

COMPARISON BETWEEN EXPERIMENTAL DATA AND NUMERICAL MODELING FOR THE NATURAL CIRCULATION PHENOMENON

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ABSTRACT

There is a crescent interest in the scientific community in the study of natural circulation phenomenon. New generation of compact nuclear reactors uses the natural circulation of the fluid as a system of cooling and of residual heat removal in case of accident or shutdown. The objective of this paper is to present a study through the comparison of experimental data and numerical simulation for the natural circulation phenomenon in one and two-phase flow regime. An experimental circuit built with glass tubes is used for the experiments. Thus, it allows the thermal hydraulic phenomena visualization. There is an electric heater as the heat source, a heat exchanger as the heat sink and an expansion tank to accommodate fluid density excursions. The circuit instrumentation consists of thermocouples and pressure meters to better keep track of the flow and heat transfer phenomena. Instrumentation data acquisition is performed through a computer interface developed with LABVIEW. Previous comparisons were presented. However, in this work pressure transducers were mounted in the heat source outlet and in the expansion tank inlet to allow fluid level variation measures. Numerical modeling and simulation is done with the thermal hydraulic code RELAP5, which is widely used for this purpose. This simulation is capable to reproduce pressure variations, expansion tank level and temperatures measured along the circuit. The observed reverse flow in the circuit is also well represented by model. Comparison between experimental and numerical simulation is presented in this work and showed to be in good agreement.

1. INTRODUCTION

A theoretical and experimental program is under development at IPEN-CNEN/SP. The objective is to understand the complex phenomena involving the instabilities in one and two-phase flow in a natural circulation circuit.

This study started at the Departamento de Engenharia Química da Escola Politécnica of USP. Experiments concerning one and two-phase flow in natural circulation regime were performed. Several articles were published [1, 2, 3 and 4].

However this circuit needed a reformulation since it was constantly presenting some troubles with the instrumentation. A remodeling program was suggested together with a proposal to move it from Escola Politécnica of USP to IPEN-CNEN/SP. After some modifications it became operational at IPEN-CNEN/SP. A new interface using Labview pack [5] was developed for the new data acquisition system.

Experiments were performed for one and two-phase flow. RELAP5 code [6] was used to simulate this circuit. Theoretical results from RELAP5 were compared to the experimental ones in order to validate the RELAP5 models.

1.1 Objective

The goal of this work is to describe the circuit modernization process and present a comparison between numerical simulation and experimental results for one and two-phase flow in natural circulation regime.

2. EXPERIMENTAL CIRCUIT DESCRIPTION

The experimental circuit consists of a rectangular glass loop with an electrical heat source and a coil cooler. Glass is used in the circuit to allow the flow visualization as to identify the flow patterns. The main dimensions of the circuit as well as the thermocouple positions are indicated in Fig. 1.

