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PERFORMANCE TEST OF A DIESEL ENGINE USING TRANSESTERIFIED SOYBEAN OIL MIXED WITH DIESEL FUEL

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ABSTRACT

The study focused on the feasibility of soybean oil to use as a biofuel. This study presented the viability of soybean oil in terms of density, flashpoint, sulfur, heating value, specific fuel consumption, and ash content. It also showed the performance result when tested on a diesel engine in terms of fuel consumption, revolution per minute, the temperature at the exhaust pipe, cylinder head, engine block, brake power, and brake thermal efficiency. Soybean oil undergoes the process of transesterification to be used as a biofuel. It was mixed with commercially available diesel fuel upon testing in the diesel engine. The mixture contained 90% diesel fuel and 10% transesterified soybean oil. After testing, the performance of the diesel engine was measured. Transesterified soybean oil was feasible to use as a fuel according to the testing conducted. However, some improvements must have been made to increase the brake thermal efficiency. Evaluating different mixtures for diesel fuel and transesterified soybean oil must also be considered to get more efficient data. It is recommended to include emission testing for future studies.

Keywords: transesterification, diesel engine, soybean oil, heating value.

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INTRODUCTION

Nowadays, fuel plays a very important role in the industrial machinery development and growth of any country. This led to a huge demand for energy derived from fossil fuels such as coal, petroleum, and natural gas. Nevertheless, the limited reserve of fossil fuels has prompted many researchers to look for alternative fuels that can be produced from renewable feedstock. Alternative fuels include biodiesel, bio-alcohol (methanol, ethanol, butane), chemically stored electricity (batteries and fuel cells), hydrogen, vegetable oil, and propane. Biodiesel is considered the better option because of its environmentally friendly characteristics. Various methods have been implemented to produce biodiesel from plant oils (such as soybeans, peanuts, rapeseed, palm, corn, sunflower, sorghum, canola, cottonseed, and others). Recycled cooking greases or oils used cooking oils and restaurant frying oils, or animal fats (such as beef, tallow, poultry fats, fish oils, pork, etc.) are also used to produce biodiesel. Because plants produce oils from sunlight and air and can do so year after year on cropland, these oils are considered renewable.

It is easy to use, biodegradable, non-toxic, and essentially sulfur-free to use biodiesel. Other than nitrogen oxides, it emits fewer air pollutants and greenhouse gasses than most diesel engines, especially more recent ones. It is safer to handle and almost as efficient as petroleum diesel in terms of energy use. It also offers advantages for lubricity that fossil fuels do not.

It has been discovered that biodiesel blends as low as B2 (2% biodiesel) considerably lower the amount of hazardous carbon-based pollutants. Considering the rising cost of petroleum-based products. Compared to conventional diesel, biodiesel is a more inexpensive option. Utilizing biodiesel lessens reliance on limited fossil fuel supplies. It is readily available and can be processed using tools like BioCube as an alternative energy source. To designate a limited region for data collection during biodiversity surveys, a BioCube is a cube-shaped structure with one foot on each edge. The adverse effects of biodiesel exhaust on human health have been proven by scientific studies. Emissions from biodiesel contain a lower concentration of nitrated and hydrocarbon chemicals, which have been known to carry cancer-causing potential.

As part of reducing pollution, the researcher has chosen soybeans to produce biodiesel using a transesterification process. Transesterification gained much acceptance in recent years for the conversion of vegetable oils into products with technically compatible fuel properties. Transesterification is an imperative process for biodiesel production, as it can reduce the viscosity of the feedstock/vegetable oils to a level closer to conventional fossil-based diesel oil.

BACKGROUND OF THE STUDY

The utilization of energy in the form of fossil fuels started at the beginning of the Industrial Revolution. This happened in stages, starting with the exploration of coal resources and ending with the extraction of oil and natural gas. Our other option is to use biofuels, which keep the environment clean by controlling the levels of carbon dioxide in the atmosphere, by preserving the carbon cycle, and by finding a means to slow down global warming. Various agricultural crops and other forms of biomass can be used to create biofuels, which are alternatives to fossil

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fuels. In a short amount of time, weeks, or even months- any hydrocarbon fuel made from organic matter (living or previously alive material) is referred to as a biofuel. They are regarded as an alternative energy source. The following factors contribute to the significance of biofuels: energy security, the demand for alternate energy sources, and rising oil prices. to encourage linear growth and lower greenhouse gas emissions.

Biodiesel is eminent from the straight vegetable oils (SVO) or waste vegetable oils (WVO) used (alone or blended) as fuels in some diesel vehicles. It is made through a chemical process called transesterification whereby the glycerin is separated from fat or vegetable oil. It is more expensive to purchase than petroleum diesel, but this differential may diminish due to the reduction of costs to a business. It is free from sulfur (< 0.001%). It is easily biodegradable with no hazard to soil or groundwater in the case of accidents.

Conceptual Framework

The conceptual framework provides an overview of the variables to be considered in the project. This includes the step-by-step process which are the requirements needed to come up with the design by the stated objectives.

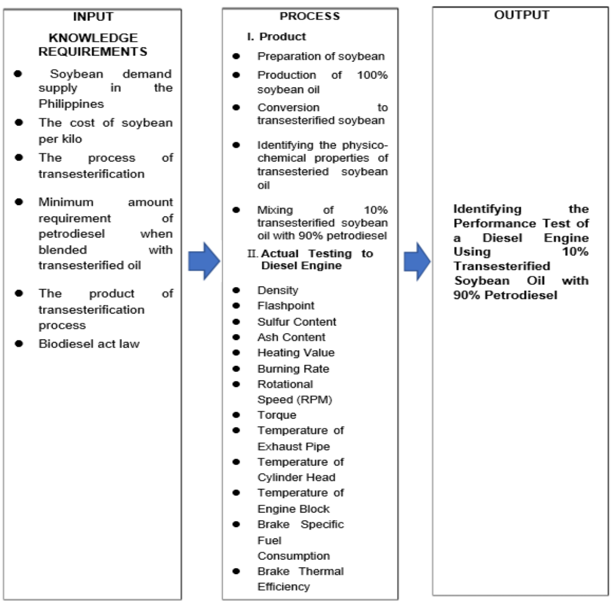

Figure-1. Project study conceptual framework.

Objectives of the Study

The study aims to characterize the physicochemical properties of transesterified soybean oil and to determine the technical viability of transesterified soybean oil as an additive to diesel fuel by conducting a performance evaluation of a diesel engine fueled with 10% transesterified soybean oil and 90% petrodiesel fuel. The following specific objectives are as follows:

1) To characterize and analyze the physicochemical properties of transesterified soybean oil from the Soxhlet extraction method in terms of:

1.1 Density
1.2 Viscosity (@30^{o}C)
1.3 Water Content
Resin Content
1.6 Ash content
1.7 Acid Number

2) To determine the performance of the diesel engine using 10% transesterified soybean oil and 90% petrodiesel. The following performance parameters will be measured:

2.1 Brake-Specific Fuel Consumption
2.2 Brake Thermal Efficiency

Scope and Limitations

The focus of the study is to identify the physico-chemical qualities of biodiesel from soybean oil. The study of the technical viability of soybean oil as fuel will be based on the burning rate and brake-specific fuel consumption of the engine; and the ash content of the flue gas. The engine tests will be limited to brake thermal efficiency, and brake power at selected speeds of the engine, including the values of temperatures at all points in the p-V diagram of the combustion cycle.

Significance of the Study

The project study will benefit the individuals involved in the applications of diesel engines such as operators, process technicians, and maintenance. The 10% transesterified soybean oil with 90% petrodiesel fuel can be used in the smooth operation of passenger cars and small commercial vehicles. It can also be used for stationary diesel engines that are not only for electricity generation but also for powering refrigerator compressors. Non-road diesel engines that are common for construction equipment will also benefit from this project.

