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SIMULATION OF A REFILL/REFLOOD EXPERIMENT USING THE RELAP5 THERMAL-HYDRAULIC CODE

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ABSTRACT

The analysis of a refill/reflood experiment was proposed as a XVII ENFIR Thermal Hydraulic Special Theme. In that experiment, a hot pressurized pressure vessel was suddenly cooled by a large cold water stream. While this vessel was being externally flooded, its internal pressure and wall temperature time behavior were tracked.
This work presents Relap5 blind calculations of that experiment considering the data supplied by the ENFIR committee together with some additional assumptions.
The RELAP5 nodalization, the initial conditions achievement and the calculated results are presented and discussed in this paper.

1. INTRODUCTION

An experimental facility was built at CDTN/CNEN in order to study a pressurized thermal shock [1]. A reduced pressure vessel model was submitted to successive thermal shock in order to assess the crack growth behavior in the pressure vessel wall.

One of these experiments was presented by Palmieri [2] as a XVII ENFIR Thermal Hydraulic Special Theme. Geometrical and initial conditions were supplied and the participants should present their calculated results in order to be compared among each other and also against the experimental data.

2. EXPERIMENTAL FACILITY

The experimental facility, as shown in Fig. 1, consists of a pressure vessel inside a cylindrical tank, so the vessel is surrounded by a 20 mm thickness annular region. Two cold water injection tank of 5000 liters each, positioned at 4212 mm of height, were connected to the bottom of the annular region through a 10 inches diameter pipe. There is an initially closed isolation valve for each one of these connection lines. .

The water inside the pressure vessel is electrically heated up to approximately constant value of 300 ºC and its pressure is maintained around 130 bar by opening the pressure vessel relief valve. When the pressure vessel wall temperature stabilizes, both injection valves are opened and cold water starts to fill the annular region around the vessel.

The time behavior of the vessel internal pressure and wall temperature were tracked. Thermocouples are installed on the inside and outside faces of the measurement station I, II and III and at 5, 10, 20 30, 45, 55, 65 and 75 mm from the outside face of measurement station II.

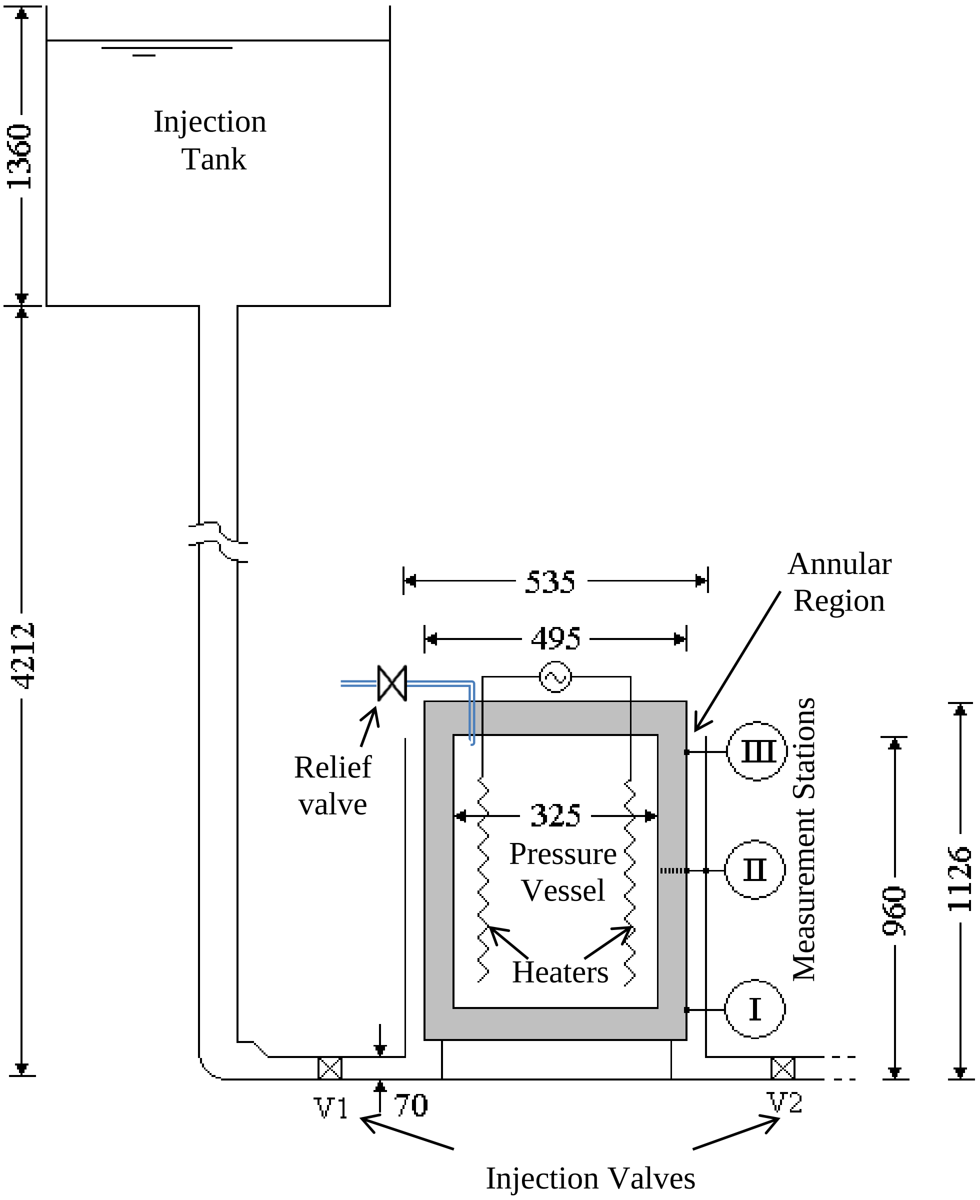

Figure 1. Experimental facility.