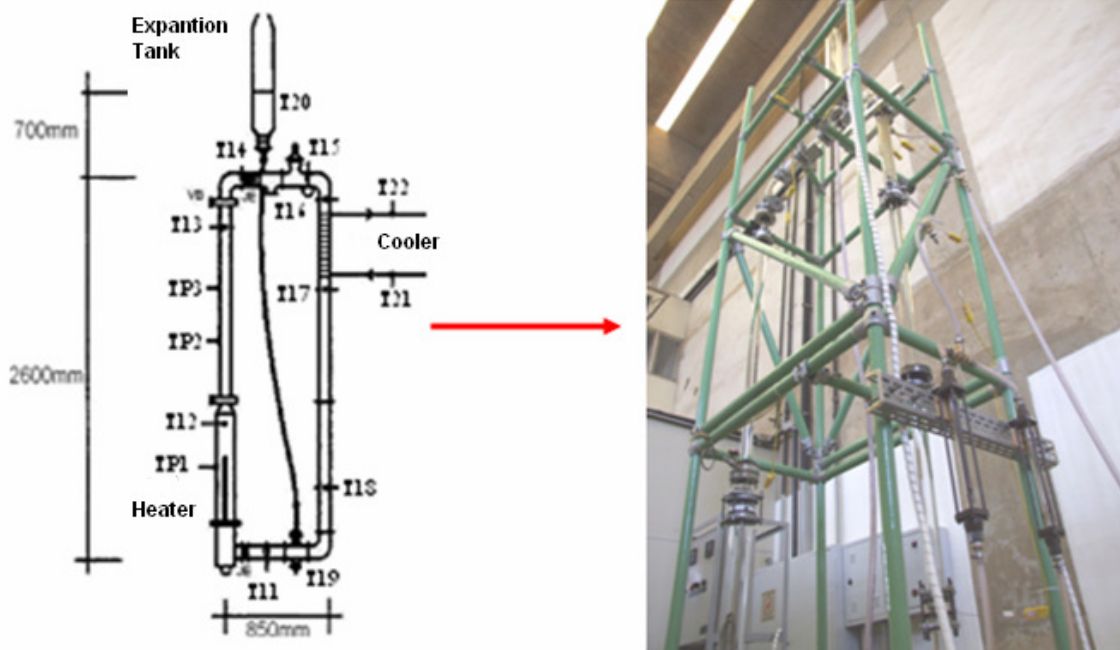


Figure 1. Loop diagram and photo

The heated section is a 75 mm cylindrical glass tube with two electrical heaters with 76.2mm diameter, 880 mm high and 8 mm of thickness, Fig. 1. The power applied is controlled in the range of 0 to approximately 8600 W. Power for the first heater is fixed and for the second varies from 0 to approximately 4400 W. So power source can be 0 W, 4200 W and any value between 4200 and the maximum power, 8600 W. The cooler is all made in glass with 33 mm internal diameter, 610 mm high and 2 parallel coils. The coolant is tap water at ambient temperature. An expansion tank, acting as a PWR pressurizer, is partially filled with water and opened to the ambient at the top end. At the bottom end it is connected to the loop in order to deal with the water specific volume changes. To prevent vapor admission to the expansion tank during two-phase flow experiments, the surge line is connected to the horizontal section of the cold leg.

The heating power is imposed through an alternate voltage controller, “variac”. At the circuit, temperature is measured in 15 points, three on the tubes surface and some others inside the tubes, Fig.1. Type K thermocouples are used. Signal conditioning and a data acquisition boards hosted in a PC complete the data acquisition system.

Thermocouple position is presented by Fig. 1. Special connections were made in order to allow the introduction of thermocouples into the tubes in a very practical way. Connections are made of Teflon and buccins are mounted on its surfaces, Fig. 2.

Coil cooler is composed of two concentric spirals. Primary water circuit flows inside the shell and refrigeration water inside the spirals.

Expansion tank is also glass made for 7 liters, 1270 mm high and 120 mm diameter. It is located at 700 mm above the horizontal section of the circuit. Its upper nozzle is opened to the environment. The lower nozzle is connected to the surge line which is connected to cold leg.

Data acquisition system and instrumentation system are supplied by National Instruments. It consists of two signal conditioner modules, two terminal blocks and an acquisition PCMCIA card installed into a notebook computer. LabView is used to create an interface, Fig. 3, through which all the configuration is done.

