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Experimental and RELAP5-3D results on IELLLO (Integrated European Lead Lithium LOop) operation

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HIGHLIGHTS

- Analysis of the behavior of the main components of the loop.
- Testing of a pressure transducer and a Vortex mass flow meter for use in LLE systems.
- Investigation of the performance of an air-cooler and a regenerative heat exchanger.
- Validation of the system code RELAP5-3D against the obtained experimental data.

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ABSTRACT

The experimental facility IELLLO (Integrated European Lead Lithium LOop) was designed and installed at the ENEA Brasimone Research Centre to support the design of the HCLL TBM (Helium Cooled Lithium Lead Test Blanket Module).

This work presents the results of the experimental campaign carried out within the framework of F4E-FPA-372 and which had three main objectives. First, to produce new experimental data for flowing LLE (Lead-Lithium Eutectic) for an analysis of the loop and the characterization of its main components. Then, to evaluate performances of commercial instrumentation as available instrumentation is not designed for use in LLE. Lastly, to use the data for validation of the model developed with the system code RELAP5-3D. The data collected could prove helpful to analyze the behavior of the LLE loop of ITER and DEMO in accidental conditions.

The results show that the regenerative countercurrent heat exchanger has an efficiency ranging from 70 to 85%, mainly depending on the LLE mass flow rate. It was verified that the air cooler has the capability to keep the cold part of the loop at 623 K, even in the most demanding situation (700 rpm and maximum temperature of the hot part). The instrumentation tested showed good accuracy, with the exception of the turbine flow meter. Nevertheless, specific limitations in the upper operative temperatures were found for the LLE direct contact pressure transducer. RELAP5-3D simulations fit very well the associated experimental results achieved.

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1. Introduction

The present work was carried out within the framework of the F4E-FPA-372-SG01 contract, which aims to support R&D activities for the conceptual and preliminary design of the European test blanket systems. To deal with the development of Breeding Blankets for future fusion reactors, ENEA designed and built a lead lithium loop, named IELLLO (Integrated European Lead Lithium LOop).

This activity was conceived to analyze the behavior of the facility and its main components. Some of these components are candidates as main or back-up solutions for the LLE (Lead Lithium Eutectic) loop of the HCLL TBS (Helium Cooled Lithium Lead Test Blanket System) [1]. Moreover, the ability to run a large LLE loop, together with the lessons learned, will be useful for the design and operation of the final LLE loop of ITER.

Several facilities have been built to investigate the problems connected with the use of LLE (corrosion, tritium extraction, MHD,

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etc.), as described in [2]. However, only IELLLO has been designed as a facility dedicated to test the HCLL TBS equipment.

Commercial measurement devices are not designed to work with LLE. Therefore, the second aim of this activity was to test new instrumentation for LLE. Many experimental analyses have been conducted on hydrogen sensors in LLE (e.g., [3]), while reliable devices to control key operative parameters, such as pressure, flow rate and level, are still under development.

The third objective was to assess the capabilities of RELAP5-3D system code to work with LLE, in parallel with the work on He performed by Barone et al. [4]. RELAP5-3D [5] is a thermal-hydraulic system code developed at the Idaho National Laboratory on the advice of the US Department of Energy. It derives from RELAP5/MOD3, from which it distinguishes for a fully integrated, multi-dimensional thermal-hydraulic and kinetic modelling capability. It also includes the working fluids (lead-bismuth, lead-lithium, helium, etc.) and the magneto-hydrodynamic model that were introduced by the ATHENA configuration of the code.

2. Description of the facility

With respect to the loop described in [6], IELLLO underwent a few modifications in 2015. In particular, the permanent magnet pump substituted the mechanical one and the expansion tank S02 was removed. The new configuration of the loop is shown in Fig. 1.

IELLLO is an eight-shaped loop with a temperature ranging from 623 K in the cold part up to 823 K in the hot part. These temperatures are foreseen for the LLE loop of the HCLL TBS and its ancillary systems (in particular, for the Tritium Extraction Unit). The loop is loaded by means of an increasing pressure of Argon in the storage tank S01, which is located in the lowest part of the facility (as shown in Fig. 1). After the loading, S01 is isolated by closing the EPV04 valve.

The LLE is circulated by the permanent magnet pump located above the storage tank S01 and increases its temperature going through the economizer E01, which is a counter-current pipe in pipe regenerative heat exchanger. Then the alloy can pass through the 40 kW electrical heater S05 or it can maintain its temperature constant by means of a bypass line. Regardless of the path chosen for the operation, the LLE passes through the test section and it cools down in the economizer and in the air cooler E02, before returning to the permanent magnet pump.