3. RELAP5 MODEL

A model for the experimental facility was developed for the RELAP5 mod 3.22 gamma [3]. Several improvements had to be added to the first nodalization attempt in order to achieve initial condition and avoid some calculation failure. They are discussed in the next two sections.

3.1. RELAP5 Nodalization

Final nodalization sketch and brief description of each component used in the nodalization are presented in Fig. 2 and Table 1 respectively.

The main aspects considered for the nodalization are:

- The two injection tanks were modeled as a 28 volume PIPE considered as regular cylinder since no more details about its geometrical form were available. In the first attempt, a four volume PIPE was used considering the "*level track model*". When using this model, the simulation always ended by failure just after the emptying of the injection tank. When this model was deactivated, air started to be entrained to the injection line ever since the tank was drained till its last volume, no matter this volume size. So, to avoid the calculation failure as well as the air early entrainment to the injection line, level track model was deactivated and small PIPE volumes were used for modeling the injection tank.
- A sliced nodalization was used for the pressure vessel region. All the parallel components were divided at the same height. The splitting points were chosen so the measurement stations were always located at the middle height of some volume.
- All the pressure drop coefficients were calculated considering appropriated formulas obtained from reference [1]. Better results should be obtained if some reference experimental data have been considered to adjust these coefficients.
- Two parallel PIPES were used to simulate the inner part of the pressure vessel in order to allow the upward and downward natural convection fluid flow. Adjacent volumes of these pipes were connected by a MTPLJUN component to allow cross flow mixing of the upward and downward flows.
- The PIPE 160 was used for simulating the metal box that is used to isolate the pressure vessel region during the heat up process. To simulate the removing of this box before the start of the flooding, VALVE 169 should be opened.
- No pressure drop was considered for injection valves and it was assumed that their opening time was 0.1 s.
- Pressure vessel wall material properties were obtained from reference [1].
- The reflood model was activated for HEAT STRUCTURE 300-0 that was used to represent the pressure vessel wall, so two-dimensional heat conduction would be considered.
- The pressure vessel relief valve and the electrical heating were represented by the typical elements since no more details about them were available.

