Experimental Studies of a Diesel Engine Run on Alternative Fuel Blends

Mehrab Alam[1], Dharmendra Rathore[2]

[1,2]Department of Mechanical Engineering, Bagula Mukhi College of Technology, Bhopal (M.P), India

ABSTRACT

The use of renewable fuels to some extent or completely replace fossil fuels is the global trend. One of the most promising renewable fuels proposed as a replacement for fossil diesel is biodiesel. In this study, a single-cylinder, four-stroke, air-cooled, direct injection (DI) engine containing sewage sludge-based biodiesel (SSB) and diesel was used to test its performance and emissions characteristics. The engine was fueled with three blends: S10, S30, S50, and S100. With diesel fuel operation, the performance and emission results were examined and compared. According to the investigation's findings, there was no need to modify the engine in order for the engine to run with Diesel-SSB blends. When compared to diesel, the engine powered by the blends had slightly lower brake thermal efficiency. When compared to diesel, SSB blends produced lower CO, HC, and smoke emissions. SSB blends increased NO emissions. This paper presents the findings.

Keywords: *Alternative Fuel; Biodiesel; Diesel Fuel; Renewable Fuel*

---

1. Introduction

The majority of biodiesel is made from edible vegetable oils; More than 95% of biodiesel produced worldwide is made from edible vegetable oils [1]. However, the high cost of common lipid feedstocks, which account for 70-85% of the overall cost of producing biodiesel and have a significant impact on the biofuel's final price, currently limits biodiesel's competitive potential. Additionally, the over-cultivation of edible oil seeds for biodiesel raises concerns about a food shortage and puts fuel production in competition. In order to make it easier to compete with petroleum diesel and reduce production costs, a feedstock that is inexpensive and not edible is required [2].

The majority of wastes and waste waters are produced and disposed of every day in the world. With population growth, urbanization, improved living conditions, and economic growth, there has been an increase in the volume of wastewater produced by domestic, industrial, and commercial sources [3]. Many investigations have been carried out to convert this waste into useful orm of energy which also helps for circular economy [4] [5]. Sludge from sewers is a mixture of waste from homes and businesses. According to studies conducted by the Central Pollution Control Board (CPCB), India has 269 sewage treatment plants (STPs), but only 231 of them are in use. It is estimated that approximately 38254 million liters of wastewater are produced each day by municipal wastewater management in urban centers, which include cities and towns with a population of more than 50,0001. Given the current situation, we need to find additional methods for transforming waste into substances that are beneficial and innocuous. The potential of wastewater treatment plants to transform sewage water into treated water that can be utilized as utility water for horticulture, forestry, irrigation, and pisciculture is promising. Municipal sewage sludge can now be used to produce energy in the form of renewable biofuels thanks to extraordinary human knowledge. Despite its complexity, the sludge biofuels conversion process is economically viable. The biological methods can simplify it. Biodiesel, bioethanol, biogas (bio H2, bio-CNG, and bio-LNG), and biosolids are all examples of biofuels. After primary and secondary, wastewater treatment plant (WWTP) facilities produce a lot of organic waste, or a byproduct called sewage sludge.

Primary sludge and secondary sludge, also known as activated sludge, are the two primary types of sludge produced by an activated sludge facility. After screening and grift removal, the solids and floating grease that are collected at the bottom of the primary settler make up the primary sludge. Microbial cells and suspended solids collected in the secondary settler during the aerobic biological treatment make up the majority of the secondary or activated sludge3. Activated sludge is a material that is either solid or semisolid when industrial and municipal wastewaters are biologically treated. It is made up of various microorganisms that make use of the water's organic and inorganic compounds as a source of energy, carbon, and nutrients. Typically, gravity-thickening or air-floatation is used to concentrate waste sludge to approximately 10% solids in 0.5 to 1.5 kg of waste. Sludge typically contains 1–2% solids. By aerobic treatment, 0.5-1.5 kg of activated sludge consists of a complex heterogeneous mixture of organic and inorganic materials. In many instances, the concentrated sludge is injected into an aerobic or anaerobic digester to reduce the level of pathogens and odors (stabilization). Organic matter typically accounts for 60% to 80% of the solids. Primary sludge's organic components range from 6% to 35% fats, 20% to 30% crude protein, and 8% to 15% carbohydrates.

The use of municipal wastewater sludge as a lipid feedstock in the production of biodiesel is the subject of this thesis. The cost of producing biomass is eliminated because municipal sewage sludge is an inevitable waste that is produced in large quantities during wastewater treatment. As a result, the production of biodiesel could be made profitable by using sewage sludge as a non-cost, readily available, and non-edible feedstock. Additionally, utilizing waste sludge as a source of lipid for the production of biodiesel is an alternative to utilizing the surplus of waste sludge generated in WWTPs.

