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Numerical Study of Subcooled Boiling In Vertical Tubes Using Relap5/Mod3.2

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Abstract--This paper presents a numerical study for prediction of the void fraction in subcooled boiling flow in the vertical pipes using the Relap5/Mod3.2 code system. This last is used for the study of the safety reactors, is an advanced computer code designed for best-estimate thermal hydraulic analysis of transient in light water reactor. Relap5 models represent the physical processes of critical flow, vertical or horizontal stratified flow, and heat transfer from heat structure. The numerical results agree satisfactorily with those of experimental and numerical results available in the literature.

I. INTRODUCTION

Subcooled boiling occurs in many practical applications, such as in nuclear reactors, heat exchangers, steam generators and various power generation systems. Prediction of the void fraction profile and others parameters in the subcooled boiling flows is essential for design and safety analysis of such system, like nuclear reactors and significant in test to many process industrie [1].

In the nuclear area, interest in the precise prediction of two-phase flow behaviors in subcooled flow boiling is of great importance to the safety analysis of nuclear reactors. Many years of extensive research work have been performed with the aim of developing and verifying various thermal-hydraulics codes, such as, TRAC, CATHARE and ATHLET and RELAP5 [14].

The prediction of void fraction in subcooled boiling flow in vertical pipes and channels has been the subject of numerous studies in the literature. Most of these studies are based on empirical correlations due to the complex nature of the subcooled boiling process. Zuber & al. developed an expression for the axial void fraction considering the relative velocity between two phases. Kroger and Zuber [3] developed an empirical formulation for the axial void fraction in a pipe depending on temperature, flow and local relative velocity. Levy [4] developed a formulation for the vapor volumetric fraction. Hu and Pan [5] developed a mechanistic model derived from a one-dimensional two-phase model. Zeitoun and Farouki [6] also developed a one-dimensional two-phase model that accounts for interfacial mass energy transport between two phases. Lai and Farouk [7] applied an advanced two phase model to subcooled boiling flow in a pipe.

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This model was very useful for predicting the axial and radial void fraction profile, temperature distribution and velocity profile in the pipe. M.D.Mat & al [8] used a bubble-induced turbulence model in subcooled boiling of water in a vertical pipe.

This study is focalized on the analysis of the numerical results for subcooled boiling in vertical tubes using Relap5/Mod3.2 thermal-hydraulic computer code; this last, is an analysis code system of realistic evaluation level. The main results of this study are compared with the experimental results of C.Bartolemi & al [1], and the numerical results of Larson and L.Tong [2] and M.Z.Podoswski & al [9]. The comparison shows that there is a good concordance between the Relap5/Mod3.2 results and literature operation data.

II. PROBLEM DESCRIPTION

Processes in a boiling flow, heterogeneous bubble nucleation occurs within small pits and cavities on the heater surface where these nucleation sites are activated and when the temperature of the surface exceeds the saturation temperature of the liquid at the local reassure. Here, bubbles are detached from the heated surface due to the forces acting on them in the axial and normal directions, which include buoyancy, drag, lift, surface tension, capillary force, pressure force, excess pressure force and the inertia of the surrounding [2]. If at the same location, the temperature of the bulk fluid remains below saturation, the boiling process is known as subcooled boiling flow. Subcooled boiling flow can usually be characterized by a high-temperature two-phase region near the heated wall and a low-temperature single-phase liquid away from the heated surface. Fig. 1 illustrates a typical axial development of the subcooled boiling process along the heated channel. It begins at a point called the onset of nucleate boiling (ONB). As it continues downstream from the ONB point, the void fraction begins to increase sharply at a location called the net vapor generation (NVG). The NVG point is the transition between two regions: low void fraction region followed by a second region, in which the void fraction increases significantly. Because of the bulk liquid remain mainly subcooled, bubbles migrated from the heated surface are subsequently condensed and the rate of collapse is dependent on the extent of the liquid subcooling. [2].

