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Sustainable Energy Solutions from Water Hyacinth Bioethanol Blends in Diesel Engines with Nano-Coated Pistons

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Abstract

The synthesis of bioethanol from water hyacinth has been of great assistance in re-establishing ecological balance as fuel alternate. In terms of both financial and ecological considerations, bioethanol is the best raw material from which to create biodiesel. The low thermal conductivity of nano ceramic coatings makes them useful as thermal barrier coatings in many engineering applications. An aluminum alloy piston sprayed with partly stabilized zirconia ceramic coating is shown to increase the working performance of engines. The use of oxygenated fuels and nano coating appears to be a practical solution to the problem of hazardous engine emissions. This study provides a comprehensive analysis of bioethanol as a potential substitute fuel for diesel engines, with the aim of achieving energy recuperation from water hyacinth. This paper investigates the performance and emission characteristics of the bioethanol blends derived from water hyacinth in the nano-coated piston diesel engine. Bioethanol blends consumed 1.1% to 11.3% more fuel than diesel. All bioethanol blends produced more carbon monoxide and hydrocarbon emissions than the diesel engine, around 2.4%–15% and 2.6%–16%, respectively, at varying loads. Blends of BE10D90 and BE20D80 show that increasing oxygen content reduces smoke and NOx by 4%–9.3% and 1.9%–7.4%, respectively, when compared to diesel.

Keywords: Bioethanol, Energy recovery, Nano coating water hyacinth, Thermal barrier coating.

Introduction

Liquid biofuels (biodiesel or bioethanol) were seen as potential replacements for fossil fuels, prompting a surge in their production and use in the latter decades of the twentieth century. Biofuels derived from the biomass found in plants are a kind of sustainable energy (1). The utilization of this bio-feed would result in a reduction in the reliance on fossil fuels, hence yielding beneficial outcomes for the preservation of the earth's resources. Progress in the bio refinery sector is driven by a desire to meet sustainability targets for the manufacture of biofuels. The word "bio refinery" refers to a system that utilizes biomass for the environmentally friendly manufacturing of a wide variety of transitional and final elements, as well as the efficient utilization of all parts of the raw materials (2).

Energy is now one of mankind's most desired commodities. This is entirely attributable to the technology at play, which is power needed to the core. As a result, cutting-edge technologies are constantly being developed to compete with conventional energy sources. Bioethanol has proven to be a strong alternative to fossil fuels, and it has the potential to become the world's only source of energy production in the near future (3). Diesel engines are widely used in industrial settings to generate electricity. Most vehicles in use today for transportation use standard fuels in one way or another. As a result, fossil fuels will become increasingly important to the world's rapidly expanding population (4).

The gradual spread of regional and worldwide environmental change as a result of the depletion of fossil fuels makes water hyacinth a viable option. With its high absorption capacity, water hyacinth has been studied for its potential as a water purification aid and a heavy metal removal tool. However, the current application methods are not cost-effective, necessitating more study.

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This suggests that a commercial, less costly method of water hyacinth eradication has been devised and put into practice (5). Three blended ratios, B3E5, B7E5, and B10E10, were chosen for fuel property investigation and engine testing. Reduced ambient temperatures allowed phase separation. The presence of ethanol reduced engine torque and output. Due to greater ethanol vaporization heat, pilot combustion was regulated and slowed in-cylinder pressure analysis. Due to ignition delay, blended fuels evaporated slower as the ethanol fraction increased. The maximum rate of heat release was associated with an increase in nitrogen oxide emissions, whilst the vaporisation and mixing times of fuel were shown to increase hydrocarbon emissions (6). It takes a two-step process to convert the cellulose, hemicelluloses, and lignin found in water hyacinth, an aquatic weed plant, into ethanol. A recombinant strain of zymomonas was used to ferment water hyacinth after it was pre-treated with sulphuric acid, detoxified using calcium hydroxide and sodium hydroxide, and finally fermented. The highest output of ethanol was determined to be 68.3 g/l under ideal circumstances (7–9).

Four varieties of gasoline with varying amounts of ethanol were used in the tests. In the experiments, pure diesel as well as 3%, 5%, and 10% ethanol blends were used. In the experiments, pure diesel as well as 3%, 5%, and 10% ethanol blends were used. Compared to pure diesel fuel, the maximum combustion pressure of a diesel fuel/ethanol blend is up to 4.1% higher, and the maximum heat release rate is up to 13.5%. Brake specific fuel consumption increased to 5.9% as the ethanol blending percentage increased, while diesel-ethanol blended fuels maintained a poor brake thermal efficiency of 23.8%. With the addition of ethanol, the coefficient of variation for the specified mean effective pressure dropped significantly, staying below 1% all through the experiment (1, 10).