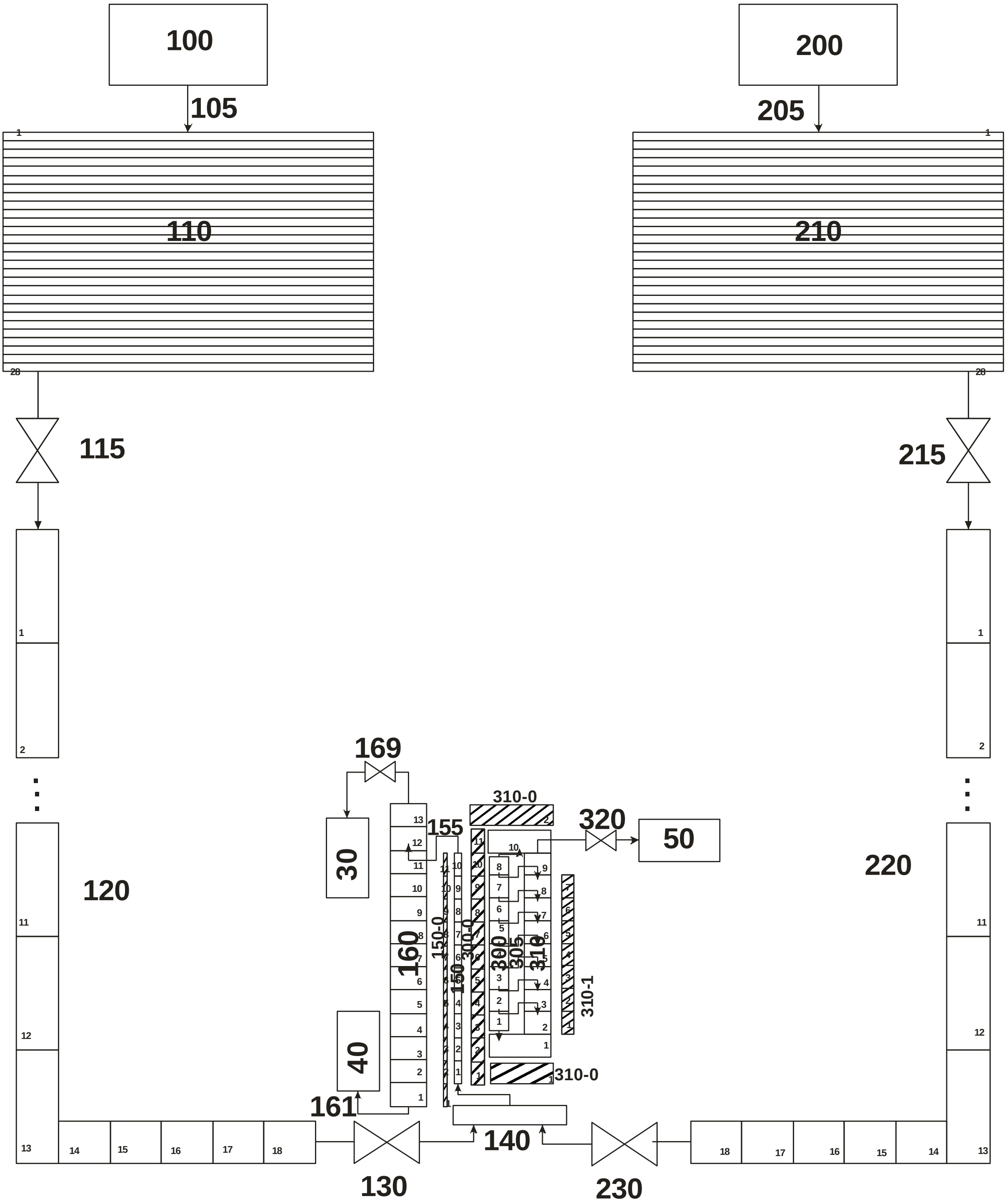

Figure 2. RELAP5 nodalization sketch.

Table 1. List of components and Heat structures used in the nodalization

Number	Description	
Components		
100 / 200	TMDPVOL	boundary condition for the top of the injection tank atmosphere.
105 / 205	SNGLJUN	connection from the injection tank to the atmosphere.
110 / 210	PIPE (28)	water injection tank.
115 / 215	VALVE	isolation valve at the bottom of the injection tank (alternative operation).
120 / 220	PIPE (18)	line from the injection tank to the annular region bottom.
130 / 230	VALVE	injection valve at the entrance of the annular region (normal operation).
140	BRANCH	plenum at the bottom of the annular region.
150	ANNULUS	annular region external to the pressure vessel.
160	ANNULUS	isolation metal box.
30 / 40 / 50	TMDPVOL	boundary condition for the atmosphere.
155	SNGLJUN	connection from the top of the annular region to the surrounding environment.
161	SNGLJUN	connection from surrounding environment bottom to the atmosphere.
169	VALVE	used to simulate the test section isolation.
300	PIPE (8)	pressure vessel outer part
305	MTPLJUN	pressure vessel inner to outer part connection
310	PIPE (10)	pressure vessel inner part
320	VALVE	pressure vessel relief/security valve
Heat Structures		
300-0 / 310-0		Pressure vessel wall
310-1		Pressure vessel heaters
150-0		Annular region external wall

3.2. Initial Conditions

The first attempt was to set the control volumes initial thermal-hydraulic conditions by hand, and simulate a zero transient problem in order to obtain a global steady state condition near the supplied experimental data. It was obtained less than 2 °C calculated temperature gradient across the pressure vessel wall. It was much smaller than the 7 °C from the experiment. It suggested that the experimental flooding has been started before a completely steady state condition has been achieved.

In order to achieve better initial conditions, the facility heating up process was simulated. It was considered that the pressure vessel heaters can supply up to 32 kW trying to keep the vessel water temperature around 315 °C. Heat up phase ended when the external wall temperature at the measurement station II reached the experimental one. Intending to match the internal initial temperatures, the heater control scheme was adjusted. The water temperature and the heater power during the heat up phase are shown in Fig. 3.

Additional assumptions were considered to reduce the external wall temperature at the measurement station I. It was assumed that there was some water left in the annular region from a previous experiment. So, this temperature would be kept near this water saturation temperature until its completely evaporation. The wall temperatures at the measurements stations are shown in Fig. 4

The heat up phase last 2383 s. During this process the relief valve was opened every time the inner pressure reached 133 bar. To avoid pressure spikes, some air was left inside the pressure vessel. Since the vessel internal temperature is below the saturation temperature, if there was no air inside the vessel, the vessel should be completely full of liquid water. In this case, even a very small release of water would decrease the pressure considerably.

The comparison between experimental and calculated initial condition is shown in Table 2. Both results are in good agreement, except the external top wall temperature. A new nodalization is under development to consider that vessel top is out of the isolation box. Preliminary results showed a substantial decrease in that temperature.

Table 2. Comparison between experimental and calculated initial values

Description	Experimental	Calculated
Vessel inner pressure (bar)	132.7	132.381
Cooling water temperature (°C)	8.0	8.0
Middle vessel cover temperature (°C)	147.0	144.711
Middle internal vessel temperature (°C)	309.0	308.843
Middle external vessel temperature (°C)	302.0	301.998
External top wall temperature (°C)	292.0	303.044
External bottom wall temperature (°C)	270.0	269.497
Cooling water volume (m^3)	10.0	10.0