The first step in making biodiesel from these wastes is extracting lipids from sewage sludge. As a result, optimizing lipid extraction from sewage sludge poses a significant challenge that could have an impact on the process's overall economics. As a result, the production of biodiesel from extracted lipids and the lipid extraction from these wastes are the primary goals of the valorization of sewage sludge for biodiesel production.

The purpose of this study is to investigate how diesel engine performance and emission characteristics are affected by sewage sludge-based biodiesel (SSB) blended with diesel in three different percentages as test fuels. In order to produce the fuel blends needed for the investigation, the SSB was mixed with diesel at low percentages (10-50% at regular intervals of 20% on a volume basis). Below are the names of the test fuels and their compositions that were used in this study.

Table 1 Fuel available in different blend

Fuel	SSB (by volume)	Diesel (by volume)
Diesel	-	100%
S100	100%	-
S10	10%	90%
S30	30%	70%
S50	50%	50%

2. Materials and Methods

Biodiesel Production

SSB was taken from a commercial biodiesel plant that uses the transesterification process to make the methyl ester for this study [6]. A series of saturated and unsaturated monocarboxylic acids and trihydric alcohol glycerides make up jatropha oil. Oleic acid, linoleic acid, palmitic acid, and stearic acid are the four main fatty acid groups that can be found in SSB. In the presence of alcohol, these major fatty acids can be transformed into fatty esters. Due to its simplicity, transesterification is the most common method for producing biodiesel.

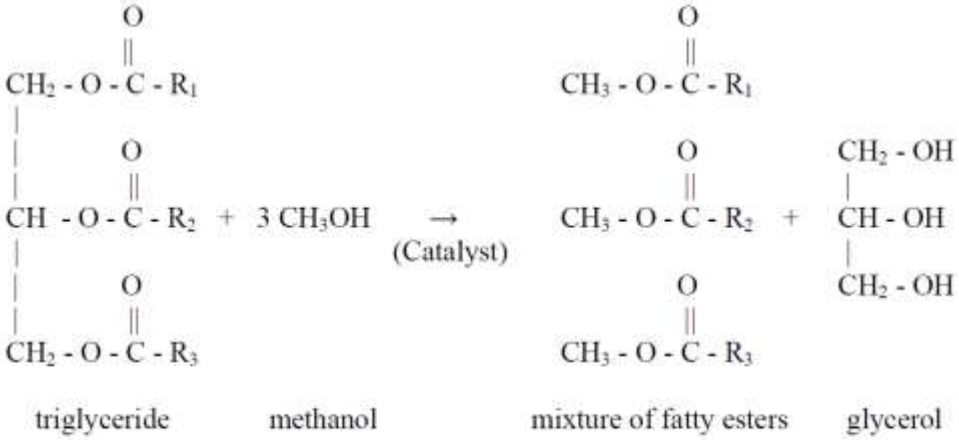
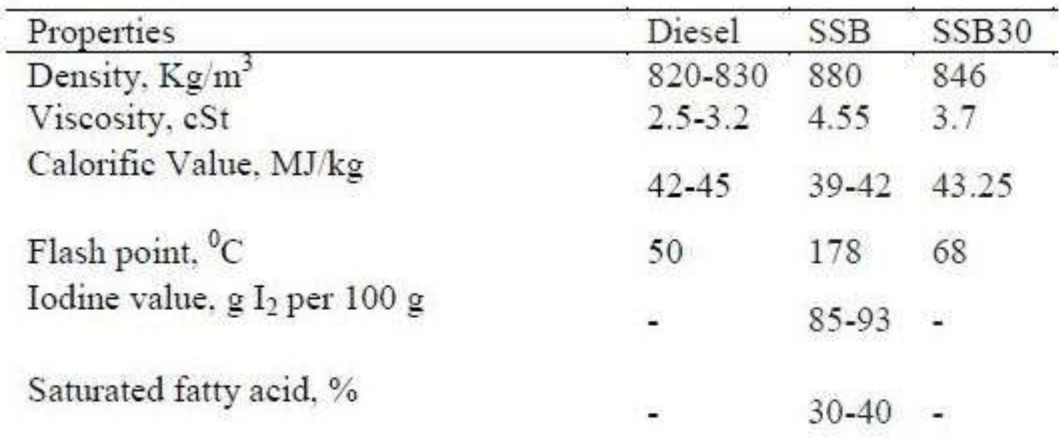


Figure 1 Inputs and outputs of the transesterification unit process

Comparison of Fuel Properties

The physical properties of SSB are compared with diesel and given in Table 2.

