EPJ Web of Conferences **196**, 00031 (2019) https://doi.org/10.1051/epjconf/201919600031
AVTFG2018

Simulating the boiling fluid outflow taking into account external condensation

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Abstract. This paper considers the axisymmetric problem of condensation at a boiling liquid outflow in a closed region filled with steam. It has been found that the unsteady condensation is due to the formation of a complex structure of lateral pressure surges, Mach disk, barrel shocks and a wall, on which the pressure exceeds the local saturation pressure.

1 Introduction

When depressurizing tanks and pipelines of power plants filled with water under high pressure, superheated water is released with a sharp decrease in pressure in the rupture zone, with the formation of a compression wave in the surrounding space and further formation of the boiling coolant jet. In previous works [1, 2] the outflow was simulated into the area with free inflow-outflow at the boundaries. As a result, there was no reflection of pressure waves and the pressure in the outer region did not rise above the local saturation pressure. The aim of this work is to study the effect of a closed region filled with steam on the condensation process in the outer region of the boiling jet.

2 Methods

This study considers the axisymmetric problem, the scheme of the computational domain of which is shown in Figure 1. The closed external volume is simulated by setting the boundary condition of “wall” - type at the external boundaries (designated as “a” in the figure). Inside the region there is a pipe channel with an internal radius $r = 20$ mm, an external radius $R = 24$ mm and a length $l = 150$ mm. At the initial time inside the channel there is water with an initial pressure $P_0 = 15.5$ MPa and a temperature $T_0 = 270$ ^{O}C. In a closed region there is saturated steam at atmospheric pressure $P_1 = 0.1013$ MPa. At the inlet of the pipe channel there is "Cauchy-Lagrange" condition of k-type described in detail in [3]. The physical model is described by a homogeneous model in one-velocity approximation with two temperatures and one pressure. Description of the phase transition requires the use of: the model based on processing the experimental data on relaxation (transition) time "nonequilibrium - equilibrium boiling" [4], thermodynamically equilibrium model and analytical relaxation model proposed in [5] and based on the

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analysis of interfacial heat fluxes "steam – superheated liquid". Calculation of steam and water properties is carried out using the TTSE software package [6]. The problem is solved using the computational complex LCPFCT [7]. A detailed description of the physical model is presented in [1, 2, 5].

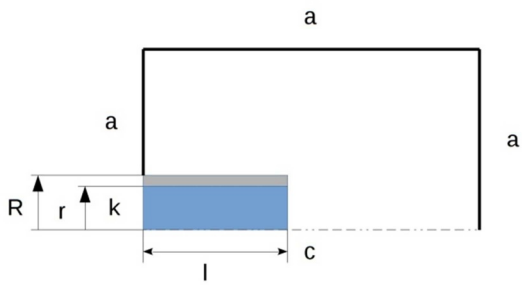

Fig. 1. Scheme of the computational domain: c – axis of symmetry, a – boundary condition of the "wall" type, k - boundary condition of the "Cauchy-Lagrange" type [2], *l* – channel length, *R* – outer radius of the channel, *r* – inner radius of the channel.

3 Results

Figure 2 shows axial profiles of steam quality and pressure over time at different distances from the end wall of the outer region to the edge of the pipe channel. The distance to the wall was 50, 100 and 200 mm.