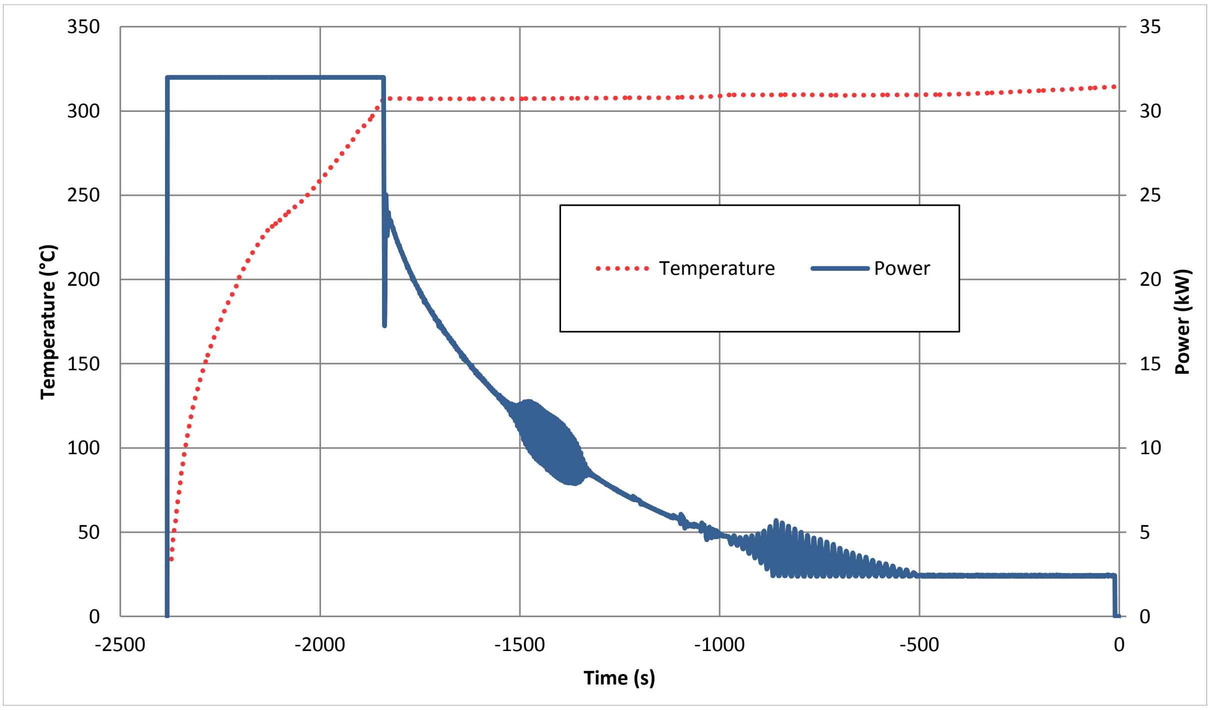

Figure 3. Pressure vessel water temperature and heating power during heat up process.

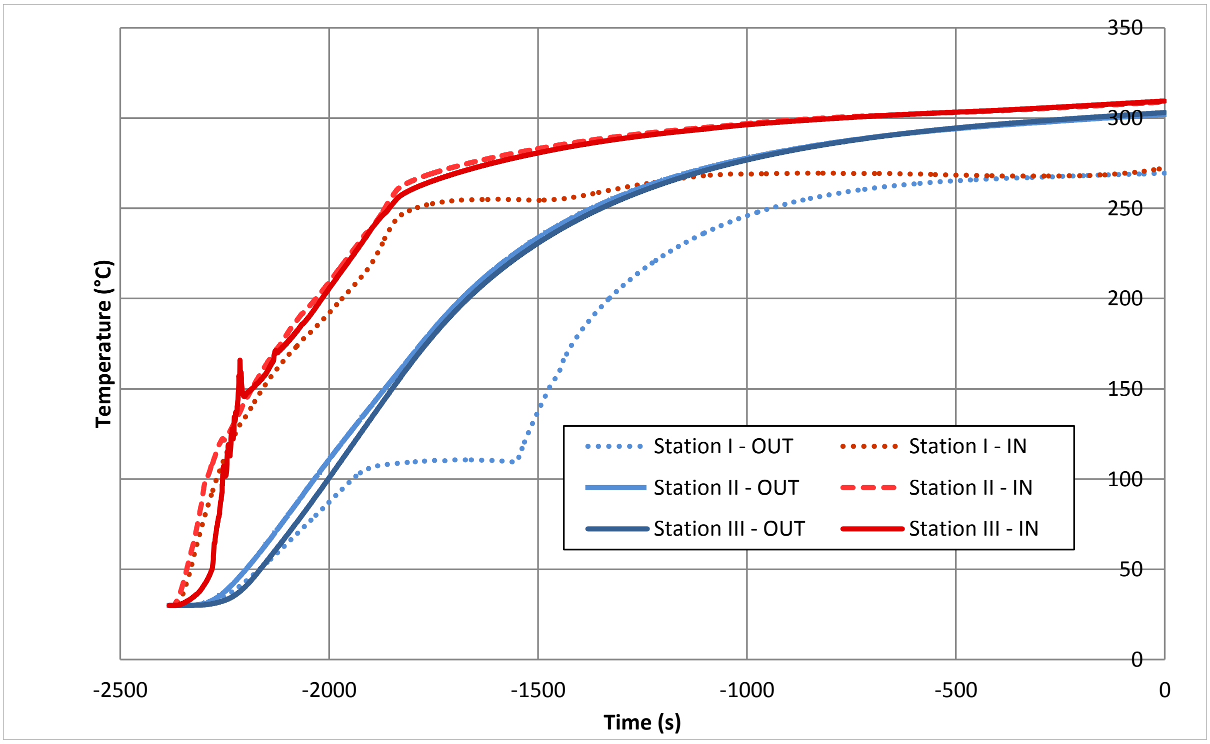

Figure 4. Pressure vessel wall temperature during the heat up process.

