Transient modelling of a natural circulation loop under variable pressure

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The objective of the present work is to model the transient operation of a natural circulation loop, which is one-tenth scale in height to a typical Passive Residual Heat Removal system (PRHR) of an Advanced Pressurized Water Nuclear Reactor, [1]. A long transient characterized the loop operation, during which a phenomenon of self-pressurization, without self-regulation of the pressure, was experimentally observed. This represented a unique situation, named natural circulation under variable pressure (NCVP). The self-pressurization was originated in the air trapped in the expansion tank and compressed by the loop water dilatation, as it heated up during each experiment.

The loop consists of a core barrel with electrically heated rods, upper and lower plena inter-connected by hot and cold pipe legs to a seven-tube shell heat exchanger of countercurrent design, and an expansion tank with a descending tube (Figure 1).

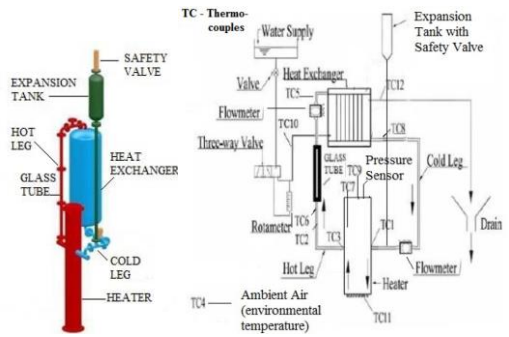

Figure 1. NCL main components (out of scale) and instrumentation.

The mathematical model, initially oriented to the single-phase flow, included the heat capacity of the structure and employed a cubic polynomial approximation for the density, in the buoyancy term calculation. The heater was modelled taking into account the different heat capacities of the heating elements and the heater walls. The heat exchanger was modelled considering the coolant heating, during the heat exchanging process. The self-pressurization was modelled as an isentropic compression of a perfect gas. The whole model was computationally implemented via a set of finite diference equations. The corresponding computational algorithm of solution was of the explicit, marching type, as for the time discretization, in an upwind scheme, regarding the space discretization. The computational program was implemented in MATLAB. Several experiments were carried out in the natural circulation loop, having the coolant flow rate and the heating power as control parameters. The variables used in the comparison between experimental and calculated data were some relevant loop temperatures and pressures, according to Figure 2 and 3.

In the case of the temperatures, a better agreement was obtained for the lower values, during the single-phase flow, to which the present model was oriented. In the case of the pressures, it was more difficult to obtain agreement between calculated and experimental data. Such difficulty arose because the NVCP pressure calculation was entirely based on the variation of the loop single-phase primary volume.

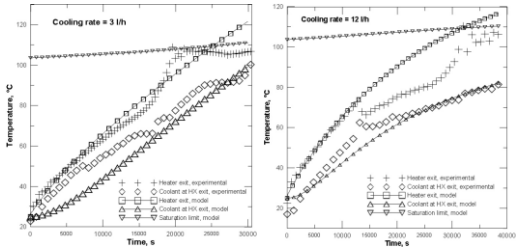

Figure 2. Comparison between experimental and modelled NCLtemperatures.

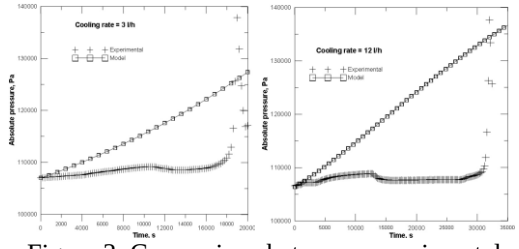

Figure 3. Comparison between experimental and modelled NCL pressure below the heater upper cover.

References

[1] VIANNA, A. L. B., FACCINI, J. L. H., SU, J. Transient modelling of a natural circulation loop under variable pressure. In: INTERNATIONAL NUCLEAR ATLANTIC CONFERENCE, ENFIR, 10., Belo Horizonte, 2017. **Anais…** Rio de Janeiro: ABEN, 2017, p. 1-80.