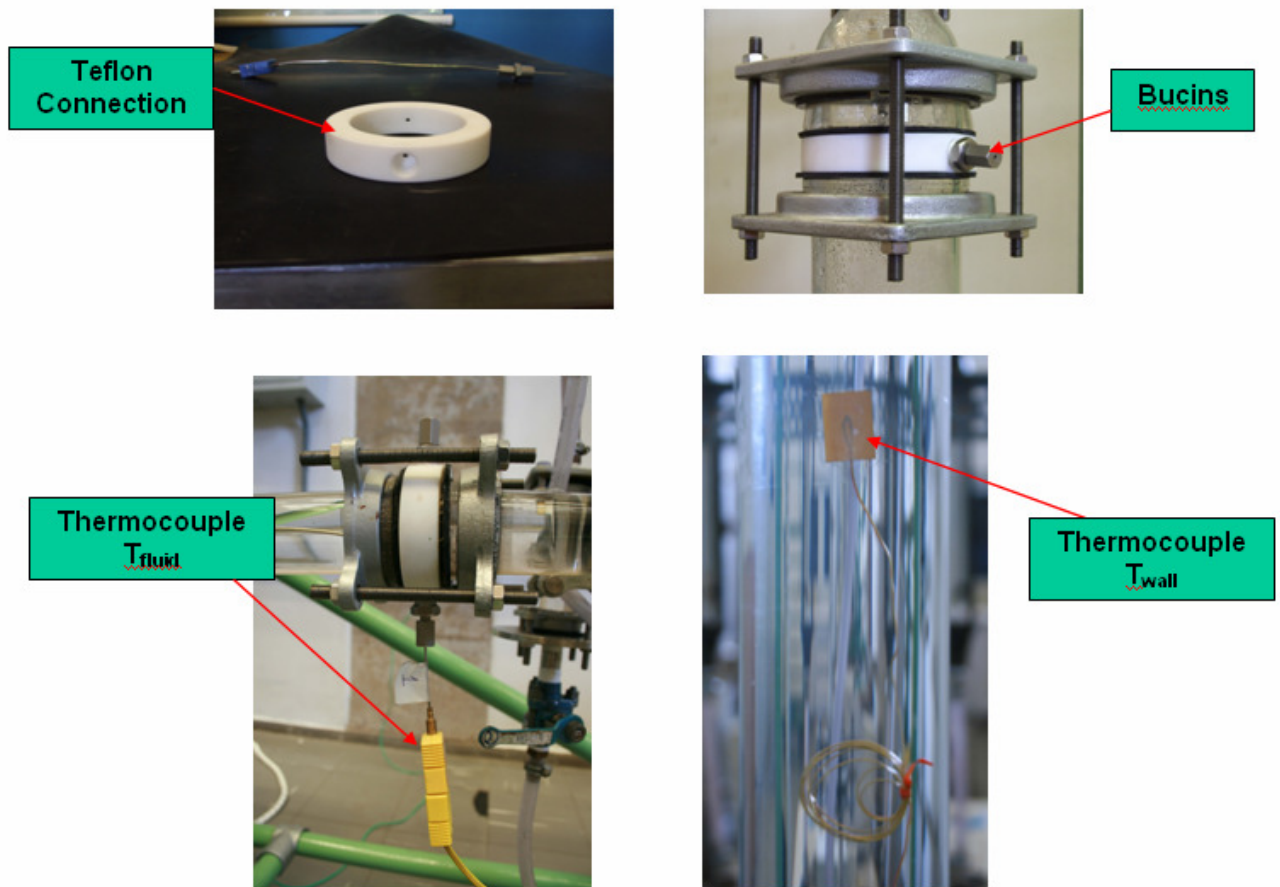


Figure 2. Connections and instrumentation

Data listed below is registered at a sampling rate of approximately 7 seconds:

- a) six temperature at the hot leg;
- b) four temperature at the cold leg;
- c) two temperature inlet/outlet of the cooling water;
- d) three temperature of the external tube walls to estimate heat losses, Fig. 1.

The secondary flow rates were measured by rotameters.

The details of the data acquisition system based on LabView 7.0 can see in the Fig.4.