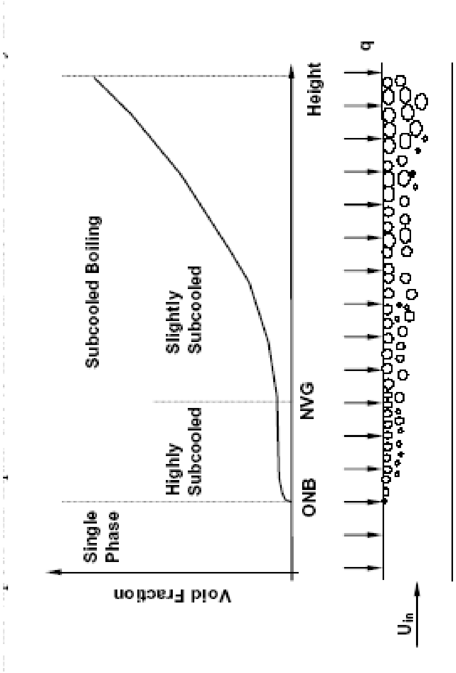


Fig. 1 Subcooled flow boiling regions

Subcooled flow boiling in this work was considered in a vertical heated pipe. Subcooled water enters the pipe from the bottom. Uniform heat flux boundary conditions are applied along the pipe wall. A 24 mm diameter pipe for the cases 1, 2, 3 and 15.4mm for the case4 are considered. The pipe length section is 2m. Specified pressure conditions were applied in the exit of the pipe. The numerical simulations were done at three pressure levels, namely, 1.5, 3.0, and 4.5MPa. For each pressure, three values of wall heat flux were considered, namely, 380 and 790 kW/m^2 for the first, second and third cases, and 570 kW/m^2 for the fourth case. These cases are chosen so that the predictions can compare with the experimental results from [1], and the numerical results of [2] and [9]. The inlet qualities and calculated subcooling and temperatures are shown in Table1.

Table1

Cases Considered

Cases	Inlet sub T (°C)	Inlet T (°C)	Outlet P (MPa)	G (kg/m^2.s)	q (kW/m^2)
Case1a	22.6	177.4	1.5	890	380
Case1b	50.9	149.1	1.5	890	790
Case2a	25.0	210.0	3.0	890	380
Case2b	48.1	186.9	3.0	890	790
Case3a	24.0	231.0	4.5	890	380
Case3b	50.0	205.0	4.5	890	790
Case4	64.5	465.5	4.5	900	570

III. NODALISATION AND SIMULATION

A. Presentation of Relap5/Mod3.2

The light water reactor (LWR) transient analysis code, Relap5/Mod3.2, was developed at the Idaho National Engineering Laboratory (INEL) for the US Nuclear Regulatory Commission (NRC). Code uses include analysis required to support rulemaking, licensing audit calculation, evaluation of accident mitigation strategies, evaluation of operator guidelines, and experiment planning analysis. Relap5/Mod3.2 has also been used as the basic for a nuclear plant analyzer. Specific applications have included simulation of transients in LWR systems such as loss of coolant. Relap5/Mod3.2 is a highly generic code that, in addition to calculating the behavior of a reactor coolant system during a transient, can be used for simulation of a wide variety of hydraulic and thermal transients in both nuclear and nonnuclear system involving mixture of steam and water. The Relap5/Mod3.2 hydro-dynamic model is based on non-homogeneous, no equilibrium, six equations system for the two phases system that solved by a fast, partially implicit numerical scheme to permit economical calculation of system transients. The general solution procedure is to subdivide the system into a number of control volumes connected by flow paths. The code includes many generic components models from which general systems can be simulated. The component models include pumps, valves, pipes, heat structures, reactor point kinetics, separators, control system components, etc. The conduction heat transfer model is one-dimensional, using a staggered mesh to calculate temperatures and heat flux vectors [10, 11].