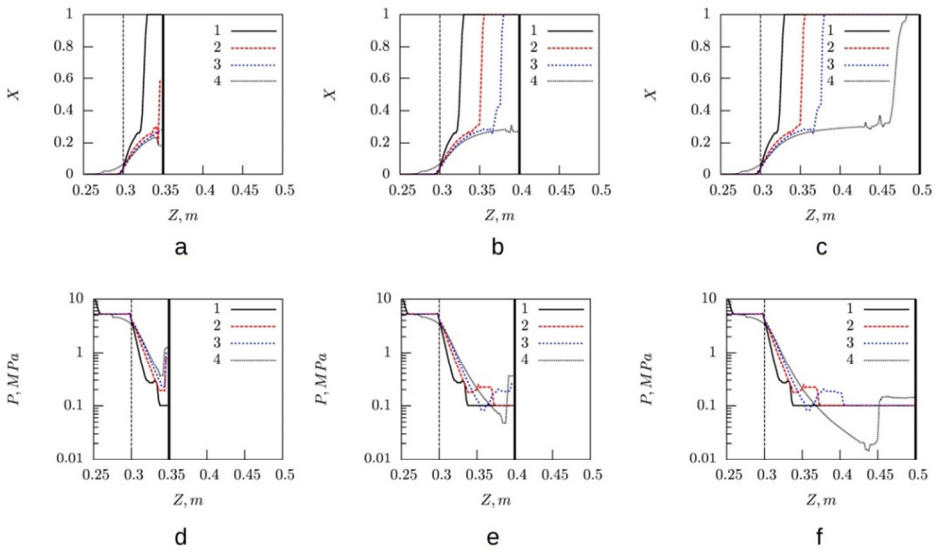

Fig. 2. Axial profile of steam quality – a,b,c and axial pressure profile – d,e,f at time : 1 – 50 μs, 2 – 100 μs, 3 – 150 μs, 4 – 1000 μs, vertical dotted line – coordinate of the channel edge, and vertical bold line – coordinate of the wall.

At a distance of 200 mm to the wall in a closed area a compression wave generates and moves to the wall (Figure 2f) causing a wave of condensation (Figure 2c). When the compression wave is reflected there is the formation of pressure profile (Figure 2f, line 4) (t=1000 μs), where an area of low pressure is realized at jet expansion and abruptly passes

into a region of high pressure near the wall. In this area, the steam quality (Figure 2c, line 4) is close to 1, and the pressure is (~0.15 MPa).

When the distance is reduced to 100 mm to the wall, the initial front of pressure and condensation (Figure 2 b and e), as in the previous case, propagates to the wall. Then, a region of reduced pressure with jet expansion is formed, and an area of increased pressure (Figure 2e, line 4) (t = 1000 μs) is observed near the wall. The pressure near the wall increases to ~0.4 MPa, while the steam quality does not change during the transition through the pressure surge (Figure 2b, line 4).

Reducing the distance to 50 mm leads to the fact that the compression wave together with the condensation front are quickly reflected from the wall, and already at a time of 150 μs the areas of low and high pressure have formed in the outflow (Figure 2b, line 3). In this case, the steam quality near the wall falls (Figure 2a, line 3), and the pressure increases (Figure 2b, line 3). Further, in the area near the wall (Figure 2b, line 4) at time t = 1000 μs, the pressure surge increases from 0.4 to 1.05 MPa, and the steam quality decreases from 0.3 to 0.18 (Figure 2a, line 4).

