohydraulic optimisation of a flexible LHe transfer line. An extensive measurement campaign with a set of dedicated transfer lines equipped with pressure and temperature sensors led to unique experimental data of this specific transfer process. The experimental results cover the heat leak, the pressure drop, the transfer rate, the outlet quality, and the cool-down and warm-up behaviour of the examined transfer lines. Based on the obtained results the design of the considered flexible transfer line has been optimised, featuring reduced heat leak and pressure drop.

1. Introduction

Small to mid scale helium liquefiers have a specific electrical energy demand of 2.0–4.5 kWh_{el}/l_{LHe}. Since a liquid helium (LHe) transfer at liquefiers in cryogenic laboratories is often unavoidable, reduced evaporation losses increase the capacity and efficiency of the whole LHe supply system. The majority of decant stations is equipped with flexible transfer lines having a single-channel design without an active shield cooling. Although flexible transfer lines are characterised by higher evaporation losses than rigid lines, a flexible design is widely used since it is advantageous regarding its handling.

The efficiency of a cryogenic transfer system is often characterised by its heat leak. But little data exists concerning the heat leak of flexible transfer lines used at LHe decant stations. Published heat leak values are mostly valid for rigid transfer lines used to cool superconducting magnets, like [1–3], which often feature a shield cooling by helium return gas or liquid nitrogen. Thereby heat leaks from 0.97 W/m to 0.04 W/m are achieved. A flexible design with a heat leak of 0.03 W/m is proposed in [4]. But this design consists of multiple concentric lines, which is not suitable for a LHe decant station. A flexible siphon for the transfer between two transport vessels has a typical heat leak of 2 W/m [5]. Published heat leak values are determined by the temperature rise of a gaseous nitrogen or helium flow through or along the outer shell, requiring a calorimeter assembly, of the transfer line. The heat leak value published in [4] is determined by evaporating all transferred LHe inside the transport vessel with an electrical heater. All proposed methods require special equipment and they lack an applicability to decant stations during a standard filling process.

The alternative approach of a LHe pump to establish a low loss LHe transfer, as proposed in [6], is considered to be not applicable to the majority of existing decant stations, since a LHe pump requires huge efforts regarding capital costs, required modifications of the liquefier, and process control.

To examine the evaporation losses caused by the heat leak and the pressure drop of a flexible transfer line, a dedicated test rig has been installed at a typical LHe decant station. At this test rig, the heat leak was determined by the zero delivery case which does neither require any great modifications of the decant station nor the transport vessel. Experimental helium transfer lines (HeTra) equipped with temperature and pressure sensors were examined to achieve a more detailed understanding of the transfer process. Based on the experimental data the transfer line sections with the highest evaporation losses were identified and the design has been successively optimised. The final and optimised transfer line

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design establishes a LHe transfer with considerably reduced evaporation losses.

2. Experimental setup

2.1. Test rig

A new test rig (see Fig. 1) to examine characteristic parameters of flexible transfer lines has been installed and commissioned. During a standard filling procedure the liquid and gaseous mass flow rates at the transfer line outlet, the recovered volumetric flow rate, the liquid level and the storage and transport vessel pressure are monitored. If an experimental transfer line is installed at the decant station additional pressure and temperature data at discrete locations of the transfer line can be acquired, too.

The volumetric flow rate of the recovered helium gas is measured by a thermal flow meter. The accuracy of the flow meter is 2% of the reading for a range of 3–100 m^3_{STP}. The scale to measure the transport vessel mass has an accuracy of ±0.28 kg referred to the absolute weight. All pressure values are acquired by gauge pressure transmitters having a range of 0–60 kPa_g and a typical accuracy of 0.6% FS. Silicon diodes type DT-670A measure the outer wall temperature of the inner tube with a typical accuracy of ±0.25 K. The self heating of the silicon diode causes a heat input of 16 μW which can be neglected. All electrical signals are acquired by a commercial data acquisition system. The additional measurement deviations caused by the acquisition system are negligible compared to the sensors' deviations. The sampling rate is 0.25 Hz.

The heat leak of the flexible transfer line was determined with a slightly modified standard filling procedure in which the mass flow rate is throttled to such an extent that saturated helium gas exits the transfer line, i.e. $x_{out} = 1$. As a result, the LHe flow evaporates completely without any superheating. It is assumed that the transport vessel acts as a perfect phase separator so that the generated cold helium gas is directed straight to the recovery line. This certain outlet state is observed during the filling procedure by a constant transport vessel mass. The measurement data is evaluated assuming that the heat leak itself can be considered as an isobaric change of state, whereas the pressure drop is considered as an isenthalpic change of state. Since no LHe is deposited in the transport vessel, this modified filling process is called the zero delivery case. Any additional heat leak, e.g. by the transport vessel, is neglected.

