Post-test Analysis of Coolant Discharge under LB LOCA Modeling on the Test Facility BC V-213 with ATHLET Code

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ABSTRACT

In this work post-test analysis of thermalhydraulic processes in the high-pressure system is presented. Main parameters for adequate simulation of loading on BC (Bubble-Condenser) during LB LOCA are coolant mass flow rate and enthalpy. Measurement system permits to determine only flow rate and enthalpy for single phase cases (liquid or vapor), which occur at the initial and final stages. So, the main aim of the post-test analysis is to reproduce behavior of all available test parameters by ATHLET mod 1.2 Cycle A code and determine leak functions based on a good agreement of calculated and experimental data.

1 INTRODUCTION

The pressurized water reactors type VVER 440-213 (Russian design) are equipped with a confinement structure for the confinement of radioactive releases following design basis accidents. The confinement structure consists out of the pressure retaining compartment which surrounds the complete primary system and a pressure retaining bubble condenser system comprising a complex pressure-suppression system and air traps.

The main objective of the TACIS/PHARE Project No. PH 2.13/95 “Bubble Condenser Experimental Qualification” was to investigate experimentally and analytically the behavior of the bubble condenser devices during phenomena induced by postulated design basis accidents. In the framework of Task 2 of the TACIS/PHARE Project No. PH 2.13/95 the experimental test facility for bubble condenser experimental qualification has been built at Electrogorsk Research and Engineering Centre.

The test facility contains high-pressure system, compartments upstream of the bubble condenser and fragment of the bubble condenser. The scaling of the test facility is 1:100. The high-pressure system is consisted of five vessels to appropriately model the leak functions (mass flow rate and enthalpy) during the loss of coolant accidents postulated in the design of VVER-440/213.

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2 SHORT OVERVIEW OF BC V-213 TEST FACILITY

The test facility for thermal-hydraulic testing BC V-213 is located in a separate building designed and built specially for this purpose. There are reinforced concrete boxes in the building, which are models of the hermetic compartments of Paks NPP confinement with a full-scale fragment of bubble condenser, and all major equipment necessary for the test facility operation and testing. The general view of the test facility is presented in Fig.1.

The models of hermetic compartments of Paks NPP confinement structure are made at a scale of 1:100 in volumes and flow sections [1]. They are dead volume, two Steam Generator (SG) boxes, accident localization shaft with a full-scale BC fragment and air trap.

To provide required initial conditions of the coolant discharging in the boxes, the high-pressure system is used, which consists of five vessels (V1, V2, V3, V4 and V5). The volumes of the vessels are chosen to provide discharge of steam-water mixture under various accident conditions (LB LOCA, MB LOCA, SB LOCA and MSLB).

![General view of the test facility](image)

Figure 1: General view of the test facility (1 – air trap; 2 – water treatment installation vessels; 3 – steam generator box No.2; 4 – bubble condenser; 5 – BC shaft; 6 – steam generator box No.1; 7 – dead volume)

The high-pressure vessels are located much close to the boxes for reduction of the length of the blowdown lines. There are three positions of the coolant discharge in the SG box: near the corridor to simulate air-steam mixture with maximum concentration of the steam, far from the corridor to simulate air-steam mixture with maximum concentration of the air and middle position.

3 TESTS N1, N4 AND N5

The same configuration of the high-pressure vessels is used for tests N1, N4 and N5:

- vessel V1, modeling “cold” part of coolant of primary side;
- vessel V2, modeling “hot” part of coolant of primary side;
- vessel V5, modeling pressurizer;
- vessels V3 and V4 were disconnect by appropriate valves.

Initial and boundary conditions are presented in Table 1. Initial temperature distribution is determined in accordance with available experimental data.
Table 1: Initial and boundary conditions

<table>
<thead>
<tr>
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<th>Pressure, MPa</th>
<th>Blowdown line position</th>
<th>Nozzle diameter, mm</th>
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</thead>
<tbody>
<tr>
<td>Test N1</td>
<td>12.4</td>
<td>Middle</td>
<td>45</td>
</tr>
<tr>
<td>Test N4</td>
<td>12.4</td>
<td>Near</td>
<td>70</td>
</tr>
<tr>
<td>Test N5</td>
<td>12.4</td>
<td>Far</td>
<td>70</td>
</tr>
</tbody>
</table>

4 POST-TEST ANALYSIS WITH ATHLET CODE

ATHLET code [2] was applied for post-test analysis of these tests.

