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SMR Experiments with the MOTEL Test Facility within the Euratom Project McSAFER

Joonas Telkkä, Heikki Suikkanen, Eetu Kotro, Antti Räsänen
LUT University
P.O. Box 20, 53851 Lappeenranta, Finland
joonas.telkka@lut.fi, heikki.suikkanen@lut.fi

ABSTRACT

The MOTEL test facility of LUT University represents a prototypical integral pressurized water small modular reactor operating with natural circulation. MOTEL has a generic core rod bundle design and a helical coil steam generator. The facility has been used in the Euratom-funded McSAFER project to study the behavior of the helical coil steam generator and core crossflows. In this paper, the steam generator test results are discussed. The first results showed an unstable temperature behavior at higher heating powers. Valuable code validation data has been produced with the first experiments.

1 INTRODUCTION

MOTEL (MOdular TEst Loop) is an integral test facility recently commissioned in the nuclear safety research laboratory at LUT University. Modularity has been the guiding design philosophy behind MOTEL, as the facility consists of exchangeable main components that could be replaced to functionally similar ones but with different designs. This way, the facility could be configured to represent various reactor designs. The current implementation of MOTEL represents a prototypical integral pressurized water small modular reactor (SMR) operating with natural circulation.

MOTEL was commissioned in 2020, and the characterizing tests were run in 2021. The results of the characterizing tests along with a more detailed presentation of the facility design philosophy and structure are presented in [1].

Currently, MOTEL is utilized in the Euratom-funded McSAFER project to investigate SMR-specific thermal hydraulic phenomena and to provide data for the validation of safety analysis tools including thermal hydraulic system codes, subchannel codes and computational fluid dynamics (CFD) codes.

This paper provides a general description of the MOTEL facility and the experimental program in the McSAFER project and presents some of the first results obtained.

2 MOTEL FACILITY

The MOTEL test facility is a model of an SMR with resemblance to the design of the NuScale type SMR [2]. The unique modularity configuration of the MOTEL facility design and construction is presented in Figure 1. The figure shows how the main part of the facility, the pressure vessel package, is constructed of the four main modules, i.e., a core, an extension piece, a steam generator, and a pressurizer module. These construction modules are placed one above the other, mounted together with large flanges, and fastened to a framework at the laboratory site with heavy supports. Together the outer walls of these modules form the outer shell of the pressure vessel of the SMR design.

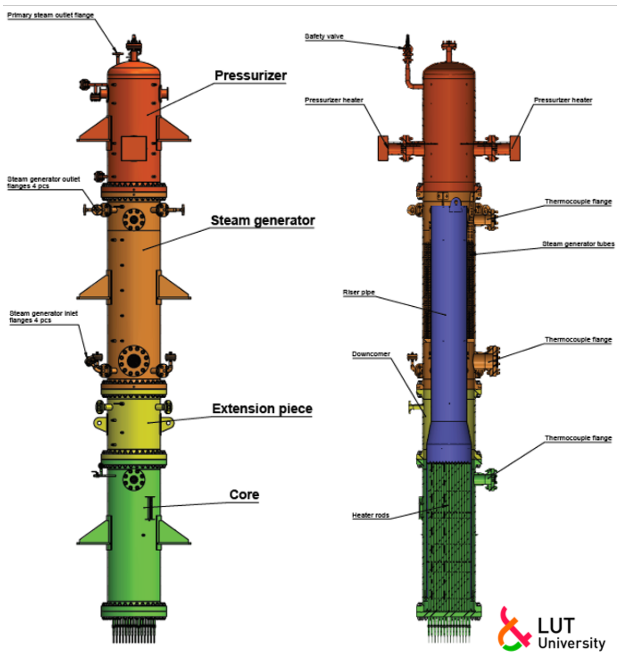

Figure 1: Modules comprising the pressure vessel (left) and insight on the SMR design (right) of the MOTEL facility.

The design of the core is emphasized in the MOTEL facility design. Traditionally in integral test facilities, the core with the heater rods is made long and thin to preserve the height scaling of 1:1 compared with the reference core in question. With MOTEL, the practice is not followed. Instead, the core of MOTEL has been designed wider and shorter than usually to enable studying both axial and radial flow phenomena inside the core region. The core heater rod bundle design is generic and does not directly represent the fuel design of any existing reactor type. The heater rods in the core are arranged in a rectangular grid.

An essential feature in the MOTEL design is the helical coil steam generator construction. A specific characteristic of this type of steam generator is that the secondary side flow and boiling takes place inside the steam generator tubes, whereas the primary side water flows outside the tubes, through the shell side of the steam generator tube bundles. The steam generator is presented in Figure 2.

