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Comparative analyses of n-butanol–rapeseed oil–diesel blend with biodiesel, diesel and biodiesel–diesel fuels in a turbocharged direct injection diesel engine

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ABSTRACT

The purpose of this work is to understand the effects of a diesel–rapeseed oil–n-butanol (70–20–10% in vol, DRSOnB) blend on engine performance characteristics and exhaust gas emissions for a four-cylinder, four-stroke, turbocharged, direct injection diesel engine as a function of engine speed, and to compare the results to those of rapeseed oil methyl ester (B100), rapeseed oil methyl ester–diesel blend (20–80% in vol, B20) and diesel fuel. Transesterification and microemulsion methods were used to produce rapeseed oil methyl ester and diesel–rapeseed oil–n-butanol blends, respectively. The engine performance and exhaust emission tests were conducted employing each of DRSOnB, B100, B20 and diesel fuel, with the engine operating at full load and eight different engine speeds between 1800 and 4400 rpm. As compared to diesel fuel, the test fuels decreased torque, brake power and exhaust gas temperature and increased brake specific fuel consumption (BSFC). While B20 and DRSOnB blends increased carbon monoxide (CO) emissions, B100 decreased it compared to diesel fuel. All the test fuels reduced hydrocarbon (HC) emissions while increasing nitrogen oxides (NO_x) formation.

1. Introduction

The increasing energy demand, surging oil prices, depleting oil reserves and environmental pollution problems associated with the use of fossil fuels have sparked renewed interest to find out sustainable, economically feasible and environmentally friendly biofuels [1,2]. Vegetable oils and bioalcohols are some of the most commonly used alternative fuel sources among many kinds of biofuels for potential use in internal combustion engines [3–5].

Vegetable oils can be used in an engine without any modification if they are blended with 80% diesel [6]. However, the direct use of vegetable oils as an alternative fuel for internal combustion engines is limited by some unfavorable fuel properties, mainly their high viscosity and density, which cause problems in poor fuel atomization, incomplete combustion and ring carbonization in the combustion chamber [7]. These problems can be overcome blending, microemulsification, transesterification, and pyrolysis as well as preheating the vegetable oils to the extent comparable to the viscosity of diesel [5–9].

Alcohols derived through biochemical processes from biomass have the potential to provide a path towards carbon based fuels that are renewable and clean burning [1]. Simple alcohols such as methanol and ethanol are the most common alcohols as additives or blended fuels in compression ignition engines although low lubricity, high auto-ignition temperature, low cetane number, solubility and high heat of vaporization are disadvantages of methanol and ethanol in compression ignition engines. Intake air preheat is a simple way to overcome the high heat of vaporization problem of simple alcohols and to improve ignition and combustion [10] and low lubricity can be improved by adding castor oil to simple alcohols [11]. In addition, methanol or ethanol is not miscible in diesel fuel but biodiesel can be used as an

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excellent binder or emulsifier to create biodiesel–alcohol–diesel [12–15] or biodiesel–alcohol blends [16–21] within certain limits of methanol/ethanol concentrations. Butanol as a potential second generation biofuel is a popular and competitive alcohol in diesel engines lately [1,2]. It can be blended with vegetable oils without any additives [22]. It was reported that 20% of isobutanol can be mixed with diesel although the optimum blend ratio was found to be 10% isobutanol [23]. As compared to methanol and ethanol, butanol has a lot of advantages such as better miscibility and longer stability with diesel, lower heat of vaporization and higher heating. Due to that, several studies were performed using diesel–butanol [23–25], biodiesel–butanol [26] and diesel–biodiesel–vegetable oil–alcohol (butanol, ethanol, methanol) [27].

Experimental studies of engine performance and exhaust emission measurements at variable operation conditions when using biodiesel, biodiesel–diesel blends and diesel–alcohols–vegetable oil/biodiesel blends reported in various works [28–32]. Besides the previous work done in the literature, it is important to research, explore and understand different combinations of biofuels in internal combustion engines. Therefore, the purpose of this work was to use the microemulsion method to convert a vegetable oil to a biofuel as diesel–vegetable oil–alcohol (70–20–10% in vol.) blend, and to compare diesel–vegetable oil (rapeseed)–alcohol (n-butanol) blend to diesel, biodiesel (rapeseed methyl ester) and B20 in terms of engine performance characteristics and exhaust gas emissions as functions of engine speed.

