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Numerical simulation of CH4-H2-AIR non-premixed flame stabilized by a bluff body

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Abstract

The aim of this study is to perform a numerical simulation of a non-premixed turbulent flame of methane-air enriched by hydrogen. The selected axisymmetric configuration is composed of a central injector of methane-hydrogen mixture surrounded by a bluff-body, which is surrounded by a co-axial air jet. The Ansys CFX software is used to solve the equations governing turbulent reactive flow (Navier Stokes averaged in sense of Favre). The Turbulence is modeled using the k-ε model. The EDM (Eddy Dissipation model), then the FRC model (Finite Rate Combustion) combined with EDM are used to modeling the combustion phenomena. The results show some concordance with the temperature profile given by experience to a hydrogen rate of 50%.

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Keywords: Non-premixed combustion, Hydrogen enrichment, EDM and FRC models, CFD, Ansys CFX

1. Introduction

Over the past three decades, there has been considerable effort in the world to develop and introduce alternative transportation fuels to replace conventional fuels such as gasoline and diesel, environmental issues, most notably air pollution and limited availability of conventional fuels are among the principle driving forces behind this

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movement. Thus, if one tries to find for the definition of perfect fuel, hydrogen probably satisfies most of the desirable characteristics of such a fuel. Plentiful and clean burning, hydrogen has very high-energy content. [1, 2]

Due to difficulties in conducting spatially resolved measurements of combustion characteristics in devices, the numerical simulation can be cost effective approach to study the combustion mechanism. In this work, Computational Fluid Dynamics (CFD) based numerical simulations have been performed to study the combustion of non-premixed and various aspects in order to use them for solving the realistic problems. This study allows us:

- The understanding of the basics of Hydrogen-oxygen reaction mechanism, its combustion and the geometry of the cylindrical chamber used in this study is very important for simulating Methane-Air combustion system enriched by Hydrogen.
- To develop a two-dimensional numerical mesh and flow model which adequately and accurately represent the physical model of combustion chamber and is simple enough to limit the amount of computational time for obtaining a solution. The objective of this study is to find and apply appropriate model that improve the simulation of combustion with the commercial CFD as Ansys CFX.
- Generate numerical data/solutions, which correlate as much as possible with the experimental data for various conditions including equivalence ratios, mass flow rates of hydrogen-air mixture.

In the same context, Zhuyin Ren [3] presents a numerical simulation of a non-premixed combustion flame methane-air enriched by hydrogen, stabilized by a recirculation zone created by an obstacle or a bluff-body : a simple approach in which we apply a different combustion model to see if the same results were been obtained. Zhuyin Ren [3] uses a reduced description with chemical tabs implemented in FLUENT is combined with the EDC model (Eddy Dissipation Concept) considers that a moderate or chemistry with model PDF (probability density function) for combustion. We decided, in the simulation of combustion, for EDM in its infinitely fast chemistry limited compared to the scale of the turbulent times. Then for model Combined EDM/FRC, firstly, that it is valid for several reactions classified from a low to a high number of Damköhler (slow or fast chemistry compared to the scale of the turbulence time) and secondly, reaction rates are firstly calculated for each model separately and then the minimum of both is used. This procedure is applied to each reaction separately, so that when the level in one-step, would be limited by the chemical kinetics, certain other steps would be limited by the turbulent mixing at the same time and in the same physical position. [4].

Our approach is a first step in choosing the appropriate mesh following a test of several types of mesh, with an infinitely fast chemistry, applying the EDM model for the combustion of methane-air flame. Then, we compare the methane-air flame at the hydrogen-air flame. In the other hand, we compare the application of EDM model to combined EDM/FRC model for simulating the combustion of an air- methane sulfonate flame enriched by hydrogen. The results of our calculations are presented in the form of temperature profiles.

1.1. Hydrogen as a fuel

Hydrogen is a colorless, odorless, tasteless, and nonpoisonous gas under normal conditions on Earth. It typically exists as a diatomic molecule. Hydrogen is the most abundant element in the universe, accounting for 90 percent of the universe by weight. However, it is not commonly found in its pure form. [1, 2, 5]

The properties of hydrogen are largely listed in reference [6] with conventional fuels i.e. Gasoline & Diesel and other alternative fuels such as CNG, LPG, and Biogas. Hydrogen has wide range of flammability in comparison with other fuels. One of the significant advantages is that hydrogen engine can run on a lean mixture. When engine is run on slightly lean mixtures fuel economy is greater and the combustion reaction is more complete. Additionally, the final combustion temperature can be lowered by using ultra-lean mixtures, reducing the amount of NO_x emissions.

Indeed, the minimum energy required for ignition for hydrogen is about an order of magnitude less than that required for gasoline. This enables hydrogen engines to run well on lean mixtures and ensures prompt ignition. Unfortunately, since very little energy is necessary to ignite a hydrogen combustion reaction, and almost any hydrogen/air mixture can be ignited due to wide limits of flammability of hydrogen, hot gases and hot spots on the cylinder can serve as sources of ignition, creating problems of premature ignition and flashback [7].