Table 2- Properties of diesel and SSB



Properties	Diesel	SSB	SSB30
Density, Kg/m^3	820-830	880	846
Viscosity, cSt	2.5-3.2	4.55	3.7
Calorific Value, MJ/kg	42-45	39-42	43.25
Flash point, ^0C	50	178	68
Iodine value, g I_2 per 100 g	-	85-93	-
Saturated fatty acid, %	-	30-40	-

3. Experimental Setup

A diesel engine with one cylinder, four stroke, air-cooled, direct injection, and 4.4 kW of power at 1500 rpm has been the subject of experiments. The experimental setup is depicted schematically in Figure 2, and the engine's technical specifications are listed in Table 4.

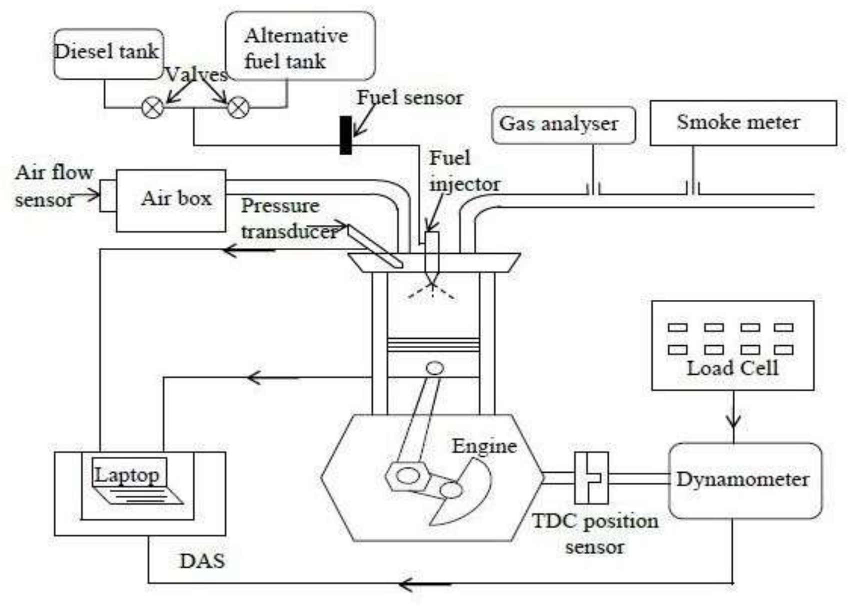
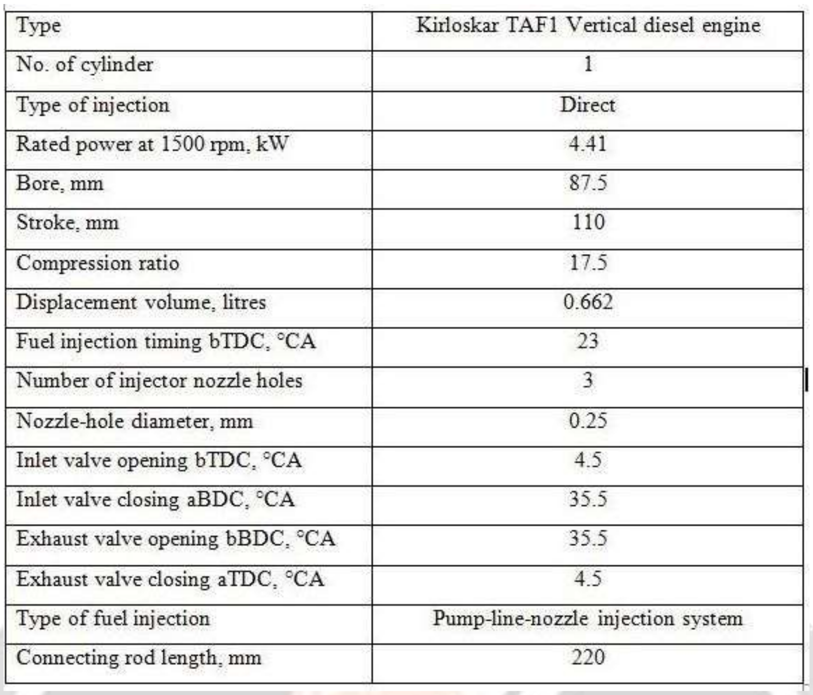


Figure 2 Schematic diagram of experimental setup

Table 3 - Engine specifications



Type	Kirloskar TAF1 Vertical diesel engine
No. of cylinder	1
Type of injection	Direct
Rated power at 1500 rpm, kW	4.41
Bore, mm	87.5
Stroke, mm	110
Compression ratio	17.5
Displacement volume, litres	0.662
Fuel injection timing bTDC, °CA	23
Number of injector nozzle holes	3
Nozzle-hole diameter, mm	0.25
Inlet valve opening bTDC, °CA	4.5
Inlet valve closing aBDC, °CA	35.5
Exhaust valve opening bBDC, °CA	35.5
Exhaust valve closing aTDC, °CA	4.5
Type of fuel injection	Pump-line-nozzle injection system
Connecting rod length, mm	220

