Improvement of Lean H_2 Combustion CFD Modeling for Nuclear Safety

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Severe accidents in nuclear power plants may result in the release of large amounts of hydrogen. Because of the wide ignition and explosion limits of hydrogen-air mixtures, the formation of a flammable mixture cloud is highly probable. Depending on mixture composition and confining geometry a flame front may accelerate and thereby cause significant overpressure in a nuclear reactor containment.

The numerical modeling of flame propagation in such scenarios is a challenging task especially for lean hydrogen-air mixtures and not sufficiently advanced for deterministic safety analysis. Especially the influence of thermal diffusive instabilities in the regime of deflagrative flame propagation is not reproduced through correlations and models for the burning speed currently in use in the nuclear safety community. Furthermore, numerical simulations using coarse-resolution grids for large scale geometries are unreliable typically showing an underestimation of flame acceleration. The research project presented on this work-in-progress poster aims at contributing to a greater understanding of the numerical modeling of flame acceleration in lean hydrogen-air mixtures. To make significant progress, both numerical and experimental work will be carried out.

Already existing knowledge in the field of lean hydrogen combustion is currently being reviewed. In particular, grid dependencies of existing models are investigated to identify promising approaches for a simulation with coarse grids. Own experiments are carried out at an entirely closed laboratory scale explosion channel [1,2] and serve as a basis for the validation of numerical work. This data will be employed for the formulation of a model describing the flame front topology and thus incorporating the effect of flame front instabilities. Shortcomings of existing TFC models are supposed to be reduced by this approach.

The proposed poster outlines the project aims and objectives and presents the first results of validation experiments. Both macroscopic and microscopic detailed information on the flame propagation and topology is shown. This is obtained through highly time-resolved optical measurement techniques. In particular, the shadow- and schlieren-technique for imaging of the macroscopic behavior and 20kHz OH PLIF for the detailed characterization of the flame topology are employed. Both techniques are applied simultaneously. Pressure measurements complement the optical data.

References

[1] Boeck, L.R., Hasslberger, J., Sattelmayer, T., Flame Acceleration in Hydrogen/Air Mixtures with Concentration Gradients; Combustion Science and Technology, Vol. 186, No. 10-11, pages 1650-1661, 2014.

[2] Vollmer, K., Ettner, F., Sattelmayer, T., Deflagration-to-Detonation Transition in Hydrogen-Air Mixtures with Concentration Gradients; Combustion Science and Technology, Vol. 184, No. 10-11, pages 1903-1915, 2012.

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