The industry that uses equipment run by diesel engines will benefit, since 90% transesterified soybean oil with 10% petrodiesel fuel increases lubricity in engines, causing longer engine life due to less wear throughout years of use.

REVIEW OF RELATED STUDIES

Transesterification

Vegetable oil is converted into biodiesel by using a transesterification process. Esters and glycerol are produced when the oil and alcohol react directly during the transesterification process. To speed up the reaction, propanol and amyl alcohols are also utilized in the procedure. The viscosity of vegetable oil changes drastically because of the transesterification process. But mostly transesterification process is mostly affected by reaction time, temperature, molar ratio, and moisture.

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Production of Biodiesel

Many scientists and researchers have developed very different methodologies to produce biodiesel from different feedstocks of vegetable oil and animal fats produced biodiesel from the transesterification process of soybean oil, with methanol (CH3OH) catalyzed by potassium hydroxide (KOH). Mata T.M. studied the viability of producing biodiesel from three types of waste animal fats (tallow, lard, and poultry fat). Avinash Kumar Agarwal in his paper reviewed the production, characterization, and current status of vegetable oil and biodiesel. Zafer Utlu in his study used methyl ester obtained from waste frying oil (WFO) as an experimental material.

To produce methyl ester, a reactor was built, and installed, and its chemical and physical characteristics were ascertained. Ahn followed a two-step reaction process to produce biodiesel. By employing sodium hydroxide, potassium hydroxide, and sodium methoxide as catalysts, canola methyl ester (CME), rapeseed methyl ester (RME), linseed methyl ester (LME), beef tallow ester (BTE), and sunflower methyl ester (SME) were all produced. The effects of water on the synthesis of biodiesel fuel by supercritical methanol treatment were discussed by Kusdiana *et al*. Ramadhas studied biodiesel production from high-free fatty acid rubber seed oil. To convert the oils with high levels of free fatty acids into mono-esters, they devised a two-step transesterification process. Waste frying oils transesterification was studied by Felizardo to achieve the best conditions for biodiesel production. A. Wisniewski Jr. in his paper reported that waste fish oil was converted into bio-oil by a fast pyrolysis process at 525 0C in a continuous pilot plant reactor with 72-73% yield. Light and heavy bio-oils were produced by distilling the bio-oil, and these biofuels were then evaluated for their physico-chemical characteristics. Sharanappa Godiganur *et al*. stated that the high viscosity of fish oil leads to problems in pumping and spray characteristics. Ineffective mixing of the air and fish oil leads to incomplete combustion. Making fish oil into biodiesel is the best way to use it as fuel in compression ignition (CI) engines. Cherng-Yuan Lin et al. investigated the fuel qualities of biodiesel made from fish soap stock, which is derived from crude fish oil. The raw material for making the biodiesel was a mixture of soap stock from marine fish. Wasted fish products were used to make the soap stock. Fish oil that has been refined has been transesterified to produce biodiesel.

The fuel properties of the biodiesel were analyzed. L. Zhu considered Algae as a promising biodiesel feedstock. Freshwater microalgae Chlorella zofingiensis wintering cultivation in pilot-scale photobioreactors and synthetic wastewater treatment were combined as a part of an integrated strategy. The focus of the study was on the design of autotrophic and mixotrophic cultures with the addition of acetic acid (a pH regulation group). The lipid and biodiesel production, characteristics of algal growth, and nitrogen and phosphate removal were examined. X.Yin studied the production of biodiesel from soybean oil deodorizer distillate which was enhanced by counter-current pulsed ultrasound and also reported the compared results of counter-current probe ultrasonic enhanced transesterification. Approximately 21.6% of crude grease was extracted from housefly (Musca domestica L.) larvae reared on swine manure.

Stauntonia chinensis (SC) seed oil obtained from processing waste was reported and studied as a potential biodiesel feedstock for the first time. E. One-third of the food produced for human consumption is lost in the food supply chain, according to research by Uçkun Kiran. Food waste is used as landfill material in several nations. However, this food waste can be considered as one of the sources for biofuel with advanced conversion technologies R. Tripathi studied a Microbacterium as a good source for the production of lipase enzyme used in transesterification reaction for biodiesel production. P. Thliveros investigated a new method in the production of biodiesel that used direct base-catalyzed methanolysis of the cellular biomass of oleaginous yeast Rhodosporidium toruloides Y4. Catalyst NaOH was used for the transesterification process. S. H. Teo studied non-edible jatropha curcus oil (JCO) as a possible feedstock for the production of biodiesel. Co-precipitation was used to create the calcium-based mixed oxides CaO-Nd2O3 (calcium neodymium) and CaO-NiO (calcium nickel). M. Pistacia chinensis Bunge was listed by Tang et al. as one of the best species for making biodiesel. D. Surendhiran created a non-alcoholic method for producing biodiesel from microalgae using a system free of solvents. N. Waste acid oil was investigated and identified by ShibasakiKitakawa as a potential feedstock for the production of biodiesel that also complied with international standards.

Properties of Biodiesel

Because biodiesel's characteristics are so similar to those of conventional fuels, it makes for an excellent and affordable substitute for diesel fuel. The transesterification process converts the triglycerides into methyl and ethyl esters, which reduces the molecular weight to one-third of the triglycerides, viscosity by a factor of about eight, and slightly increases the volatility. Biodiesel contains 10-12% more oxygen by weight, which accelerates the rate of combustion in an engine. Approximately the cetane number of biodiesels is around 50. Biodiesel also has a high flash point but lower heating value than conventional diesel.

Different properties of biodiesel were studied in various parts of the world. A comprehensive review is presented to study the experimental methodology for understanding the various properties of biodiesel. Pedro Benjumea studied the basic properties of palm oil biodiesel-diesel blends. Murugesan reviewed biodiesel as an alternative fuel for diesel engines. Ertan Alptekin studied commercially available two diesel fuels which were blended with the biodiesels produced from six different vegetable oils (sunflower, canola, soybean, cottonseed, corn oils, and waste palm oil). Key fuel properties like density and viscosities of the blends were measured by ASTM test methods for the blends (B2, B5, B10, B20, B50, and B75), which were prepared on a

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volume basis. S. Bajpai *et al*. used methanol, ethanol, propanol, and butanol for formation of alkyl esters of Jatropha, Karanja, and Castor and optimized alcoholises process for producing alkyl esters of ethyl, propyl, and butyl esters of Jatropha and Karanja feedstock had properties similar to methyl esters at lower blends, but there was a deviation in the properties at higher blending ratios, according to a study of Jatropha, Karanja, and Castor oil. A. B. Fadhil tested how well biodiesel could be purified using activated carbon made from used tea grounds.

According to the study's findings, using activated carbons to purify biodiesel improved the fuel's properties in comparison to purifying it with silica gel and water washing. M. H. M. Yasin investigated the physical properties of alcohol-added biodiesel blends. They claimed that the presence of alcohol in the blends' concentration reduced the density and viscosity of biodiesel blended with mineral diesel. However, the cetane number increased significantly as the alcohol concentration started to rise. The properties of the recently developed biodiesel complied with EN14214 requirements.

One of the most crucial resources for humanity's sustainable development is energy. The energy crisis is one of the major problems facing the world today. Because they can be burned to create a significant amount of energy, fuels are very important. Fuels are essential to many facets of daily life, particularly the movement of people and goods. The primary energy sources are fossil fuels like gasoline, coal, and natural gas. 80% of the energy required by the world is provided by fossil fuels. Diesel-powered equipment is used in the majority of industries for production. Private cars, buses, trucks, and ships all use a lot of types of diesel in the transportation industry. This situation results in a heavy reliance on fossil fuels in daily life. However, domestic crude oil production cannot keep up with population growth. Fuels called fossil oils come from extinct animals and microorganisms.