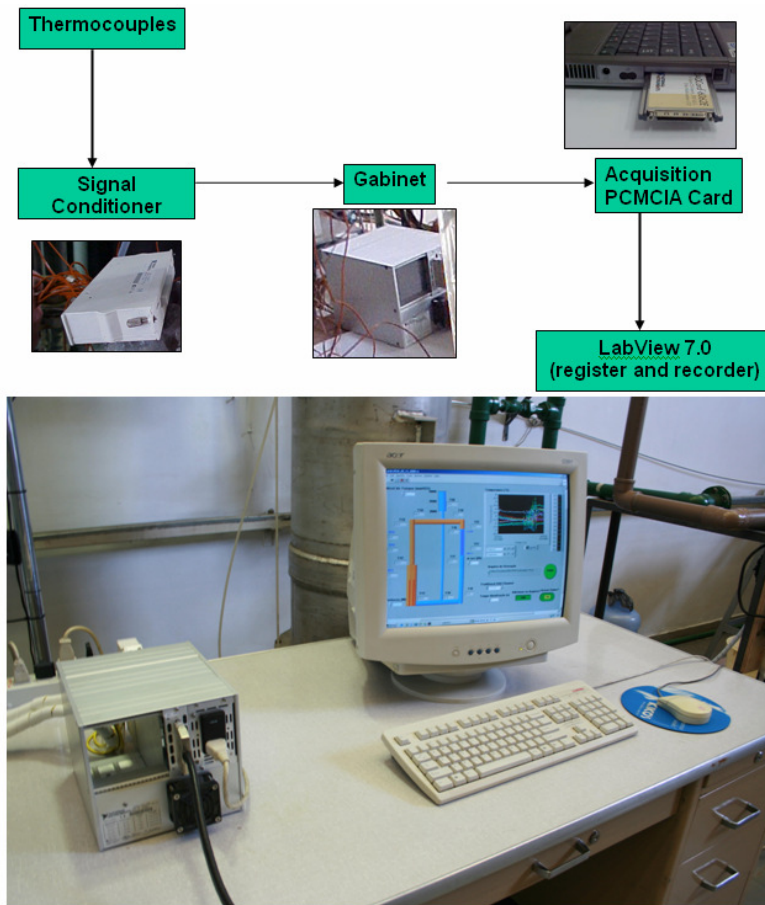


Figure 3. Acquisition data

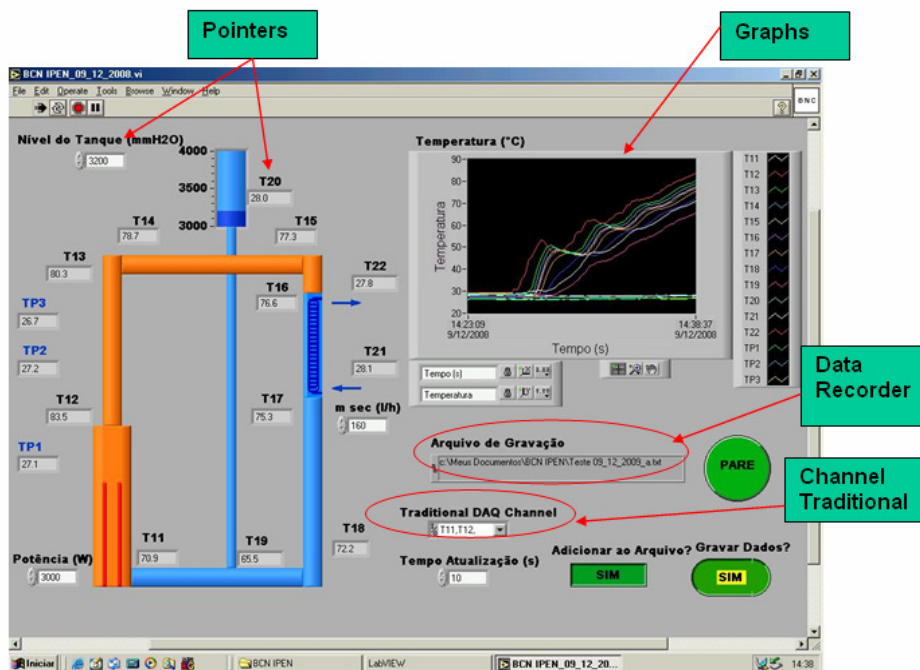


Figure 4. Software interface

3. METODOLOGY

The methodology used in this work consists in the experimental and mathematical study of the natural circulation circuit using the RELAP5 code. This code was originally developed for the analysis of thermal hydraulic transients in Pressurized Water Reactors (PWR). RELAP5/MOD3.2 can model the primary and secondary cooling system of experimental facilities and of Nuclear Reactors with geometric details. The program uses the two fluid model and takes into account the mass, momentum and energy equations for the liquid and gaseous phases. One dimensional models are used to treat the fluid flow and the heat conduction at the structures. However this assumption is not assumed for the cross flow in the Plant core and for the flooding model which uses the bidimensional heat conduction in the neighborhoods of the rewetting region.

