SUPERCRITICAL WATER LOOP FOR IN-PILE MATERIALS TESTING

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Abstract

The Supercritical Water Loop (SCWL) has been designed and built within the HPLWR Phase 2 project, with the objective of testing materials under supercritical water conditions and radiation. The design parameters are set to 25MPa and 600°C in the testing area, where material samples shall be located. The loop has recently undergone pressure and leakage tests, during which the strength and tightness of the loop were proved. The loop has been also subjected to the first trial operation at nearly maximum operating parameters (temperature 550°C was reached); loop operation was steady during several days. Presently, loop operation is envisaged in order to test the loop's long term operation ability. Samples of a material that needs further testing under out-of-pile conditions shall be exposed in the loop; the choice shall be made in agreement with the results of the WP4 – Materials of the HPLWR Phase 2 project.

1. Introduction

The Supercritical Water Loop (SCWL) is an experimental loop operating with water under supercritical conditions (25MPa, 600°C in the test section), and is meant for in-pile corrosion testing of candidate materials, for testing and optimization of suitable water chemistry for the future HPLWR, and for studies of radiolysis of water at supercritical conditions. The loop is currently located in an experimental hall for out-of-pile testing. The design of the irradiation channel with the test section, as well as the auxiliary circuits, has been described elsewhere [1].

Materials testing in the SCWL shall follow the outcomes and materials choices resulting from autoclave tests. So far, the SCWL loop has been built for general corrosion tests under irradiation; however, future plans include a loading device that could be installed into the active channel for Stress Corrosion Cracking (SCC) tests. The choice of materials to be tested will follow the results of the many autoclave tests performed during the European project HPLWR Phase 2, carried out between 2006 and 2010, during which a significant number of materials were tested. The materials originated from the following groups: (i) austenitic stainless steels, (ii) ferritic/martensitic (F/M) steels and (iii) Ni-alloys; several steels were ODS (Oxide Dispersion Strengthened); ODS steels are, however, still under development and Ni-based alloys are unacceptable for the core structures due to high parasitic neutron absorption of nickel. The water chemistry regimes chosen for tests are the Normal Water Chemistry (NWC), simulated in autoclaves by additions of ~150ppb oxygen, and Hydrogen Water Chemistry (HWC) – pure water with ~30cc/kg hydrogen. More details can be found in [2].

2. Trial operation – purpose

The first trial operation was performed in two sequential steps: first, operation of the loop with a dummy irradiation channel that did not contain the final internals (recuperator, electrical heating), but only simplified internal providing the corresponding pressure drop. The second step was carried out with internals according to the design as described in [1].

The purpose of the first operation was to achieve full operating conditions in the loop and compare the calculations and simulations of the loop parameters with the real measurements. Given the absence of the final irradiation channel, the loop was operated at the design parameters of the primary circuit in order to prove the functionality of the primary and auxiliary circuits. The required conditions – 25MPa, 390°C at inlet to the irradiation channel – were successfully achieved. During the second trial operation, the irradiation channel with its proper internals was installed and connected to the rest of the loop. In the test section, where the maximum parameters will be reached, a temperature of 550°C at 25MPa was achieved. The maximum design temperature of 600°C was not achieved due to the limitation in the electrical heating, which was set to operate at only 50% of nominal power because of its malfunctioning controller. It is expected, however, that the maximum temperature in the test section (600°C) will be achieved with the available electrical power.

3. Water chemistry

The SCWL is supplied with ultra-pure water, which is prepared in an ion exchange station, then is passed through a mix-bed filter, charcoal filter and finally treated in a Millipore Milli-Q® reference A+ system for final purification of water to ultra-pure quality. The final quality of water in terms of conductivity is <0.1μS/cm.

From the viewpoint of water chemistry, the loop was initially filled with pure water; the loop was flushed several times before the start of operation in order to rinse out any possible impurities. Flushing of the loop prior to the start of operation revealed a high initial content of organic contamination, which required several flushing runs.