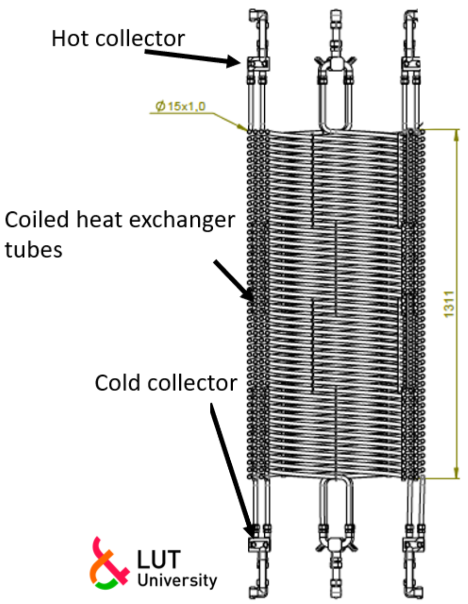

Figure 2: MOTEL steam generator.

The pressurizer of MOTEL is located at the top part of the pressure vessel. The pressurizer has two heating elements to adjust the primary pressure inside the test facility. During normal operation, the primary side is filled with water up to a chosen set elevation at the level of the pressurizer. The main relief valve (safety valve) of the facility is located at the top of the pressurizer.

MOTEL represents an integral SMR where the whole primary circuit is inside the reactor pressure vessel. The primary system of MOTEL operates passively by natural circulation, and thus no primary pumps are needed to circulate the primary side water.

The secondary side is actively operated, as the feedwater from the water reservoir is pumped through a water manifold to four collectors, each distributing the water to four steam generator tubes. Tables 1 and 2 summarize the main characteristics of the facility and the steam generator.

Table 1 Main characteristics of MOTEL

Characteristics	MOTEL
Total height [m]	7.4
Outside diameter of main vessel [mm]	711
Max. primary/secondary pressure [bar]	40
Max. primary/secondary temperature [°C]	250
Helical coil steam generator tubes	16
Max. core heating power [kW]	990
Heater rods	132
Heated length of heater rods [mm]	1830
Diameter of heater and measurement rods [mm]	19.05
Measurement rods	16
Dummy rods	145
Diameter of dummy rods [mm]	18

Table 2 Characteristics of the steam generator

Characteristics	MOTEL SG
Number of tubes / tube bundles	16 / 4
Tube outer diameter / wall thickness [mm]	15 / 1.0
Tube lengths [m]	20.0 / 21.7 / 23.4 / 25.1
Helical coil loop diameters [mm]	515 / 560 / 605 / 650
Total heat transfer area [m^2]	17.0

3 MCSAFER EXPERIMENTS

McSAFER is a three-year Euratom-funded project with a collaboration of 13 organizations coordinated by Karlsruhe Institute of Technology. The project aims to advance the safety research for SMRs by combining experiments and numerical simulations [3]. LUT leads the work package dedicated to thermal hydraulic experiments and code validation and performs tests with the MOTEL facility.

Two series of experiments were conducted with the MOTEL test facility within the McSAFER project in 2021-2022. The first series studied the behavior of the helical coil type steam generator of MOTEL, and the second series focused on studying core crossflows by applying asymmetrical radial core power distributions. A specific aim of the experiments was to provide measurement data for the validation of thermal hydraulic system, subchannel and CFD codes within the project.

3.1 Steam Generator Experiments

The first test series consisted of two steam generator experiments, which were performed in the autumn 2021. Steady states with different uniform core heating power levels were run with MOTEL. In the first experiment, the used power levels were 250 kW, 500 kW, 750 kW and 1 MW, which is the maximum heating power of MOTEL. In the second experiment, lower power levels were used; 75 kW, 100 kW, 125 kW and 150 kW. Particularly, the temperature behavior of the steam generator, both on the shell and tube sides, was studied.

3.2 Core Crossflow Experiments

In the second MOTEL test series within McSAFER, MOTEL core crossflows were studied by imposing different asymmetric radial core power distributions. These experiments were performed during the spring 2022. The MOTEL core is divided into twelve separately adjustable radial power regions as illustrated with different colors in Figure 3. This structure enables application of various radial core power distributions in the experiments.

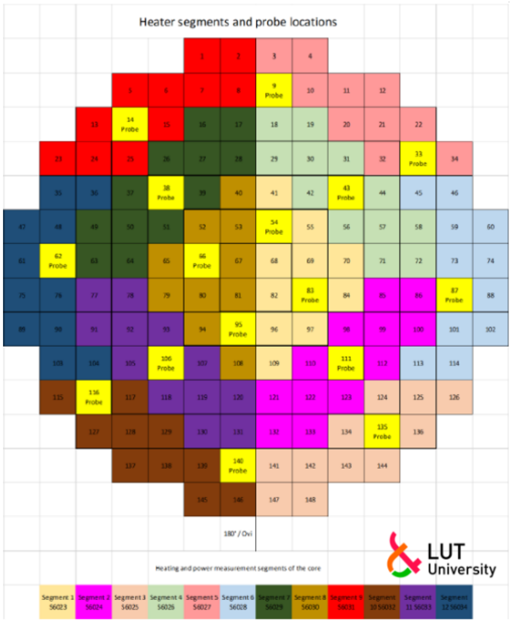

Figure 3. Radial power segments of the MOTEL core. Each square represents one heater rod, excluding the yellow measurement rods. Different colors represent the adjustable heating segments.

