Experimental study of ISHTAR thermostatic irradiation device for the MARIA research reactor

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Abstract

Materials and core components for the next generation power reactors technologies require testing that can be performed in existing research reactors. Such experiments employ devices dedicated to reflect the relevant thermal and neutron parameters simulating conditions present in, for example, but not limited to, HTGR reactors. A novel thermostatic irradiation device named ISHTAR (Irradiation System for High-Temperature Reactors) has been designed and constructed in the MARIA research reactor. Its mission is to enable irradiation of samples in controlled, homogeneous temperature field reaching 1000°C and inert gas atmosphere.

Introduction

The ISHTAR (Irradiation System for High-Temperature Reactors) thermostatic irradiation rig ensure homogenous temperature both by nuclear and electrical heating during in-core irradiation. The prototype used for the mock-up tests has an elevated electrical heating to fill in the nuclear heating during out of the core safety testing procedures. The main feature of the rig is the homogeneous irradiation temperature of 40 cm specimen's holder length which is quite impressive comparing to the 1 m of active reactor core height. The homogenous temperature of 1000°C was achieved by helium gas insulation layer. The outer diameter of the rig d = 48.3 mm can be easily fitted to the vertical channel which internal diameter equals 54 mm. The rig is cooled by the forced convection of water in reactor pool. The main goal of ISHTAR thermostatic device was to demonstrate the possibility of graphite specimen irradiation in high temperatures. The thermostatic device irradiates four graphite specimen, each 100 mm long. Samples from this irradiation campaign are intended for the pull tests. The samples are fitted with six thermocouples as part of the temperature monitoring inside the thermostatic device. The specimen is implemented inside the rig's tray, with cylindrical loading space of diameter 28 mm and 400 mm long. The tray encapsulating the loading space is wrapped in 7 high-temperature heaters. The heaters are placed in spiral grooves and interlaced at the bottom, allowing both cold ends of each heater directly upwards. The heater interfaces stainless steel sleeve tube's outer diameter allows maintaining 3.15 mm isolating gap between thermostatic device tray and thermostatic device outer tube. The gap is filled with helium with a pressure of 1.5 bar, providing isolation necessary to reach a temperature of 1000°C inside the tray. Thermal expansion shrinks the gap to about 2.85 mm, which was taken into account in the calculations. The Upper and lower ends of the tray in the sleeve are additionally isolated by rings manufactured from Zirconium-Yttrium ceramic with low thermal conductivity of 2 Wm-1K-1 combined with the helium volumes. The whole assembly is locked within the stainless steel (AISI316) cylinder, providing structural rigidity. The design is presented below in the Figure 1.

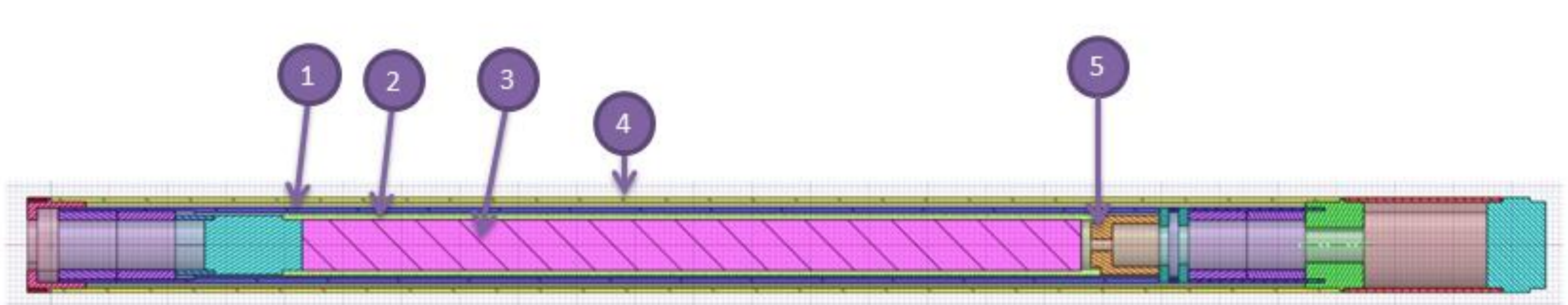

Fig. 1: Geometrical model of the in-core part of the thermostatic device.
1 – inner shell, 2 – electrical heater, 3 – samples with holder, 4 – outer shell, 5 – "crown" (lower insulation).