4. Loop operation – results

4.1 Primary circuit

The first tests were performed with a dummy channel, which simulated the thermal-hydraulic losses; the losses were varied as the real irradiation channel may have variable internal dimensions as required by the actual experimental program. In this way, the behavior of the loop over a range of thermal-hydraulic parameters was tested.

During the first operational tests, agreement of measured parameters with design values was to be verified. Operational parameters for the primary circuit at the inlet to the irradiation channel were reached, i.e. the pseudo-critical point at 25MPa was exceeded by several degrees. The tests revealed minor flow instability, and consequently temperature instability, in the primary circuit, see Fig. 1. These variations were neither significant nor critical, but nevertheless, focus was directed to eliminate this behavior. The following tests were focused on finding the reasons for these minor deviations. It was necessary to redesign the control valve and improve its regulating characteristics. Operational parameters after repairing the valve did not show the previous instabilities, as demonstrated in Fig. 2.

Comparison of the temperature distribution in the primary circuit can be seen on a simplified loop diagram, as shown in Fig. 3. Blue values are calculated design data; red values are real data from loop operation. Good agreement between design and operational data was found. Larger differences at the inlet and outlet of the main pump are caused by slightly different sampling point positions where the parameters were measured.

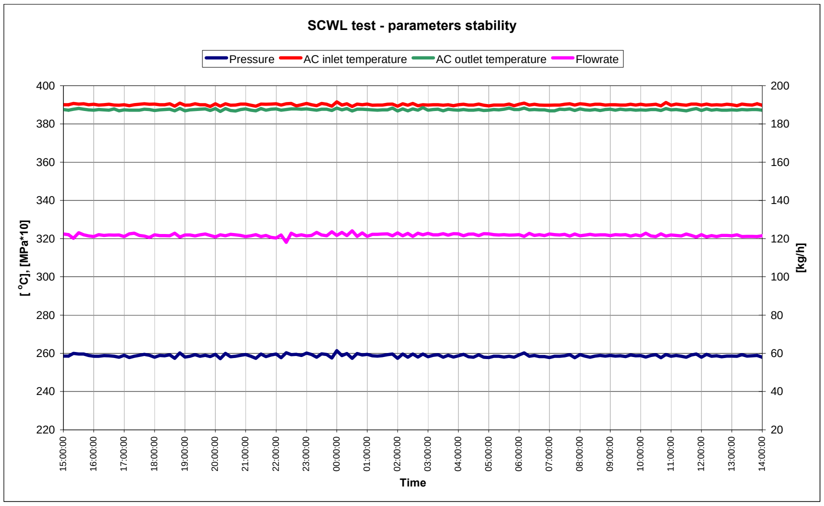

Figure 1 Small instability of flow-rate and temperatures.

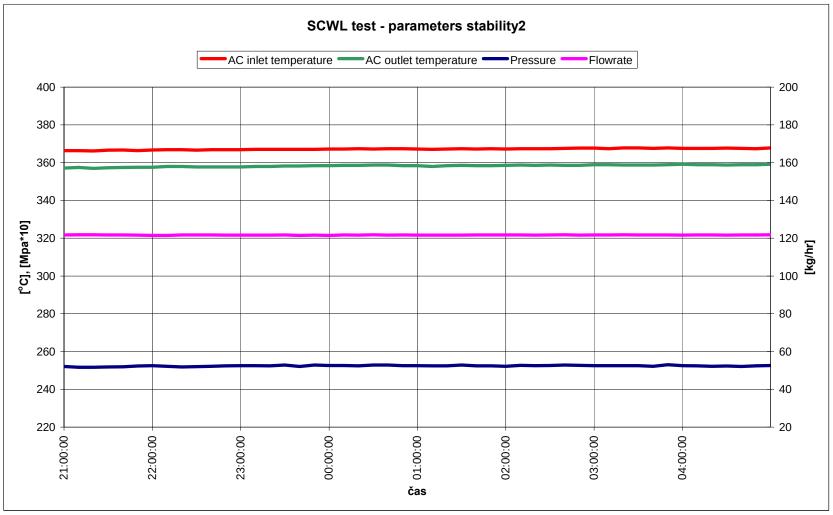

Figure 2 The equivalent situation to Figure 1 after repair of the control valve.

