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Uncertainty Quantification of Fuel Compositions on Premixed Bio-Syngas Combustion at High-Pressure

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Abstract : Effect of fuel variabilities on premixed combustion of bio-syngas mixtures is of great importance in bio-syngas utilisation. The uncertainties of concentrations of fuel constituents such as H2, CO and CH4 may lead to unpredictable combustion performances, combustion instabilities and hot spots which may deteriorate and damage the combustion hardware. Numerical modelling and simulations can assist in understanding the behaviour of bio-syngas combustion with pre-defined species concentrations, while the evaluation of variabilities of concentrations is expensive. To be more specific, questions such as 'what is the burning velocity of bio-syngas at specific equivalence ratio?' have been answered either experimentally or numerically, while questions such as 'what is the likelihood of burning velocity when precise concentrations of bio-syngas compositions are unknown, but the concentration ranges are pre-described?' have not yet been answered. Uncertainty quantification (UQ) methods can be used to tackle such questions and assess the effects of fuel compositions. An efficient probabilistic UQ method based on Polynomial Chaos Expansion (PCE) techniques is employed in this study. The method relies on representing random variables (combustion performances) with orthogonal polynomials such as Legendre or Gaussian polynomials. The constructed PCE via Galerkin Projection provides easy access to global sensitivities such as main, joint and total Sobol indices. In this study, impacts of fuel compositions on combustion (adiabatic flame temperature and laminar flame speed) of bio-syngas fuel mixtures are presented invoking this PCE technique at several equivalence ratios. High-pressure effects on bio-syngas combustion instability are obtained using detailed chemical mechanism - the San Diego Mechanism. Guidance on reducing combustion instability from upstream biomass gasification process is provided by quantifying the significant contributions of composition variations to variance of physicochemical properties of bio-syngas combustion. It was found that flame speed is very sensitive to hydrogen variability in bio-syngas, and reducing hydrogen uncertainty from upstream biomass gasification processes can greatly reduce bio-syngas combustion instability. Variation of methane concentration, although thought to be important, has limited impacts on laminar flame instabilities especially for lean combustion. Further studies on the UQ of percentage concentration of hydrogen in bio-syngas can be conducted to guide the safer use of bio-syngas.

Keywords : bio-syngas combustion, clean energy utilisation, fuel variability, PCE, targeted uncertainty reduction, uncertainty quantification
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