Experimental setup

Due to several major uncertainities (such as coolant velocity in the channel) as well as due to the complex geometry of the heater it is difficult to simulate the temperature field numerically within the rig. Those works have been preseneted in the previous article. Therefore, it has been decided to perform an additional experimental investigation in order to determine cooling parameters and verify technical solutions by performing out-of-core experiments in reactor channel mock-up. It allowed to adequately test selected insulators, connectors, etc. A purpose-designed mock-up of the irradiation channel with full simulation of its cooling capacity has been therefore constructed. The mock-up called FLOW-30 is presented in Figure 32. The transparent structure of the mock-up made out of the plexiglass tubes enables observation of the flow type: laminar or turbulent after the addition of the reagent to water, also boiling and its regimes can be investigated in this manner if they occur.

The experimental stand FLOW-30 allows performing thermal and hydraulic measurements in 1:1 scale, both in heat transfer and geometrical terms. The stand is equipped with water temperature and flow rate measurement and control systems. A number of pressure sensors allow to determine pressure drop. It is possible to correlate the flow rate with pressure drop and water gap thickness. The heat transfer coefficient [W·m-2·K-1] can be therefore determined.

Parameters of stand FLOW-30:

- Flow rate: 0÷30 m3·h-1
- Measurements of pressure drop: 0÷250 kPa
- Heating power: 0÷5000 W
- Cooling power: 0÷7000 W
- Measurements of vacuum on the end of the channel: -100÷0 kPa
- Nominal working fluid temperature: 0-60°C

Results

Initially a set of measurements was performed in order to determine the pressure drop characteristics of the irradiation channel with thermostatic rig inside. Linear pressure drop was consistent with the smooth-pipe regime theory, however local pressure drop at the outlet of the channel due to the complexity of the geometry behaves somewhat differently and is slightly higher than in the simple 1-D theory. The channel outlet was printed in 3D and put inside of the measurement stand. This part is presented in Figure 3, as it can be seen, the geometry contains multiple outlets with different diameters, so the pressure drop is a combination of linear and local ones. Pressure drops of the whole outlet part were measured with cylinders of different diameters attached to the outlet, representing the linear part of the ISHTAR irradiation device. The results of the measurements have been presented in Figure 3. Those results, combined with the pressure drop measurements in the linear part, enabled hydraulic calibration of the irradiation channel. They were used to create a mathematical model for calculating the flow in a channel with variable geometry.

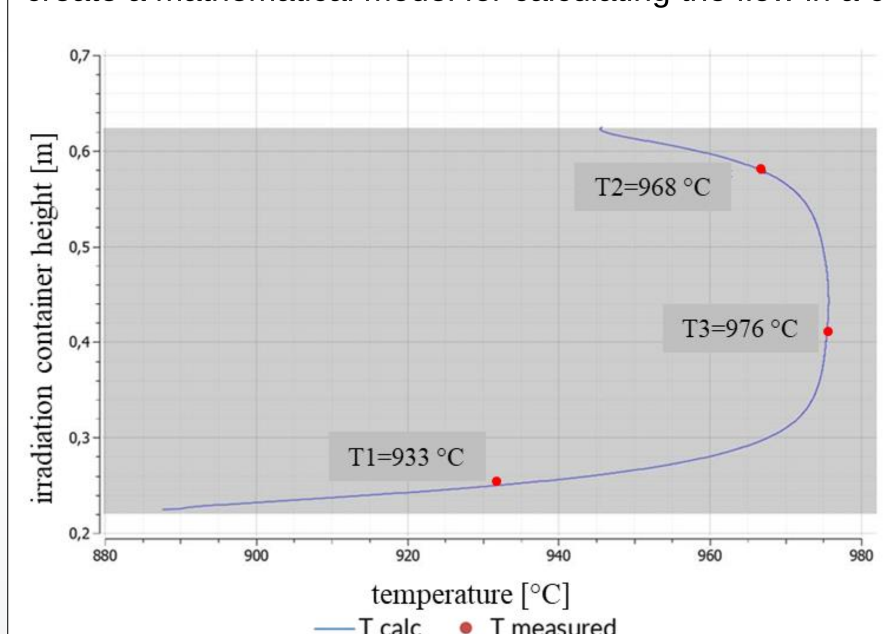

Fig 3: 3D calculation comparison with temperature measurements

When steady state was achieved, comparison of the computations with the measurements results became possible. As it was presented in figures 6 and 7, both 1D and 3D calculations proved to be in-line with the measurements. As expected, temperature inside the insulation gap was rising alongside the electrical heaters power increase. Temperature of the helium gap was initially rising and then stabilized at the level 330°C, probably due to the stabilization of the natural circulation cell within the gas. Heat transfer coefficient was consistent with the theoretical one, calculated from the pressure drop measurements with Gnielinski formula. Time series is presented in figure 4..