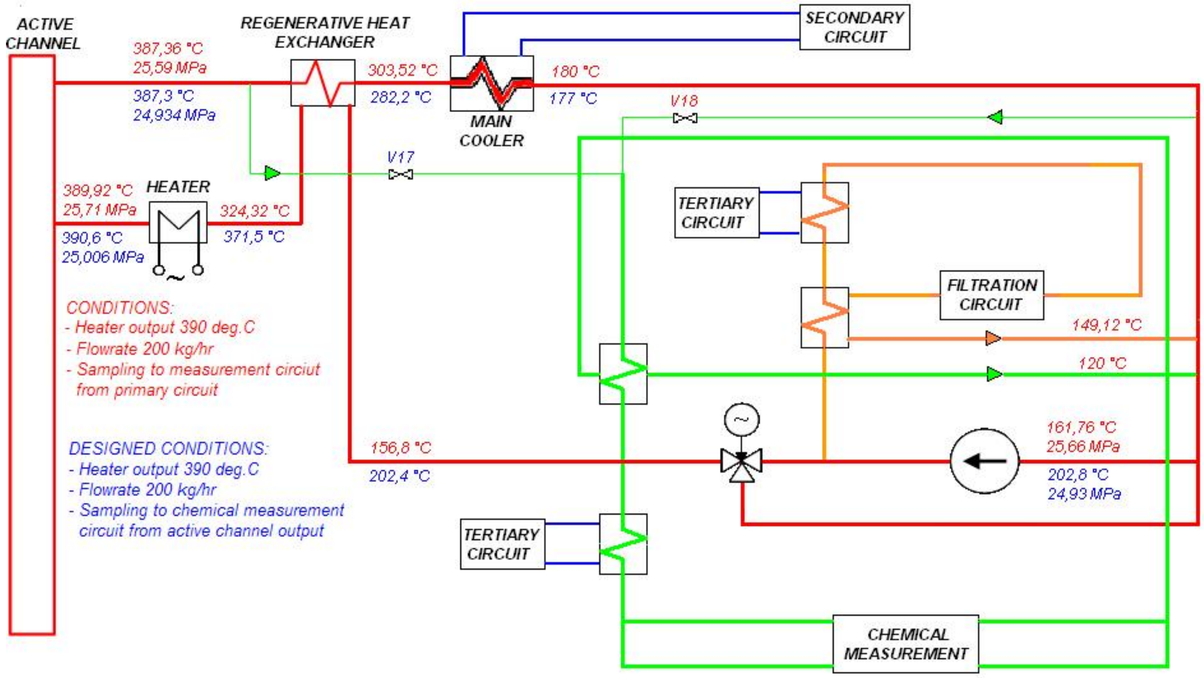

Figure 3 Comparison of the design and real temperature distributions in the primary circuit.

4.2 Active channel

After the loop behavior was tested, the designed internals were manufactured and inserted into the channel, and a new headpiece with wiring attached to thermocouples and heating elements was connected to the channel. The design of internals is described elsewhere [1]. A schematic representation of the flow through the active channel is shown in Fig. 4; note: the proportions have been changed to make such a representation possible (the real dimensions are 57mm diameter and ~5000mm length).

This test was focused on the performance of the channel itself, especially on water flow through the channel's internal parts, temperature distribution and on achieving the uppermost temperature in this regime without gamma heating. To achieve the required temperature in the channel, flow optimization was necessary. One of the ways to accomplish this is flow splitting. The temperature distribution inside the channel with electrical heating power of 15kW is shown in Fig. 5. The temperature distribution presented was calculated for the optimized flow through the channel. The marked points represent real data measured during tests. Circles represent the temperature distribution at the full water flow of 200 kg/hr through the channel, and triangular points represent the temperature distribution with flow splitting and with heating power reserve. The heating power had to be limited for this test due to unresolved problems with the heating power control system. However, there is very good agreement between calculated and measured data.