Diesel was used to start the experiments, then SSB and various SSB blends were used after the engines had time to warm up. The total amount of fuel used is measured using a fuel level indicator. The intake air flow rate is measured with a U-tube manometer. To measure the temperature of the exhaust gas, a K-type thermocouple was installed. An AVL DiGas444 exhaust gas analyzer was used to measure the engine's exhaust emissions. The smoke emission was measured with an AVL437 smoke meter. In order to avoid deposits and issues with cold starting, diesel was used to run the engine once more after all of the tests with the blends were completed. This was done to make sure that no SSB/SSB blends were present in the fuel.

5. Performance Parameters

Performance parameters such as brake thermal efficiency, brake specific energy consumption (BSEC) and exhaust gas temperatures (EGT) of SSB blends are compared with diesel and discussed below.

Brake Thermal Efficiency

Figure 3 portrays the variation of brake thermal efficiency with brake power for diesel and SSB blends.

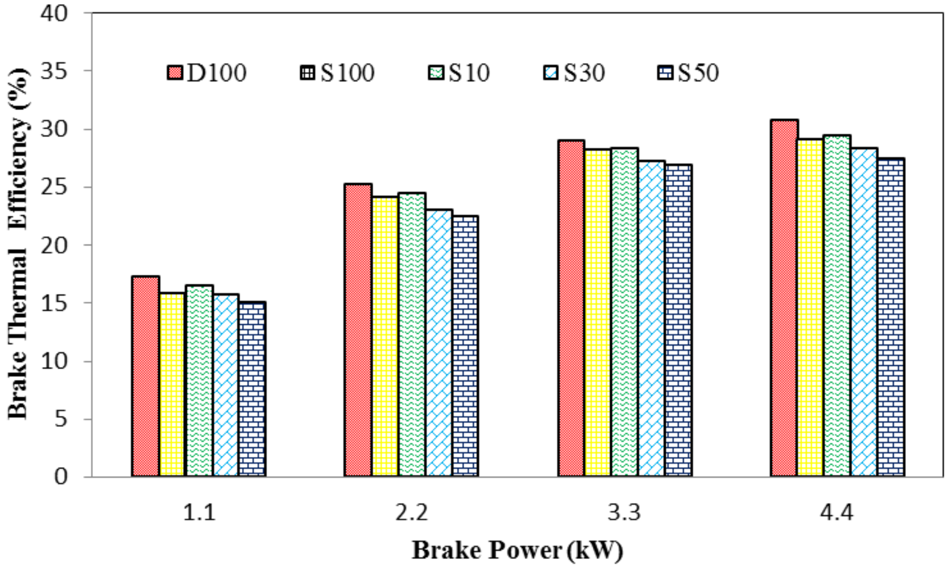


Figure 3 Variation brake thermal efficiency with brake power

As was anticipated, diesel and SSB-diesel blends' brake power increase the engine's brake thermal efficiency [7]. Diesel brake thermal efficiency was found to be 29.89% at full load. At full load, the S100, S10, S30, and S50's brake thermal efficiency is 29.40, 29.87, 29.88, and 29.88%, respectively. However, the thermal efficiency of all SSB blends is slightly lower than that of diesel. This could be because SSB blends have less calories. Due to the higher viscosity of SSB blends, poor atomization of blend droplets may also contribute to lower brake thermal efficiency than diesel operation [8].

Brake Specific Energy Consumption (BSEC)

Because blends have a different calorific value and density than diesel fuel, the brake-specific fuel consumption is not a very reliable way to compare the two fuels [9][10]. The variation of BSEC for diesel and SSB-DIESEL blends is depicted in Figure 4. At full load, diesel has a BSEC of 11.86 MJ/kWh. As a result of the blends' inclusion of SSB and diesel, the net calorific value decreases, and BSEC varies accordingly. Due to their lower calorific value, all of the SSB-DIESEL blends have a higher BSEC than diesel. At full load, the BSEC values for S100, SSB10, S30, and S50 were discovered to be 12.24, 12.67, 11.92, and 12.67 MJ/kWh, respectively.

