Study of the Natural Circulation Phenomenon for Nuclear Reactors

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Abstract. *The objective of this paper is to study the natural circulation phenomenon in one and two-phase regime. There has been a crescent interest in the scientific community in the study of the natural circulation. New generation of compact nuclear reactors uses the natural circulation for residual heat removal in case of accident or shutdown. For this study, the modeling and the simulation of the experimental circuit is performed with the RELAP5 code. The theoretical results showed to be satisfactory when compared with the experimental ones.*

Keywords: Natural Circulation, RELAP5, Two- Phase Flow.
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INTRODUCTION

Natural circulation phenomenon is very important for the safety and design of nuclear reactors. Advanced reactors have been designed using passive safety systems based on natural circulation [1]. There are also some conceptual designs using the natural circulation where the components and systems have been simplified by eliminating pumped recirculation systems and pumped emergency core cooling systems [2].

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 da* USP. Experiments concerning one and two-phase flow in natural circulation regime were performed. Several articles were published [3, 4, 5 and 6]. Other experiments were carried out by different authors as found in the literature [7, 8 and 9].

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 [10] was developed for the new data acquisition system.

Experiments were performed for one and two-phase flow. RELAP5 code [11] was used to simulate this circuit. In order to validate RELAP5 models, the results compared to the experimental ones.

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.

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 Figures 1 and 2.

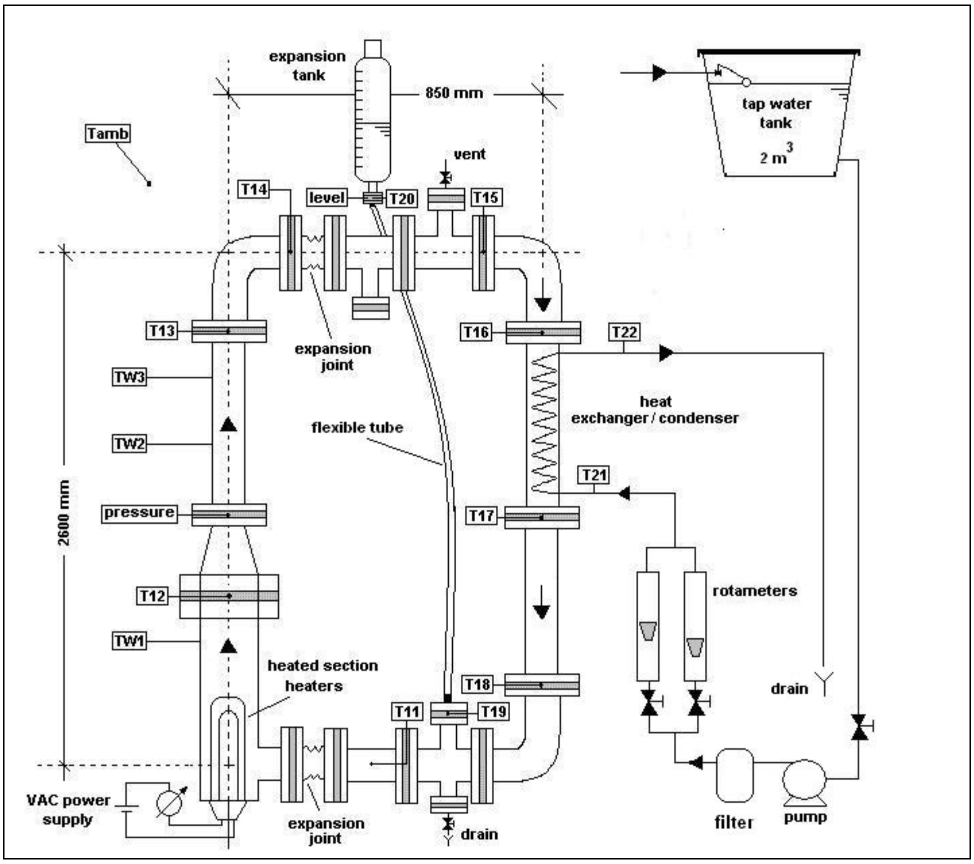

FIGURE 1. Loop diagram

The heated section is a 75 mm cylindrical glass tube with two electrical heaters. The power applied is controlled in the range of 0 to 8600 W. The cooler is all made from 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.