The experiment starts with the primary circuit filled with water at rest and the heater turned off. The fluid temperature is completely homogeneous and equal to the ambient temperature all along the loop. The heater is turned on with a constant heating power. The secondary flow rate and the inlet temperature at the coil cooler are also kept constant. This procedure is repeated for different power levels and flow rates at the coil cooler.

The difference of the hydrostatic head from the hot and cold legs increases, creating a flow rate at the circuit. The hot water is replaced at the heater by cold water from the coil cooler. Then the vapor production at the heater decreases and the horizontal part of the hot leg is partially filled with water again. At this time a natural circulation flow, similar to one-phase flow, is established for a short period until two-phase flow process starts again.

One and two phase flow behaviors are described as follows. The vapor bubbles, generated at the heater, merge at the contraction, creating a slug flow at the vertical part of the hot leg. During this period, the vapor remains at the upper horizontal leg of the loop drying this part of the circuit. At this period, the pressure of the circuit grows expelling the liquid from the cold leg to the expansion tank. A thermocouple at the heater inlet shows the gradual rise of the liquid temperature.

4. THEORETICAL AND EXPERIMENTAL SIMULATION

To simulate the thermal hydraulic behavior of the circuit a first model [7] was developed, using PIPE and BRANCH components to represent all the facility. At the beginning, all the volumes were filled with water except that one representing the upper part of expansion tank, which has also some air. Heat losses to the environment were also considered. This model was able to predict the behavior of the one and two-phase experiments.

Observing the experiments, it was noted that the two-phase oscillation only started when the upper part of the hot leg became completely full of vapor. The saturation temperature is considered as the temperature to the change from liquid to vapor phase, in the pressure of the circuit, disregarding the presence of non-condensable gases. Table 1 presents operational conditions for the one and two-phase flow.

Table 1. Operational condition of the experiment

One-phase flow Operational conditions	Two-phase flow Operational conditions
Power: 4706 W	Power: 6536 W
Cooling Water: 0.05 kg/s	Cooling Water: 0.0233 kg/s
Initial Temperature: 20 °C	Initial Temperature: 20 °C
Environment Temperature: 21 °C	Environment Temperature: 21 °C

RELAP5 nodalization is presented in Fig. 5. Table 2 represents the components association between RELAP nodalization and the loop.