The trend of parameters in the channel is presented in Fig. 6. Fluctuations of the temperature at the heater outlet (maximum temperature in the channel) are expected to be eliminated by flow optimization.

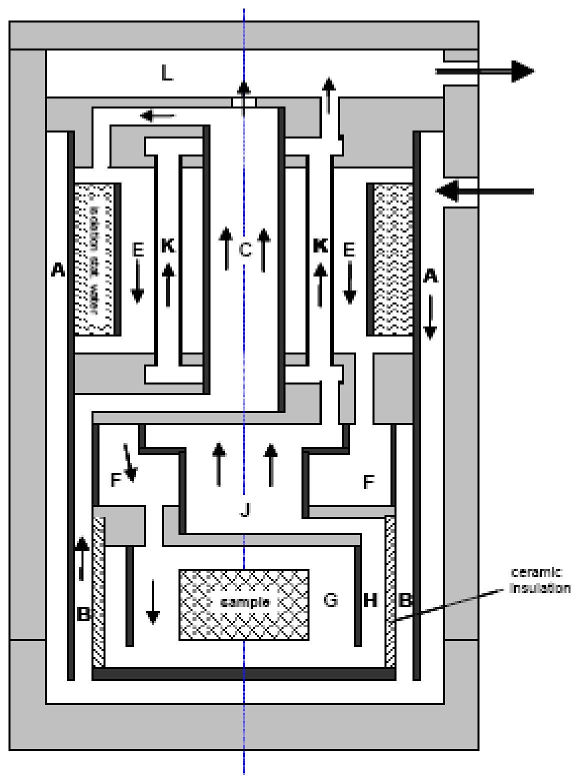

Figure 4 Schematic representation of water flow through the active channel.

5. Conclusion

The commissioning of the SCWL loop, together with functional tests, is considered a success, considering the immense effort devoted to loop and channel design and optimization of flow inside the channel. The tests performed confirmed that the proposed design allows the required supercritical conditions to be achieved. The results obtained during out-of-pile tests sufficiently justify the opinion that at full heating power and after the irradiation channel is inserted into the active core of the LVR-15 research reactor, i.e. with additional gamma heating, the final design parameters (25MPa, 600°C) will be reached in the test section.

Currently, it is planned that operational out-of-pile tests shall continue in order to reach the final design temperature of 600°C; then, a long-term experiment shall be performed with coupon-type specimens of materials that performed well during general corrosion autoclave tests, as well as tests under mechanical loading, carried out within the WP4 – Materials of this project. The loop is expected to be transferred to the reactor hall for in-pile operation in 2012.

