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RELAP5 SIMULATION FOR ONE AND TWO-PHASE NATURAL CIRCULATION PHENOMENON

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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 experimental circuit is mounted in the Chemical Engineering Department of the University of São Paulo. It is presented in this work the theoretical/experimental comparison for one and two-phase flow. These results will be stored in a database to validate RELAP5 calculations. This work was also used to training some users of RELAP5 from IEAv.

1. 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 design 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 development program concerning natural circulation is in progress at the "Instituto de Pesquisas Energéticas e Nucleares"– IPEN – CNEN/SP. A set of activities, including experimental and theoretical ones, are scheduled.

This paper treats the problem of one and two-phase flow in a natural circulation rectangular loop. To understand this complex problem, an experimental loop was built with an electrical heater as the heat source and a coil cooler as the heat sink. Besides the experimental procedure, a theoretical model was developed using the RELAP5/MOD3.2.2gama [3]. This work has been used for training some RELAP5 users from Instituto de Estudos Avançados – IEAv and also for training students in the laboratory. The following tasks were accomplished:

- Experiments in one and two-phase flow natural circulation;
- The experimental circuit nodalization and the input data to RELAP5 code, using the PREREL5 [4] preprocessor;
- Simulation of one and two-phase flow with RELAP5 and
- Analyses of the theoretical/experimental results in order to validate the nodalization.

The RELAP5 is a code that was originally developed for the analysis of thermal hydraulic transients in Pressurized Water Reactors (PWR), Boiling Water Reactor (BWR) and associate systems. This code can model the primary and secondary cooling system of experimental facilities and Nuclear Reactors. The code uses the two fluid models and takes into account the mass, momentum and energy equations for the liquid and gaseous phases. One dimensional model is 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 main drawback within RELAP5 code is the big quantity of information necessary to simulating thermal hydraulic accidents. Moreover, there is the necessity of a reasonable amount of mathematical operations to the calculation of the existent components geometry. Therefore, in order to facilitate the manipulation of this information, it was necessary the development of a friendly preprocessor for the mathematical calculations. Although, MS-EXCEL or any other similar spreadsheet may be used for some of these calculations, a mathematic preprocessor was developed. It was named PREREL5 and is based on Visual Basic for Application, VBA [5].

2. EXPERIMENTAL CIRCUIT

The experimental circuit was built in 1980 decade for natural circulation studies. However, part of this circuit became obsolete. In the begging of 2004 the circuit was upgraded. New instrumentation was used as well as new software, based on LabView 7.0 [6] for data acquisition.

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 and the thermocouple positions are indicated in Fig. 1.

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 7000 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 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.

2.1. Instrumentation and data acquisition system

The whole data acquisition system is supplied by National Instruments [7]. It consists of two signal conditioner modules, two terminal blocks and an acquisition PCMCIA card installed in the notebook computer. LabView 7.0 is used to create an interface, Fig.1, through which all the configuration is done.

The data listed below is registered at a sampling rate of approximately 5 seconds:

- six temperatures at the hot leg;
- three temperatures at the cold leg;
- two temperatures inlet/outlet of the cooling water;
- three temperatures of the external tube walls to estimate heat losses, Fig. 1.

The heating power is calculated by measuring the electric current and the voltage. A digital multimeter (3 1/2 digits) was used. The uncertainty at the electric power is two percent of the calculated value. The temperature measuring system consists of type T thermocouples with a global uncertainty estimated in 0.5^{o}C. The secondary flow rates were measured through a rotameter.