2.2. Flexible transfer lines

Three experimental transfer lines with built-in temperature and pressure sensors were designed and examined at the described LHe decant station. Each line varies regarding the internal design representing a certain development step (see Table 1). Nevertheless, the principle design as shown in Fig. 2 was unchanged.

2.2.1. Reference design

The reference design is equivalent to a standard flexible transfer line. Since different manufactures and designs are present in this particular market, a common state of the art is hardly definable. But the authors are confident that the chosen reference design is representative for the majority of transfer lines used in cryogenic laboratories today.

The considered single-channel flexible transfer line consists of two concentric tubes. The diameter of the outer tube or shell of sections inserted into the storage and transport vessel is limited to 12 mm because of the free diameter of the compression fitting that separates the helium inventory from the ambiance. Sections outside of the helium vessels have a shell diameter of 34 mm. The diameter of the inner or process line is set to be 6 mm for the rigid and the flexible part. Several PTFE spacers are positioned in discrete distances to keep the shell and the process line apart from each other to avoid a thermal bridge. The flexibility of the horizontal section is achieved by two concentric corrugated tubes. The radial gap between the shell and the process line is evacuated to 10^{-5} mbar to reduce heat leak by convection and conduction in

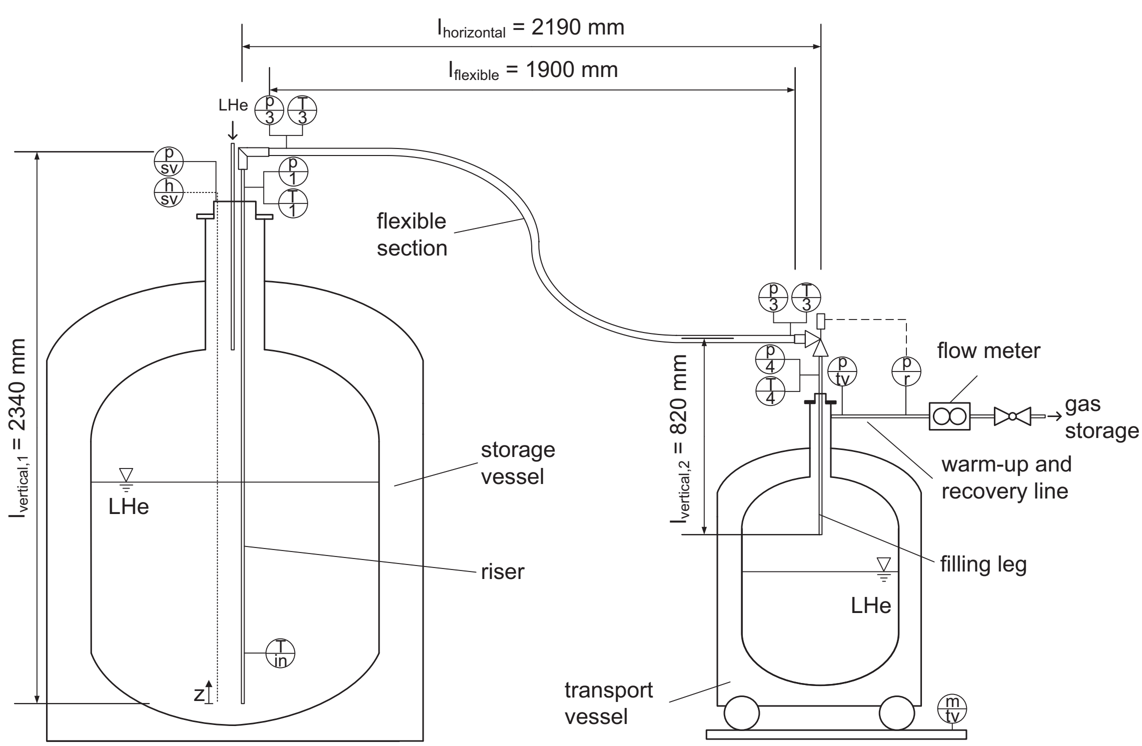

Fig. 1. Scheme of the test rig installed at the LHe decant station (in: inlet; sv: storage vessel; tv: transport vessel; r: recovery line).