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Effect of fuel oxygen on the energetic and exergetic efficiency of a compression ignition engine fuelled separately with palm and karanja biodiesels

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ABSTRACT

Exergy analysis of any thermodynamic system can take care of the limitations of energy analysis such as irreversible losses, their magnitude and the source of thermodynamic inefficiencies apart from energy losses. In the present study, both the analyses along with heat release analysis are conducted on a natural aspirated diesel engine fuelled separately with palm biodiesel (PB), karanja biodiesel (KB), and petrodiesel (PD) using the experimental data. Since the engine performs best at about 85% loading condition, the energetic and exergetic performance parameters of the engine are evaluated at 85% loading condition for each type of fuel. The aim of the study is to determine the effect of fuel oxygen on energy and exergy efficiencies of a CI (compression ignition) engine. Various exergy losses, exergy destruction and their ratios associated with the heat transfer through cooling water, radiation, exhaust gas, friction, and some uncounted exergy destruction are investigated. Apart from exergy loss due to heat transfer; the uncounted exergy destruction (due to combustion) also plays a major role in the system inefficiency. Based on the comparative assessment of the obtained results, it is concluded that a better combustion with less irreversibility is possible with the increase in O_2 content in the fuel.

1. Introduction

The compression ignition (CI) engine is the most preferred prime mover in many applications, owing to its reliability combined with excellent fuel efficiency. In general, CI engines are designed to run with petroleum fuel (fossil fuel). Combustion of fossil fuel is the major source of CO_2 and GHG_S emissions to the atmosphere, which resulting severe environmental problem like Global warming and unnatural climate change. In this regard, biofuels may be considered as one of the alternative fuel options provide a partial solution to both these problems, by replacing fossil fuel use and thereby reducing CO_2 concentration and GHG emissions. The fuel properties of these biofuels are similar to petrodiesel in most ways and hence may be used with little or no engine modification. So exploitation of biofuel efficiently in the CI engine is highly required. In order to analyse engine performance and to evaluate quantitatively the inefficiencies associated with various processes; second law analysis is a better option. Second law analysis deals with the key word – "exergy" that explains the potential of the system to produce useful work. Unlike energy, exergy can be destroyed, which is a result of some phenomena such as combustion, friction, mixing, throttling etc [1]. The exergy destruction is a source for insufficient use from fuel exergy to produce useful mechanical work in an IC engine. The reduction of exergy destruction (irreversibility) can lead to better engine performance by more efficient exploitation of fuel [2]. Flynn et al. [3] explained a new observation in IC engine studies. They developed a computer model for second law analysis of a turbocharged diesel engine under transient condition. It was reported that combustion irreversibility was the important factor for system inefficiency and transient in-cylinder irreversibilities were different from steady-state. Alasfour [4] applied an energy and exergy analysis to an SI engine operating at steady-state, to evaluate the use of a butanol–gasoline blend as fuel and found that energetic efficiency was about 28% of the fuel input energy. Canakci and Hosoz [5] presented a comparative study of energy and exergy analyses for a 4-cylinder turbocharged diesel engine fuelled with various biodiesels and petrodiesel. Caliskan et al. [6] applied exergy analysis to a John Deere 4045T diesel engine run with no. 2 diesel fuel, Soybean oil Methyl Easter and High-Oleic Soybean oil Methyl Easter at