As a result, fossil fuels are considered non-renewable energy sources. Global and international conflicts as well as economic recessions are frequently brought on by an increase in the price of oil. The significant economic growth associated with fossil fuel resources will be exhausted in just 65 more years, particularly in some developing nations. A further factor in air pollution and global warming is the emission brought on by the burning of fossil fuels. International pressure on issues related to global warming is also increasing for the majority of nations. As a result, the use of clean, renewable alternative fuels has gained attention both now and in the future. The environmental effects of petroleum-fuelled diesel engines and the depleting supply of petroleum have made biodiesel one promising replacement for fossil fuel for diesel engines. Any natural oil or fat can be chemically combined with an alcohol like methanol or ethanol to create biodiesel. The alcohol most frequently used in the industrial production of biodiesel is methanol. Numerous studies on biodiesel have demonstrated that the fuel produced from vegetable oil is suitable for use in diesel engines. In actuality, biodiesel and regular diesel have similar energy densities. Soybean and methanol can be transesterified to create biodiesel in the presence of acid catalysts. The combustion characteristics of biodiesel and diesel derived from petroleum are comparable, making the former one of the most promising renewable and sustainable fuels for automobiles.

Studies on the use of commercial diesel blends and biodiesel date back to the years between the Industrial Revolution and the Second World War, when there was an urgent need for fuel due to a global oil supply crisis brought on by the war. Currently, the introduction of biofuel into the market is required for reasons of environmental viability in terms of reducing the emission of pollutants and gases emitted by the road transportation modal, in addition to balancing the supply/demand ratio. Due to rising consumer demand for environmentally friendly, renewable fuel sources, the production of biofuels has become a lucrative industry. Since environmental viability is a major concern, the introduction of biofuels to the market raises discussions regarding their technical and economic viability. In recent decades, several nations, including Germany, Spain, and France, have spread the culture of biofuels alongside other fuels that are already widely used on the market, like diesel. Brazil has also contributed significantly, primarily by introducing ethanol made from sugar cane.

Higher combustion efficiency, a higher cetane rating, greater biodegradability, and lower carbon monoxide emissions are advantages of biodiesel over diesel fuel. The drawbacks of using biodiesel should be mentioned in addition to its inherent benefits. The drawbacks of biodiesel include slightly higher NOx emissions, issues with cold starts, less energy, increased copper strip corrosion, and difficulty pumping fuel due to higher viscosity. Currently, biodiesel costs more to produce than diesel, which seems to be the main barrier to its wider adoption. Vegetable oil and animal fat are currently not produced in sufficient quantities to completely replace the use of liquid fossil fuels. These factors led to the growing significance of biodiesel blends with other fuels like diesel, bioethanol, etc. According to the literature, there has been a significant amount of work done on the process design and production of biodiesel from different vegetable oils, but there is a severe lack of experimental data and/or prediction models for the thermodynamic properties of feed oils (vegetable oils) and other crucial biodiesel properties. The process simulation tools ask for the thermodynamic data required for an adequate characterization of the feed oils. In actuality, these simulation tools make use of correlations that are derived from a small set of data points. There is a dearth of experimental data available in the literature. With the rising demand for diesel fuel, there is a significant opportunity to create precise models that can predict the characteristics of biodiesel and, more importantly, their blends.

Biodiesel is a substitute for diesel fuel made from non-edible oil and alkyl monoesters of fatty acids from vegetable or animal fats. Recent studies have

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demonstrated the renewable nature of biodiesel and its ability to lower harmful gas emissions. The production of biodiesel can use the vegetable oil as a raw material. There have been many non-edible oils studied, including waste (used or fryer) vegetable oil as well as non-edible oils like Jatropha, Pongamia, Mahua, Neem, and waste vegetable oil (WVO). In a diesel engine, burning vegetable oils for brief periods is safe. A diesel engine may develop severe engine deposits, piston ring sticking, injector coking, and thickening of the lubricating oil if raw vegetable oil is used in the engine for an extended period. Because raw oil has a high viscosity, fuel spray penetration is increased while fuel atomization is decreased. The problems with engine deposits and thickening of the lubricating oil are thought to be partially caused by higher spray penetration. However, by transesterifying the oil to create biodiesel, these effects can be minimized or even avoided. According to numerous studies, biodiesel even outperformed petroleum-based diesel in several engine performance facets, such as brake thermal efficiency (BTE) and exhaust emissions.

Studies on diesel engines have revealed that brake-specific fuel consumption (BSFC) increases when using different blends of biodiesel from Pongamia and WCB. According to the results, using biodiesel instead of diesel for the same power output results in a higher BSFC. This is due to biodiesel's lower heating value when compared to diesel. It was discovered that using Pongamia biodiesel (PB) up to PB20 did not significantly change the thermal efficiency, but using PB100 did cause a slight decrease in thermal efficiency because of the lower energy content of the biodiesel. Pongamia biodiesel emits lower gaseous emissions than diesel fuel while expected NOx increases to 2% with PB20 and 10% with PB100. The higher cetane of PB as compared to petrol diesel implies its much-improved combustion profile in an internal combustion engine.

PB reduces both the pollutant elements of exhaust and their total amount. According to Suresh Kumar, PB blends up to 40% by volume (PB40) could replace diesel in applications requiring diesel engines to produce less emissions and perform better, aiding in the achievement of energy efficiency, environmental protection, and rural economic development. According to the investigation, diesel and BSFC for PB20 and PB40 are on par. BSEC is inferior to diesel. All PB blends have lower CO and HC emissions than diesel while having higher CO2 and NOx emissions.

Biodiesel is an alternative fuel that burns relatively cleanly and is made from domestic and renewable resources. Although biodiesel doesn't contain any petroleum components, it can be mixed with petroleum diesel at any ratio to produce a biodiesel blend. It requires little to no modification for use in diesel engines that use compression ignition. Simple to use, biodegradable, nontoxic, and essentially free of sulfur and aromatics are all attributes of biodiesel. Glycerine is separated from fat or vegetable oil during a chemical process called transesterification to create biodiesel. A triglyceride is made to react with alcohol during the transesterification process while a catalyst is present. Methyl ester, which is the chemical name for biodiesel, and glycerine are the byproducts of the process. Using vegetable oils as fuel for diesel engines is said to have several drawbacks, including poor fuel atomization and low volatility due to their high viscosity, high molecular weight, and density. Vegetable oils used as fuel in CI engines for an extended period may result in serious engine problems like damaged injectors and valves. Because it is produced from renewable resources and emits fewer greenhouse gases than traditional petroleum diesel, biodiesel is better for the environment. Monohydric alcohols like methanol and ethanol are transesterified in the presence of an alkali catalyst. Without making significant changes to the engine, biodiesel and its blend with petroleum-based diesel fuel can be used in diesel engines. The benefits of biodiesel include protecting the environment from threats such as tailpipe emissions, hydrocarbons, carbon monoxide, and other air toxins, which are frequently present when using petroleum products as fuel. Fuel pumps wear less quickly and are better lubricated thanks to biodiesel.

Current Potential for Use as Biofuel

At the moment, soybean oil is a significant feedstock used to produce biodiesel (NBB). The most common method for producing biodiesel involves using sodium hydroxide as a catalyst to react vegetable or animal fats with methanol or ethanol. The transesterification reaction results in the production of glycerin and methyl or ethyl esters (biodiesel).

Keep in mind that biodiesel is not created when pure vegetable oil is burned in a diesel engine. Numerous studies conducted between 1980 and 2000 show that using straight vegetable oils, such as soybean oil, causes carbon deposits and shortens engine life.

METHODOLOGY

A. Project Design

The following procedures are carried out by the researchers:

a) Sourcing of soybeans

b) Preparation of soybeans
c) Extraction of soybean oil using the Soxhlet method.
d) Conduct the transesterification process to produce transesterified soybean oil. E. Identify the physicochemical characteristics of transesterified soybean oil for the following: density, viscosity (@ 30^{o}C), water content, resin content, ash content, and acid number using these methods: gravimetric, Engler, Toluene distillation, spectrophotometric, and Titrimetric.
e) Conduct the testing of the diesel engine using 10% transesterified soybean oil in 90% Petro diesel by volume.
f) Conduct the testing of a diesel engine that powers a fiberglass type of boat at the Navotas Fishing Port.