When diesel engines were subjected to mixtures of diesel, ethanol, and biodiesel, the results revealed that BTE decreased while ignition delay and SEC increased. Researchers discovered that emissions of nitrogen oxide and carbon monoxide declined as ethanol concentrations increased. Prior research has demonstrated that reducing emissions of smoke and nitrogen oxides can be achieved by increasing the proportion of ethanol in diesel fuel. This is thought to be due to the fact that the combustion process is accelerated by the ethanol's increased oxygen content (11,12).

Light, medium, and heavy loads were tested and compared to a constant air-fuel ratio diesel engine. It may reduce negative effects and gain better information from experiments by using the same air-fuel ratios to give almost identical energy on each cycle across ethanol-diesel-biodiesel combinations (13). When compared to ethanol made from sugarcane, ethanol made from rice straw has a noticeably lower effect on the environment. If the production costs are taken into consideration, the If manufacturing costs could be brought down to $1.01 per unit, and if efficiency could be raised to the level of the theoretical value, it would be ideal. Nevertheless, the price is significantly greater than that of ethanol derived from sugarcane below one dollar (14).

The diesel-bioethanol co-solvent combination saw a loss of power and torque of nearly 10% in the experiments. The engine's performance suffered from the presence of fatty acids and methyl esters, which also contributed to the subsequent decline of these metrics. Further, as compared to diesel oil, esters increase hydrocarbon and carbon monoxide emissions. For what it's worth, this gasoline did have the added benefit of lowering PM emissions. The fuel lacking methyl esters of fatty acids, however, resulted in even lower particulate matter emissions than diesel oil. At the same time, emissions of the other dangerous compounds under examination were at the same level as for diesel oil (15, 16). The engine's NOx emissions were lowered by the use of ethanol. In practically all load settings, the E10 mix had the lowest NOx emissions. At full load, the blend's CO emissions were 53.14% lower than those of diesel. The results of these experiments show that it may be possible to use a combination of additives in diesel to enhance the fuel's performance and reduce its emissions. The research also suggests that a combination of 80% diesel and 10% diethyl ether with 10% ethanol can be more effective than diesel-diethyl ether blends alone (17).

Commonly utilised in diesel engines are biodiesel and bioethanol, two well-known biofuels; in petrol engines, bioethanol is the fuel of choice. Biodiesel and diesel share many of the same properties. Diesel fuel also cannot dissolve large amounts of bioethanol. Then, additional research into the impact of bioethanol and diesel fuel mixtures on diesel engine performance is necessary. To improve the blends' lubricity and cetane number, biodiesel is added to bioethanol and diesel fuel mixtures as a co-solvent (18). Food sector wastes, which include a significant amount of organic and nutritional components, are utilised for the generation of bioethanol by microorganisms using several fermentation methods. Enzyme hydrolysis of the total polysaccharides in food industry wastes improves the generation of bioethanol by converting them into metabolizable sugars (19). The aviation sector faces significant challenges in implementing a 'carbon neutrality' plan due to the limited options available for replacing traditional petrol and diesel fuel. While bioethanol and biodiesel have been successfully used to replace a portion of these fuels, further advancements are needed to achieve complete carbon neutrality (20). The government of India has enhanced the nationwide ethanol production capacity to 1500 crore litres. The implementation of E10 fuel will be gradually introduced by April 2022. The implementation of E20 will be gradually introduced starting in April 2023, with full availability expected by April 2025. The introduction of automobiles complying with E20 materials and equipped with E10 engines will begin in April 2023. The commencement of manufacturing E20-tuned engine vehicles is scheduled for April 2025 (21).

Piston heat insulation in diesel engines is implemented to reduce heat dissipation during combustion, hence improving overall thermal efficiency. Thermal barrier coatings, made of ceramics with low thermal conductivity, effectively decrease the passage of heat from the high-temperature fuel mixture to the metal surface. The temperature within the combustion chamber were increased, it would considerably improve the efficiency of their operation. An aluminium alloy piston sprayed with partly stabilized zirconia ceramic coating is shown to increase the working performance of engines (22). This study examines the efficiency and pollution levels of bioethanol blends made from water hyacinth in a diesel engine equipped with a piston coated with nanoparticles.

Material and methods

Bioethanol

Diesel engines can run on ethanol blended with diesel fuel, but not on pure ethanol. Because of its many desirable properties, ethanol is an excellent fuel for internal combustion or diesel engines, which increases their volumetric efficiency. Among these are its great evaporative cooling, low sulphur content, low viscosity, high oxygen content, and high hydrogen/carbon ratio (23, 24). Ethanol improves fuel atomization when mixed with diesel because its lower viscosity allows it to mix with air more effectively, which is why it is so useful in diesel engines. Because of its high latent heat of evaporation, ethanol can reduce the intake and compression stroke temperatures, which in turn increases the efficiency of diesel engines when blended with diesel or biodiesel fuel (6, 25).