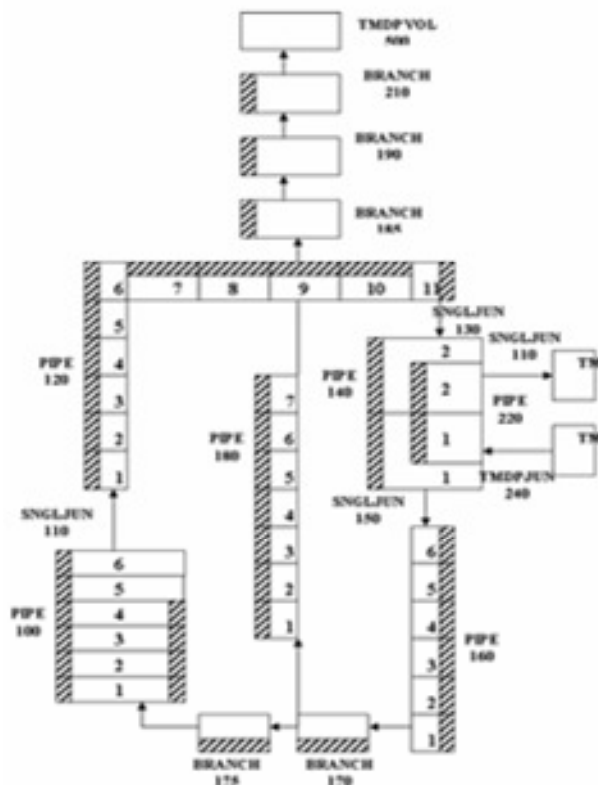


Table 2. Nodalization of the natural circulation experimental facility

COMPONENT	COMPONENT NUMBER.	COMPONENT TYPE
Heater	100	PIPE
Hot Leg	120	PIPE
Primary Cooler	140	PIPE
Cold Leg	160	PIPE
	170	BRANCH
	175	BRANCH
Surge Line	180	PIPE
Expansion Tank	185	BRANCH
	190	BRANCH
	210	BRANCH
Secondary Cooler	220	PIPE
Cooling Water (in)	230	TMDPVOL
	240	TMDPJUN
Cooling Water (out)	250	SINGLJUN
	260	TMDPVOL
Containment	500	TMDPVOL

Figure 5. RELAP5 – Facility nodalization

5. RESULTS

For low power levels, there is no phase change and, after a damped oscillatory initial behavior, a stationary flow regime is established. For higher power levels the two-phase flow patterns are observed at the beginning, followed by a two-phase oscillatory regime.

Fig. 6 shows the comparison of measured and calculated temperature for three points of the circuit to one-phase flow. These points correspond to T12, T17 and T22 thermocouples represented in Fig. 1.

Fig. 7, 8 and 9 show the results of measured and calculated temperature for three points of the circuit for two-phase flow. These points are correspondent to those of the one-phase flow.

Fig. 10 and 11 show the flow mass and void fraction in the primary circuits, respectively, obtained of the RELAP5 simulation in two-phase flow.

According to the results, the RELAP5 was able to represent the natural circulation behavior in one and two-phase flow. The temperatures and oscillatory regime obtained with RELAP5 had good agreement with the experimental results.

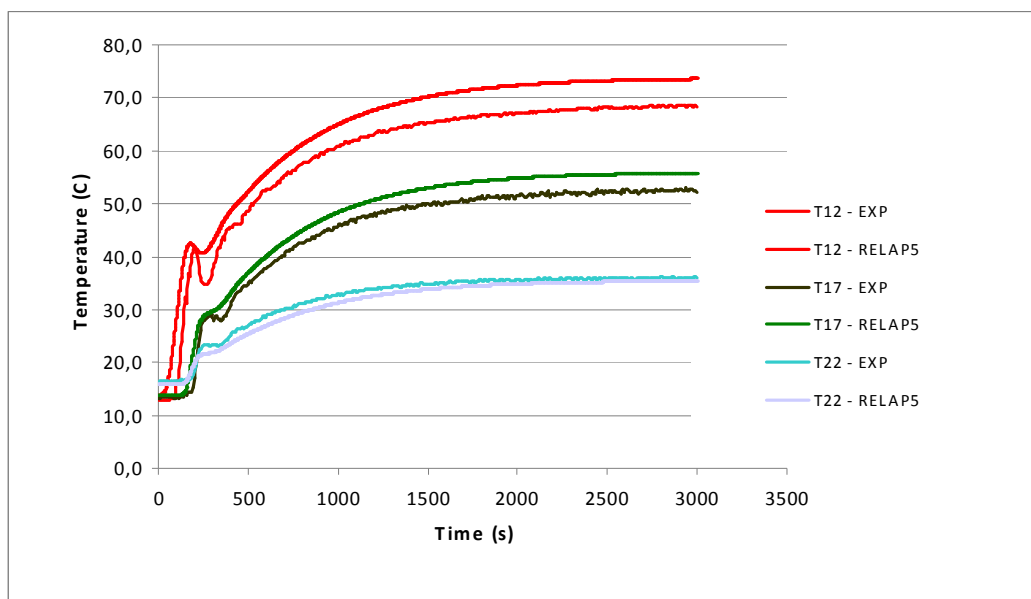


Figure 6. Temperature theoretical/experimental out of the heater (T12), out of the cooler (T17) and Out of secondary (T22) in one-phase flow