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g) Determine the technical viability of transesterified soybean oil as an additive to Petro diesel in terms of density, flashpoint, sulfur content, ash content, heating value, burning rate, the temperature at the exhaust pipe, temperature of the cylinder head and temperature of the engine block. Comparison of the commercial diesel fuel used and the 10% transesterified soybean oil with 90% Petro diesel in terms of brake-specific fuel consumption and brake thermal efficiency.

B. Project Development

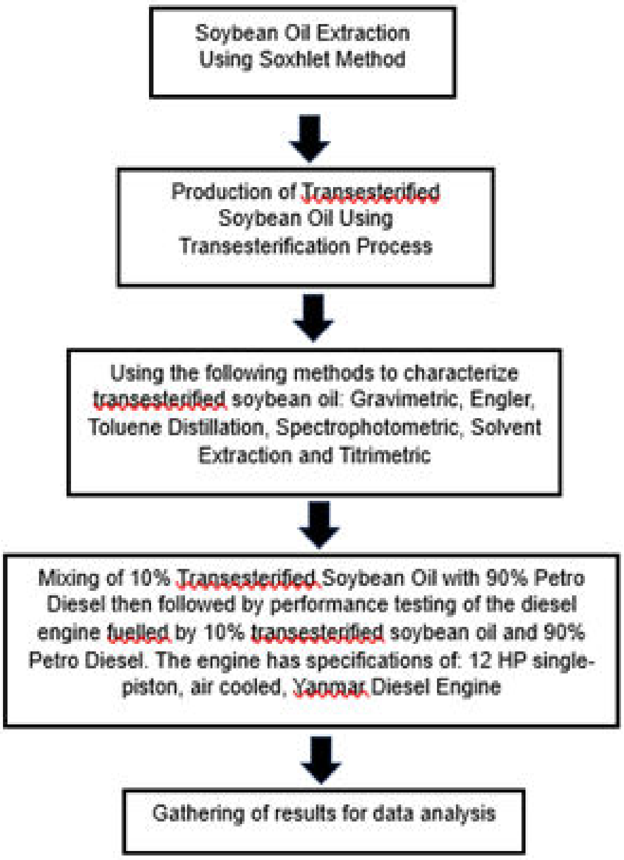

Figure-2. Block diagram from extraction of soybean oil to performance testing of 10% transesterified soybean oil with 90% petro diesel.

Figure-3. Crane scale.

A crane scale was used to measure the weights at two different rotational speeds. The fiberglass type of boat was fixed or stationary at one end and the other end was freely moving. A rope was used to attach the crane scale to the other end which was freely moving to measure the weight produced at a certain rotational speed.

The rotational speed of the diesel engine was at 1000 RPM for its first testing. The testing conducted lasted for 10 minutes and consumed 100 mL of biodiesel (10% transesterified soybean oil and 90% diesel fuel). The weight measured at one end of the fiberglass boat that freely moved was 16.32 kgs.

The second testing conducted used 1400 RPM of the diesel engine. The testing lasted for 1 minute and consumed 20 mL of biodiesel (10% transesterified soybean oil and 90% diesel fuel). It only took 1 minute because the weight measured stabilized already. The weight measured at 1400 RPM was 31.55 kgs.

C. Operation and Testing Procedure

The following steps will be done to determine the technical viability of the transesterified soybean oil as an additive to Petro diesel:

- Comparison of the physico-chemical characteristics of the 10% transesterified soybean oil with 90% Petro diesel to soybean seeds biodiesel.
- Comparison of the performance testing results in the diesel engine of 10% transesterified soybean oil with 90% Petro diesel and commercial diesel fuel.

RESULTS AND DISCUSSIONS

Physico-Chemical Characterization of the Transesterified Soybean Oil

Table-1.0 shows the result of characterized transesterified soybean oil with specific analytes and parameters. The density of the characterized soybean oil is 0.8448 g/mL using the gravimetric method. Its viscosity @

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30°C is 8 cSt using the Engler method. The water content is <0.50 % by the Toluene distillation method. Resin content is <0.11% using the gravimetric method. Ash content is <0.25% using the gravimetric method.

Table-1. Characteristics of the transesterified soybean oil.

Analytes/Parameters	Results	Units	Methods
Density	0.8448	g/ml	Gravimetric
Viscosity (@30°C)	8	cSt	Engler
Water Content	<0.50	%	Toluene Distillation
Resin Content	<0.11	%	Gravimetric
Ash Content	<0.25	%	Gravimetric
Acid Number	<0.1	mg KOH/g	Titrimetric

Comparative Analysis of Transesterified Soybean Oil to Soybean Seeds Biodiesel and Standard Fuel Oil

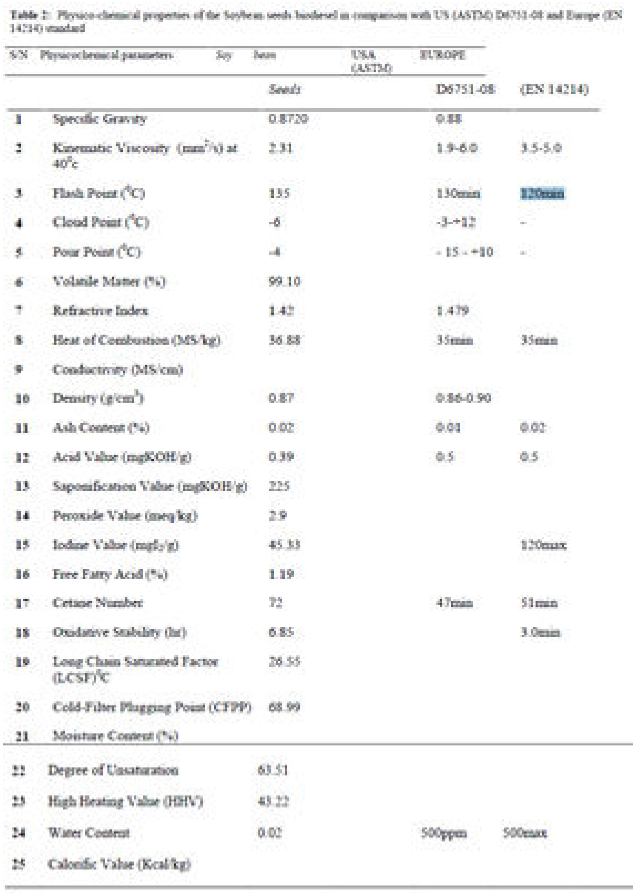
Table 2: Physico-chemical properties of the Soybean seeds biodiesel in comparison with US (ASTM) D6751-08 and Europe (EN 14214) standard

S/N	Physicochemical parameters	Soy bean Seeds	USA (ASTM) D6751-08	EUROPE (EN 14214)
1	Specific Gravity	0.8720	0.88	
2	Kinematic Viscosity (mm²/s) at 40°c	2.31	1.9-6.0	3.5-5.0
3	Flash Point (°C)	135	130min	120min
4	Cloud Point (°C)	-6	-3-+12	-
5	Pour Point (°C)	-4	- 15 - +10	-
6	Volatile Matter (%)	99.10		
7	Refractive Index	1.42	1.479	
8	Heat of Combustion (MS/kg)	36.88	35min	35min
9	Conductivity (MS/cm)			
10	Density (g/cm³)	0.87	0.86-0.90	
11	Ash Content (%)	0.02	0.01	0.02
12	Acid Value (mgKOH/g)	0.39	0.5	0.5
13	Saponification Value (mgKOH/g)	225		
14	Peroxide Value (meq/kg)	2.9		
15	Iodine Value (mgI₂/g)	45.33		120max
16	Free Fatty Acid (%)	1.19		
17	Cetane Number	72	47min	51min
18	Oxidative Stability (hr)	6.85		3.0min
19	Long Chain Saturated Factor (LCSF)°C	26.55		
20	Cold-Filter Plugging Point (CFPP)	68.99		
21	Moisture Content (%)			
22	Degree of Unsaturation	63.51		
23	High Heating Value (HHV)	43.22		
24	Water Content	0.02	500ppm	500max
25	Calorific Value (Kcal/kg)			

Figure-4. Physico-chemical properties of the soybean seeds biodiesel in comparison with US (ASTM) D6751-08 and Europe (EN 14214) standard.