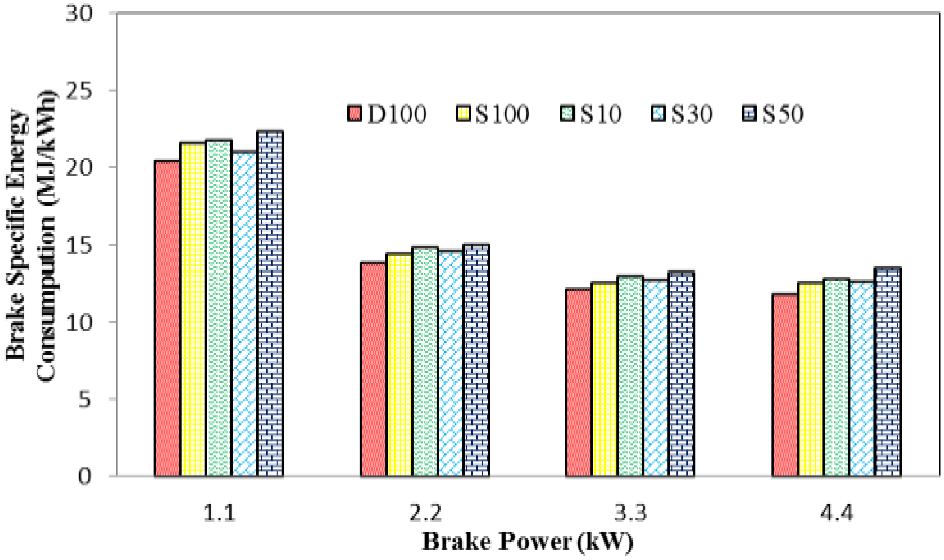


Figure 4 Variation of BSEC with brake power

Exhaust Gas Temperature (EGT)

The relationship between brake power and the temperature of the exhaust gas is depicted in Figure 5. It demonstrates that for each of the fuels tested in this study, the EGT increased with increased brake power [11]. At full load, the diesel EGT was 303 oC, while the S100, S10, S30, and S50 EGTs were 318, 297, 330, and 325 ^{o}C, respectively. SSB blends have higher EGT values.

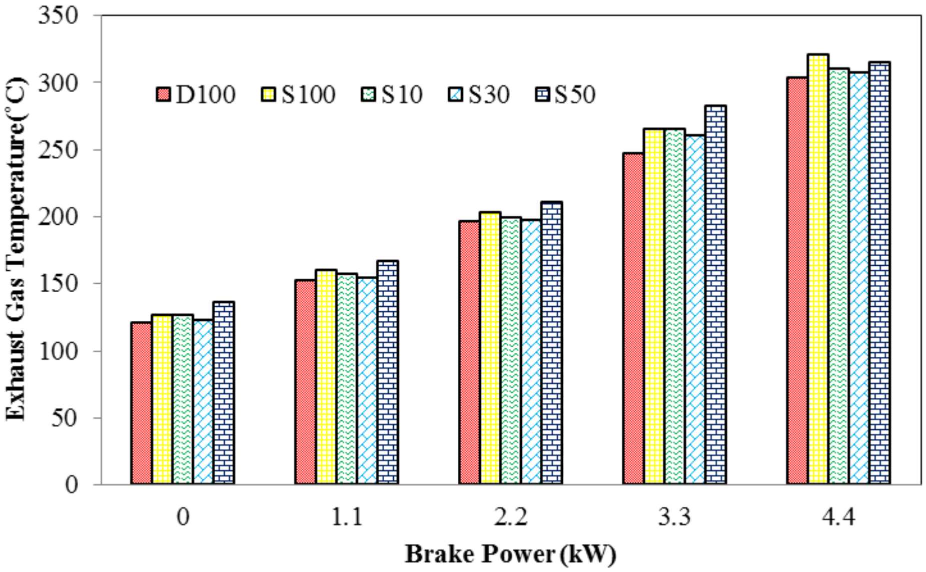


Figure 5 Variation of exhaust gas temperature with brake power

Poor volatility and high viscosity are the reasons for the higher exhaust gas temperature for the SSB blends [12].

EMISSION PARAMETERS

Emissions such as carbon monoxide, unburnt hydrocarbon, nitric oxide and smoke for diesel and SSB blends are discussed in the subsequent sections.

Carbon Monoxide (CO) Emission

The CO emission for diesel and SSB blends based on brake power is shown in Figure 6. The operation of a CI engine with a lean mixture result in lower oxygen availability and poor mixture formation, both of which contribute to CO emissions [13]. The graph makes it clear that diesel emits more CO than SSB blends do. The SSB's excess oxygen aids in complete combustion, which reduces the amount of CO released [14].

