Modeling and Simulation of the Turbulent Mixing in Non-reacting and Reacting Spray Flows

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Abstract

The mixing process in turbulent non-reacting and reacting spray flows is fundamental for many technical applications. If chemical reactions are to be considered in non-premixed spray combustion processes, the turbulent mixing of evaporated liquid and the gaseous environment is a key process that determines the combustion efficiency. The use of transported (joint) probability density functions (pdfs) is an excellent tool to describe the turbulent mixing in terms of the mixture fraction. However, the solution of these transport equations is quite complex so that presumed pdfs are more convenient. In gas combustion processes, the standard two-parameter β-function provides an excellent way of describing the turbulent fluctuations of the mixture fraction. The two parameters that determine the shape of the β-function are obtained from modeled transport equations of the mixture fraction and its variance, which vary throughout the turbulent flow field and thus, the shape of the β-function varies as well. The advantage of the β-function is its boundedness between zero and unity and its very flexible shape ranging from unimodal to bimodal and non-symmetric forms which matches the experimental data found in these flames. In spray processes where the evaporation dominates the flow characteristics, however, the standard two-parameter β-function fails. Therefore, the transported pdf approach offers a way to predict the shape of the pdf of the mixture fraction which may be used to develop a suitable four-parameter presumed pdf. In turbulent combustion processes, premixed or partially premixed flame regimes may also occur due to the use of pilot flames for flame stabilization or due to the spray evaporation. In this situation, a reaction progress variable may be defined to describe the premixed combustion regime. On formulating the joint transport equation of the mixture fraction and the reaction progress variable, the molecular mixing must be modeled through appropriate mixing models for both the mixture fraction and the reaction progress variable. The solution of the joint pdf then may be used to evaluate marginal distributions of the mixture fraction and the reaction progress variable that will be used to determine a presumed pdf for these quantities. The piloted turbulent ethanol/air spray flames studied experimentally by A. Masri from Sydney University, Australia, are simulated. The chemical reactions are included using a spray flamelet model for partially premixed flames. The numerical results agree well with the experimental data, and the study provides new insight into the interaction of evaporation, turbulent mixing, and chemical reactions in turbulent spray flames.