

A progress variable model for fast combustion of H₂ and CO in large confined atriums with inhomogeneous mixtures of multiple gases

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Deflagration and flame acceleration are critical phenomena in nuclear safety. During a hypothetical severe accident in a nuclear power plant (NPP), H₂ and CO might be generated promoting a flammable atmosphere in the containment building of the power plant. This might lead to a sequence with a potential slow deflagration, a fast deflagration or a deflagration to detonation transition (DDT). Numerical simulations play a crucial role in the assessment of these potential sequences as they provide useful information for the implementation of new recommendations for the safety guidelines of the existing NPPs. Numerical models for this kind of combustion sequences (where the volume within the containment is typically of the order of 50000 m³ in western nuclear power plants) require both a realistic 3D geometrical description of the spatial domain and robust numerical solvers, suitable for relatively coarse meshes. Due to limited mesh resolution, RANS approach is the preferred choice for turbulence modeling, since the LES requires finer meshes. Conversely to the use of skeletal or detailed chemical schemes for the combustion modeling, which requires a high mesh resolution to resolve the flame front, the progress variable model arises as a potential compromise option for NPP safety studies. Besides, the progress variable models commonly found in the literature are capable of operating with constant values of reactant concentrations. However, accident sequences at NPP frequently show stratification of the reactive atmosphere. Therefore, these models need to be further developed to operate under stratified conditions. The current work presents a progress variable model developed to handle multiple flammable gases with non-homogeneous compositions. The present study shows the results for 3D combustion of non-homogeneous mixtures composed of H₂, CO, air, H₂O and CO₂. The presented code tracks the initial fluid particles within the unburned side of domain, determining the local composition on the unburned side of the flame front. A database generated using CANTERA provides laminar burning velocities and combustion rates of H₂ and CO for each local composition. This enables the model to handle local starving conditions of O₂ and local gradients of H₂O, CO₂ or temperature. In this work, validation tests performed with numerical comparison with DNS data and experimental data available for flame acceleration at the ENACCEF-2 (CNRS-ICARE) [1] and other facilities are provided. Once validated, the model will be used to investigate severe accident scenarios within NPP containment building.

References

[1] Bentaib A et al. Etson-samhyco-net benchmark on simulations of upward flame propagation experiment in representative hydrogen-air-steam mixtures of severe accidents containments atmosphere. Proc. of 19th Int. Topical Meeting Nucl. Reactor Thermal Hydraulics NURETH-19. 2022. pp. 1-11.