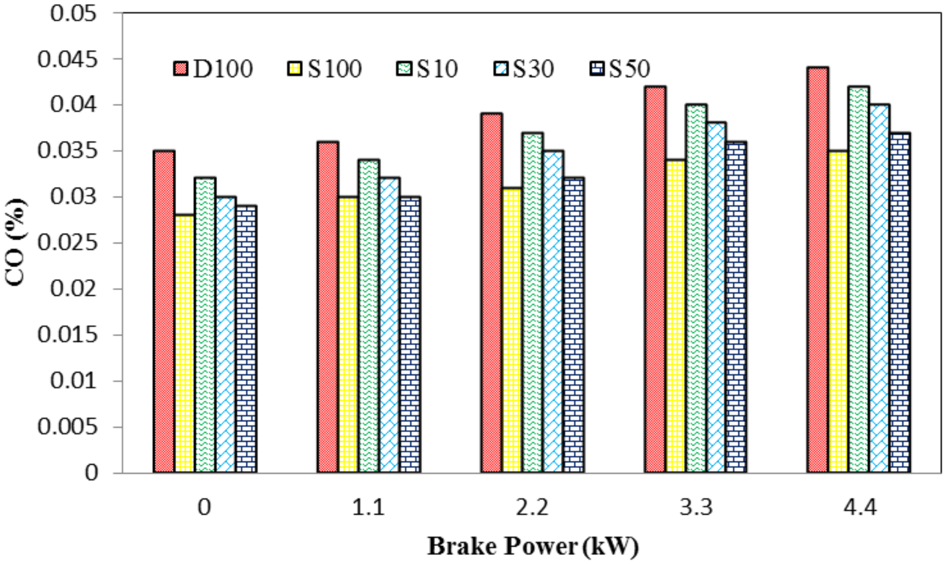


Figure 6 Variation of carbon monoxide with brake power

Hydrocarbon (HC) Emission

The values of HC emission from the engine in case of SSB blends is less than diesel as evident from the Figure 7.

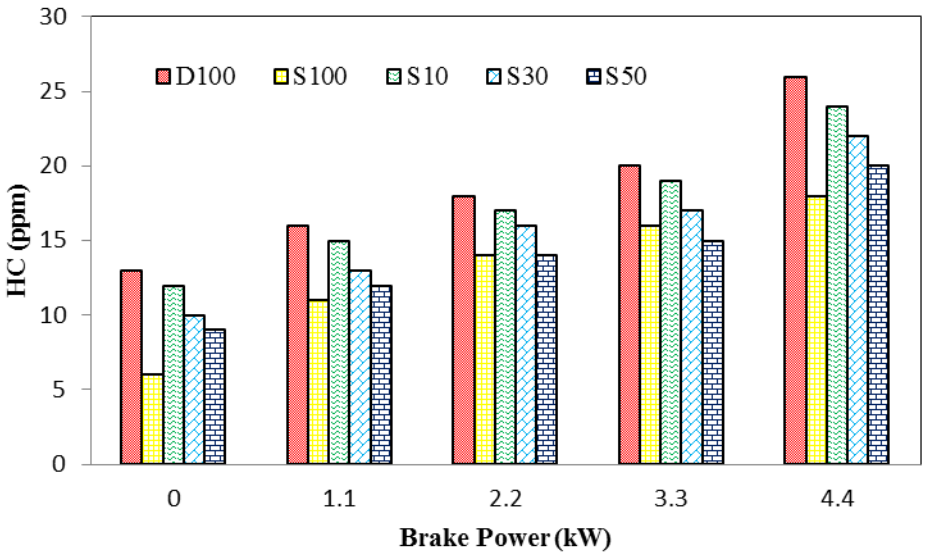


Figure 7 Variation of hydrocarbon with brake power

Hydrocarbon emission is mainly due to incomplete combustion. HC emissions are increasing with increasing load for all the fuels tested [15]. HC emission for diesel at full load was 23 ppm. At full load HC emission are 18 ppm, 19 ppm, 20 ppm and 21 ppm for S100, S10, S30 and S50 respectively. The reduction in HC emission is mainly due to the result of improved combustion with SSB blends, as SSB is oxygenated fuel.

Nitric Oxide (NO) Emission

Figure 8 depicts the relationship between brake power and NO emission for the tested fuels. NO emission is highly influenced by temperature and oxygen supply within the cylinder. The temperature inside the cylinder rises along with the load. Diesel, SSB5, SSB10, SSB15, and S50 had NOx emissions of 452,612, 589, 574, and 564 at full load, respectively. However, when compared to diesel, the NO emissions of all SSB blends are lower. Because volatility decreases with increasing SSB percentage, this could be because of lower combustion temperature as a result of poor combustion.