4. CALCULATED FLOODING RESULTS

After the heat up of the plant, both injection valves were opened and 8 °C cold water started to be injected in the annular region, flooding it in less than 1 second. Despite the annular region had already been filled, the vessel outside surface is not instantly rewetted. The occurrence time of the main events are summarized in Table 3.

A mass flow of 32 kg/s through each injection line started just after the valve opening. It decreased almost linearly as a function of the level as seen in Figs. 2 and 3. When the injection tank level reaches the PIPE last volume, air started to be entrained to the injection line and its collapsed level started to decrease even before the injection was completely empty. The emptying of the injection tank was delayed about 5 s due to the air entrainment to the injection line. This delaying time depends on the size of this PIPE last volume.

The vessel wall temperatures are shown in Figs. 7 and 8. The outside temperatures tended asymptotically to values that depend on the injection mass flow. As the mass flow has a decreasing step, an increasing step in the asymptotic temperature was observed. After the injection has ended, the wall temperature tended to the external saturation temperature of 100 °C.

The vessel internal water pressure and temperature are shown in Figs 9 and 10. The temperature is a function of the heat removal through the vessel wall which depends on the wall material properties. The internal pressure depends not only on the internal temperature but also on the amount of air left inside the vessel. If there was no air inside, it would be the saturation pressure. Higher pressures would have been obtained if greater air quantities were considered to be inside the vessel.

Results presented in this work are dependent of several assumed hypotheses. More reliable results could be obtained if the following items had been supplied:

- initial condition before heating up the facility;
- description about the facility heating up process;
- some experimental results to assess the pressure drop and material properties;
- details of pressure vessel heater and other internal components.

Table 3. Occurrence time of the main events

EVENT	Time (s)
Injection valve opening	0.0
Measurement station I rewetting	0.207
Complete annular region flooding	0.875
Measurement station II rewetting	2.336
Measurement station II rewetting	4.074
Injection tank emptying	171.9
Partial injection line emptying	184.74

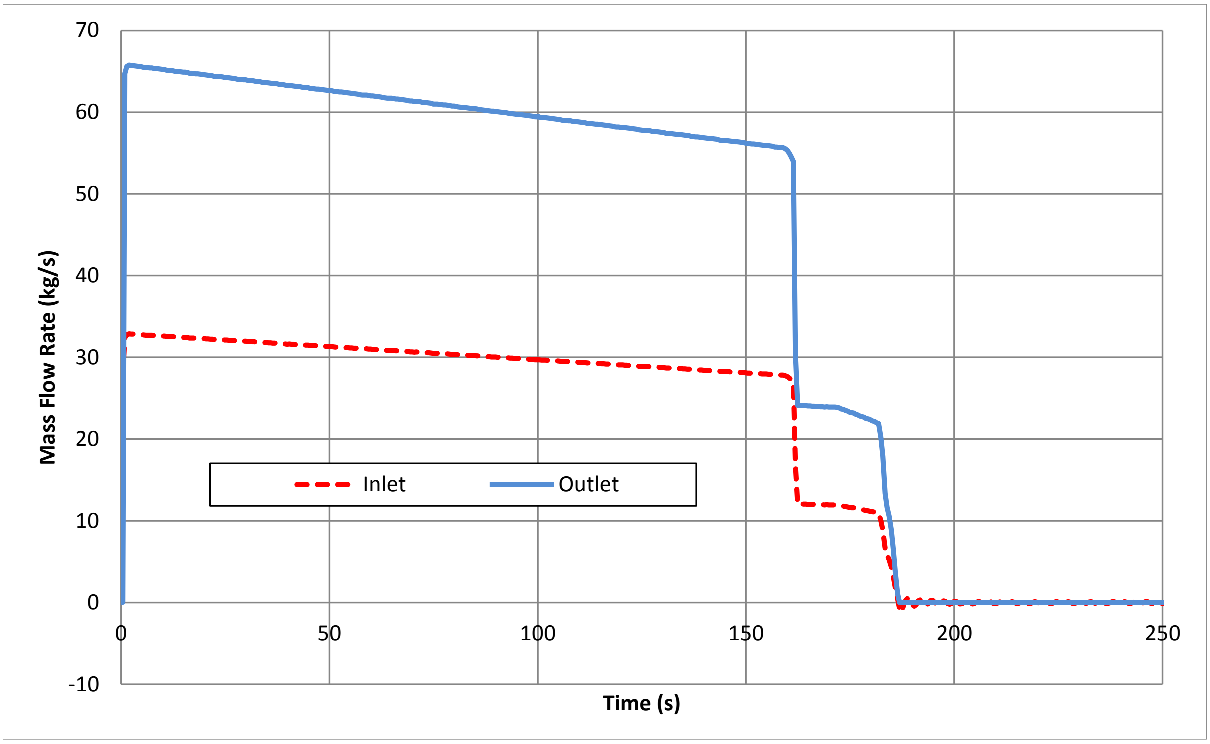

Figure 5. Mass flow rate at the injection points and outlet of annular region.

