MODELING OF GAS MIXING PROCESSES IN THE PRESENCE OF NEAR-WALL CONDENSATION IN THE PROBLEMS OF HYDROGEN SAFETY ANALYSIS OF NPPS DURING SEVERE ACCIDENTS

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During a severe accident (SA) at a nuclear power plant (NPP) with water-cooled reactors, a significant amount of hydrogen may be released into the containment building, which can lead to the formation of explosive hydrogen-air mixtures. The combustion and detonation of these mixtures pose a serious threat to the containment.

The dispersion of hydrogen in the containment building is determined by complex thermal and hydraulic processes occurring at various stages of the severe accident, including steam condensation on cold surfaces and the associated convective heat and mass transfer.

The study of hydrogen explosion safety for nuclear power plants during severe accidents is a complex scientific and technical problem that requires a comprehensive approach, including both computational-analytical and experimental studies.

The development of the CABARET-SC1 software complex [1], aimed at CFD modeling of hydrogen explosion safety problems of nuclear and hydrogen energy infrastructure facilities is being carried out at the Nuclear Safety Institute (IBRAE RAS). The CABARET balance-characteristic scheme [2] is used for approximating the equations of multi-component gas dynamics. The scheme is characterized by improved dispersion and dissipation properties in the class of second-order accuracy schemes with a compact computational template. This approach allows the simulation of turbulent flows in eddy-resolving approximation without the use of tuning parameters, offering enhanced predictive capabilities for modeling the propagation and mixing of multi-component gas mixtures.

Due to the diversity and complexity of interacting processes, caused by the sources of steam and hydrogen, the operation of safety systems, and the complexity of the containment geometry, the study of processes affecting the distribution of hydrogen in the containment during a severe accident is carried out step by step, progressing from simple to complex.

The OECD SETH and ERCOSAM-SAMARA experiments studied large-scale mixing/stratification processes and the transfer of the medium between two communicating volumes, occurring as a result of steam injection at constant pressure and under conditions of increasing pressure.

In the OECD HYMERES HP1_8 experiment, the erosion of the helium layer caused by a vertical steam jet interacting with a horizontal obstacle was investigated in a “realistic” setup – in a three-component environment (air, steam, and helium) under conditions of increasing pressure and steam condensation on the vessel walls.

Modeling of the considered OECD SETH, ERCOSAM-SAMARA, and OECD HYMERES experiments using the CABARET-SC1 software complex allowed the analysis of the impact of wall condensation on the parameters of the transient steam injection process and the erosion of light gas stratification in a large-scale experimental setup. It also helped develop recommendations for using data from these experiments to validate CFD codes.

The research is carried out using the equipment of the shared research facilities of HPC computing resources at Lomonosov Moscow State University [3].

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