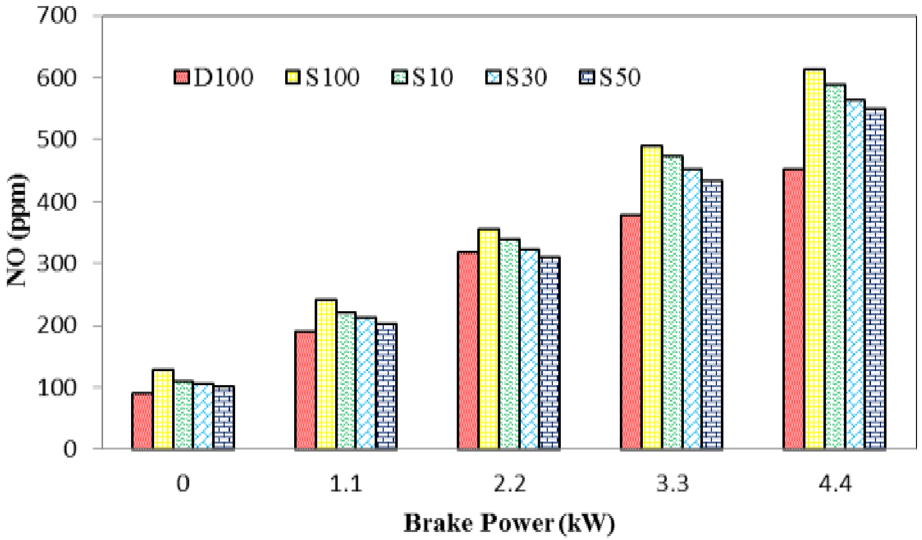


Figure 8 Variation of nitric oxide with brake power

Smoke Emission

Solid soot particles suspended in exhaust gas constitute smoke [16]. Figure 9 depicts the relationship between brake power and smoke emission for various tested fuels. All tested fuels produce more smoke with increasing brake power, but SSB blends produce less smoke than diesel. This decrease is the result of SSB's lack of sulfur and presence of oxygen, which is necessary for complete combustion. However, as the blend's SSB percentage rises, so does the aromatic content and carbon-to-hydrogen ratio, resulting in stronger smoke [17].

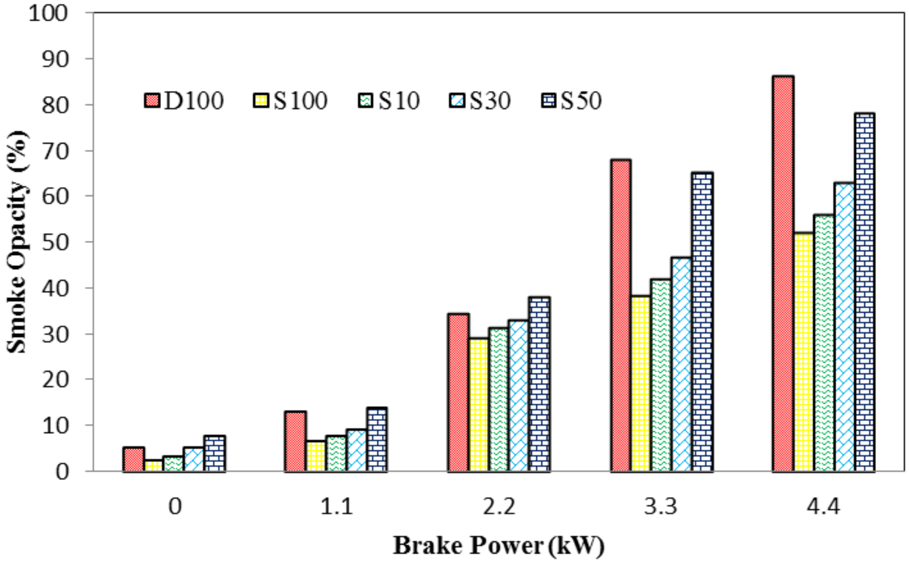


Figure 9 Variation of smoke emission with brake power

Smoke emission for diesel at full load is 86.3%. At full load smoke emissions were 39.5, 56.2, 54.5, and 63.1% for S100, S10, S30 and S50 respectively.

5.Conclusions

In the present investigation, experiments were conducted in a single cylinder, 4 stroke, air cooled, and DI diesel engine with S100, SSB10, S30 and S50. The conclusions of the investigation are summarized and given below.

- Engine works smoothly with SSB blends and exhibited similar performance and lower HC, CO, smoke emission, but higher NO emission compared to that of diesel. S30 gives optimal result compared to other SSB blends.
- The brake thermal efficiency of S30 is almost same to that of diesel at full load.
- The BSEC for S30 is 11.92MJ/kWh and for diesel 11.86MJ/kWh at full load. BSEC increases by about 0.05% with SSB15.
- The EGT is higher for S30 compared to that of diesel at full load.
- Carbon monoxide is decreased by about 11.36% for S30 compared to that of diesel.
- NO emission is increased by about 19.5% for S30 lower for compared to that of diesel.

