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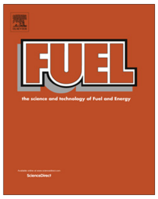

Exergy analysis of air injection at various loads in a natural aspirated direct injection diesel engine using multidimensional model

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HIGHLIGHTS

- Exhaust temperature increase by 6.5%, 6.5%, 7.54%, and 7.99%.
- The accumulative burn fuel exergy increases by 10%, 7.8%, 7.2%, and 8.3%.
- The irreversibility increases by 12.8%, 14.7%, 13.4% and 13.7%.
- The exergy efficiency decreases by 5.69%, 10.5%, 10.9%, and 10.8%.

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ABSTRACT

Research studies indicate that the Soot and NOx emissions in natural aspirated DI diesel engines, can be reduced through applying an air jet. In order to achieve this aim, an air-cell can be designed inside the piston body by maintaining the performance parameters. The diameter of the air cell is 35 mm and its height is 1.2 mm and the diameter of the throats is 1 mm. At the present work, however, exergy analyses are carried out for an MT4.244 engine, which is modeled with an air-cell. Energy analyses and numerical combustion have been performed for compression ratios of 25%, 50%, 75% and 100% full load. A three-dimensional CFD code is employed for this purpose in a closed cycle. The numerical results of cylinder pressure are compared with the measured experimental data and show a good agreement. Exergy analysis is carried out using an in-house computational developed code which uses the results of combustion and energy analysis. Various rates and the cumulative exergy components are identified separately for two engine cases at various loads. The comparison of the results show that, as load engine increases from 25% to 100% full load (in 25% increments), the exergy efficiency in air injection engine decreases by 5.69%, 10.5%, 10.9%, and 10.8% in comparison to baseline engine.

1. Introduction

Nowadays, DI diesel engines are being used more frequently than other engines due to their higher efficiency. Although NOx and Soot emissions generated in these engines are higher than those of Indirect Injection (IDI) diesel engine, but there are utilitarian technologies to reduce these emissions. Due to contrasting behavior in Soot and NOx emissions production, it is essential to employee an appropriate methodology to reduce the corresponding emissions [1]. Some of the useful technologies to reduce the Soot and NOx, which have been adopted so far, include high-pressure fuel injection, multiple injections, advancing and retarding the fuel injection time and using swirl with higher intensity [2–8]. In the other method, the amount of Soot and NOx reduced significantly by adopting air-cell inside piston body [9–12].

In order to improve engine performance and emissions formation, the combustion and emission processes are studied more thoroughly these days, implemented by applying the first and second laws of thermodynamics. Exergy is the key concept in the second law analysis; that has roots in more fundamental concept, energy availability, which has been introduced in [13]. For analyzing the performance of engine subsystems, exergy analysis can be a useful alternative to energy analysis, because it is able to reveal more information about engine processes [14–16]. Over the years, many reports have been published on details over the use of the second law of thermodynamics with respect to internal combustion engines [17–20]. A summary of other studies on the subject of DI and IDI diesel engine was provided below.

Jafarmadar and Zehni [21] carried out a numerical analysis about the effect of dwell time duration in a two-stage injection

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Nomenclature

E	internal energy (J)
G	Gibbs function (J)
Ex	exergy (J)
S	entropy (J/K)
T	temperature (K)
kk	number of species
I	irreversibility (J/K)
y	mass fraction of species
Greek letters	
μ	chemical potential (J/kg)
θ	crank angle (degree)
z	number of carbon atom
Abbreviations	
BTDC	before top dead center
ATDC	after top dead center
EVO	exhaust valve opening (degree)
CA	crank angle (degree)
EBU	eddy break up
ID	ignition delay(crank angle)
Subscript	
ch	relating to chemical exergy
tm	relating to thermo-mechanical exergy
f	relating to fuel
w	associated with work transfer
Q	associated with heat transfer
0	dead state, or environment state
pr	relating to combustion products
ox	relating to oxidants
fuel	relating to fuel
Superscript	
0	restricted dead state

