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Performance and emission characteristics of diesel fuel containing microalgae oil methyl esters

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HIGHLIGHTS

- Possibilities to use algae oil methyl esters as fuel were examined.
- Characteristics of algae oil methyl esters are presented.
- Algae and rapeseed oil methyl esters were used for engine tests.
- Engine and environmental characteristics of engine are presented.

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ABSTRACT

This report includes assessments of comparative studies on the physical, chemical, and motor properties of diesel fuels containing 30% (vol.) algae oil methyl esters (AME).

The properties of this biofuel were compared with the properties of fossil diesel fuel and those of diesel fuel mixtures containing 30% conventional diesel fuel – standardized rapeseed oil methyl esters (RME).

Motor studies were performed on a VALMET 320 DMG diesel generator onboard a ship while using fuel blends consisting of 30% AME (B30AME) or RME (B30RME) and 70% fossil diesel fuel. The B30AME's environmental and energy indicators were compared with indicators related to the B30RME and fossil diesel fuel (D). The experiments allowed the researchers to establish that the quality of the algae oil methyl esters and their mixing with the fossil diesel fuel complied with standard requirements. After measuring the emission of hazardous components, it was found that the main improvement to environmental indicators was related to a 10–75% reduction in the smokiness of the exhaust gas and a 5–25% reduction of hydrocarbons (HC) emissions compared to those of D. The smokiness of the exhaust gas when the engine was running at capacities close to the maximum was approximately 10% lower for B30RME compared to B30AME.

1. Introduction

As reserves of mineral resources have decreased and greenhouse gas emissions increased, biodiesel has been used in increasingly growing amounts in the transportation sector. Vegetable oil is the main feedstock used in the production of biodiesel, and its type depends on the region of the world. Soybean oil is the most commonly used oil in the United States, while rapeseed and sunflower oils are common in Europe, and palm oil is frequently used in Indonesia and Malaysia. A major portion of European biodiesel (84%) is obtained from rapeseed oil, while sunflower oil accounts for 13% of the feedstock used for production [1]. Soybean oil, palm oil and other oil types have accounted for only 1% of the feedstock used there. Biodiesel can be produced from many other types of raw materials, including other vegetable oils, lard and animal fat, and waste from catering enterprises (i.e., restaurants and cafés), such as used cooking oil.

Growing biodiesel production and the related increasing demand for feedstock has increased agricultural produce prices and competition with the food sector. Internal World Bank study attributed 70–75% of the 2006–2008 increases in food commodity prices to biofuels [2]. Alternative feedstock for biodiesel production has been researched to reduce the negative impact of biodiesel production on the food sector, with new types of oil plants and various fatty wastes being considered as potential options.

Algae have frequently been mentioned as a source of oil in recent years. Expanded scientific research has been performed to

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utilize this raw material for biodiesel production in the most efficient manner. The data from short small scale experiments show that algae biodiesel has economic disadvantage and cannot complete with fossil fuel. However some authors believe that fuel production from algae can be cost competitive in the next 7–10 years when new strains of algae will be created and more cost effective methods for algae cultivation and conversion will be developed [3].

The use of algae for energy needs has several advantages. Excess CO_2, which causes the greenhouse effect when emitted into the atmosphere, can be used for algae cultivation. Algal biomass can be distributed over vast spaces of land, and its processing would not require additional resources that increase CO_2 emissions. Finally, algae grow faster than ordinary oil plants [4].

All types of algae contain oils, and their oil content is sufficiently high, being 20–40% of the organism's dry mass, and the oil content in some algae strains can be as high as 75% [5]. The fact that microalgae grow much faster than land plants is one of the most compelling reasons for the use of algae in biodiesel production. Moreover, the amount of oil obtained from algae is approximately 7–31 times greater than that obtained from the best land crops, such as palms, cultivated in the same area [6,7] Algae can be cultivated in special water tanks, so it is not necessary to allocate agricultural lands currently used for food production.

Extensive studies have been performed on biodiesel synthesis using microalgae oil. Their results have shown that microalgae oil transesterification can be carried out following the procedures applied in the production of ordinary biodiesel. Biodiesel obtained from such oil is characterized by physical and chemical properties that depend on the type of microalgae and composition of the oil's fatty acids and that are similar to those of ordinary biodiesel created from rapeseed oil [8]. Polyunsaturated fatty acids, which are also characteristic of biodiesel obtained from rapeseed oil, dominate between the fatty acids in most microalgae oil types [9,10]. Having performed studies on biomass gains for different microalgae types, Talebi et al. have found that *Chlorella vulgaris* microalgae, frequently found in water reservoirs in various countries, such as Lithuania, can potentially be used in biodiesel [11].

