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Exergy analysis of hydrogen/diesel combustion in a dual fuel engine using three-dimensional model

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ABSTRACT

In the present study, the energy and exergy analysis were carried out for a Deutz dual fuel (diesel + hydrogen) engine at different gas fuel-air ratios ($ø_{H2}$ = 0.3, 0.4, 0.5, 0.6, 0.7, and 0.8) and constant diesel fuel amount (6.48 mg/cycle). The energy analysis was performed during a closed cycle by using a three-dimensional CFD code and combustion modeling was carried out by Extend Coherent Flame Model- Three Zone model (ECFM-3Z). For the exergy analysis, an in-house computational code is developed, which uses the results of the energy analysis at different fuel-air ratios. The cylinder pressure results for natural gas/diesel fuelled engine are verified with the experimental data in the literature, which shows a good agreement. This verification gives confidence in the model prediction for hydrogen-fuelled case. With crank position at different gas fuel-air ratios, various rate and cumulative exergy components are identified and calculated separately. It is found that as gas fuel-air ratio increases from 0.3 to 0.8, the exergy efficiency decreases from 43.7% to 34.5%. Furthermore, the value of irreversibility decreases from 29.8% to 26.6% of the mixture fuels chemical exergies. These values are in good agreement with data in the literature for dual fuel engines.

Introduction

Owing to the growing price of the oil and its restricted resources, the engine manufacturers use other energy resources instead of oil fuels. Alternative fuels are very important since they can be extracted from renewable resources, and their emissions levels are lower than those of traditional fossil fuels. The advantage of these fuels is that they emit lesser air pollutants in comparison to diesel fuel and most of them are more economical compared to the oil as well as they are renewable [1–3]. Hydrogen appears to be greener alternatives for internal combustion engines [4,5]. This fuel has high auto-ignition temperature, hence cannot be used in CI engines without a means of the initiating combustion, as the temperature attained at the end of the compression stroke is too low for the mixture to be auto-ignited. Therefore, dual-fuel-mode engine operation is required, in which gaseous fuel is ignited by little amount of diesel fuel. Dual fuel diesel engines are widely used in automotive applications because of their high thermal efficiencies. In recent years, some researchers have already made significant effort on the numerical and experimental studying of the combustion process and pollution formation of hydrogen- fuelled engines [6–9].

In a fast-paced, competitive world, the improvement of these engines performance has become an important issue for automotive manufacturers. In order to improve engine performance, the combustion process is studied more

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comprehensively nowadays via using simultaneous application of the first and second laws of thermodynamics. Exergy is the key concept in the second law analysis; it is a special case of the more fundamental concept, the available energy, which has been introduced in Ref. [10]. Previous studies show that traditional energy balance theory often fails to give a good insight into the engine's operation [11–13]. Over the years, many reports have been published on the detailed use of the second law of thermodynamics with respect to internal combustion engines [11–15]. A summary of dynamic field of interest on this subject has been provided as given below.

Rakopoulos et al. [16] carried out a numerical analysis on the exergy balance during combustion of hydrogen enriched natural and landfill gases by using a zero-dimensional model. Results of this study revealed monotonic decrease in combustion irreversibility by increasing hydrogen component of CH_4–H_2 mixture in an engine chamber. Nieminen and Dincer [17] developed comparative exergy models for the naturally aspirated gasoline and hydrogen fuelled spark ignition engines, based on the second law of thermodynamics. It was found that the exergy efficiency of hydrogen- fuelled engine is higher than that of gasoline- fuelled engine. Bibhuti et al. [18] tested exergy analysis in diesel engine fuelled with a syngas under varying load conditions from the second law point of view. They showed that increasing the hydrogen quantity of syngas increases the cumulative work availability and reduces the destroyed availability. Amjad et al. [19] used a single-zone model to perform a numerical availability analysis of the combustion of n-heptane and natural gas blends in HCCI engines. They showed that with increase of the mass percentage of natural gas in the fuel blend, irreversibility decreases, and the second-law efficiency increases. Adding the EGR to the intake charge of the dual-fuel HCCI engine, up to an optimum value, enhances the exergy efficiency. EGR values over this optimum point could deteriorate engine performance. Hosseinzadeh et al. [20] carried out a numerical exergy analysis regarding comparison of the thermal, radical, and chemical effects of EGR gases using a single-zone model in dual-fuel engines operating at 50% loads. Jafarmadar and Javani [21] investigated an HCCI engine, fuelled with the mixture of dimethyl ether (DME) and natural gas (NG) in terms of exergy. They showed that when the excess air ratios of DME increases at constant air ratio of NG, exergy efficiency increases by 30.2% while irreversibility decreases by 15.4%. Moreover, the initial temperature increase brings about the irreversibility reduction and increases the heat loss exergy.

