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Effect of hydroxy and hydrogen gas addition on diesel engine fuelled with microalgae biodiesel

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ABSTRACT

Owing to high growth rate, being non-edible, and environmental friendliness; microalgae is a promising third generation biodiesel raw material. In this study, hydrogen and hydroxy gas aspirated compression ignition engine which was fuelled with microalgae biodiesel and low sulphur diesel fuel blend were investigated in order to evaluate their combined effect. The results showed that the brake power and torque output of the test engine decreased with microalgae biodiesel usage. Moreover, microalgae biodiesel addition results in lower carbon monoxide and nitrogen oxides emissions, and higher carbon dioxide. The introduction of hydrogen and hydroxy gas compensated the decrement of torque and power output and increment of carbon dioxide emission. The study enlightened that usage of microalgae biodiesel with hydrogen and hydroxy gas addition is a very promising combination from the environmental viewpoint.

Introduction

Increasing world population, industrialization, and transportation demand lead to excessive use of fossil fuels [1]. Thus, the resource of fossil fuels is face to the threat of depletion in all over the world [2]. Due to its high thermal efficiency, application of diesel engine is getting more and more. Therefore, many countries have set the targets to increase the production of biofuels to decrease the usage of fossil-based fuels [3,4]. Alternative fuels have gained great attention by the community since it has the advantage of being environmentally cleaner and sustainability [5,6]. Among alternative to fossil-based diesel fuels, biodiesel and their blends have a major advantage; there is little or no need to modify diesel engines which are already in use, since the fuel properties of most biodiesel similar to conventional diesel fuel [7–10]. Environmental friendliness and similarity of fuel properties make biodiesel a very popular alternative fuel [11–13]. Animal fats, edible and non-edible vegetable oils can be utilized for biodiesel production [14,15].

First generation of biofuels were produced from the feedstocks of human such as sunflower, olive, corn, palm, soybean, rapeseed oils etc. Production from such sources would lead the communities to suffer from nutrition [16,17]. Therefore, second generation of biodiesel was taken place. In this generation, fuels were produced from non-edible feedstocks, waste oils, animal fats, Jatropha oil, Karanja etc. [18]. Although the feedstocks are non-edible, the problem arises when second generation crops occupy too many agricultural land which lessen the food production [19]. The latest trend of biodiesel production is from algae. The approach calls as third generation [20]. Due to its fast grow rate and high amount of oil contamination algae is considered as promising biodiesel feedstock [21]. Although the oil content of algae is generally 20–50% by weight, some species can yield 80% oil of dry

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biomass and the doubling time of biomass is up to two days [22,23]. Another advantage of algae is ability to grow on non-arable area [24]. Macroalgae and microalgae are the two types of algae. Macroalgae also known as seaweeds are classified into three groups which are named as Phaeophyceae, Rhodophyceae, and Chlorophyceae whereas, Chlorophyceae, Cyanophyceae, Chryosophyceae, Xanthophyceae and Bacillariophyceae are some types of microalgae [25,26]. Since cultivation of microalgae is easier than macroalgae by mass culture methods, microalgae is more favourite [27].

Hydroxy gas (HHO) also known as Brown's gas is another alternative fuel source. Essentially, the gas produced from the electrolysis process of water thus, it contains hydrogen (H_2) and oxygen (O_2) molecules. The gas usually utilizes as a supplementary fuel to liquid fuels since the self-ignition temperature of hydrogen is too high to use it solely as a fuel source in conventional diesel engines [28]. The researchers who carried out their experiments on conventional diesel engines used HHO gas as secondary fuel as a performance and emission improver. Arat et al. (2016) were studied with HHO. The results showed that HHO addition improved the brake torque, brake power, and brake specific fuel consumption by 2.7%, 3.18%, and 17.4%, respectively compared with conventional diesel fuel. CO, CO_2 and NO_x emissions were also lowered by HHO gas addition [29]. Another research was carried out by Ozcanli et al. (2017). They investigated the effect of the gas with Castor biodiesel. According to their results, NO_x emissions increased with HHO addition when the engine was primarily fuelled with biodiesel blend [30]. Ismail et al. (2018) compared three different HHO dry cell to supply engine. Experiments indicated to 15% reduction of fuel consumption, 17% and 27% reduction of CO and HC emissions, respectively and 15% and 1% increment of oxygen and CO_2 [31]. Uludamar et al. (2017) were focused on the vibration characteristic of a diesel engine when it was fuelled with HHO and biodiesel blends [14]. Furthermore, they predicted the effect of fuel properties and HHO amount with ANN approach. The average decrement of vibration acceleration of engine block was measured as 1.23% with 2 l/min, 2,34% with 4 l/min, and 3,54% with 6 l/min flow rates of HHO gas into the intake air.