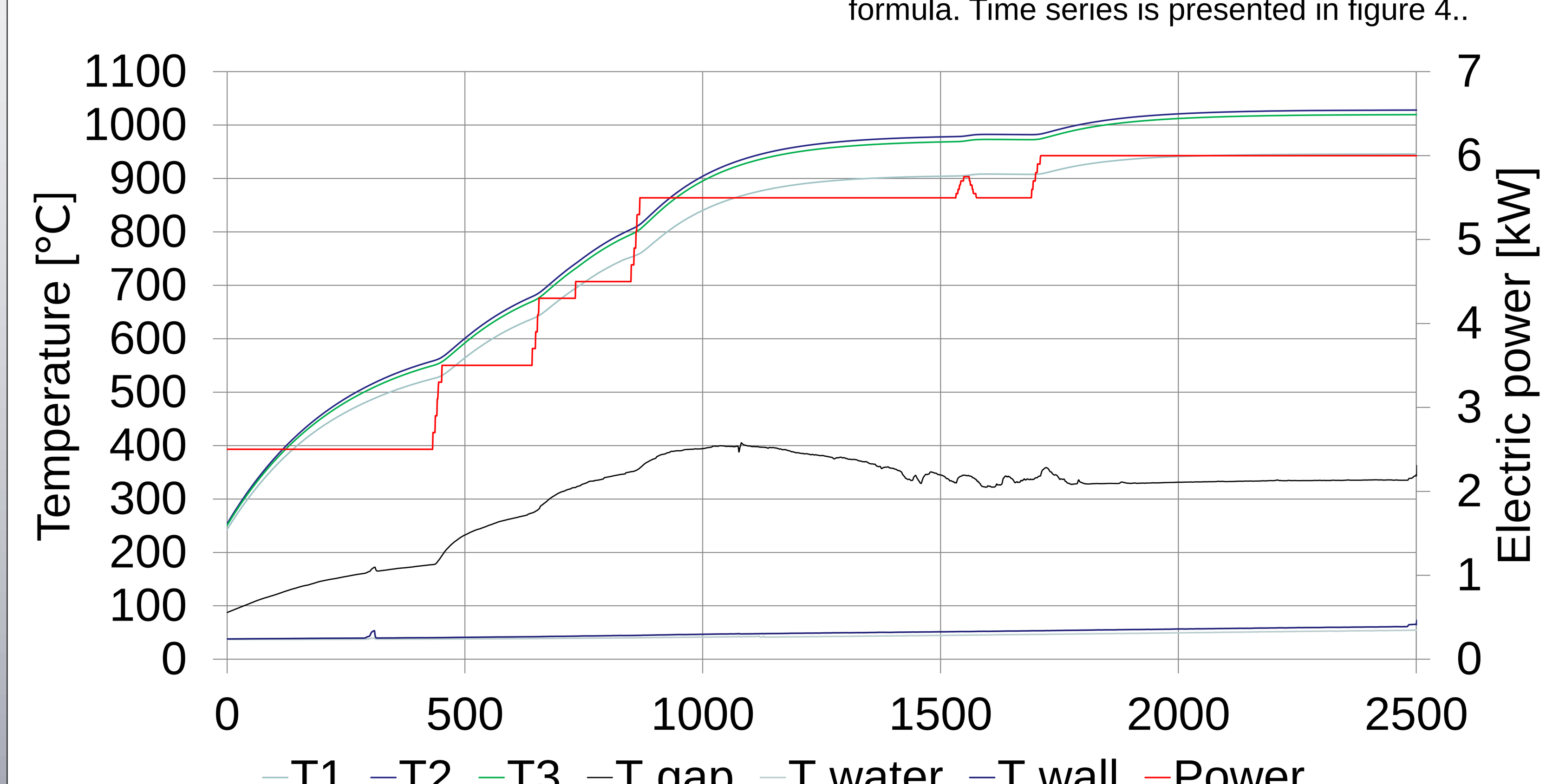

Fig. 5: Time series of the experiment.
T1, T2, T3 – temperatures in the samples region, T gap – temperature in the insulation helium gap, T wall – outer wall temperature, T water – cooling water temperature, power – electric power

Conclusions

Measurements of the pressure drop in the irradiation channel filled with the thermostatic device were performed., followed by thermal measurements of the temperature field inside and outside the ISHTAR capsule. The temperature measurement's results proved the adequacy of the computational methods and the design. ISHTAR thermostatic irradiation device is able to achieve desired parameters, that is, temperature >1000 °C. The ISHTAR device will be tested inside the core of the MARIA reactor in the fourth quarter of 2021.

Acknowledgement

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