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Effect of exhaust gas recirculation on diesel engine nitrogen oxide reduction operating with jojoba methyl ester

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ABSTRACT

Jojoba methyl ester (JME) has been used as a renewable fuel in numerous studies evaluating its potential use in diesel engines. These studies showed that this fuel is good gas oil substitute but an increase in the nitrogenous oxides emissions was observed at all operating conditions. The aim of this study mainly was to quantify the efficiency of exhaust gas recirculation (EGR) when using JME fuel in a fully instrumented, two-cylinder, naturally aspirated, four-stroke direct injection diesel engine. The tests were carried out in three sections. Firstly, the measured performance and exhaust emissions of the diesel engine operating with diesel fuel and JME at various speeds under full load are determined and compared. Secondly, tests were performed at constant speed with two loads to investigate the EGR effect on engine performance and exhaust emissions including nitrogenous oxides (NO_x), carbon monoxide (CO), unburned hydrocarbons (HC) and exhaust gas temperatures. Thirdly, the effect of cooled EGR with high ratio at full load on engine performance and emissions was examined. The results showed that EGR is an effective technique for reducing NO_x emissions with JME fuel especially in light-duty diesel engines. With the application of the EGR method, the CO and HC concentration in the engine-out emissions increased. For all operating conditions, a better trade-off between HC, CO and NO_x emissions can be attained within a limited EGR rate of 5–15% with very little economy penalty.

1. Introduction

The interest in renewable energy sources for energy production is not new. Many studies have been conducted to qualify various oil and their blends from plants and vegetables as alternative renewable energy sources. This renewable source of fuel may also help in reducing the net production of CO_2 from combustion sources and our dependence on fossil fuels. Often the vegetable oils investigated for their suitability as biodiesel are those which occur abundantly in the country of testing. Therefore, soybean oil is of primary interest as biodiesel source in the United States while many European countries are concerned with rapeseed oil, and countries with tropical climate prefer to utilize coconut oil, hazelnut or palm oil [1–3]. Other vegetable oils, including sunflower, rubber, etc., have also been investigated. Furthermore, other sources of biodiesel studied include animal fats, salmon oil and or waste cooking oils [4–7]. One of the several renewable sources, and yet not widely known, jojoba oil, appears to be promising with scope for cultivation in the relatively hot weather. Many studies have been carried out on jojoba as vegetable oil fuel for diesel engines for many years [8–11]. The jojoba shrub was grown in Africa and also grown in the Sonora Desert at the south of the USA. El-Moogy [12] has collected a considerable amount of data about jojoba and its cultivation for investment in Egypt. Jojoba seeds contain 50% of its weight as oil, so an acre can produce 270–300 kg of oil after four years but will increase to 675–750 kg of oil after ten years of cultivation. These studies [8–11] showed that the viscosity of jojoba raw oil is high and that lead to blockage of fuel lines, filters, high nozzle valve opening pressures and poor atomization [13–15], thus warrants treatment of oil before it becomes a viable engine fuel. Also, it was found that JME is efficient oil substitute and offered the same product guarantees for JME as for gas oil due to the fact that the physiochemical properties of JME are close to those of gas oil.

To solve the problems associated with the high viscosity of jojoba raw oil, Abdel Kader [16] synthesized the jojoba methyl ester in the laboratory and showed that methyl ester formation was 60–65% complete at respective molar ratios of methanol/jojoba oil

Abbreviations: bsfc, brake specific fuel consumption; bmep, brake mean effective pressure; CO, carbon monoxide; CO_2, carbon dioxide; DI, direct injection; COV of imep, coefficient of variation in indicated mean effective pressure; EGR, exhaust gas recirculation; HC, unburned hydrocarbons; $imep_{mean}$, mean indicated mean effective pressure; JME, jojoba methyl ester; NO_x, nitrogen oxides; ppm, parts per million (volume); TDC, top dead center.

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Nomenclature

η_{th}	brake thermal efficiency
$m^{\cdot}$	mass flow rate
N	engine speed
P	pressure
σ_{imep}	standard deviation of the mean effective pressure
T	temperature
V	volume

4.6:1. The alkaline catalyst used was (NaOH) and was added with a percentage of 1% which proved to produce maximum yield. At 60 °C, 65% JME was produced in 2 h. In addition, these studies concentrated on measuring the ignition delay period of JME and JME-gas oil blends at different conditions in shock tube. An optimum method for JME fuel production was developed by Radwan et al. [8] on the grounds of production economy and fuel properties. Radwan et al. [8] measured the burning velocity of JME at different conditions in constant volume bomb. It was found that JME liquid fuel exhibited lower burning velocities than isooctane.