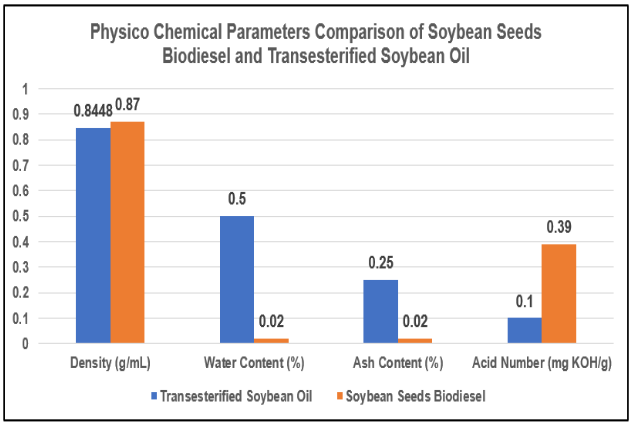

Figure-5. Physico chemical parameters comparison of soybean seeds biodiesel and transesterified soybean oil.

Figure-5 shows the comparison of the soybean seeds' biodiesel and transesterified soybean oil in terms of density (g/mL), water content (%), ash content (%), and acid number (mg KOH/g). Water and ash contents are more highly visible in transesterified soybean oil than in soybean seeds biodiesel. The densities of soybean seeds biodiesel and transesterified soybean oil have minimal differences. The acid number for soybean seeds biodiesel is higher compared to transesterified soybean oil. The methods and other production processes involved in transesterified soybean oil need to be enhanced and improved to achieve high-quality diesel. Soybean seeds biodiesel is better to use than transesterified soybean oil since it has lower ash and water content.

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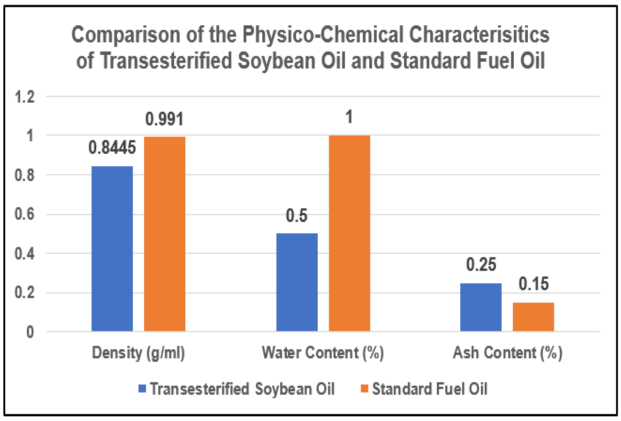
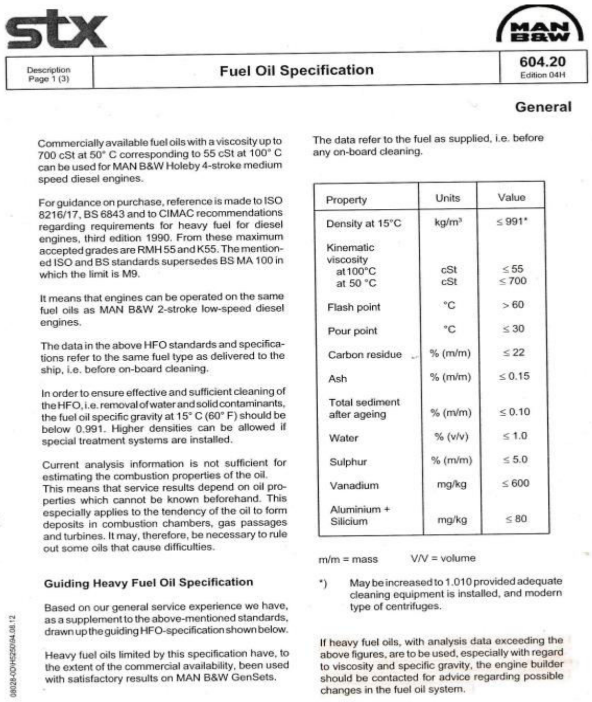


Figure-6. Standard fuel oil specification.



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MAN B&W

Description Page 1 (3)	Fuel Oil Specification	604.20 Edition 04H

General

Commercially available fuel oils with a viscosity up to 700 cSt at 50° C corresponding to 55 cSt at 100° C can be used for MAN B&W Holeby 4-stroke medium speed diesel engines.

For guidance on purchase, reference is made to ISO 8216/17, BS 6843 and to CIMAC recommendations regarding requirements for heavy fuel for diesel engines, third edition 1990. From these maximum accepted grades are RMH 55 and K55. The mentioned ISO and BS standards supersedes BS MA 100 in which the limit is M9.

It means that engines can be operated on the same fuel oils as MAN B&W 2-stroke low-speed diesel engines.

The data in the above HFO standards and specifications refer to the same fuel type as delivered to the ship, i.e. before on-board cleaning.

In order to ensure effective and sufficient cleaning of the HFO, i.e. removal of water and solid contaminants, the fuel oil specific gravity at 15° C (60° F) should be below 0.991. Higher densities can be allowed if special treatment systems are installed.

Current analysis information is not sufficient for estimating the combustion properties of the oil. This means that service results depend on oil properties which cannot be known beforehand. This especially applies to the tendency of the oil to form deposits in combustion chambers, gas passages and turbines. It may, therefore, be necessary to rule out some oils that cause difficulties.

Guiding Heavy Fuel Oil Specification

Based on our general service experience we have, as a supplement to the above-mentioned standards, drawn up the guiding HFO-specification shown below.

Heavy fuel oils limited by this specification have, to the extent of the commercial availability, been used with satisfactory results on MAN B&W GenSets.

The data refer to the fuel as supplied, i.e. before any on-board cleaning.

Property	Units	Value
Density at 15°C	kg/m^3	≤ 991*
Kinematic viscosity at 100°C at 50 °C	cSt cSt	≤ 55 ≤ 700
Flash point	°C	> 60
Pour point	°C	≤ 30
Carbon residue	% (m/m)	≤ 22
Ash	% (m/m)	≤ 0.15
Total sediment after ageing	% (m/m)	≤ 0.10
Water	% (v/v)	≤ 1.0
Sulphur	% (m/m)	≤ 5.0
Vanadium	mg/kg	≤ 600
Aluminium + Silicium	mg/kg	≤ 80

m/m = mass V/V = volume

*) May be increased to 1.010 provided adequate cleaning equipment is installed, and modern type of centrifuges.

If heavy fuel oils, with analysis data exceeding the above figures, are to be used, especially with regard to viscosity and specific gravity, the engine builder should be contacted for advice regarding possible changes in the fuel oil system.

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Figure-7. Comparison of the physico-chemical characteristics of transesterified soybean oil and standard fuel oil.

Based on Figure-7, the density of the transesterified soybean oil is lower than that of the standard fuel oil. The water content of the standard fuel oil is higher than the transesterified soybean oil. However, the ash content of standard fuel oil is much lower than that of transesterified soybean oil. Standard fuel oil is much better to use than transesterified soybean oil since it has lower ash content and higher density.