B. Tube Modeling

The aim of this work is the numerical study of numerical study of subcooled boiling in vertical tubes using Relap5/Mod3.2. The nodalisation of the tube for the Relap5/Mod3.2 code is given in the Figur.2. The philosophy of using Relap5/Mod3.2 code consists in subdividing the tube in volumes of control connected by junctions of flow**.** The tube model includes 8 regular volumes, 7 junctions and 8 heat structures**.** The heat structure included in the model simulate the behavior of the material mass, and heat transfer between the material mass and the fluid in the tube. The thermo-hydraulic conditions at the inlet and outlet of the pipe were imposed by the Time-Dependent Volume, Time-Dependent Junction and Single Junction model, component *TMDV-100 and TMDJ-110, TMDV-200* et *SJ-120.* The heat densities involved between the thermal flux and the external tube surface are imposed by table entry.

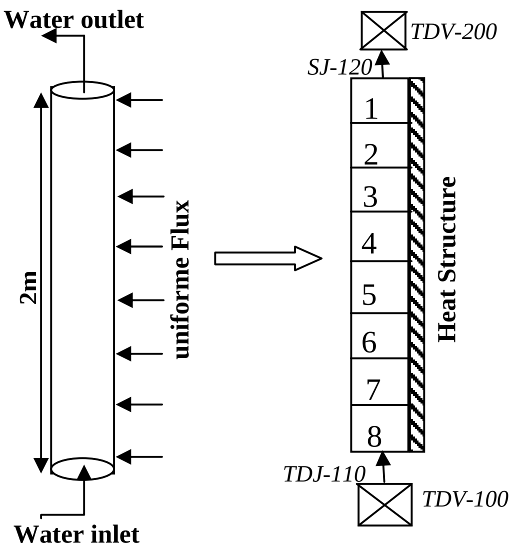
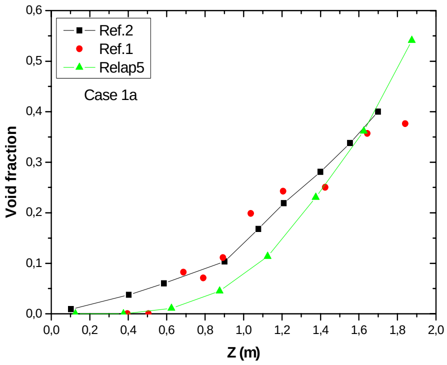
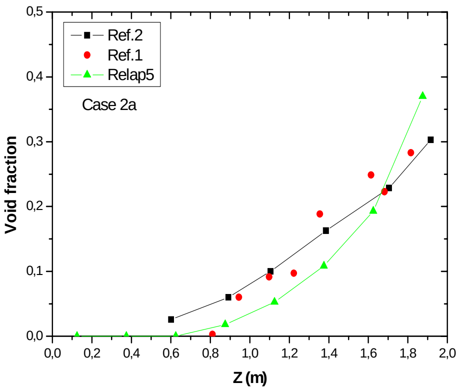


Fig.2 Nodalization scheme of the pipe.

IV. RESULTS AND DISCUSSION

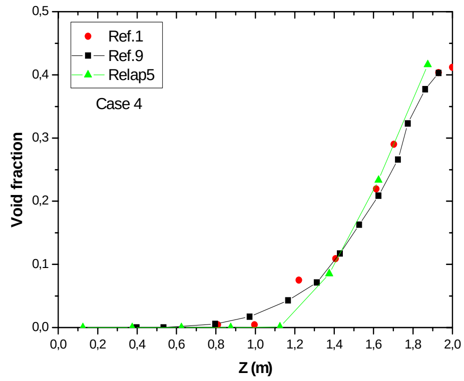
The code system Relap5/Mod3.2 was applied to predict the void fraction for subcooled flow boiling in a vertical pipe for different flow and wall heat flux conditions. There is four cases were considered for the vertical pipe as shown in Table1. Lower inlet subcooling and lower wall heat flux were considered for cases 1a, 2a and 3a. Higher inlet subcooling and higher wall heat flux were given to cases 1b, 2b, 3b and 4.

