DEVELOPMENT OF THE CABARET-SC1 CFD CODE FOR HYDROGEN SAFETY PROBLEMS

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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. A significant part of the validation base of the CABARET-SC1 software complex consists of experiments from international projects ERCOSAM-SAMARA, HYMERES, HYMERES-2 [1]. These projects together represent systematic studies of hydrogen propagation and mixing processes aimed at studying the mechanisms of formation and destruction of light gas stratification, including during the operation of safety systems.

To calculate the problems of combustion and detonation of hydrogen-containing gas mixtures a special module CABARET-COMBUSTION is being developed within the computational platform of the CABARET-SC1 software complex. This module which implements modern mathematical models of combustion and detonation: (1) – a model based on detailed chemical kinetics, (2) – a model of large-scale combustion in homogeneous and stratified gas mixtures TFC (Turbulent Flame speed Closure), (3) – a diffusion combustion model EDM (Eddy Dissipation Model), (4) – a detonation model based on single-stage irreversible chemical kinetics. The combustion and detonation models were validated using data from domestic (RFNC – VNIITF, RUT) [3] and foreign experiments (THAI HD, ENACCEF) and by participating in the blind phase of the international benchmark ENACCEF2 (2022) [4].

In combustion and detonation problems, in addition to barometric loads, it is also important to calculate thermal loads from radiation of hot reaction products. Moreover, radiation can significantly influence the processes of mixing and stratification of hydrogen in the hot and humid atmosphere of a containment. To simulate heat exchange by radiation, two models were implemented in the CABARET-SC1 software complex: (1) – the Rosseland diffusion model for optically dense media, and (2) – the Finite Volume Method (FVM) of discrete ordinates . To validate the radiation model, data from the H2P2 series experiments [5] from the HYMERES-2 program and the Sandia National Laboratory experiment on studying the characteristics of turbulent diffusion hydrogen flame [6] were used.

This paper presents a brief overview of the mathematical models implemented in the CABARET-SC1 software complex and the results of their validation, and discusses further directions for code development.

The research is carried out using the equipment of the shared research facilities of HPC computing resources at Lomonosov Moscow State University [7].

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