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The study of gas injection modes from a long tube to a channel filled with liquid

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Abstract. The results of experimental and numerical studies of the gas phase injection into the liquid column and sudden gas-liquid interaction are presented. Experimental study was performed by means of high-speed shadowgraph and analysis of signals of pressure transducers. The numerical part of the work was carried out using the OpenFOAM software. The data about void fraction distribution and pressure evolution are presented. In general, a good agreement between the experimental and calculated data was found. The data obtained can be used for verification and validation of different numerical codes, as example ones for the prediction of the process of the steam generation leakage on nuclear power plant.

1. Introduction

One of the most dangerous accidents in heavy liquid metal (HLM) cooled reactors is the steam generator tube rupture (SGTR). If it happens, the following phenomena could be observed:

- pressure fluctuations in lead coolant flow with very high amplitudes;
- injection of steam bubbles into the coolant, generation of steam cavities near the breakdown point;
- fluctuations of the level of lead coolant connected with pressure fluctuations in upper gas blanket;
- bubble occurrence in the main pump and the core (uncontrolled change of reactivity).

This is a reason why the studies of gas or vapor injection in HLM are suitable for nuclear reactor safety. Two main regimes can occur when the steam generator heat exchange pipe is damaged. In the case of small damage, the small leakage will take place [1-7]. To study another one (large leakage), a large-scale experimental facility was utilized [9]. But some information about the phenomena of gas-coolant interaction could be determined from relatively simple experiments, as an example, from the studies of light phase injection to the liquid column.

Earlier, the authors carried out numerical and experimental studies of pulsed gas injection into a vertical pipe filled with liquid (water or HLM) with a diameter of 25 mm from a cylinder under pressure via the solenoid valve [10, 11]. As it is difficult to construct the numerical model of the valve, the verification of the thermal-hydraulic code HYDRA/IBRAE/LM was performed using the experimental data as a boundary conditions (the volume of the injected gas, the initial front velocity, the change in the liquid column level etc.) [11].

To model processes which occur in real emergency in a steam generator, a continuous injection is more preferable. In contrast to previous works the goal of this study is experimental (by means of flow shadow visualisation and pressure transducers signal analysis) and numerical (by using OpenFOAM)



investigation of gas injection from the straight overpressure pipe into the liquid column. The pinched rubber pipe was used instead the solenoid valve. Due to this simplification of the test section, we can minimize the quantity of simplifications of the numerical models. This allows us to satisfactory predict the processes of gas injection in the liquid column both by CFD approaches and thermal hydraulic codes using just initial parameters of experiments (initial pressure, liquid column height).

2. Experimental setup and numerical scheme

Due to the small volume of tubes, the pressure waves inside a long thin tube can change the outflow mode. In this study (as opposed to [10, 11]) the gas was injected from a thin tube 1 m long. The volume of this tube was filled with air. A rubber tube was used as a valve between the tube and the liquid column. Quick opening of the channel was released by means of weakening a clamp mounted on the rubber tube. The time for “valve” opening was about 5-10 ms.

The scheme of the experimental setup is shown in Figure 1.a. It consists of a tube with high pressure air 1, a rubber tube (valve) 2, an inlet injector 3, a working channel pipe 4. In the lower part of tube 1 there was an inlet valve V which was connected to the high-pressure line P_0 . The internal diameter of the tube with a high pressure was $d_1 = 6$ mm, the length of the tube was $h_1 = 1020$ mm. The length of the rubber tube (valve) was $h_r = 60$ mm, the inner diameter was $d_r = 8$ mm. The length of the injector was $h_i = 40$ mm, the internal diameter of the injector was $d_i = 6$ mm. The height of the test section was $h_c = 1200$ mm, internal diameter was $d_c = 25$ mm. The high-speed camera (frame rate 400 fps), was utilized to obtain information about the dynamics of the process. Figure 1.b – 1.d shows the axisymmetric computational domain. As it was noted above, numerical simulation was performed using the OpenFOAM code. The area is made in the form of a sector (Fig. 1.b – frontal projection, Fig. 1.c – lateral projection, Fig. 1.d – axonometric projection).

