W4P134: TURBULENT FLAME SPEED DATA FOR HYDROGEN-RICH FUEL GASES AT GAS TURBINE RELEVANT CONDITIONS
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Characteristics of turbulent combustion for high hydrogen-content fuel gases (H2 > 70 vol. %; “hydrogen-rich”) are addressed in this work. An experimental investigation is performed in a perfectly-premixed axial-dump combustor under gas turbine relevant conditions. OH-PLIF diagnostics is implemented to evaluate the fundamental features of the flame fronts for these mixtures. To supplement the observations from experiments, combustion properties (e.g. unstretched laminar flame speed SL0 and laminar flame thickness δL) are derived from chemical-kinetic calculations that are based on two reaction mechanisms, the GRI-Mech 3.0 and the model by Li et al. (2007).
Based on the SL0 and δL derived from each of the aforementioned reaction mechanisms, distinct allocations of the data points on the regime diagram of premixed turbulent combustion are observed. The distinction is most explicitly revealed for the data collected at 1.0 MPa, even though all data points still exhibit the general characteristics of the thin reaction zone regime. While those normalized with the properties derived from GRI-Mech 3.0 approach the broken reaction zones, those evaluated via the “Li” model completely lie across the border of Da = 1 and toward the corrugated flamelets. This is consistent with the fact that the “Li” model is generally considered capable of capturing the fast chemistry of hydrogen-rich fuel gases more appropriately. The observation indicates that caution should be taken when selecting reaction mechanisms for interpreting the combustion characteristics of hydrogen (-rich) flames.
For the hydrogen-rich fuel gases, flashback occurs at much leaner conditions compared to methane or even syngas mixtures (H2 + CO). The averaged profile of the flame front is generally approaching that of an ideal cone. Accordingly, a simplified correlation based on the location of the flame tip can be applied to evaluate the turbulent flame speed (ST).
The ST data are summarized with a correlation that incorporates the effects of preferential diffusive-thermal and hydrodynamic instabilities. The general trend of ST/SL0 versus u'/SL0 with both linear and bending features still holds for the hydrogen-rich fuel gases. The effects of hydrogen content on the linear-to-bending transition start to appear above 0.5 MPa, and the transition with the elevated pressure is significantly delayed for the mixture with higher hydrogen content. The connection between the combustion regimes and the distinct behavior of the linear-to-bending transition on normalized ST is still to be established. Appropriate time/length scales capable of depicting the characteristics of flame-turbulence interaction are currently under investigation.
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W4P135: COMBUSTION OF LOW-CALORIFIC BIOMASS SYNGAS
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In the process of waste biomass utilisation in industrial gasifiers the low-calorific syngas with varying composition is produced. These gaseous fuels, despite their low-calorific value, fluctuating compositions and admixture of different components, such as tars and solid particles, become a valuable energy source of growing importance. Splitting the utilisation of waste biomass into two separate stages, gasification of the solid material and burning of the produced gases, enables easier control over both processes and reduces the level of emission of pollutants. The combustible biomass syngas, which leaves the gasifier, is hot and polluted, mainly with gaseous tars and solid particles of soot and other hydrocarbons. Because of such contaminants, it is impossible to fuel engines with raw syngases without purification. Considering the extra cost and complication of installing the filtration units, the better choice for small industrial installation is to burn syngas for steam production rather than fuel an engine to produce electricity. Direct burning in a combustion chamber adjacent to the gasifier would be the only choice for the low-calorific waste biomass syngas. When such gas leaves the gasifier even half of its total energy is in thermal energy of the gas and up to one-third of its chemical energy is contained in tars. In heat production most of the syngas total energy is used, but in an engine much of the thermal energy contained in the high-temperature gas and the energy contained in tars are wasted. The above considerations lead us to the design of an industrial steam production technology based on three-component system, with gasifier, combustor and boiler, all robust and cheap. The main difficulty comes from the requirement that the combustion process should be clean enough to fulfill stringent emission norms, which are much more restrictive for biomass classified as waste.
When the norms are exceeded, purification units and ammonia injection must be implemented and the cost of construction, operation and maintenance are growing. In the present paper we show that low-calorific biomass syngas, produced from the gasification of turkey feathers and wood, can be burnt on industrial scale respecting all environmental restrictions. The results of the simulations are complemented by the measurements taken in the gasification plant in Olsztyn, Poland. We describe the properties of these fuels analysing two syngases, produced in two different installations. One type of syngas is made from waste wood chips and the other from turkey feathers. We present the detailed analysis of the flame structures in the space of mixture fraction (Flamelet Libraries) for each of those two syngases at two different temperatures. Using this data we perform numerical simulations of real combustion chambers burning up to 3500 m³ of waste biomass syngas per hour. Our analysis and simulations show that the temperature of the syngases entering the combustion chamber has to be at least 800 K, while the supplied air mass flux should be comparable with the fuel flux. Such conditions enable stable and clean combustion.