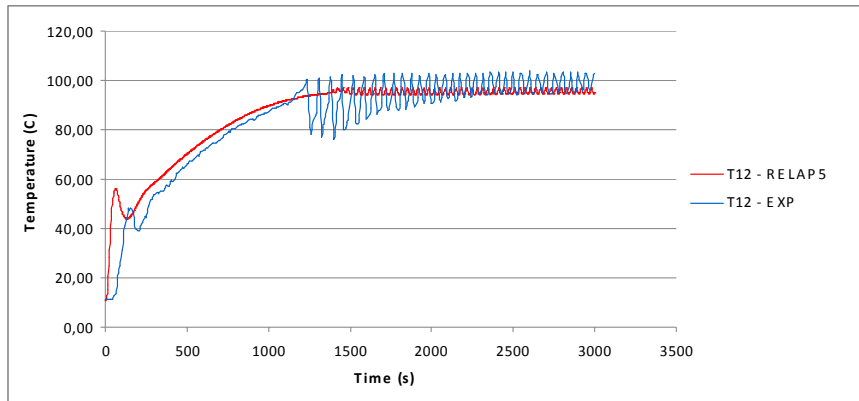


Figure 7. Temperature theoretical/experimental out of the heater (T12) in two-phase flow

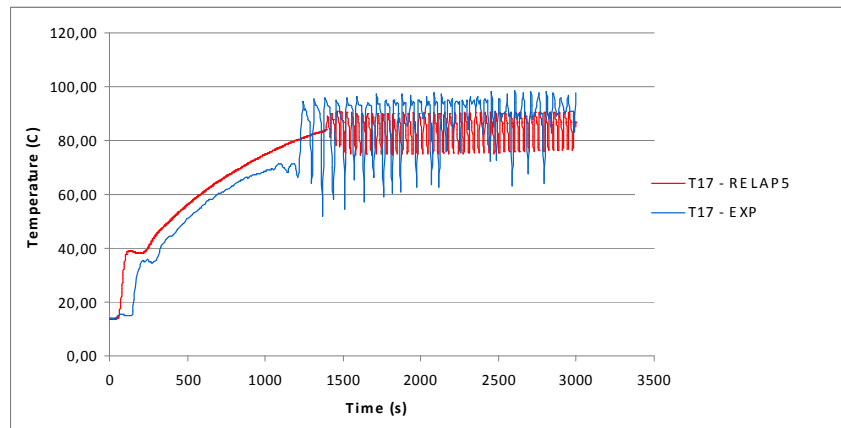


Figure 8 Temperature theoretical/experimental out of the cooler (T17) in two-phase flow

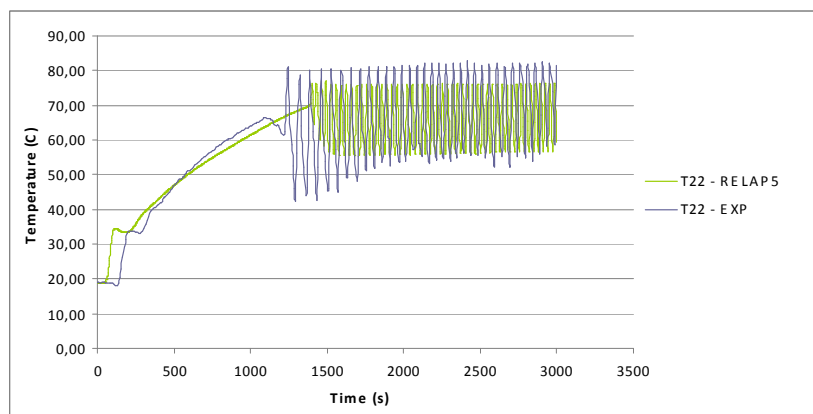


Figure 9. Temperature theoretical/experimental out of the secondary (T22) in two-phase flow