As can be seen in relevant literature, no attempt has been made so far to determine 3-dimensionally the effect of the gas

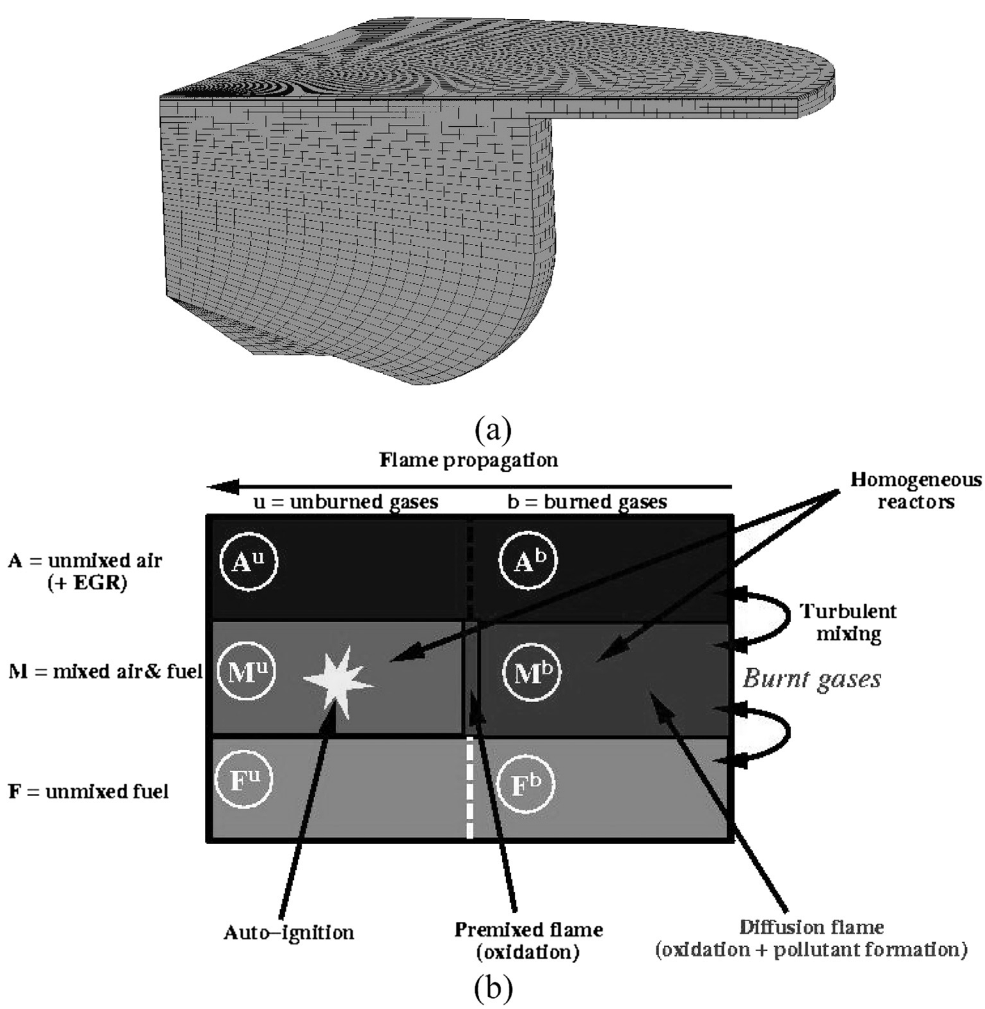

Fig. 1 – (a) Mesh of the combustion chamber at TDC (b) zones in ECFM-3Z model.