In the crossflow experiments the aim was to achieve measurable temperature differences in the radial directions of the core by means of applying asymmetrical power distributions, first imposing uniform power distributions in the beginning of the experiments for reference.

4 FIRST RESULTS

Both the steam generator and crossflow experiments have been conducted. However, the analysis of the crossflow experiments is not yet finished and thus only results from the steam generator experiments are briefly discussed in this paper.

At low heating powers up to 250 kW no significant superheating was observed except in some individual tubes. On average, the saturation temperature was reached in the bottom part of the steam generator at all power levels. Also, steady primary and secondary temperatures were obtained towards the end of each step. The primary temperatures during the 75 kW to 150 kW steps are shown in Figure 4.

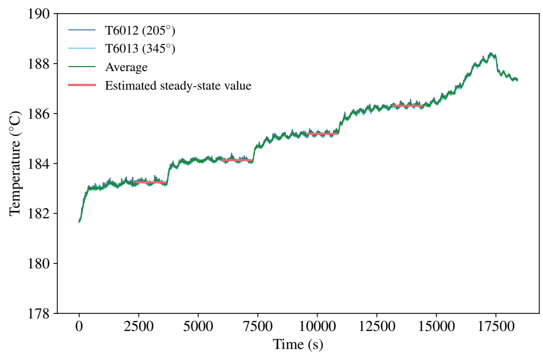

Figure 4. Thermocouple measurements in the primary side corresponding to the top part of the steam generator. Core power levels from 75 kW to 150 kW.

At power levels over 250 kW, significant superheating started. However, the behaviour also turned to unstable with oscillations in the temperatures as can be seen in Figure 5. Also, the average temperatures in the primary and secondary side did not reach a steady state but kept on increasing towards the end of each step.

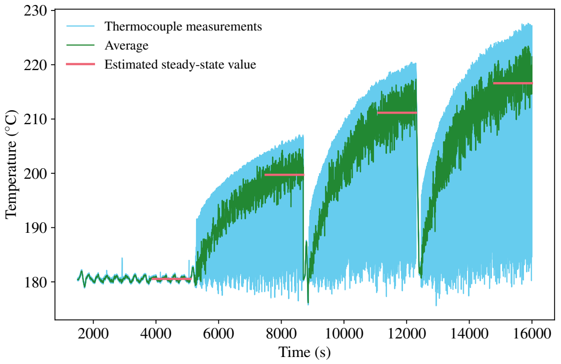

Figure 5. Thermocouple measurements (blue) in the secondary side along with their average (green) and estimated "steady-state" values. Core power levels from 250 kW to 1 MW.

Figure 6 shows an axial secondary temperature profile based on the estimated steady state temperatures based on averaging the temperature measurements in all tubes at the same elevation. On average, the saturation temperature is exceeded with heating powers over 250 kW.

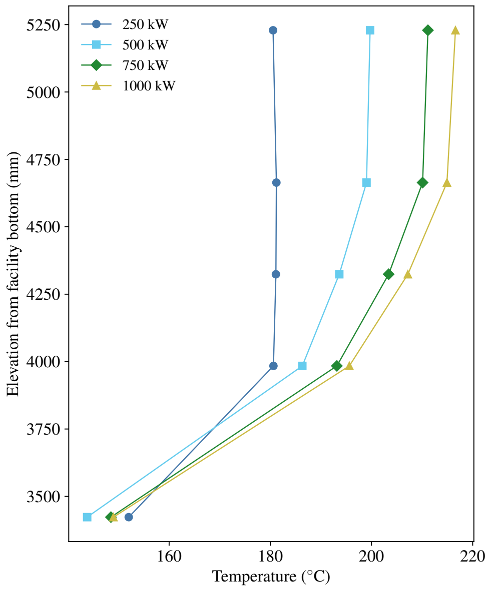

Figure 6. Axial distributions of the averaged secondary temperatures at different power levels.

5 CONCLUSIONS

A modular test facility MOTEL, currently representing an integral pressurized water SMR, was commissioned at LUT University in Lappeenranta in 2020 and is currently utilized in experiments within the Euratom-funded research project McSAFER to provide data for code validation and insight to the behaviour of a prototypic SMR operating at natural circulation. MOTEL features a helical coil steam generator, whose behaviour was specifically investigated within McSAFER. Another set of experiments in McSAFER focused on crossflows in the core module.

The steam generator experiments provided first insight to the behaviour of the MOTEL facility and particularly the steam generator. The unstable superheating behaviour at higher heating powers warrants further investigations to determine the operating parameter boundaries for stable behaviour. Yet, the experiments have already provided useful data for the validation of thermal hydraulic system and CFD analysis codes to be completed with crossflow measurements for the validation of subchannel codes.

ACKNOWLEDGEMENTS

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