An experimental investigation has been carried out to examine for the first time the performance and combustion noise of an indirect injection diesel engine running with JME, and its blends with gas oil [9]. A Ricardo E6 compression swirl diesel engine was fully instrumented for the measurement of combustion pressure and its rise rate and other operating parameters. Test parameters included the percentage of JME in the blend, engine speed, load, injection timing and engine compression ratio. Results showed that the new fuel derived from jojoba is generally comparable and good replacement to gas oil in diesel engine at most engine operating conditions. With the same test rig, JME was investigated as a pilot fuel as a way to improve the performance of dual fuel engine running on natural gas or liquefied petroleum gas at part load [10,11]. Results showed that using the JME fuel with its improved properties has improved the dual fuel engine performance, reduced the combustion noise and extended knocking limits. Also, an experimental evaluation of using blends of jojoba oil with gas oil as compared to gas oil has been conducted by Bawady et al [17]. Heat flux mapping and metal temperature distribution was carried out using a single cylinder, naturally aspirated, indirect injection four-stroke diesel engine [18]. Results at variable loads and speeds were taken with JME and were compared with those obtained with gas oil. It was found that the heat flux level and gas face metal temperature in the cylinder liner and head with JME were higher than those with gas oil. Also, an increase in the emissions of nitrogenous oxides (NO_x) at all operating conditions has been observed.

Oxides of nitrogen are formed during combustion when localized temperatures in the combustion chamber exceed the critical temperature that molecules of oxygen and nitrogen combine. Recently, exhaust gas recirculation has received attention as a potential solution. Research work results showed that EGR is one of the most effective methods used in modern engines for reducing NO_x emissions [19,20]. There are two types of EGR; internal and external. Internal EGR uses variable valve timings or other devices to retain a certain fraction of exhaust from a preceding cycle. External EGR uses piping to route the exhaust gas to the intake system, where it is inducted into the succeeding cycles and that type is used in this study. While EGR is effective in reducing NO_x, it also has adverse effects on the engine efficiency and may cause pollution of lubricating oil and corrosion of inlet manifold and moving parts, as exhaust gas contains a lot of particulate matter [21]. In this paper diesel particular filter adopted for diesel particulate reduction to supply nearly particle-free exhaust gas. The objective of this work was to quantify the efficiency of exhaust gas recirculation (EGR) when using JME as a renewable fuel for NO_x reduction. In this paper, all experiments described were performed on a direct injection diesel engine in first to compare diesel fuel and JME fuel in terms of engine performance and exhaust emissions at various speeds under full load and the second to investigate the effect of various EGR rates with JME fuel for NO_x reduction at engine speed of 1600 rpm. EGR effects on engine performance, engine emissions, exhaust gas temperature, combustion quality and fuel economy for both high and low load engine operating conditions at a speed of 1600 rpm were investigated Also, the effect

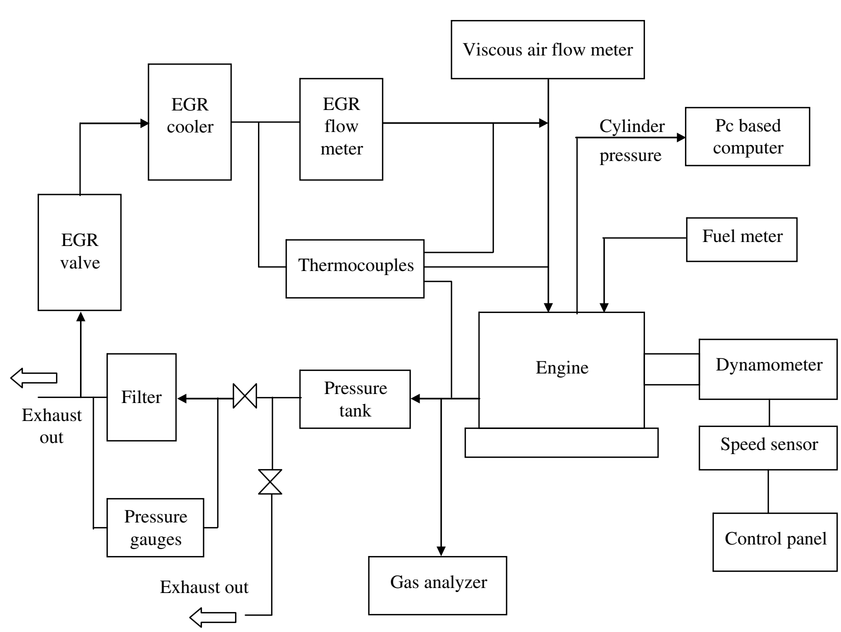

Fig. 1. Schematic of the experimental test rig.