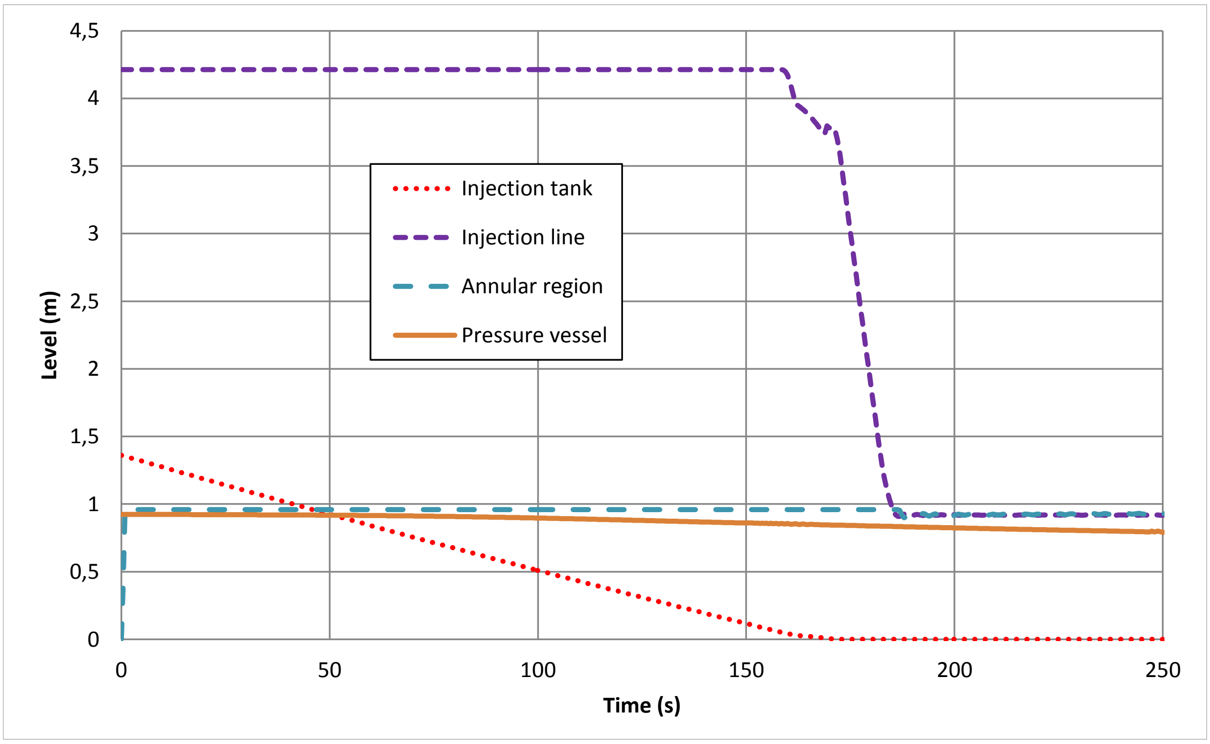

Figure 6. Collapsed level of the injection tank, injection line, annular region and pressure vessel.