Viability of Transesterified Soybean Oil as Fuel

Table-2 presents the results and methods of the 10% soybean transesterified and 90% diesel samples taken. The density is 0.8517 g/mL using the gravimetric method. The flashpoint is 110 °C using the open-cup method. Sulfur is 0.94% using the spectrophotometric method. Ash is less than 0.25% using the gravimetric method. The heating value is 19,546 Btu/lb as calculated. The burning rate is 11 mL/min. The speeds are 1,000 RPM and 1,400 RPM measured by the tachometer. The temperatures at the exhaust pipe, cylinder head, and engine block are 130 °C, 104 °C, and 107 °C respectively using a thermal scanner.

Table-2. The results and methods used for 10% transesterified soybean oil and 90% petrodiesel.

Analytes/Parameters	Results	Units	Methods
Density	0.8517	g/mL	Gravimetric
Flashpoint	110	°C	Open-Cup
Sulfur	0.94	%	Spectrophotometric
Ash	<0.25	%	Gravimetric
Heating Value	19,546	BTU/lb	Calculated
Burning Rate	11	mL/min	Calculated
Temp of Exhaust Pipe	130	°C	Thermal Scanner
Temp of Cylinder Head	104	°C	Thermal Scanner
Temp of Engine Block	107	°C	Thermal Scanner

Commercial Diesel as Fuel

Table-3 presents the results and methods of the commercial diesel as a sample. The burning rate is 12.0 mL/minute. The temperature of the exhaust pipe is 119 °C using the thermal scanner. The temperature of the cylinder head is 89 °C using a thermal scanner. The temperature of the engine block is 65 °C. The measured RPM is 1372 using a tachometer. The distance traveled is 763 meters. The number of minutes the engine is burning is 5 minutes using speedometer lead. The fuel consumption is 12.71 km/liter as calculated.

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Table-3. The results and methods used for commercial diesel fuel.

Analytes/Parameters	Results	Units	Methods
Burning Rate	12.0	mL/min	Calculated
Temperature of Exhaust Pipe	119	°C	Thermal Scanner
Temperature of Cylinder Head	89	°C	Thermal Scanner
Temperature of Engine Block	65	°C	Thermal Scanner
Measured RPM	1400	RPM	Tachometer
Distance Travelled	763	Meter	GSP
Number of Minutes Engine is Burning	5	mins	Speedometer Lead
Fuel Consumption	12.71	km/liter	Calculated

Comparative Analysis of Using 10% Transesterified Soybean Oil with 90% Petrodiesel to Commercial Diesel via Actual Testing

The table and charts below show the comparison of using 10% Transesterified Soybean Oil with 90% Petrodiesel Fuel in terms of burning rate, the temperature of the exhaust pipe, the temperature of the cylinder head, the temperature of the engine block, brake-specific fuel consumption and brake thermal efficiency.

Table-4. Comparison of commercial diesel fuel and 10% transesterified soybean oil with 90% petrodiesel.

Analytes/Parameters	Commercial Diesel	10% Transesterified Soybean Oil and 90% Petrodiesel
Burning Rate	12.0 mL/min	11mL/min
Temperature of Exhaust Pipe	119 °C	130 °C
Temperature of Cylinder Head	89 °C	104 °C
Temperature of Engine Block	65 °C	107 °C
Measured RPM	1400	1000 and 1400
Number of minutes engine is running	5	10 and 1
Brake-Specific Fuel Consumption	@1400 RPM: 7.326×10^{-8} Kg/J	@1000 RPM: 1.0329×10^{-7} kg/J @1400 RPM: 2.199×10^{-8} kg/J
Brake Thermal Efficiency	@1400 RPM: 30.194%	@1000 RPM: 21.289% @1400 RPM: 28.817%

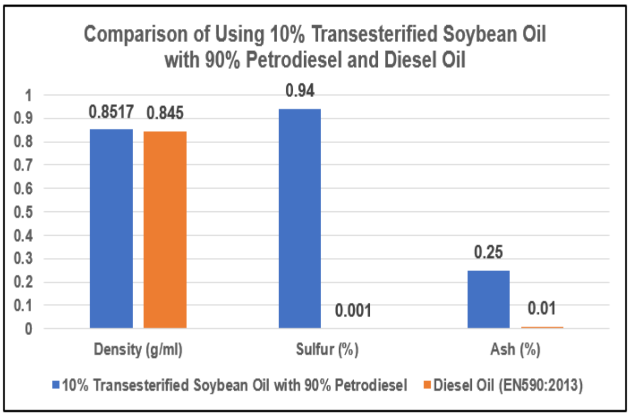

Figure-8. Diesel engine performance testing result comparison of 10% transesterified soybean oil with 90 % petrodiesel and commercial diesel.

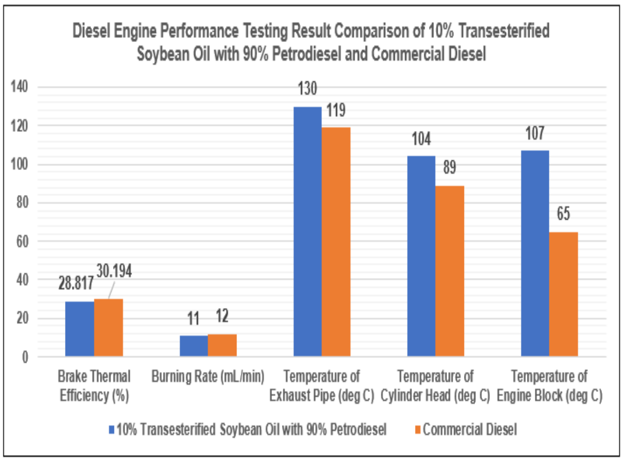

Figure-9. Brake specific fuel consumption (Kg/J) comparison of 10% transesterified soybean oil with 90 % petrodiesel and commercial diesel.

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Figures 8 and 9 show the comparison of the petrodiesel used and 10% transesterified soybean oil mixed with 90% petrodiesel in terms of burning rate, the temperature of the exhaust pipe, the temperature of the cylinder head, the temperature of the engine block, brake specific fuel consumption and brake thermal efficiency. The diesel engine uses the 1400 RPM rotational speed. The brake thermal efficiency of using 10% transesterified soybean oil mixed with 90% petrodiesel is much lower than the efficiency of using petrodiesel which has a 5% significant difference. Commercial diesel is still better to use than the 10% transesterified soybean oil with 90% petrodiesel since the diesel engine that used the commercial diesel had brake thermal efficiency ranging from 30% to 35%.

Comparative Analysis of Using 10% Transesterified Soybean Oil with 90% Petrodiesel to Diesel Oil (EN590:2013)

The table and charts show the comparison of using 10% Transesterified Soybean Oil with 90% Petrodiesel Fuel in terms of density, sulfur content, and ash content.

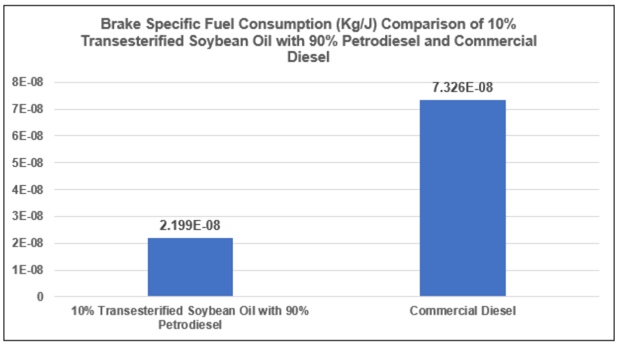

Figure-10. Specification of diesel oil (EN590:2013).