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W4P136: A FLAMELET MODEL FOR LES OF HIGH KARLOVITZ # PREMIXED FLAMES
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Turbulent premixed flames in the thin and broken reaction zones regimes are difficult to model with large eddy simulation (LES) because turbulence strongly perturbs subfilter scale flame structures. In this poster a strained flamelet model for LES is proposed to address this modeling challenge. The proposed model extends a previously developed premixed flamelet approach to improve its accuracy in the context of high Karlovitz number flames. The model describes combustion processes by solving strained premixed counterflow flames, tabulating the results in terms of a progress variable and hydrogen radical, and invoking a presumed PDF framework to account for subfilter physics. The model is tested by performing an LES of a premixed slot-jet direct numerical simulation (DNS) from Sandia National Laboratory. In the premixed regime diagram this slot-jet is found at the edge of the broken reaction zones regime. Comparisons of the DNS, the strained flamelet model LES, and an unstrained flamelet model LES confirm that turbulence perturbs flame structure to leading order effect, and that the use of an unstrained flamelet LES model under-predicts flame height. It is shown that the strained flamelet model captures the physics characterizing interactions of mixing and chemistry in highly turbulent regimes.

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W4P137: HYSTERESIS OF METHANE DIFFUSION FLAMES ASSISTED BY ARGON PLASMA JETS
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The present study investigates the flame stabilization characteristics of methane diffusion flames by applying plasma jets. With the ejection of an argon stream into a methane diffusion flame, and with the application of an alternative voltage to the argon stream charged as a plasma jet, the flame stability will be acted under the combined interaction among argon dilutions, the effects of electrical fields and plasma behaviors. In this study, first, a flame in the hysteresis region was examined for different fuel jet velocities with the application of an argon plasma jet. Data were collected on the lift-off heights, and initial lift-off and hysteresis reattachment velocities at various voltage magnitudes for plasma charge are presented. Second, the flame hysteresis features are physically studied based on the topological geometry method in catastrophe theory, and the catastrophe boundaries of flame are obtained. Third, the physical laws of methane diffusion flames assisted by argon plasma jets are interpreted along typical control routes around the catastrophe boundaries.

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W4P138: TURBULENT FLUX OF MIXTURE FRACTION IN INERT AND REACTIVE TRANSVERSE JET IN CROSS-FLOW
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Turbulent flux of mixture fraction in inert and reacting transverse jet in cross-flow (JICF) is studied using compressible three-dimensional direct numerical simulations with detailed chemical kinetics and transport
properties. A nitrogen diluted hydrogen jet issuing from a round nozzle into a turbulent cross-flow of heated air is considered. Counter-gradient diffusion occurs extensively in both inert and reacting JICF and the behaviour on the windward and leeward sides is qualitatively different. Significant differences are also found between the inert and reacting cases in a near field region close to the flame anchoring location, whereas in the far field they are similar. This is attributable to the influence of intense heat release in the near field and its reduced influence in the far field. The scalar flux transport equation in the Reynolds averaged Navier-Stokes (RANS) context is analysed and reveals two dominant mechanisms: pressure driven transport and transport by Reynolds stresses, which dictate the overall gradient/counter-gradient behaviour on both the windward/leeward sides and for inert/reacting cases. The former mechanism is usually associated with turbulent premixed flames and its prevalence here, even in the inert case, is owing to the difference between the jet and cross-flow fluid densities. The predominance of the latter implies that second moment closure approaches might be necessary for reliable predictions.

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