Preliminary operational tests of biodiesel obtained from microalgae oil have shown that it, similar to ordinary biodiesel, is characterized by positive environmental properties [12]. The results of studies carried out by Tuccar and Aydın have shown that microalgae methyl esters can be used as an alternative fuel in a diesel engine, and their use has a positive environmental effect compared to mineral diesel fuel because lower concentrations of carbon dioxide and nitrogen oxides occur in its exhaust gas [13]. Accounting for the fact that research on the use of algae for energy needs is relatively new, the operational and environmental properties of biodiesel obtained from microalgae oil require further study.

The literature has provided a relatively small amount of research associated with both the use of pure algae oil methyl esters in diesel engines and the operational and environmental properties of mixtures containing mineral diesel fuel. No data have been identified on comparative operational tests of ordinary biodiesel containing rapeseed oil methyl esters and biodiesel obtained from microalgae oil or on the differences between diesel engines' operational properties and concentrations of hazardous components when a diesel engine runs on these different biofuels or mineral–biofuel mixtures. When implementing more extensive production and use of algae methyl esters and using them to replace ordinary biodiesel (rapeseed oil methyl esters), it would be necessary to assess whether the properties of the new fuel would be equivalent to those of ordinary diesel fuel and whether they would be characterized by worsened environmental impacts and higher concentrations of hazardous components in the exhaust gas.

Therefore, the objective of our study was to compare the properties of biodiesel obtained from *Chlorella* sp. microalgae oil and biodiesel mixtures created using mineral diesel fuel with standard fuel requirements. A second goal was to assess and compare the operational and environmental properties of the algae oil and rapeseed oil methyl ester mixtures with those of mineral diesel fuel.

2. Materials and methods

2.1. Preparation of algae oil methyl esters

Microalgae *Chlorella* sp. were isolated from Lithuanian lakes, and autotrophic growth was initiated by growing in modified BG11 media [14]. A 140-l laboratory tabular reactor was used. The microalgae were grown at room temperature by shaking with airflow under white fluorescent lamp illumination.

After 30 days of cultivation, the microalgae biomass was centrifuged for 10 min at 16,000 rpm, washed with distilled water and then dried in an oven at 105 °C to a constant weight. After oven drying, the algae were pulverized and subjected to oil extraction in a Soxhlet apparatus using hexane as a solvent. After the hexane evaporated, the microalgae oil was used for transesterification. The fatty acid composition of the algae oil was determined using standards EN ISO 5508 and EN ISO 5509, and the analysis was carried out using a Clarus 500 (Perkin Elmer) gas chromatograph.

Algae oil used for biodiesel fuel production contained 7.6% of saturated fatty acids, 64.9% of unsaturated and 27.5% of polyunsaturated fatty acids.

The two-step transesterification procedure was performed in a laboratory reactor equipped with a heater, stirrer and water-cooled glass condenser. Analytical-grade pure methanol was mixed with sodium hydroxide (the product of this reaction being sodium methoxide) before reacting with the algae oil, which was heated to 65 °C. In the first stage, 11% methanol and 0.8% sodium hydroxide were used, followed by 6% methanol and 0.3% sodium hydroxide in the second stage. At the end of the first stage, the reaction product was separated from the glycerol by decantation, sodium methoxide was added to the oil, and the second stage reaction was performed under the same conditions as those for the first stage. At the end of the reaction, the biodiesel was washed twice with a 5% phosphoric acid solution and distilled water, dried at 105–110 °C and with silica gel, and purified by filtration.

The quality parameters of the microalgae oil methyl esters were determined by applying the test methods indicated in the standard EN 14214.

2.2. Diesel engine tests

Fuel mixtures containing 30% (vol.) biodiesel fuel (rapeseed oil methyl esters or microalgae oil methyl esters) and 70% (vol.) mineral diesel fuel were used for the engine tests. These engine motor tests were carried out under operating conditions to evaluate the expected energy utilization efficiency and environmental effects when operating in-service diesel engines with AME biodiesel and D. The actual impact of operational conditions, such as environmental (air and water) parameters and the loading modes of engine energy users, were considered. In many cases, the operational factors may have influenced changes in the fuel's motor properties compared to engine rig tests [15].

To approximate the results of the tests measuring actual operating conditions, these tests were performed in a VALMET 320 DMG diesel generator onboard a ship. The engine, manufactured by AGCO SISU POWER, Finland, is intended to run on a wide range of fuels, including pure (100%) biodiesel fuel, which by itself ensures the engine's optimal operating characteristics and eliminates the need to change the adjustment parameters when running on biofuels. The main operating parameters for the engine are