Specification: Diesel Oil EN590 | 2013

Property		EN 590:2013	ASTM D975:15b
Appearance at +25 °C			
Cetane number		≥ 51.0	≥ 40
Density at +15 °C	kg/m³	820.0...845.0 ≥ 800.0 *	
Total aromatics	% (m/m)		≤ 35
Polyaromatics	% (m/m)	≤ 8.0	
Sulfur	mg/kg	≤ 10.0	≤ 15
FAME-content	% (V/V)	≤ 7.0	
Flash point	°C	> 55	> 52
Carbon residue on 10 % distillation	% (m/m)	≤ 0.30	≤ 0.35
Ash	% (m/m)	≤ 0.010	≤ 0.01
Water	mg/kg	≤ 200	
Total contamination	mg/kg	≤ 24	
Water and sediment	% (V/V)		≤0.05
Copper corrosion		Class 1	Class 3
Oxidation stability	g/m³ h	≤ 25 ≥ 20 **	
Lubricity HFRR at +60 °C	µm	≤ 460	≤ 520
Viscosity at +40 °C	mm²/s	2.000 ... 4.500 ≥ 1.200 *	1.9...4.1
Distillation 95% (V/V) 90% (V/V)	°C °C	≤ 360	 282...338
Final boiling point	°C		
Cloud point and CFPP *****	°C	Down to -34	
Antistatic additive			
Conductivity	pS/m		≥ 25

Figure-11. Comparison of using 10% transesterified soybean oil with 90 % petrodiesel and diesel oil (EN590:2013)

The density of the 10% transesterified soybean oil with 90% petrodiesel is higher than the density of diesel oil (EN590:2013) but with minimal difference. Sulfur and ash contents of 10% transesterified soybean oil with 90% petrodiesel are very high compared to diesel oil (EN590:2013). Based on these comparisons, diesel oil (EN590:2013) is better to use than 10% transesterified soybean oil with 90% petrodiesel because of the negligible content of ash and sulfur.

A. PROJECT COMPUTATION

Data Gathered

- Diesel Engine Specifications: 12 HP Single Piston Air Cooled Yanmar Diesel Engine
- Measured RPM during testing: 1000 rpm and 1400 rpm
- Engine ran for 10 minutes at 1000 rpm and 1 minute at 1400 rpm
- Fuel consumed at 1000 rpm and 1400 rpm were 100 mL and 20 mL respectively

Solution

a. Brake Specific Fuel Consumption

Brake Specific Fuel Consumption = Fuel Consumption Rate/ Brake Power

ρ of (10% transesterified soybean oil and 90% diesel fuel) = 0.8517 g/mL (Laboratory data)

mass of fuel @ 1000 rpm = (0.8517 g/mL)(100 mL) = 85.17 g

mass of fuel @ 1400 rpm = (0.8517 g/mL)(20 mL) = 17.034 g

mass flow rate of fuel @ 1000 rpm = $\frac{85.17\ g\ x\ 1kg\ x\ 1\ min}{1000\ g\ x\ 10\ mins\ x\ 60\ secs}$ = 1.4195 x 10^{-4} kg/s

mass flow rate of fuel @ 1400 rpm = $\frac{17.034\ g\ x\ 1\ kg\ x\ 1\ min}{1000\ g\ x\ 60\ secs}$ = 2.839 x 10^{-4} kg/s

Fuel Power @ 1000 rpm = (1.4195 x 10^{-4} kg/s) (45,469.37 kJ/kg)

Fuel Power @ 1000 rpm = 6.454 KW

BSFC @ 1000 rpm = (1.4195 x 10^{-4} kg/s)/1,374.342 Watts

BSFC @ 1000 rpm = 1.0329 x 10^{-7} Kg/J

BSFC @ 1400 rpm = (2.839 x 10^{-4} kg/s)/12,908.754 Watts

BSFC @ 1400 rpm = 2.199 x 10^{-8} Kg/J

b. Brake Thermal Efficiency

Torque @ 1000 rpm = $\frac{16.32\ kg\ x\ 9.80665\ N\ x\ 8.2\ cm\ x\ 1\ m}{1\ kg\ x\ 100\ cm}$ = 13.124 Nm

Torque @ 1400 rpm = $\frac{31.55\ kg\ x\ 9.80665\ N\ x\ 8.2\ cm\ x\ 1\ m}{1\ kg\ x\ 100\ cm}$ = 25.371 Nm

Brake Power @ 1000 rpm = 2πTN/60

Brake Power @ 1000 rpm = (2π x 13.124 N-m x 1000 RPM)/60

Brake Power @ 1000 rpm = 1,374.342 Watts = 1.374 KW

Brake Power @ 1400 rpm = 2πTN/60

Brake Power @ 1400 rpm = (2π x 25.371 Nm x 1400 RPM)/60

Brake Power @ 1400 rpm = 3,719.583 Watts = 3.72 KW

mass of fuel @ 1000 rpm = (0.8517 g/mL)(100 mL) = 85.17 g

mass of fuel @ 1400 rpm = (0.8517 g/mL)(20 mL) = 17.034 g

mass flow rate of fuel @ 1000 rpm = $\frac{85.17\ g\ x\ 1kg\ x\ 1\ min}{1000\ g\ x\ 10\ mins\ x\ 60\ secs}$ = 1.4195 x 10^{-4} kg/s

mass flow rate of fuel @ 1400 rpm = $\frac{17.034\ g\ x\ 1\ kg\ x\ 1\ min}{1000\ g\ x\ 60\ secs}$ = 2.839 x 10^{-4} kg/s

Heating Value of 10% esterified soybean oil and 90% diesel fuel = 19,456 Btu/lb = 45,469.37 kJ/kg

Fuel Power = m_f x Cv

Fuel Power @ 1000 rpm = (1.4195 x 10^{-4} kg/s) (45,469.37 KJ/kg)

Fuel Power @ 1000 rpm = 6.454 KW

Fuel Power @ 1400 rpm = (2.839 x 10^{-4} kg/s) (45,469.37 KJ/kg)

Fuel Power @ 1400 rpm = 12.909 KW

Brake Thermal Efficiency (%) = $\frac{Brake\ Power}{Fuel\ Power}\ x\ 100$

Brake Thermal Efficiency (@ 1000 rpm) = $\frac{1.374\ Kw}{6.454\ Kw}\ x\ 100$

Brake Thermal Efficiency @ 1000 rpm = 21.289%

Brake Thermal Efficiency (@ 1400 rpm) = $\frac{3.72\ Kw}{12.909\ Kw}\ x\ 100$

Brake Thermal Efficiency @ 1400 rpm = 28.817%

Calculations using Commercial Diesel Fuel

Data Gathered:

$Volume_{diesel}$ = 100 mL

N = 1400 RPM

Weight = 32.8 kgs

$Density_{diesel}$ = 0.85 kg/L

Number of minutes the engine running = 5

Calorific Value of Diesel Fuel = 45,206.64 kJ/kg

a) Brake Specific Fuel Consumption

BSFC = Fuel Consumption Rate/Brake Power

Mass of fuel @ 1400 RPM = (0.85 kg/L)(0.1L) = 0.085 kg

Mass flow rate of fuel @ 1400 RPM = $\frac{0.085\ kg}{5minsx60secs}$ = 2.833 x 10^{-4} kg/s

Fuel Power @ 1400 RPM = (2.833 x 10^{-4} kg/s) (45,206.64 kJ/kg) = 12.807 KW

Torque at 1400 RPM = $\frac{32.8\ kg\ x\ 9.80665\ N\ x\ 8.2\ cm\ x\ 1\ m}{1\ kg\ x\ 100\ cm}$

Torque at 1400 RPM = 26.376 Nm

Brake Power @ 1400 RPM = $\frac{2\pi TN}{60} = \frac{2\pi(26.376\ Nm)(1400\ RPM)}{60}$ = 3866.924 W

Brake Power @ 1400 RPM = KW

BSFC @ 1400 RPM = (2.833 x 10^{-4} kg/s)/(3866.924 W)

BSFC @ 1400 RPM = 7.326 x 10^{-8} Kg/J

b) Brake Thermal Efficiency

BTE @ 1400 RPM = $\frac{Brake\ Power}{Fuel\ Power}$ x 100%

BTE @ 1400 RPM = $\frac{3.867\ KW}{12.807\ KW}$ x 100 %

BTE @ 1400 RPM = 30.194%

B. ENGINEERING ECONOMIC ANALYSIS

Data

Price of 12 Hp Yanmar Diesel Engine (based on DEQ AGRO Machineries Supply) – Php 18,000