Hydrogen is a promising alternative fuel [32,33]. The major advantage of hydrogen is on environmental impact. However, since hydrogen has a high self-ignition temperature similar to HHO gas, there must be another fuel as an ignition source to start combustion of hydrogen in diesel engines. Thus, hydrogen can be used as secondary fuel [34,35]. In literature, there is numerous number of studies about hydrogen usage in diesel engine. Chiriac and Apostolescu (2013) were used 20% rapeseed methyl ester as primary fuel and hydrogen as second fuel. In the experiments, they observed that higher NO_x emission formation and lower smoke and CO emission formation with hydrogen aspiration under 60% load condition [36]. Szwaja and Grab-Rogalinski (2009) were deal with hydrogen combustion. They found out that addition of hydrogen shorten the diesel ignition lag [37].

In literature, researchers generally fuelled diesel engine with first and second generation of biodiesel [38–42]. The oils of such biodiesel bring about their disadvantages in application. Therefore, in present study, it is aimed to evaluate the performance and emission characteristic of an unmodified diesel engine which was fuelled with diesel and microalgae-diesel fuel blend with HHO and hydrogen enrichment through intake manifold. The fuel properties of microalgae biodiesel and its blend with low sulphur diesel (LSD) fuel were determined.

Material and method

Determination of fuel properties

Fuel properties of the test fuels were measured in Çukurova University Automotive Engineering Department with Kyoto Electronics DA-130, Zeltex ZX440, Saybolt Universal Viscosimeter, Tanaka MPC-102, Tanaka Automated Pensky-Martens Closed Cup Flash Point Tester.

Kyoto Electronics DA-130 which has ± 0.001 g/cm^3 was used for measurement of density of the test fuels. Cetane number is the parameter about the fuel's ignition quality [43]. In the measurements, Zeltex ZX440 was used for cetane number determination. Viscosity of the test fuels, which is the major drawback property of most of the biodiesel fuel is measured with the Saybolt Universal Viscosimeter [44,45]. Cold fuel properties of the biodiesel fuel is another disadvantage for some biodiesel fuels. The biodiesels which produced from palm, rapeseed and safflower biodiesels has higher pour and cloud point than conventional diesel fuel, whereas castor biodiesel has the lower [46–49]. Cloud point is the point of wax cloud crystals first appears in fuel during the cooling and the pour point is the temperature which the fuel loses its flow characteristic [50]. The cold properties of the test fuels were determined by Tanaka MPC-102. The process, stock and logistic safety of the fuels depend on their flash point [51]. The biodiesel fuels from different sources have usually higher flash point than conventional diesel fuel [52]. In the study, the flash point of the fuels was measured with Tanaka Automated Pensky-Martens Closed Cup Flash Point Tester.

Production of biodiesel

The microalgae oil that used to produce microalgae biodiesel was obtained from the *Chlorella protothecoides*. The oil was converted to biodiesel fuel via transesterification reaction. In the process, the oil was heated to 55 °C while methanol as reactant and sodium hydroxide as catalyst were mixed in another beaker until the sodium hydroxide was dissolved in methanol. The homogeneous mixture was added into the flask that contains the heated oil. The mixture was stirring for 1.5 h. After the transesterification step, the methyl ester was poured into the separation funnel in order to separate crude methyl ester from the glycerine. The methyl ester waited inside the funnel for 8 h before the separation. After the separation, the crude methyl ester was washed with warm water for 3 times and then heated up to 105 °C to vaporize water from the crude methyl ester. At the last step, filtering operation was carried out in order to remove small impurities.

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