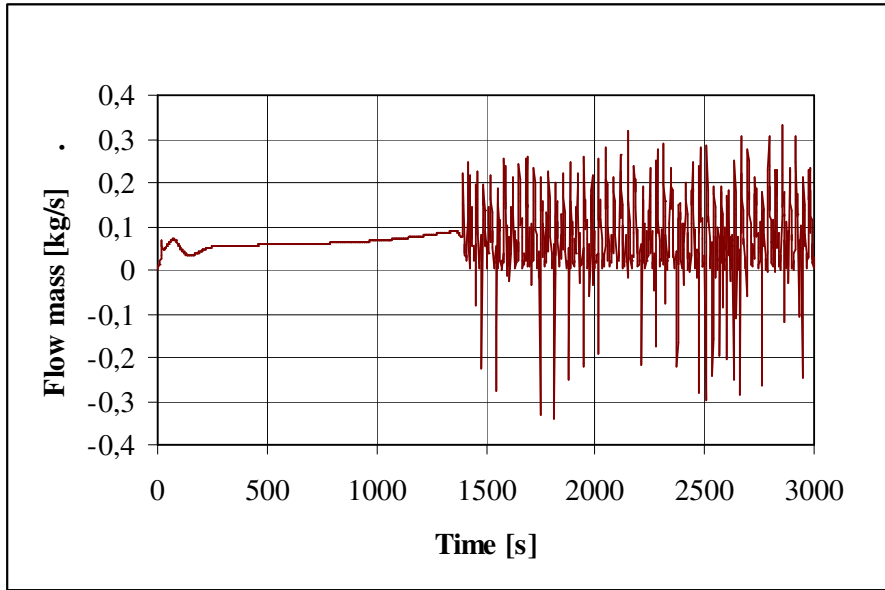


Figure 10. Flow mass in the primary circuit in two-phase flow (RELAP5)

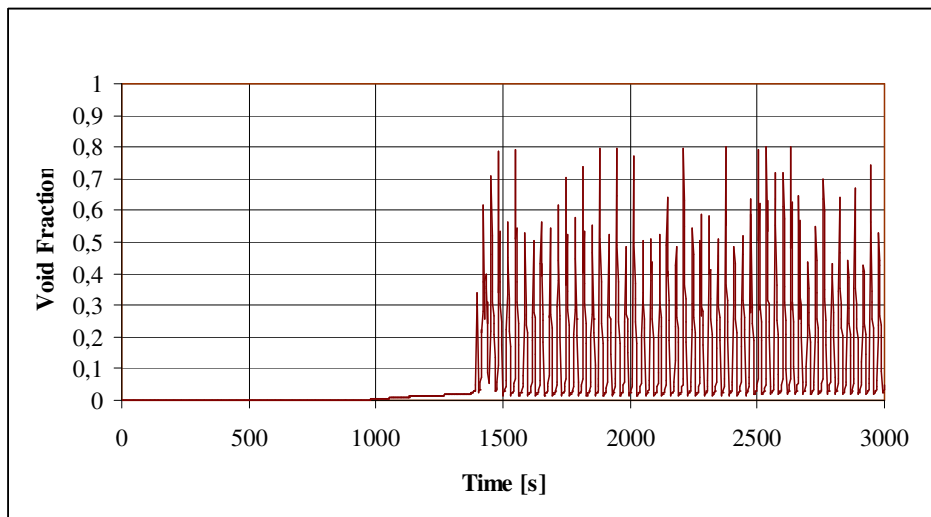


Figure 11. Void fraction in the secondary circuit in two-phase flow (RELAP5)

RELAP5 was able to represent the natural circulation behavior in one and two-phase flow. For one-phase flow the results are excellent. RELAP5 was able to capture the oscillations for the two-phase flow.

6. CONCLUSIONS

Remodeling of natural circulation circuit was successfully done and all the stages were presented.

Experiments were performed in one and two-phase flow. It was also numerically simulated with RELAP5. The experimental / theoretical comparison showed to be in a good agreement. This work was also used to train some users with RELAP5 for natural circulation basic model.

Additional experiments are programmed in order to register pressure distribution, primary circuit flow, expansion tank temperature and level. These measures will contribute to the better understanding of the one and two-phase natural circulation phenomena.

Some series of experiments are programmed to be executed soon. Experimental measures of flow rate, void fraction, pressure and level of the expansion tank will be acquired to provide data to validate numerical simulations.

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