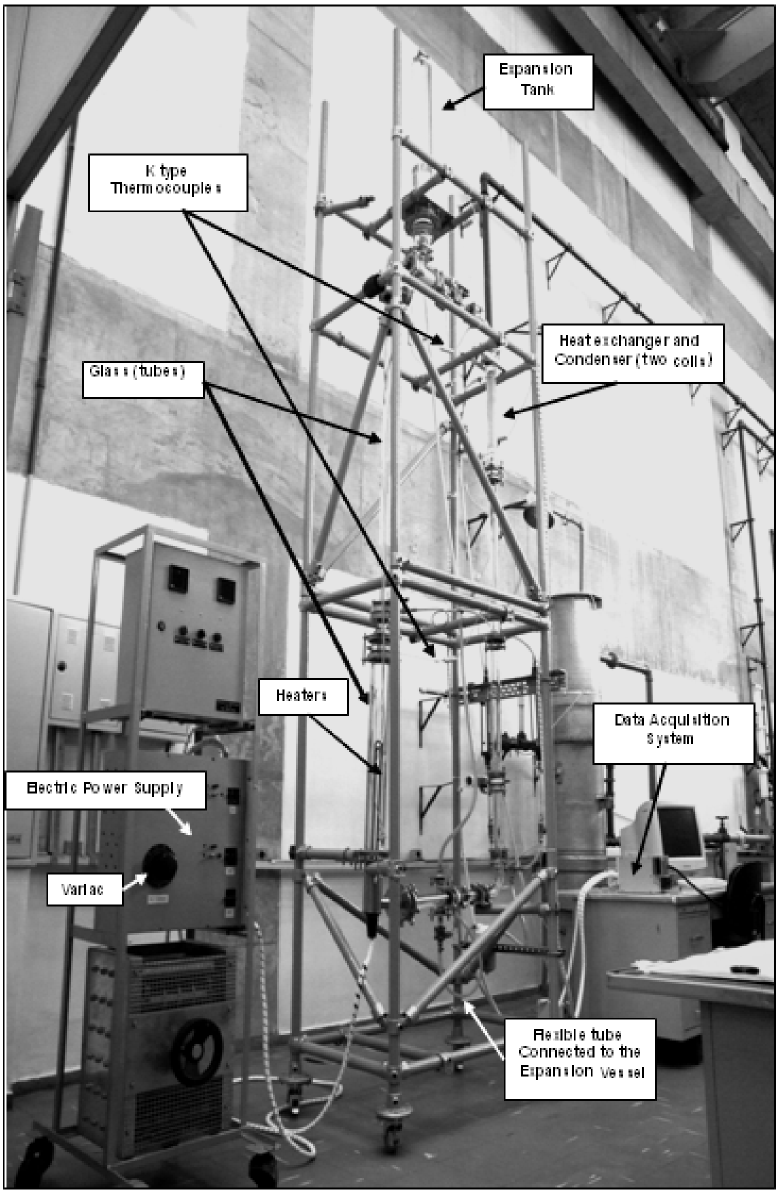

FIGURE 2. Natural Circulation Circuit photo

To simulate the thermal hydraulic behavior of the circuit a first model [12] was developed to RELAP5 code. PIPE and BRANCH components 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.

Experiments showed 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: 1000 W	Power: 7500 W
Cooling Water: 0.0278 kg/s	Cooling Water: 0.0278 kg/s
Initial Temperature: 22.4 ^{0}C	Initial Temperature: 23.3 ^{0}C
Environment Temperature: 21^{0}C	Environment Temperature: 18 ^{0}C

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.

Figures 3 and 4 show the comparison of measured and calculated temperature for one point of the circuit to one and two-phase flow, respectively. This point corresponds to T12 thermocouple represented in Figure 1.

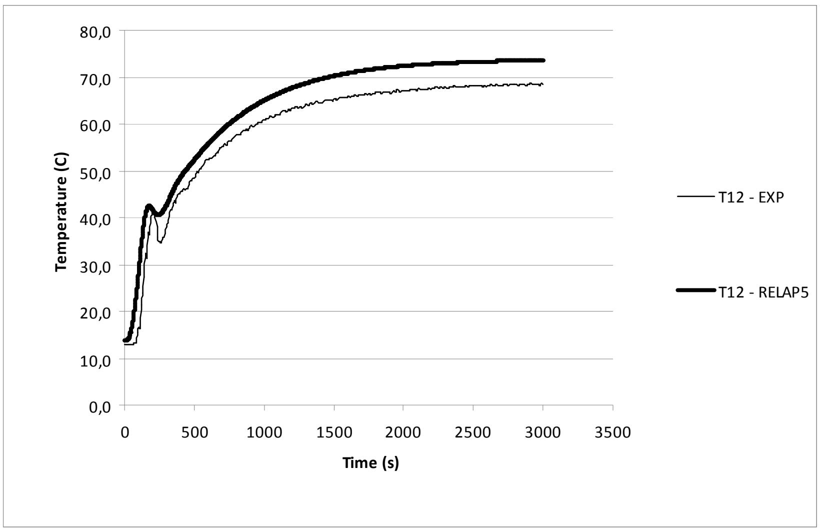

FIGURE 3. Temperature theoretical/experimental (T12) in one-phase flow

RELAP5 was able to represent the natural circulation behavior in two-phase flow, capturing its oscillations, Figure 4.

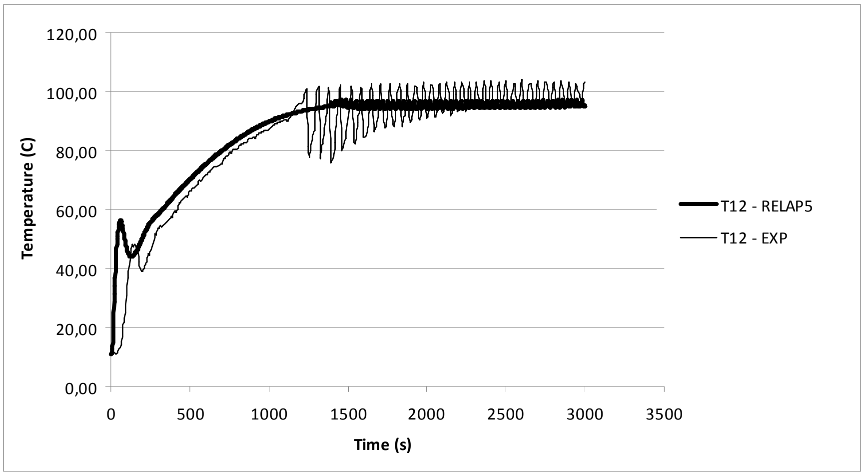

FIGURE 4. Temperature theoretical/experimental (T12) in two-phase flow

CONCLUSION

Experiments were performed in one and two-phase flow. It was also numerically simulated with RELAP5. Theoretical and experimental results showed good agreement.

ACKNOWLEDGEMENTS

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