scheme on exergy terms in an IDI diesel engine by three-dimensional modeling. The results show that the results show that the values of work exergy and exergy efficiency decrease when the dwell duration is changed from 5°CA to 30°CA. Also, there is a sharp change in the exergy parameters when the dwell time reaches 25°CA. Jafarmadar and Javani [22] 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, increase in initial temperature brings about the irreversibility reduction and increases the heat loss exergy. Amjad et al. [23] used a single-zone model to perform a numerical availability analysis for the combustion of n-heptane and natural gas blends in Homogenous Charge Compression Ignition (HCCI) engines. Hosseinzadeh et al. [24] carried out a numerical study by comparing the thermal, radical and chemical effects of EGR gases using a single-zone model to analyze availability in dual-fuel engines operated at 50% loads. Turan [25] studied exergeticinfluence of some design parameters on the small turbojet engine for unmanned air vehicle applications. Jafarmadar [26] studied the effect of EGR mass fraction on exergy terms in an indirect injection diesel engine. He showed that, as EGR mass fraction increases from 0% to 30% (in 10% increments), exergy efficiency decreases from 31.74% to 25.38%. Also, the cumulative irreversibility related to the combustion chamber decreases from 29.8% of the injected fuel exergy to 25.5%. Jafarmadar [27] carried out a numerical exergy analysis in pre-chamber and main chamber of an indirect injection diesel engine by three-dimensional model. Also in another research, Jafarmadar [28] carried out a numerical analysis about the effect of engine load on the exergy terms of an (indirect injection) IDI diesel engine by three-dimensional modeling. Jafarmadar et al. [29] carried out an exergy analysis at various loads in an IDI low heat rejection diesel engine by three-dimensional modeling. They showed that the best operational load is 75% full load from second law viewpoint.

The study of the relevant literature shows that no attempt has been done up to now in order to three dimensionally study the effects of air injection at various loads on the exergy terms in DI naturally aspirated diesel engine. In the present numerical work, the effect of creating an air jet by embedding an air-cell within piston on combustion parameters in a DI diesel engine has been studied at various loads from the second law perspective.

2. Initial and boundary conditions

Inlet temperature at 300 K, initial pressure at 1.85 bar, and engine speed at 2000 rpm are set to be. In-cylinder swirl for both base and modified conditions are considered to be uniform, the amount of exhaust gas recirculation is assumed to be zero.

Regarding that the analysis is done on the closing cycle, from intake valve closure (140 BTDC) to exhaust valve opening (130 ATDC), so the domain of the calculation include the space of cylinder, which is divided into head, liner and piston bowl. Simulation of modified engine condition follows the above-mentioned process. In this condition, an air cell and four throats are added to the initial geometry. The diameter of the air cell is 35 mm and its height is 1.2 mm. The diameter of the throats is 1 mm. Fig. 1(a) and (b) demonstrates the simulated engines in base and modified conditions, respectively. In order to investigate grid dependency, combustion chamber pressure at 100% load condition for 22,504 cells and 56,321 cells is presented in Fig. 1(c). As can be seen in the figure, increasing or decreasing the number of the cells has no effect on the results. Boundary temperatures in the combustion chamber are as follow:

Head temperature: 510 K. Piston temperature: 540 K. Cylinder temperature: 480 K.

3. Energy analysis

In the present work, AVL Fire U. 8.3 software is used for numerical simulation of combustion, exhaust emissions, and precise modeling of spraying fuel jet and injecting droplets [30]. The investigated engine is a direct injection diesel engine MT. 4.244 made by Motor Sazan Iran company and its specifications are given in Table 1. In order to explore the effects of air jet, an air cell is annexed to the main combustion chamber. It should be mentioned that compression ratio in both base and modified engines were equal. For the 3D simulation, firstly engine cylinder is modeled by Solid work software. Considering the strategy applied in AVL Fire software for creating meshes, there is a need to create a surface mesh for the model. Thus, the mentioned mesh is created by fame hybrid assistant tool in AVL Fire software while the piston is located in top dead center. Next, complicated 3D simulation of engine and creating moving mesh is carried out by means of fame engine plus tool in AVL Fire. The modeling of the auto ignition for hydrocarbon fuel is carried out by Shell auto-ignition model. The

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