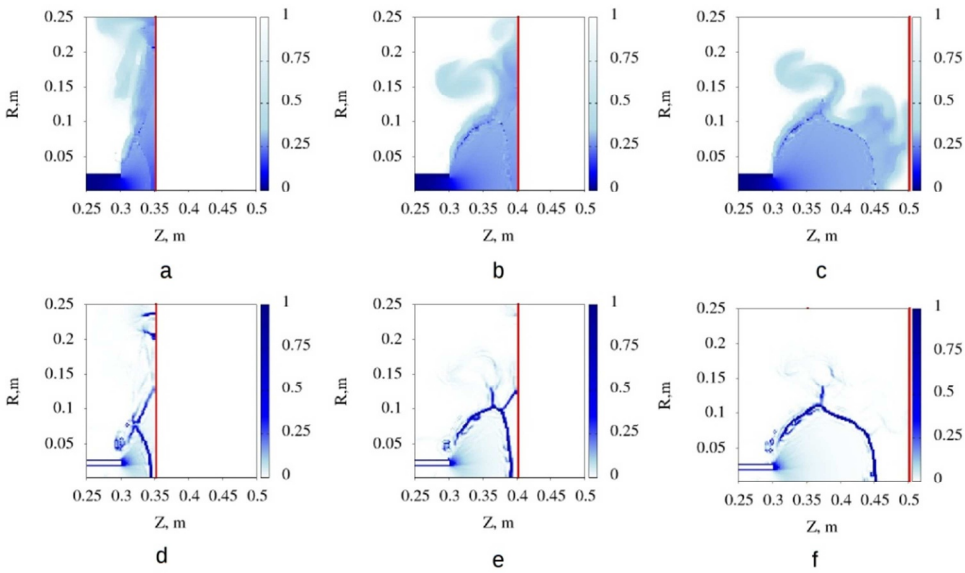

Fig. 3. Field of steam quality – a, b, c and normalized pressure gradient field – d, e, f at the time of 1000 μs, vertical red line – wall location.

Let us consider the field of steam quality and the field of normalized pressure gradient at the time of 1000 μs for different distances from the end of the pipe channel to the end of the outer wall (Figure 3). Figure 3.d-f shows that there are pressure surges in the space relative to the pipe section and the outer wall. It may be noted that the structure of pressure surges is close to the quasi-stationary gas-dynamic outflow from the nozzle to the wall, experimentally fixed for superheated steam [8] and numerically calculated in [2]. The process of phase transition dramatically changes the pattern of gas-dynamic discontinuities.

For a distance of 200 mm from the channel to the wall (Figure 3f) the Mach disk and lateral surges degenerate into a spherical shape as opposed to a barrel shape for the outflow of superheated steam. Because of this, a stagnant zone is realized in the area near the wall, where there is no condensation of steam (Figure 3c).

Reducing the distance to 100 mm (Figure 3e) leads to the fact that near the wall there is increased pressure, limited by the Mach disk and lateral barrel shocks closed on the wall. The structure of lateral surges with the Mach disk degenerates into a conical shape. The

steam quality does not change at the transition through the Mach disk and lateral pressure surges (Figure 3b).

For a distance of 50 mm from a closed area near the wall bounded by the Mach disk and the lateral barrel shock (Figure 3d) the condensation region is formed (Figure 3a). The highest condensation intensity is observed near the axis.

The research shows that in the presence of the wall in the outer region, the condensation is possible during the depressurization of the boiling coolant. Non-stationary condensation is due to the formation of the complex structure of lateral pressure surges, the Mach disk, the barrel shocks, and the wall, where the pressure is above the local saturation pressure. It is shown that the presence of a phase transition changes the shape of the Mach disk, and the distance between the wall and the pipe channel leads to a decrease in pressure near the wall and a decrease in the intensity of condensation.

The work was financially supported by state contract III.22.7.3.

References

1. M.V. Alekseev, I.S. Vozhakov, S.I. Lezhnin, N.A. Pribaturin, Thermophysics and Aeromechanics **23**, 6 (2016)
2. M.V. Alekseev, M.E. Kuznetsova, S.I. Lezhnin, N.A. Pribaturin, J. Phys. Conf. **754**, 042001 (2016)
3. G.V. Hoffmann, A.E. Kroshilin, B.I. Nigmatulin, High Temperature **19**, 6 (1981)
4. P. Downar-Zapolski, Z. Bilicky, L. Bolle, J. Franco, Int. J. Multiphase Flow **22**, 3 (1996)
5. S.I. Lezhnin, M.V. Alekseev, I.S. Vozhakov, N.A. Pribaturin, Interfacial Phenomena and Heat Transfer, **6**, 1 (2018)
6. *Guideline on the Tabular Taylor Series Expansion Method for Calculation of Thermodynamic Properties of Water and Steam Applied to IAPWS-95 as an Example*. The International Association for the Properties of Water and Steam (2003)
7. J.P. Boris, A.M. Landsberg, E.S. Oran, J.H. Garder, LCPFCT - *Flux-Corrected Transport Algorithm for Solving Generalized Continuity Equation* (Report NRL/MR/6410-93-7192, 1993)
8. F. Masuda et.al, Nuclear Engineering and Design **67**, 2 (1982)