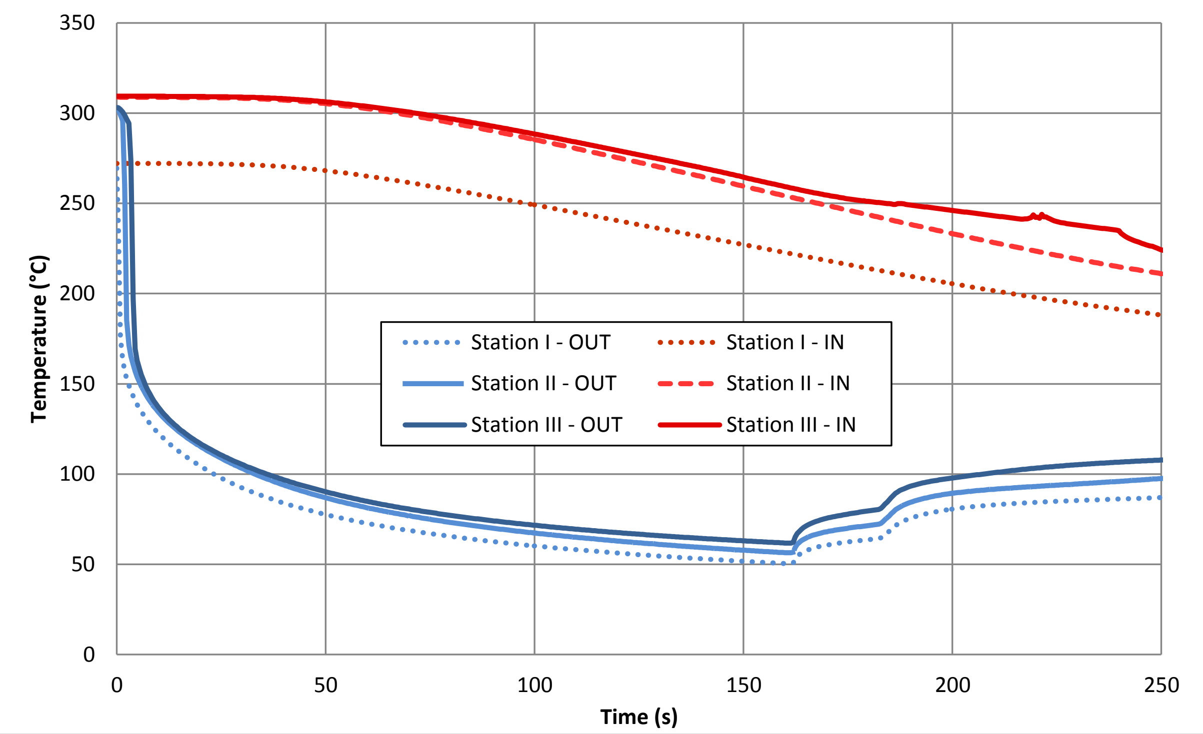

Figure 7. Pressure vessel wall inside and outside temperatures at measurement stations