3. METODOLOGY

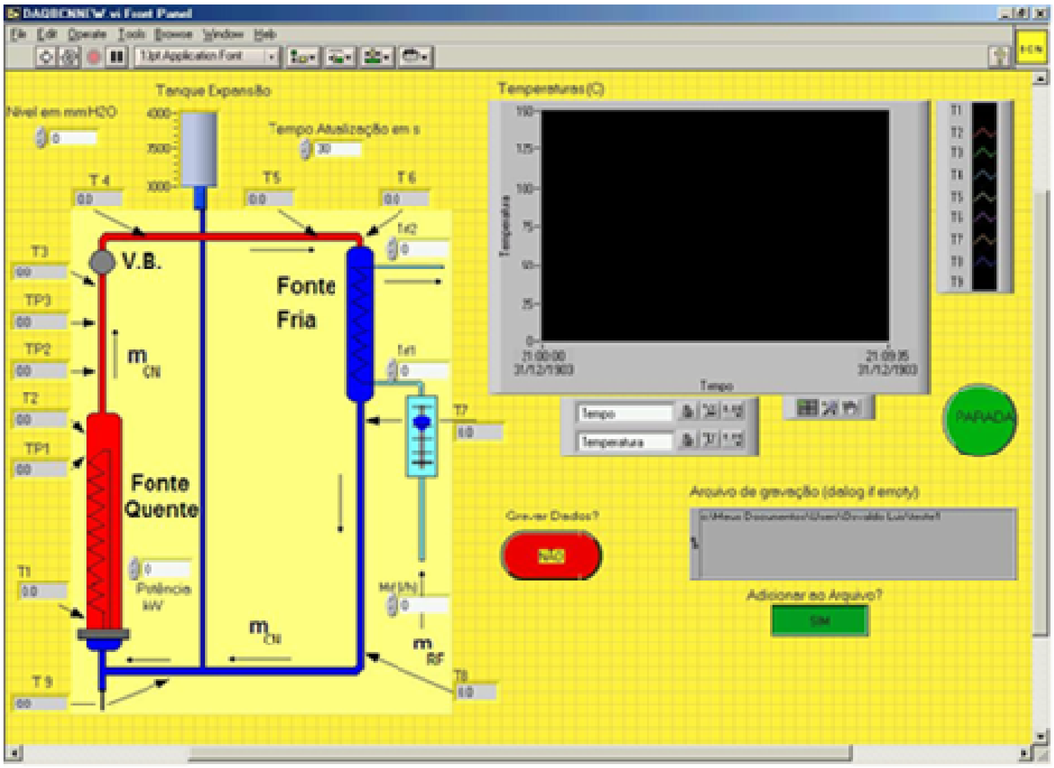
The methodology used in this work consists in the experimental and mathematical study of the natural circulation circuit using the RELAP5 code.

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.

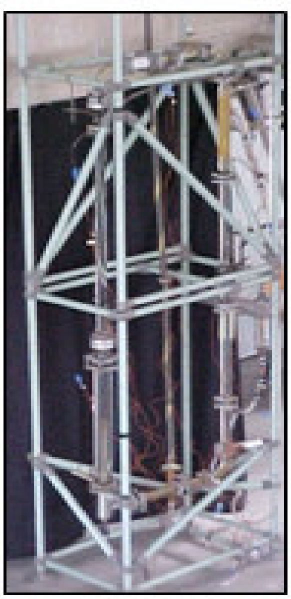
The hydrostatic head difference, between the hot and cold legs, increases creating a flow rate at the circuit. The hot water is replaced at the heater by cold water from the coil cooler. Then the vapor production at the heater decreases and the horizontal part of the hot leg is partially filled with 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 expulsing the liquid from the cold leg to the expansion tank. A thermocouple at the heater inlet shows the gradual rise of the liquid temperature.

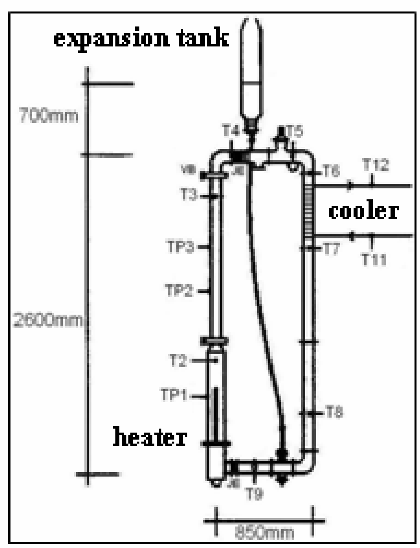
As more and more vapor is generated at the heater, the slug flow is replaced by a churn flow with the expulsion of liquid, entrained by the vapor, to the cold leg through the coil cooler. This period characterizes the expulsion period. During this period, the expansion tank water level rises, consequently, increasing the pressure inside the circuit.



a – Software interface



b – Photo



c – Diagram

Figure 1. Circuit View. a - Software interface; b – Photo; c – Diagram.

4. THEORETICAL AND EXPERIMENTAL SIMULATION

To simulate the thermal hydraulic behavior of the circuit a first model [8] was developed, using PIPE and BRANCH components to represent all the facility. The nodes used for this nodalization are about 0.3 m long. 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.

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

Table 1. Operational conditions

One-phase flow Operational conditions	**Two-phase flow Operational conditions**
Heater Power: 4706 W	Heater Power: 6536 W
Cooling Water: 0,05 kg/s	Cooling Water: 0,0233 kg/s
Initial Temperature: 20 ^{0}C	Initial Temperature: 20 ^{0}C
Environment Temperature: 21 ^{0}C	Environment Temperature: 21 ^{0}C