The ATHLET input deck describes all five vessels with connected and blowdown pipelines with corresponding valves. Nodalization scheme of the high-pressure system is presented in Fig.2.

Scheme consists of 37 thermofluid objects with 309 control volumes and 314 junctions. Also 26 heat structures with 298 layers are used for description of tubes and vessels walls and thermoinsulation. The object AMBIENT (TDV) with constant pressure 0.1 MPa and temperature 25 °C is used to model heat exchange with environment. Heat transfer coefficient from the surface of thermoinsulation to environment equals 10 W/(m²K).

Figure 2: Nodalization scheme of high-pressure system of BC V-213 test facility

Comparison of experimental and calculated data is presented in Figs.3-8.

The main difference of tests N4 and N5 from the test N1 is larger diameter of rupture disc – 70 mm (45 mm for test N1). The larger diameter of leak leads to more rapid emptying of the high-pressure system and stronger non-equilibrium processes.

After the rupture of the disc, the pressure in the vessels V1 and V2 is sharply decreased down to ~7.12 MPa (Test N1). Note, that saturation pressures corresponding to initial temperatures of water in V1 (271.5 °C) and V2 (298.5 °C) are 5.63 MPa and 8.41 MPa, respectively. So, coolant flashing begins in the “hot” vessel V2 after pressure decreasing at
1.29 MPa compared with saturation value, liquid superheating achieves 11.5 K. But in the vessel V1 the water is kept subcooled. After initial sharp decreasing, the pressure in the vessels V1 and V2 increases up to ~7.6 MPa and then gradually decreases.

**Figure 3:** Experimental and calculated pressure in the vessels (Test N1)

**Figure 4:** Experimental and calculated temperature in the blowdown line (Test N1)

ATHLET evaporation model uses parameter ZBO characterizing initial number of vapour bubbles in the liquid. The reduced value of the bubbles permits to achieve strong non-equilibrium processes. Recommended number of vapour bubbles is ZBO=5·10^9 m^-3. Reduction of this parameter down to ZBO=10^6 m^-3 provides reproduction of the initial decreasing of the pressure in the vessels V1 and V2. This is explained by the decreasing of vapor generation rate due to decreasing of ZBO parameter.

As for tests N4 and N5, in Test N1 in the V1 vessel the temperature is kept constant at the initial stage (~3-4 s), then it grows with supply of the hot water from V2. The water is
subcooled during ~10 s. In V1 all temperature measurements, except for T.71.06, show approximately uniform readings. Calculation provides non-uniformity of temperature distribution during initial stage.

In the blowdown pipeline pressure and temperature are close to ones in the V1. Comparison of the coolant temperature in the blowdown pipeline with saturation temperature shows that subcooled water flows out during 11 s (Test N1), then discharging two-phase mixture occurs. So, measurement of the flow rate is correct only for 11 s of the test N1 (Fig.7).

It should be noted that besides changing of ZBO, parameter DSCON was also changed to predict flow rate F.76.01 at the initial stage, DSCON=70 mm (Test N1), DSCON=20 mm (Tests N4 and N5).

![Figure 5: Experimental and calculated pressure in the vessels (Test N4)](image)

![Figure 6: Experimental and calculated temperature in the blowdown line (Test N4)](image)
Figure 7: Experimental and calculated mass flow rate in the blowdown line (Test N5)

Figure 8: Calculated coolant enthalpy through the break (Test N5)

CONCLUSIONS

The nodalization scheme of high-pressure system and appropriated input deck were developed and calculations of coolant discharge were carried out with ATHLET code. In general, satisfied agreement between calculated and experimental data was obtained. The post-test analysis has revealed that correct modeling of non-equilibrium processes of evaporation and related initial decreasing of pressure was possible only under diminished value of initial concentration of vapour bubbles, which governed evaporation dynamics and liquid superheating. The corresponding dependencies of flow rate and enthalpy of discharged coolant were taken as leak functions.
REFERENCES