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1400 rpm. They found the thermal efficiencies between 39.93% and 41.31% and exergetic efficiencies are between 37.46% and 38.48% with no statistically significant difference. Zhang et al. [7] have studied the effect of ambient oxygen concentration on biodiesel and diesel spray combustion under simulated compression ignition engine conditions for a constant-volume chamber. They have concluded that, 18% ambient O_2 condition worked better for biodiesel than petrodiesel in reducing soot particle. With 12% ambient O_2 condition, diesel combustion was significantly degraded. However, both fuels experienced low temperature combustion at 10% of ambient O_2. Thus, biodiesel could be able to achieve the desired lower soot production under a moderate oxygen level with higher combustion efficiency. Mohsen et al. [8] have investigated on the exergy recovery from a turbocharged OM314 DIMLER diesel engine by varying the engine speeds (1200, 1400, 1600, 1800 and 2000 rpm) and torques (20, 40, 60, 80 and 100 N m). They have used a double pipe heat exchanger in the exhaust of the engine with counter current flow. They have found that the recovered exergy was increased with the increase of load and engine speed. Further, they reported that using recovered exergy, bsfc was decreased by approximately 10%. Misra et al. [9] have applied exergy analysis method to a diesel engine run with petrodiesel and palm biodiesel. They reported that the Exergetic efficiency of the engine running with PB was approximately 2.12% higher than petrodiesel. Ismail and Mehta [10] discussed a method of estimating the availability destructions and exergetic efficiencies of combustion for different fuels, viz. hydrogen, hydrocarbons, alcohols and biodiesel surrogates. It was reported that availability destruction is greater for heavier hydrocarbon fuels and oxygenated fuels with higher oxygen fraction. The maximum and minimum exergetic efficiency was found for hydrogen and acetylene fuel, respectively. Further they have found that availability destruction increases with exhaust gas recirculation (EGR) and decreases with oxygen enrichment of the supplied air. Ozkan et al. [11] have investigated the effect of the dwell time of multiple injection events on the energetic and exergetic efficiencies of a CI engine. The test engine was run using three different injection strategies. Using the experimental data of the engine, the heat release rate, combustion temperature, heat balance, thermal efficiency, and exergetic efficiency were calculated. No significant difference in the energetic efficiency, exergetic efficiency and also on various engine irreversibilities was obtained. But they reported that the nitrogen oxides (NOx) emissions were decreased by 7.4% via implementing appropriate pre-injection mass and injection advance. Thus from the available literature it may be inferred that no significant contribution has been reported regarding the influence of the irreversibility components on the performance of CI engine operated on biofuels with respect to the O_2 content by the fuel. Once this influence is established, more intensive research may be possible in finding the effective biofuel mix for better engine performance.

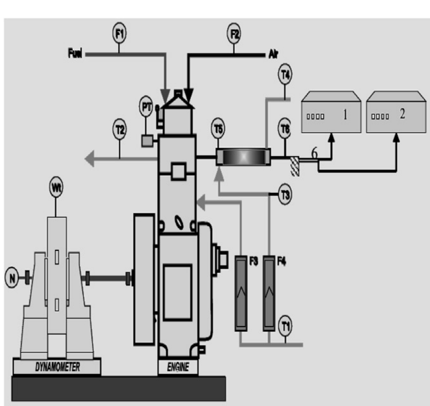
Since all the biodiesels developed so far are having oxygen content in the range of 8–12% by wt, therefore any biodiesel(s) may be suitable for this purpose. Although edible biodiesels are easily available but their demand for human consumption restricted them to be used as biodiesels in many countries. In this regard non-edible biodiesels are having advantage over their edible counterpart. However, organized plantations of non-edible oil bearing trees are very limited, even though a number of such oils already have been established. Considering these aspects, one established non-edible biodiesel – karanja biodiesel (KB) and one established edible biodiesel – palm biodiesel (PB) were considered in this work. Further, the conventional fuel for the engine, i.e. the petrodiesel (PD) was also considered for effective comparison.

In this study, an attempt has been made to study the influence of fuel oxygen on various irreversibility components, exergetic efficiency and energetic efficiency of a single cylinder, 4-stroke diesel engine operated separately on petrodiesel (PD), palm biodiesel (PB) and karanja biodiesel (KB). The considered fuels are tested in the engine at various loading conditions, viz., at 0%, 25%, 50%, 75%, 85%, 90% and 100%. It has been found that the engine performance is best at about 85% loading condition, which is also supported by available literature [12]. The reaction equations, energy rate balance and exergy rate balance for the engine are determined by using the experimental data of 85% loading condition. The energy and exergy analyses are then investigated by solving the combustion reaction equation using (CO_2, CO, H_2O, H_2, O_2, NO, N_2, and unburned HC) as combustion products. Subsequently, various energetic and exergetic performance parameters of the engine are evaluated for each fuel and compared with each other.

2. Material and method

2.1. Experimental setup

The engine setup consists of a single cylinder, 4-stroke water cooled diesel engine with compression ratio of 17.5 and 7 bhp at 1500 rpm. The uses of this type of engine are found in rural/agricultural sector for running the irrigation pump-sets, small capacity electrical generators etc. A Labview based engine performance analysis software package "EnginesoftLV," Apex Innovations, 1995 [13] is used for online performance evaluation.



F1: Fuel injection pressure sensor
F2: Air flow measuring sensor
PT: Piezo sensor
N: Rpm pick up and TDC encoder
T1: Cooling water inlet temp to engine
T2: Cooling water outlet temp from engine
T3: Cooling water inlet temp to calorimeter
T4: Cooling water outlet temp from calorimeter
T5: Exhaust gas inlet temp to calorimeter
T6: Exhaust Gas outlet temp from calorimeter
1: AVL 5 gas analyzer
2: AVL 437 smoke-meter

Fig. 1. Schematic diagram of experimental setup of engine test rig.

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