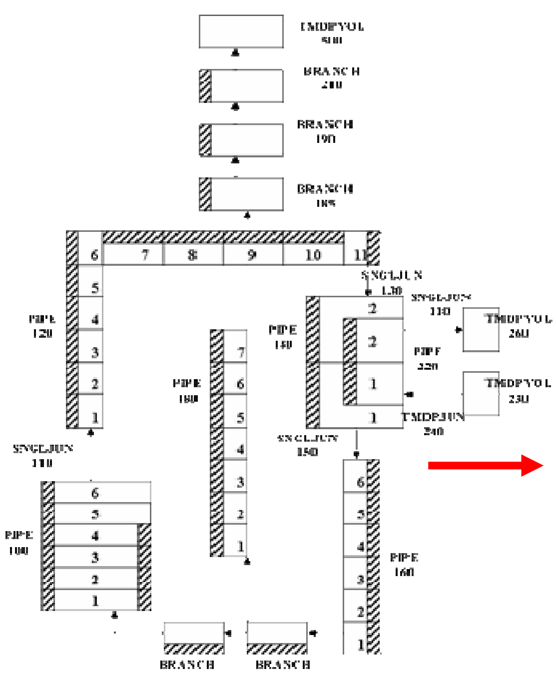


Figure 2. RELAP5 – Circuit nodalization

Table 2. Nodalization of the Natural Circulation Experimental model: Hydraulic Regions and Code Component Correspondence

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

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.

Figure 3 shows the comparison of measured and calculated temperature for three points of the circuit to one-phase flow. These points correspond to T2, T7 and T12 thermocouples represented in Fig. 1. Figure 4 shows the primary flow rate calculated with RELAP5 as expected.

Figures 5 and 6 show the results of measured and calculated temperature for four points of the circuit to two-phase flow. These points are the same of the one-phase flow.

RELAP5 model successfully represented the natural circulation behavior in one and two-phase flow. The temperatures and oscillatory regime obtained with RELAP5 are substantiated by the experimental results.

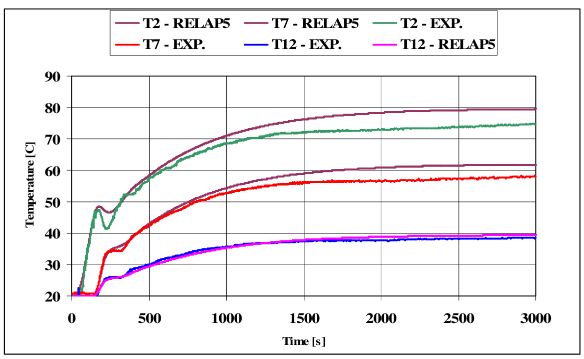


Figure 3. Comparison for the measured and calculated temperatures (one-phase flow).

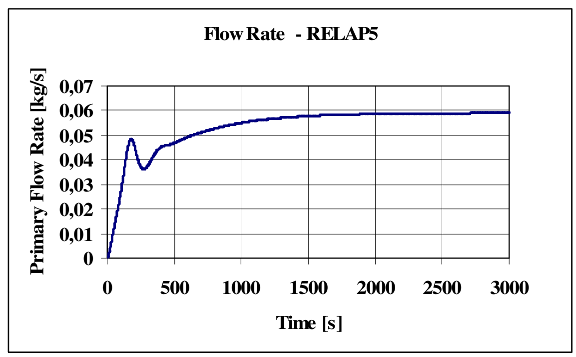


Figure 4. Primary flow rate calculated with RELAP5 (one-phase flow).

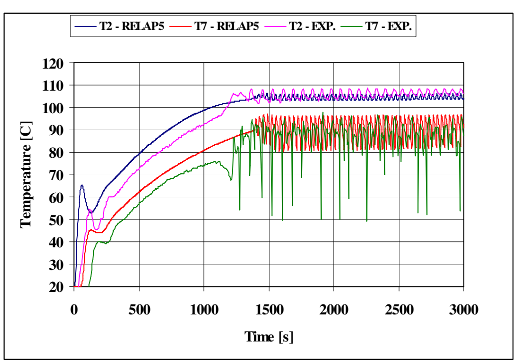


Figure 5. Comparison for the measured and calculated temperatures (two-phase flow).

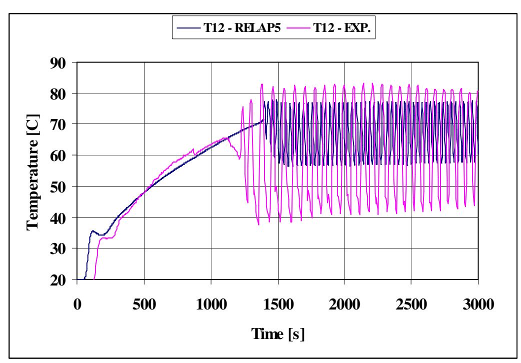


Figure 6. Comparison for the measured and calculated temperatures (two-phase flow).

6. CONCLUSIONS

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

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

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