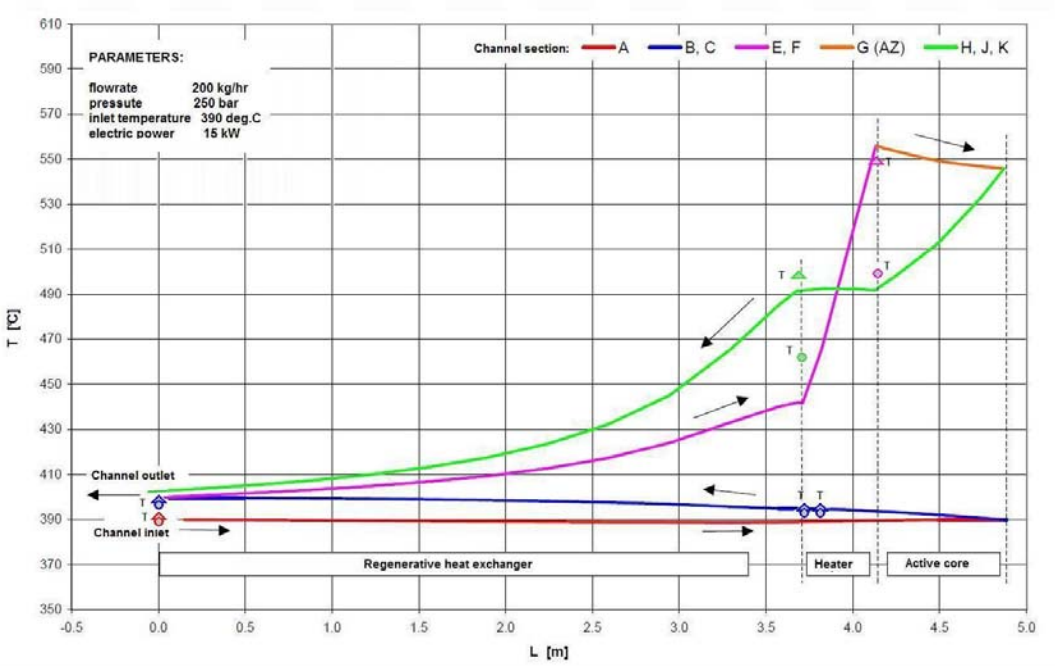

Figure 5 Temperature distribution in the channel – comparison of calculated vs. measured values.

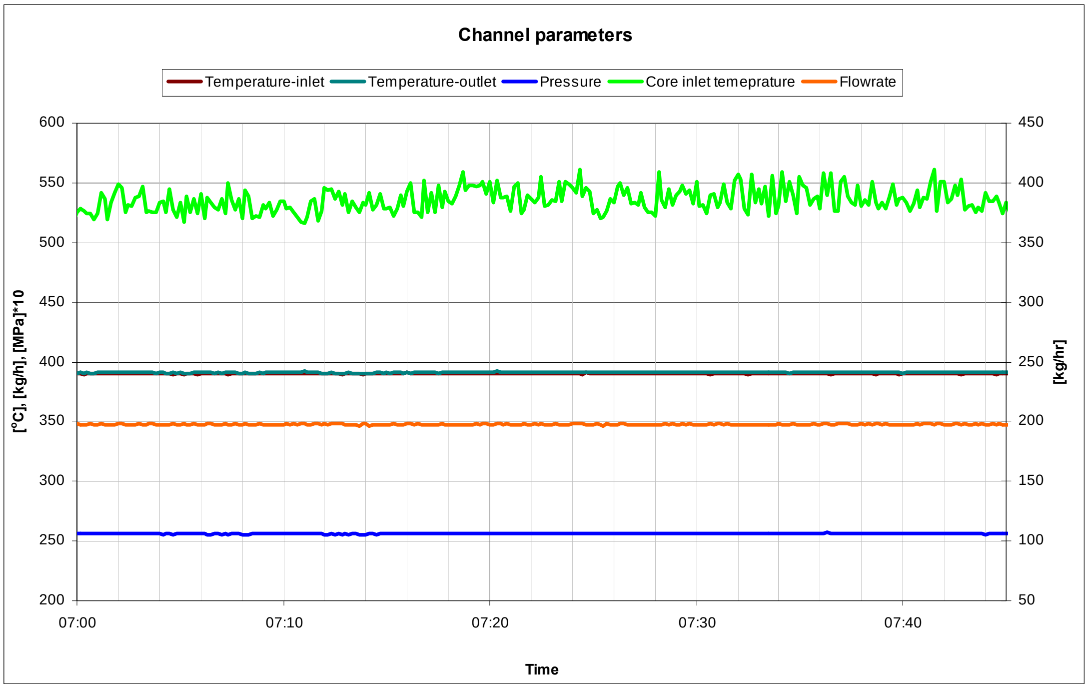

Figure 6 Supercritical conditions in the channel without gamma heating.

[1] P. Hájek, R. Všolák, M. Růžičková, ”First Experience with Operating the Supercritical Water Loop”, 4th International Symposium on Supercritical Water-cooled reactors, March 8-11, 2009, Heidelberg, Germany

[2] S. Penttilä, A. Toivonen, L. Heikinheimo, R. Novotny: ”Corrosion Studies of Candidate Materials for European HPLWR”, Proceedings of ICAPP ’08, June 8-12, 2008, Anaheim, CA USA, Paper 8163