References

[1] A. Sharma, S. Murugan, Investigation on the behaviour of a DI diesel engine fueled with Jatropha Methyl Ester (JME) and Tyre Pyrolysis Oil (TPO) blends, Fuel. 108 (2013) 699–708. https://doi.org/10.1016/j.fuel.2012.12.042.

[2] M. Nagappan, A. Devaraj, J.M. Babu, N.V. Saxena, O. Prakash, P. Kumar, A. Sharma, Impact of additives on Combustion, performance and exhaust emission of biodiesel fueled direct injection diesel engine, Mater. Today Proc. (2022).

[3] D.P. Kumar, C.S. Ramakrishna, P. Tiwari, N.V. Saxena, S.K. Mishra, S. Tiwari, P. Kumar, A.S. Yadav, A. Sharma, Challenges and prospects of waste management in Rajasthan, Mater. Today Proc. (2022).

[4] A. Sharma, S. Murugan, Potential for using a tyre pyrolysis oil-biodiesel blend in a diesel engine at different compression ratios, Energy Convers. Manag. 93 (2015) 289–297. https://doi.org/10.1016/j.enconman.2015.01.023.

[5] A. Sharma, S. Murugan, Combustion, performance and emission characteristics of a di diesel engine fuelled with non-petroleum fuel: A study on the role of fuel injection timing, J. Energy Inst. 88 (2015) 364–375. https://doi.org/10.1016/j.joei.2014.11.006.

[6] A. Devaraj, M. Nagappan, D. Yogaraj, O. Prakash, Y.A. Rao, A. Sharma, Influence of nano-additives on

engine behaviour using diesel-biodiesel blend, Mater. Today Proc. (2022).

[7] M. Karthick, K. Logesh, S. Baskar, A. Sharma, Performance and Emission Characteristics of Single-Cylinder Diesel Engine Fueled with Biodiesel Derived from Cashew Nut Shell, in: Adv. Mater. Manuf. Energy Eng. Vol. II, Springer, 2022: pp. 521–529.

[8] K. Logesh, M. Karthick, S. Baskar, A. Sharma, Performance and Emissions Characteristics of Diesel Engine Run on Citrullus Colocynthis Biodiesel with Zinc Oxide Additive, in: Adv. Mater. Manuf. Energy Eng. Vol. II, Springer, 2022: pp. 513–520.

[9] A. Sharma, S. Murugan, Combustion Analysis of a Diesel Engine Run on Non-conventional Fuel at Different Nozzle Injection Pressure, in: Innov. Energy, Power Therm. Eng., Springer, 2022: pp. 109–118.

[10] R.S. Powar, A.S. Yadav, C.S. Ramakrishna, S. Patel, M. Mohan, S.G. Sakharwade, M. Choubey, A.K. Ansu, A. Sharma, Algae: A potential feedstock for third generation biofuel, Mater. Today Proc. 63 (2022) A27–A33.

[11] S. Sparsh, C.S. Ramakrishna, R. Sahu, R.S. Narain, J.K. Sohal, M. Sahu, N. Sharma, V. Kumar, A. Sharma, Future prospects of biodiesel production from jatropha in India, Mater. Today Proc. 63 (2022) A22–A26.

[12] S.S. Kumar, K. Rajan, V. Mohanavel, M. Ravichandran, P. Rajendran, A. Rashedi, A. Sharma, S.A. Khan, A. Afzal, Combustion, Performance, and Emission Behaviors of Biodiesel Fueled Diesel Engine with the Impact of Alumina Nanoparticle as an Additive, Sustainability. 13 (2021) 12103.

[13] S. Taneja, P. Singh, A. Sharma, G. Singh, Use of Alcohols and Biofuels as Automotive Engine Fuel, in: Energy Syst. Nanotechnol., Springer, 2021: pp. 161–183.

[14] A. Sharma, D. Khatri, R. Goyal, A. Agrawal, V. Mishra, D. Hansdah, Environmentally Friendly Fuel Obtained from Pyrolysis of Waste Tyres, in: Energy Syst. Nanotechnol., Springer, 2021: pp. 185–204.

[15] A. Sharma, G. Gupta, A. Agrawal, Utilization of Waste Lubricating Oil as a Diesel Engine Fuel, IOP Conf. Ser. Mater. Sci. Eng. 840 (2020). https://doi.org/10.1088/1757-899X/840/1/012015.

[16] Abhishek Sharma, S. Murugan, Experimental Evaluation of Combustion Parameters of a DI Diesel Engine Operating with Biodiesel Blend at Varying Injection Timings, (2016) 169–177. https://doi.org/10.1007/978-81-322-2773-1_13.

[17] A. Sharma, S. Murugan, Durability analysis of a single cylinder DI diesel engine operating with a non-petroleum fuel, Fuel. 191 (2017) 393–402. https://doi.org/10.1016/j.fuel.2016.11.086.