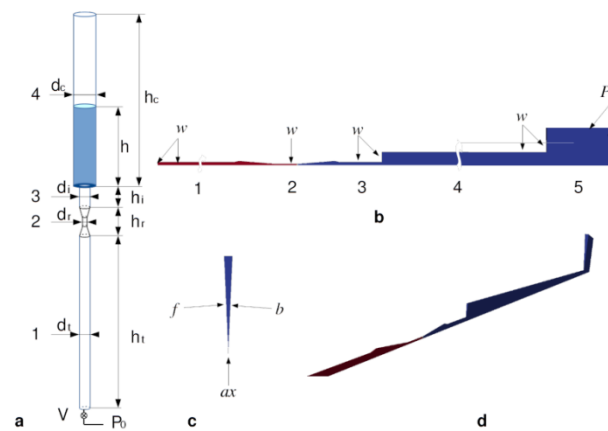


Figure 1. Scheme of the test section (a) and calculation area: frontal projection (b), side projection (c), axonometric projection (d): 1 – tube with high pressure air, 2 – rubber tube, 3 – injector, 4 – test section, 5 – receiver, V – valve, P_0 – high pressure line, h_1 – tube length, d_1 – tube diameter, h_r – rubber tube length, d_r – rubber tube diameter, h_i – injector length, d_i – injector diameter, h_c – channel length, d_c – channel diameter, h – water level, w – wall type condition, P_a – inflow condition at atmospheric pressure, ax – condition type axis of symmetry, b – condition type edge mating – back, f – condition type edge mating – front.

The geometry of the experimental setup and the computation domain were the same. The receiver was introduced into the computational domain (Fig. 1.b) 5 for a stable calculation with matching of the boundary inflow and outflow at constant pressure $P_a = 101.3$ kPa. The Figure 1.b shows the initial pressure distribution (red is the high pressure area, blue is the low pressure area). The condition of the axis of symmetry type ax was set at the edge of the sector angle (Fig. 1.b). At the initial moment of time,

the pressure $P_a = 201.3\text{--}601.3$ kPa was established in tube 1. The rubber tube was compressed so that the flow area was zero. Full opening of the rubber tube occurred to be 10 ms. The injector 2 was filled with water, the working volume was filled at the level $h = 500$ mm. The problem was solved by the “compressibleInterFoam” solver in the OpenFOAM package [8]. The calculation method is described in detail in [10, 12].

3. Results of the study

After the rubber tube was opened, a complex process of the gas-liquid interaction was started. It can be affected by many different factors. We compared the cases with equal initial pressure but different orifice of gas injection as an example. In one case the orifice diameter was 6 mm. At another one, a diaphragm with inner diameter of 2 mm was mounted on the top of the orifice. Figure 2 shows the experimental evolution of the interphase surface during the injection of air ($P_0 = 200$ kPa) into water at different times in the absence (Fig. 2 a) and in the presence of a diaphragm (Fig 2 b). During injection in the absence of a diaphragm, a substantial dispersion of gas into bubbles occurs. In the presence of a diaphragm, the gas phase grows in the form of one large gas bubble.

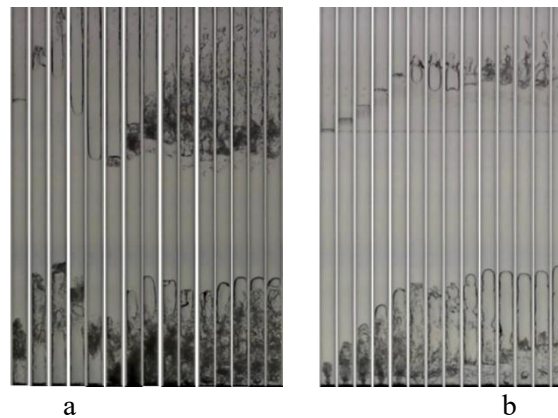


Figure 2. The development of the interphase surface during the injection of gas (air) into water at different points in time; top - no diaphragm, bottom - aperture with a hole of 2 mm., time between frames 25 ms.

Experimental and numerical studies were performed for both cases (with and without diaphragm) and different liquid levels and initial pressures. Examples of the results of our studies which were obtained for overpressure of 100 kPa are presented in the figures below.

The data of experimental visualization of the flow structure (see Fig. 3a) and the numerical data about void fraction distribution (see Fig. 3b) were compared. In general, a good agreement was found. At the initial time the gas cavity was formed. After that, the gas cavity grew, and void fraction level increased. This relates to the pressure decrease both in the liquid column and the long tube initially filled by air (see Fig. 4). After that the liquid was started to go down which leads to a decrease in the void fraction. At this time period the bubble is compressed, and the pressure is growing. A good agreement was found between the experimental and numerical results for the initial study of the process. After the moment when the liquid column starts to move down, a difference was found for the experimental and numerical results obtained inside the long tube.

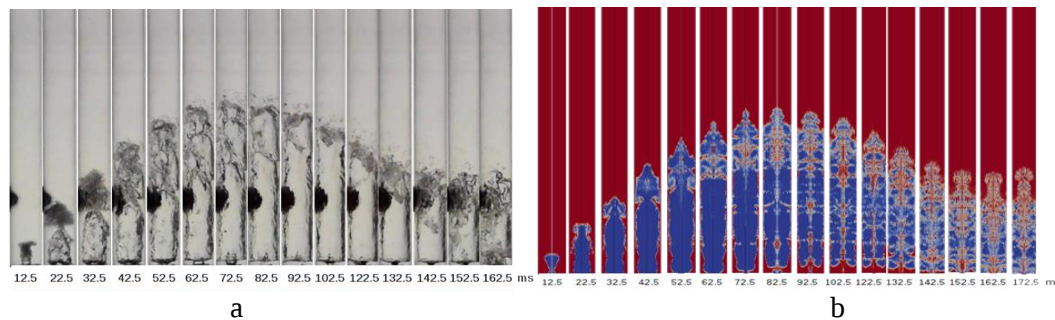


Figure 3. Experimental (a) and numerical (b) phase dynamics, overloads pressure 1 Bar.