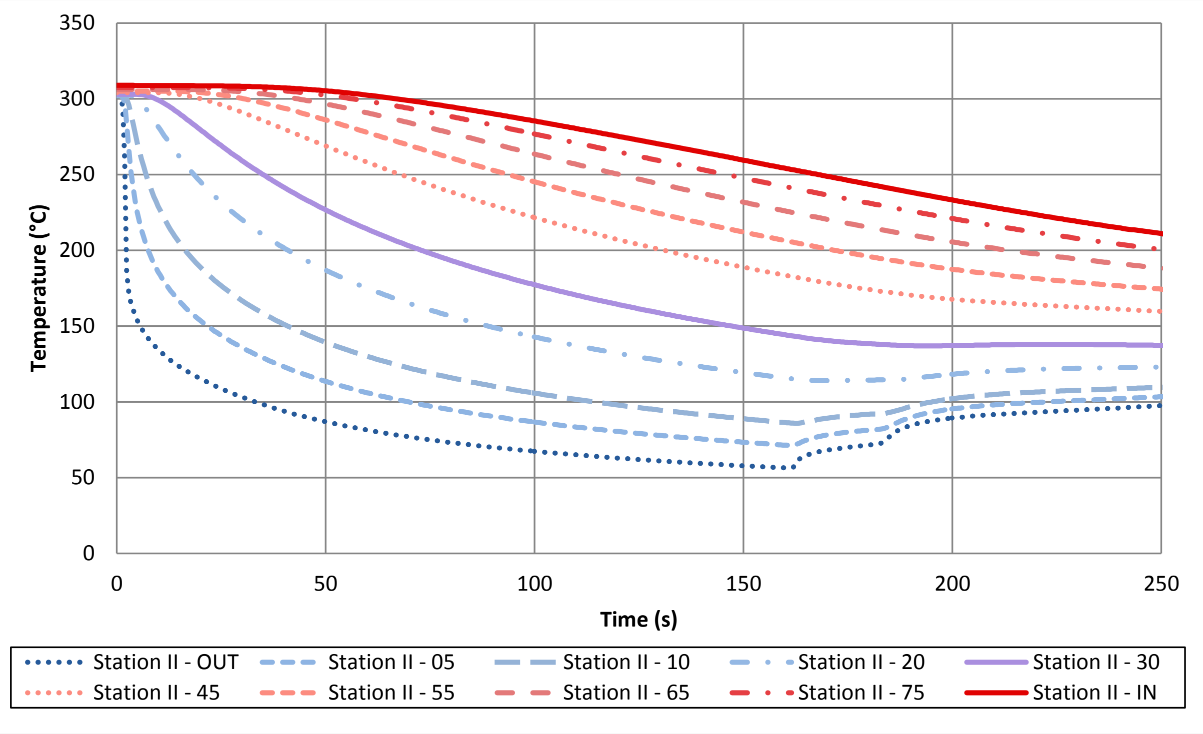

Figure 8. Pressure vessel wall temperatures at the measurement station II

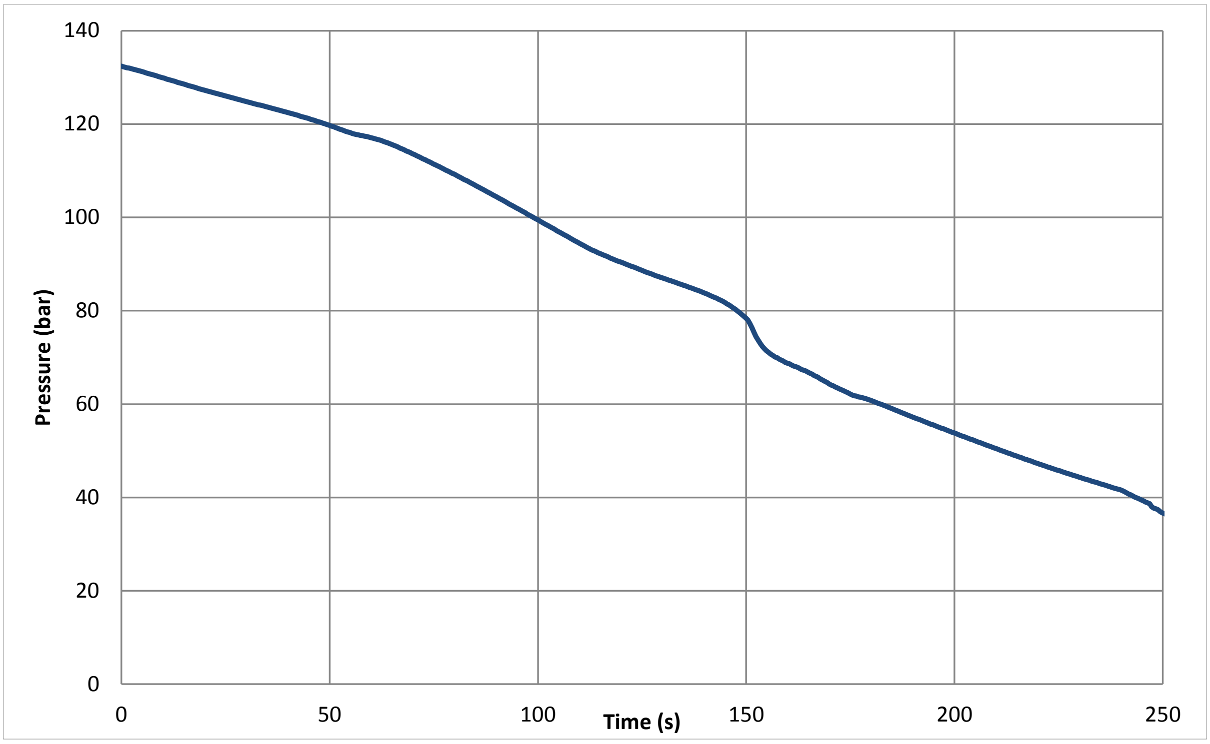

Figure 9. Pressure vessel internal pressure

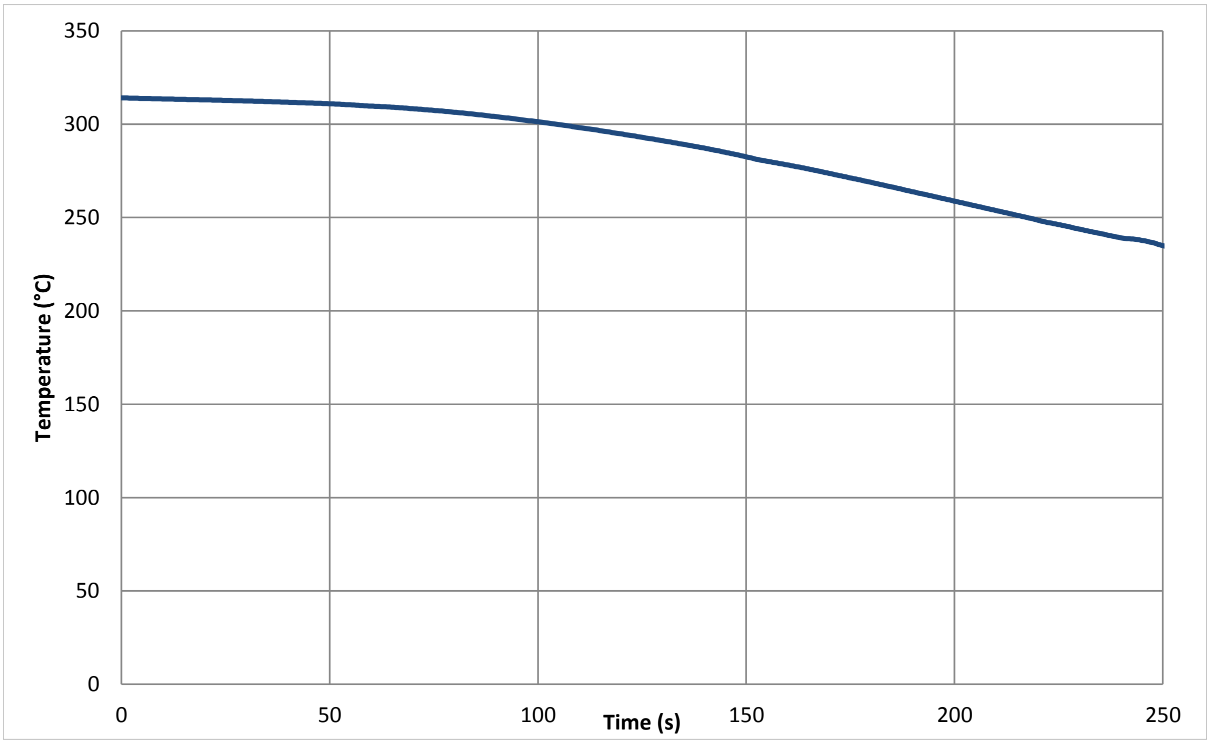

Figure 10. Pressure vessel internal temperature

5. CONCLUSIONS

A RELAP5 model of the experimental facility was developed and the proposed experiment was simulated. In order to achieve better initial conditions, the facility heating up process was simulated and several hypotheses were assumed.

The required results to be compared among the Thermal Hydraulic Special Theme participants were presented and commented.

A new model is under development intending to match even closer the initial conditions. A comparison against the experimental data is also needed for further modeling improvements.

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