The buffer tank S04 with a volume of 0.45 m^3 has the task to compensate the volumetric changes of the LLE and to remove any trace of inert gas from the loop. As IELLLO can be coupled with the helium facility HEFUS-3 [7], the expansion tank S03 was connected both to the test section inlet and outlet by means of two rupture disks for each side to prevent the dangerous consequences of a LOCA.

The pump can work at different speeds and, together with a dedicated bypass, can provide a maximum mass flow rate of 2.41 kg/s, when the bypass is completely closed. The mass flow rate has been chosen to produce data in the entire range of interest for ITER (0.2–1.3 kg/s approximately), but also at higher values that could be interesting for DEMO or for other blanket concepts.

The piping is made of AISI316L Sch. 40 with a nominal diameter of 1″, with the exception of the test Section inlet and outlet (1–1/2″ Sch. 80). The piping is equipped with heating cables, thermal insulating concrete with a thickness ranging from 6 to 12 cm and aluminum sheets.

IELLLO is equipped with a vortex flow meter (capable to measure from 0.93 to 2.49 kg/s), a mini-turbine flow meter (from 0.2 to 1.0 kg/s) and an absolute pressure transducer supplied by GEFRAN. Level sensors and cover gas pressure gauges are installed in all the tanks.

3. Nodalization

The one-dimensional RELAP5-3D nodalization simulates the entire IELLLO loop (Fig. 2). The hydraulic part of the nodalization has 283 nodes and 292 junctions. All hydraulic volumes have a length between 0.15 and 0.6 m to correctly simulate the characteristics and the geometry of the loop but also not to lengthen the calculation time. The axial heat structures are 360, with 5500 mesh points overall. The passive heat structures were specifically modelled by implementing the properties of the thermal concrete and of the

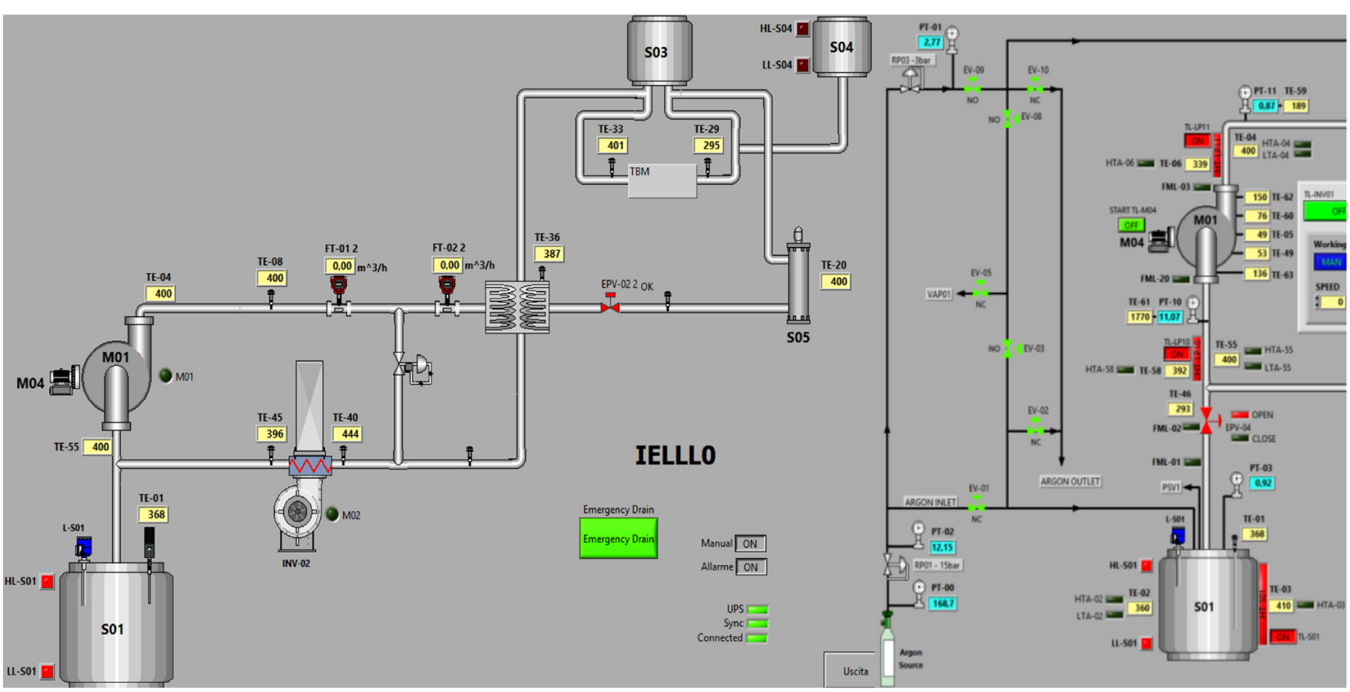

Fig. 1. Layout of IELLLO (left) and detail of the lower part of the loop (right).

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