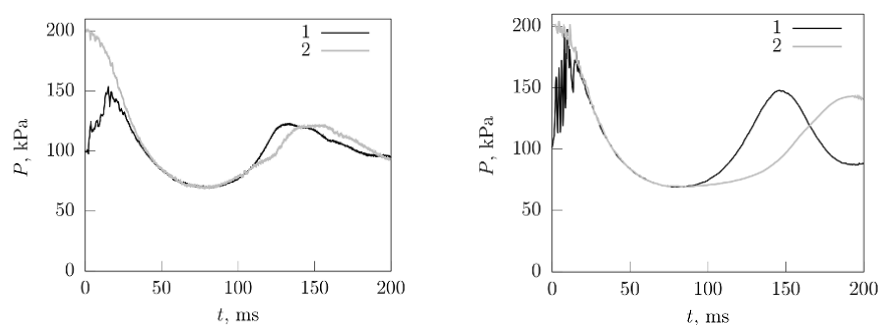


Figure 4. Experimental (a) and numerical (b) pressure dynamics, $P_0 = 1$ Bar: 1 – pressure inside the liquid column; 2 – pressure at the center of the long pipe.

The difference in pressure behavior in the test section for experimental data and numerical results can be explained by the effect of blocking of the output of the long tube. In the calculation there is a complete blocking by liquid; in the experiment partial blocking is observed. The complete blocking in calculations is obtained due to the restriction of the computational grid and inability to calculate in detail the dispersion-annular flow at the exit of a long tube (see Fig. 4).

Conclusions

Experimental and numerical study of the gas phase injection into the liquid column and sudden gas-liquid interaction was carried out. To perform calculations using just initial conditions of experiments, the experimental model was simplified in comparison to previous studies [11]. A rubber tube was used instead of the solenoid valve and long tube was used instead of the pressured tank. The data about void fraction distribution and pressure evolution are presented. A good agreement between the experimental and numerical data was found. The data can be used to test various numerical approaches to predict the processes that can occur when a light phase suddenly interacts with liquid media (for example, SGTR).

Acknowledgments

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References

- [1] Saito Y, Mishima K and Matsubayashi M 2006 *International Heat Transfer Conference 13* (Begel House Inc.)
- [2] Takahashi M, Sofue H, Iguchi T, Pramono Y, Huang F, Matsumoto M, Matsuzawa T, Uchida S et al. 2005 *Progress in Nuclear Energy* **47** 569–76
- [3] Jeltsov M 2011 *Application of cfd to safety and thermal-hydraulic analysis of lead-cooled systems*
- [4] Abdulla S H, Liu X, Anderson M H, Bonazza R, Corradini M L, Cho D and Page R 2005 *Nuclear*

- science and engineering* **150** 182–220
- [5] Abdulla S H, Liu X, Anderson M, Bonazza R, Corradini M, Cho D, Page R and Hurtault D 2002 *10th International Conference on Nuclear Engineering* (American Society of Mechanical Engineers) pp 607–12
 - [6] Cho D, Page R, Hurtault D, Abdulla S, Liu X, Anderson M, Bonazza R and Corradini M 2002 *Direct contact heat exchange interfacial phenomena for liquid metal reactors: Part i-heat transfer. Tech. rep.* (Argonne National Lab., IL, US)
 - [7] Takahashi M, Yumura T, Yoda I and Sa R 2010 *18th International Conference on Nuclear Engineering* (American Society of Mechanical Engineers) 533–9
 - [8] The OpenFOAM Foundation, OpenFOAM v5 User Guide <https://cfd.direct/openfoam/user-guide>
 - [9] Pesetti A, Forgione N and Del Nevo A 2014 *22nd International Conference on Nuclear Engineering* (American Society of Mechanical Engineers) V003T05A009
 - [10] Alekseev M V, Vozhakov I S, Lobanov P D, Svetonosov A I, Mohan V K, Lezhnin S I and Pribaturin N A 2018 *Journal of Physics: Conference Series* **1105** 012085
 - [11] Lobanov P D, Usov E V, Butov A A, Pribaturin N A, Mosunova N A, Strizhov V F, Chukhno V I and Kutlimetov A E 2017 *Thermal Engineering* **64** 770–6
 - [12] Lezhnin S I, Alekseev M V and Vozhakov I S 2018 *Journal of Physics: Conference Series* **1128** 012037