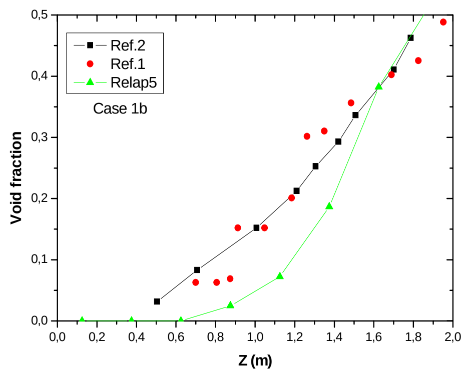


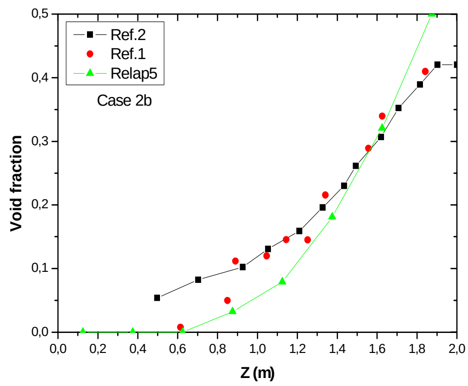


The effects of the exit pressure, inlet subcooling and wall heat flux on the subcooled flow boiling can be determined from the results of these cases. The estimate axial void fraction distribution along the pipe for the all cases is given in the figure 2. The numerical results of this study are compared with the experimental data of Bertolemei and Chanturiya [1], and the numerical data of Lai and Frouk [7] and Larsen and Tong [2].

It is seen that the main results gotten by the code Relap5/Mod3.2 of this work and the data of [1], [2] and [7] are in good agreement. So there is somewhat lower than the experimental data [3] at the bottom half of the pipe, the predictions at the upper half of the pipe are, however, agrees well with the results data. The differences are considered acceptable. The deviations are essentially due to the models of heat transfer used by the code Realp5/Mod3.2. The present results estimate the initial point of vapor generation better in all the cases compared whit the experience data.







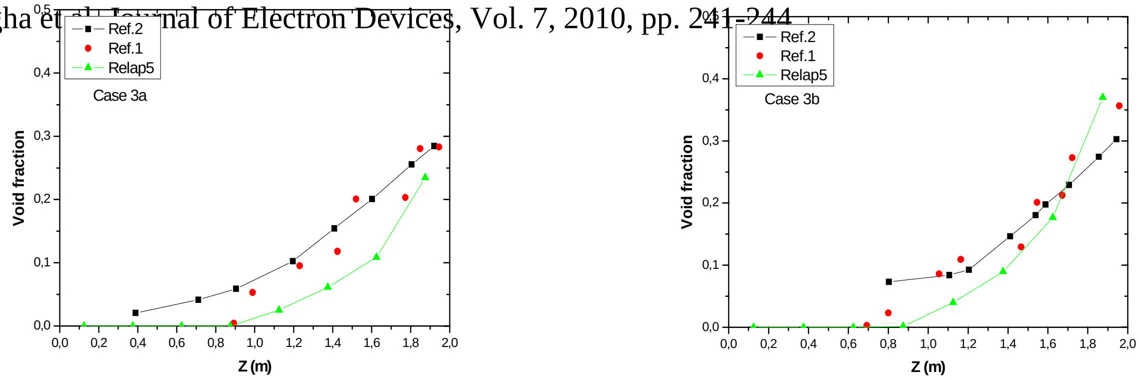


Fig.3 Comparison of axial void fraction

V. CONCLUSION

This work is focused on the numerical study of subcooled boiling in vertical tubes using the thermal hydraulic code system Relap5/Mod3.2. The validation of the results has been made with comparing the theoretical results of the RELAP5/Mod3.2 code whit the experimental and numerical data in the literature with the same conditions of experience (pressure, mass flow rate, tube diameter and heat flux), for a vertical tube heated uniformly in steady-state. The gotten theoretical results are in good agreement with the data. The present results estimate the initial point of vapor generation better in all the cases compared with the experience data. Is show the reliability of the thermo hydraulic code Relap5 in the analysis of subcooled boiling flow.

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