2. Experiment and procedure

2.1. Experimental setup and procedure

Engine performance tests were undertaken using a hydraulic dynamometer (BT-190) with a maximum brake power of 119 kW, a maximum speed of 7500 rpm, a load cell capacity of 2500 N and a brake water pressure of 1–2 kg/cm^2. Fuel mass consumption was measured using Siemens MASS 600 Ex-d transmitter. Fig. 1 shows the experimental setup with the main components.

The revolution frequency of the crankshaft was determined with an incremental type digital rotary encoder. The ambient air humidity was measured by HT-785 transmitter. In order to stable engine cooling water temperatures between 80 and 85 °C during the whole test conditions, PT-100 temperature sensors were mounted on inlet and outlet water pipes of the cooling water tank. Exhaust gas and engine oil temperatures were measured using a K-type thermocouple. Exhaust gas emissions were measured using a Testo 350 exhaust gas analyzer which determines CO, NO, NO_2, CO_2 and HC emissions within the ranges of 0–10,000 ppm, 0–4000 ppm, 0–500 ppm, 0–50 vol.% and 100–40,000 ppm, respectively. CO and CO_2 measuring instrument uses electrochemical (EC) and non-dispersive infrared (NDIR) sensors, respectively.

A four-cylinder, four-stroke, direct injection, turbocharged diesel engine was used in this study. Table 1 shows the technical specifications of the test engine. All the tests were performed in accordance with Turkish Standards 1231 – Internal Combustion Engines Inspection and Test Procedure [33]. As stated in TS 1231, the test engine's speed was increased to twice as the neutral engine rpm (720 rpm) without load. The dynamometer loaded the engine until the brake power of 8.2 kW was achieved at the same engine speed. Under these conditions, the engine was operated until the cooling water temperature was 80–85 °C. And, the engine was operated 5 min at 720 rpm after the load was taken off at the operating temperature. Then, performance parameters of the engine were measured at 4400 rpm (max) with full throttle.

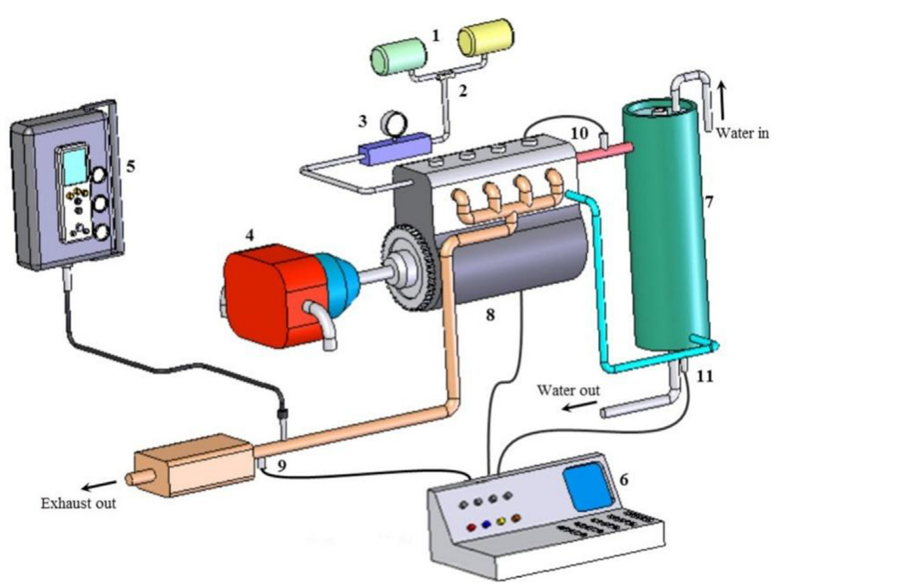

Fig. 1. Experimental test layout.