Abstract

Flameless combustion, also called MILD combustion (Moderate or Intense Low Oxygen Dilution), is a technology that reduces NO_x emissions and improves combustion efficiency. It is based on the aerodynamic recirculation of flue gas inside the furnace diluting air and/or fuel streams. Therefore, appropriate turbulence-chemistry interaction models are needed to address this combustion regime via computational modelling. In this Thesis the applicability of two different turbulence-chemistry interaction models, the Eddy Dissipation Concept (EDC) and the Flamelet Generation Manifold (FGM) models, are studied and then some extensions of both models are developed and implemented in ANSYS Fluent for better predict flameless combustion.

Overcoming the limitations of the standard EDC model, the New Extended Eddy Dissipation Concept model (NE-EDC) is developed. This model considers standard EDC's model coefficients space dependent as a function of the local Reynolds and Damköhler numbers, so that the existing dilution in flameless combustion is considered. Later, the Generalized NE-EDC model is developed, which includes the interaction among the reaction zones suggested by Direct Numerical Simulation (DNS) modelling. In the Generalized NE-EDC model the chemical time scale is calculated considering the reaction rates of CH_4, H_2, O_2, CO and CO_2, so that the interaction among the reaction zones is included by a global mechanism. However, detailed chemistry (smooke-25) is still used for temperature and species mass fraction calculation during modelling. Once the two EDC model's extensions are developed, they are implemented in ANSYS Fluent by User Defined Function (UDF) and User Defined Memory (UDM) and their modelling results (mean temperature and mean axial velocity at different heights of the furnace) are compared against experimental data. Additionally, a comparative study of the modelling results of (1) the EDC model with specific, fixed values of the model coefficients optimized for the current application, (2) the NE-EDC model and (3) the Generalized NE-EDC model is made. The mean temperature predictions by the Generalized NE-EDC model show the best agreement with experimental data at different heights of the furnace and it presents a slight improvement over the NE-EDC model.

The flamelet based models, like the FGM model, present lower computational time than the EDC model using detailed chemistry, so that their suitability for flameless combustion is studied. The FGM model available in ANSYS Fluent generates flamelet tables based on pure fuel and pure air as boundary conditions, so that it does not consider the dilution effect existing in flameless combustion. Due to that, in this Thesis the Diluted Air Flamelet Generation Manifold (DA-FGM) model is for the first time implemented in ANSYS Fluent. This model includes the dilution effect during flamelets generation, and it has been implemented in ANSYS Fluent by generating the flamelet and Probability Density Function (PDF) tables outside ANSYS Fluent and loading and managing those tables by UDF. The DA-FGM model implementation methodology and ANSYS Fluent limitations for it are described and then the FGM and DA-FGM modelling results (mean temperature and mean axial velocity at different heights), are compared with experimental data.

The models are validated using experimental data of the Delft Lab Scale furnace (9kW) burning Natural Gas (T=446 K) and preheated air (T=886 K) injected via separate jets, at an overall equivalence ratio of 0.8.

It could be concluded that both models, the Generalized NE-EDC and the DA-FGM, are a good choice for Delft lab scale flameless combustion furnace modelling. It should be noted that the Generalized NE-EDC model provides better mean temperature results close to the burner and at the mid height of the furnace, and only, on the highest side of the furnace, where the dilution effect is more noticeable, the DA-FGM model shows better consistency with experimental data. Finally, it should be mention that the computational time of the DA-FGM model is around %28 lower than the Generalized NE-EDC model.