Price of diesel (based on Market Insider as of June 27, 2023) - Php 54.65/L

Price of Soybean (based on Market Insider as of June 27, 2023) - Php 15/kg

Price of Soybean Oil (based on Market Insider as of June 27, 2023) – Php 74.66/li

Formula

Total Annual Cost = Annual Depreciation using Sinking Fund Method + Minimum Required Profit or Interest on Investment + Operation and Maintenance Expenses + Annual Taxes and Insurances + Miscellaneous Expenses (from Engineering Economics by Sta. Maria)

From Engineering Economics by Sta. Maria,

Operation and Maintenance percentage = 10% - 15%

Taxes and Insurances = 3% - 5%

Miscellaneous = 10% - 12%

Let i = 12% and number of years is 10

Solution:

Annual Depreciation = $\frac{(Co-CL)i}{(1+i)^{\wedge}10-1}$

C_o = First cost

C_L = Salvage value

Annual Depreciation = $\frac{(Php\ 18{,}000-Php\ 1{,}800)(0.12)}{(1+0.12)^{10}-1}$ = Php 923.14

a) For 100 mL of fuel (10% transesterified soybean oil and 90% Petro diesel) @ 1000 rpm:

a.1) 90 mL of Petro diesel = Php 4.92
10 mL of transesterified soybean oil = Php 0.7
Cost of fuel = Php 4.92 + Php 0.7 = Php 5.62
Total Investment = Cost of fuel + Cost of engine
Total Investment = Php 5.62 + Php 18,000.00
Total Investment = Php 18,005.62

a.2) Interest on Investment = (Total Investment)(i)
Interest on Investment = (Php 18,005.62)(0.12)
Interest on Investment = Php 2,160.67

a.3) Operation and Maintenance Expenses = (Total Investment)(0.13)
Operation and Maintenance Expenses = (Php 18,005.62)(0.13)
Operation and Maintenance Expenses = Php 2,340.73

a.4) Annual Taxes and Insurances = (Total Investment)(0.04)
Annual Taxes and Insurance = (Php 18,005.62)(0.04)
Annual Taxes and Insurance = Php 720.22

a.5) Miscellaneous Expenses = (Total Investment)(0.11)
Miscellaneous Expenses = (Php 18,005.62)(0.11)
Miscellaneous Expenses = Php 1,980.62

a.6) Electricity Cost
Let the engine run for 10 mins and the engine rating is 12 Hp (8.948 KW). Use the current consumption of Php 12.00/kw-hr from Meralco.

Electricity cost = $\frac{8.948\ KW\ x\ \ 10\ mins\ x\ 1\ hour\ x\ Php\ 12.00}{60\ mins\ x\ KW-Hr}$ = Php 6,533.5

a.7) Total Annual Cost = Php 923.14 + Php 2,160.67 + Php 2,340.73 + Php 720.22 + Php 1,980.62 + Php 6, 533.5 = Php 14,658.88

b) For 100 mL of Petro diesel @ 1000 rpm

Cost of fuel = $\frac{100\ mL\ x\ 1L\ x\ Php\ 54.65}{1000\ mL\ x\ 1L}$ = Php 5.47
Total Investment = Cost of fuel + Cost of engine
Total Investment = Php 5.47 + Php 18,000.00
Total Investment = Php 18,005.47

b.1) Interest on Investment = (Total Investment)(i)
Interest on Investment = (Php 18,005.47)(0.12)
Interest on Investment = Php 2,160.66

b.2) Operation and Maintenance Expenses = (Total Investment)(0.13)
Operation and Maintenance Expenses = (Php 18,005.47)(0.13)
Operation and Maintenance Expenses = Php 2,340.71

b. 3) Annual Taxes and Insurances = (Total Investment)(0.04)
Annual Taxes and Insurance = (Php 18,005.47)(0.04)
Annual Taxes and Insurance = Php 720.22

b.4) Miscellaneous Expenses = (Total Investment)(0.11)
Miscellaneous Expenses = (Php 18,005.47)(0.11)
Miscellaneous Expenses = Php 1,980.6

b.5) Electricity Cost
Let the engine run for 10 mins and the engine rating is 12 Hp (8.948 KW). Use the current consumption of Php 12.00/kw-hr from Meralco.

Electricity cost = $\frac{8.948\ KW\ x\ \ 10\ mins\ x365X\ 1\ hour\ x\ Php\ 12.00}{60\ mins\ x\ KW-Hr}$ = Php 6,533.5

b.6) Total Annual Cost = Php 923.14 + Php 2,160.66 + Php 2,340.71 + Php 720.22 + Php 1,980.6 + Php 6533.5 = Php 14,658.83

C. SUMMARY OF FINDINGS

The following findings were observed and noted after conducting the testing for 10% transesterified soybean oil and 90% diesel fuel:

Physico-Chemical Characterization

1. Density is closer to 10% transesterified soybean oil blended with 90% petrodiesel which only has a 0.0069 g/mL discrepancy.
2. The viscosity @ 30°C is 8 cSt.
3. The water content is less than 0.50%.
4. The resin content is less than 0.11%.
5. The ash content is less than 0.25%.
6. The acid number is less than 0.1 mg/g

Viability as Fuel and Effect on Engine Performance

The following findings were observed and noted for 10% transesterified soybean oil blended with 90% Petro diesel fuel:

1. The density is 0.8517 g/mL.
2. Flashpoint is at 110 °C.
3. Sulfur content is 0.94%.
4. Ash content is less than 0.25 %.
5. The heating value is around 19,546 BTU/lb.
6. The burning rate is at 11 mL/min.
7. Temperature is 130 °C for the exhaust pipe, 104 °C for the cylinder head, and 107 °C for the engine block.
8. Measured torques are 1000 rpm and 1400 rpm with forces of 16.32 kg and 31.55 kg respectively.
9. The length of strokes is 8.2 cm and the diameter of the piston is 8.7 cm.
10. The economic feasibility of using transesterified soybean oil is break-even compared to using commercial diesel available in the market. However, it may still vary since the price of diesel fuel fluctuates and normally increases.

CONCLUSIONS

Considering the objectives, summary of the findings of the study, and comparative analysis conducted, the following conclusions were drawn:

a) The physico-chemical characteristics of transesterified soybean oil have shown similar characteristics to those of existing soybean seeds biodiesel therefore transesterified soybean oil can be considered as a good resource for biodiesel production. However, processes and methods to be used must be done thoroughly to achieve high-quality diesel fuel.

b) Soybean seeds biodiesel is better to use for diesel engines than transesterifed soybean oil due to it has lower ash and water content.
c) Standard fuel oil is better to use for diesel engines than transesterified soybean oil because it has lower ash content and higher density.
d) Though 10% transesterified soybean oil with 90% petrodiesel had achieved nearly 30% brake thermal efficiency, still commercial diesel is better to use for diesel engines because it achieved 30% to 35% brake thermal efficiency.
e) Diesel oil (EN590:2013) is better to use than the 10% transesterified soybean oil with 90% petrodiesel because of the negligible content of ash and sulfur.

RECOMMENDATIONS

According to the findings and conclusions of this project study, the following recommendations were made:

a) Doing the transesterification process of soybean oil as feedstock with the addition of a catalyst to enhance viscosity and pour point quality.
b) Performing emission testing for diesel engines.
c) Using the right proportion of transesterified soybean oil content to the mixture with other fuel to improve brake thermal efficiency following the minimum 10/90 mixture.
d) Increasing the intake charge temperature to improve the brake thermal efficiency.
e) Modification of injection fuel and intake charge conditions which is especially important for low engine speeds.
f) Use another additive that has lower sulfur content to blend in the mixture of transesterified soybean oil and petrodiesel.

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Conflicts of interest

The authors have no conflicts of interest to declare.

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