This is due to the fact that renewable energy sources do not conform to the availability of certain locations or seasons in India. Sugarcane and maize are the main crops used to make ethanol fuel. Because of its potential to lessen both our need on fossil fuels and our impact on the environment, ethanol is a compelling alternative to conventional fuels. Full combustion was enhanced, and harmful emissions were decreased on the adding of oxyhydrogen to fuel (26). There have been complaints regarding a decrease in engine performance caused by the usage of diesel fuels combined with ethanol. Diesel fuel containing ethanol has a low volumetric heating value. Ethanol blended with diesel has a lower cetane rating. Depending on how much ethanol is present in diesel fuel, mixes can lengthen the time it takes for ignition to occur and accelerate the pace at which heat is released (3, 7).

Cellulose and hemicelluloses make up around 46.7 wt.% of water hyacinth. Glycogen (19.8 wt.%) and galactose (6.5 wt.%) make up the entirety of the C6 sugar content, which totals 26.3 wt.%. In addition, the leaves of water hyacinth contain 11.5 and 9.0 wt.% of the C5 sugars xylose and arabinose, respectively. C5 and C6 sugars, once extracted, can be fermented by yeast or bacteria to produce bioethanol. From lignocellulose biomass, bioethanol may be successfully produced by basic procedures (3, 27). The bioethanol blends properties are tabulated in Table 1.

Table 1: Bioethanol blends properties

Fuel Properties	Unit	Diesel	Bioethanol	BE10D90	BE20D80	BE30D70	BE40D60
Calorific Value	kJ/kg	44800	26800	41255	39210	37165	35920
Density	g/cc	0.830	0.785	0.790	0.780	0.764	0.771
Viscosity	cSt	2.8	1.2	2.54	2.36	2.20	2.07
Oxygen content	(wt%)	0	34.80	3.13	6.48	9.05	12.67
Carbon content	(wt%)	86.5	52.4	79.7	75.8	71.9	69.6
Hydrogen content	(wt%)	24.6	13.2	22.6	21.3	20.1	19.2

Thermal insulation by nano Coating

Thermal barrier coatings (TBC) composed of ceramics with low thermal conductivity lead to a significant reduction in the amount of heat that is transferred from the high-temperature fuel combination to the surface of the metal. Therefore, the temperature at which operate within the combustion chamber were to be raised, the efficiency of their operation would be greatly enhanced (28, 29).

The implementation of piston heat insulation in diesel engines serves to mitigate heat dissipation during the combustion process, hence enhancing overall thermal efficiency. The significance of ceramic insulation techniques is increasing due to global efforts to enhance pollution regulations and achieve fuel efficiency (24,26). Ceramics are a good insulator since they are inert. Numerous novel ceramic coating materials have been developed by the researchers, who also investigated the impact these materials had on the engine performance when using a variety of fuels (Table 2). On that note, yttria-stabilized zirconia and alumina are the ones that are employed extensively as materials for thermal barrier coatings, and some of those instances went unmanaged (28, 30).

Table 2: Nano materials used for coating on piston

Nano Materials used for Coating	Coating Thickness (µm)	Investigation Fuel [Authors]
$CaZrO_3$	350	Diesel (31)
88% of ZrO_2, 4% of MgO and 8% of Al_2O_3.	400	Waste cooking oil (32)
Titanium dioxide	100	Diesel (33)
Zirconia, Zirconia + Aluminum Oxide (ZrO_2 +Al_2O_3) and Fused Zirconia (40FZA).	500	Diesel (22)
Titanium dioxide (TiO_2) and Yttria-stabilized zirconia (YSZ)	500	CNG (34)
Al_2O_3/8*Yttria-stabilized zirconia* and CeO_2/8*Yttria-stabilized zirconia*	300	Diesel (35)
7YSZ, 2% Gd_2O_3 + 5% Y+93% ZrO_2, 5% Gd2O3+ 2% Y + 93% ZrO_2	250	Diesel (36)

A ceramic covering is applied on top of a metal bond coating to create a thermal barrier layer. Ceramics should exhibit a stable phase structure, low thermal conductivity, high Poisson's ratio, and high coefficient of thermal expansion at elevated combustion temperatures. Among the several coating techniques employed by researchers to mitigate heat loss caused by elevated temperatures, plasma spray coating stands out. A bonding layer of 200 µm thick nickel chromium aluminium yttrium was first applied to the top crown of the aluminium alloy piston. Additional ceramic coating on the piston surface was a 300 µm layer of zirconia (24, 37).

Experimental details

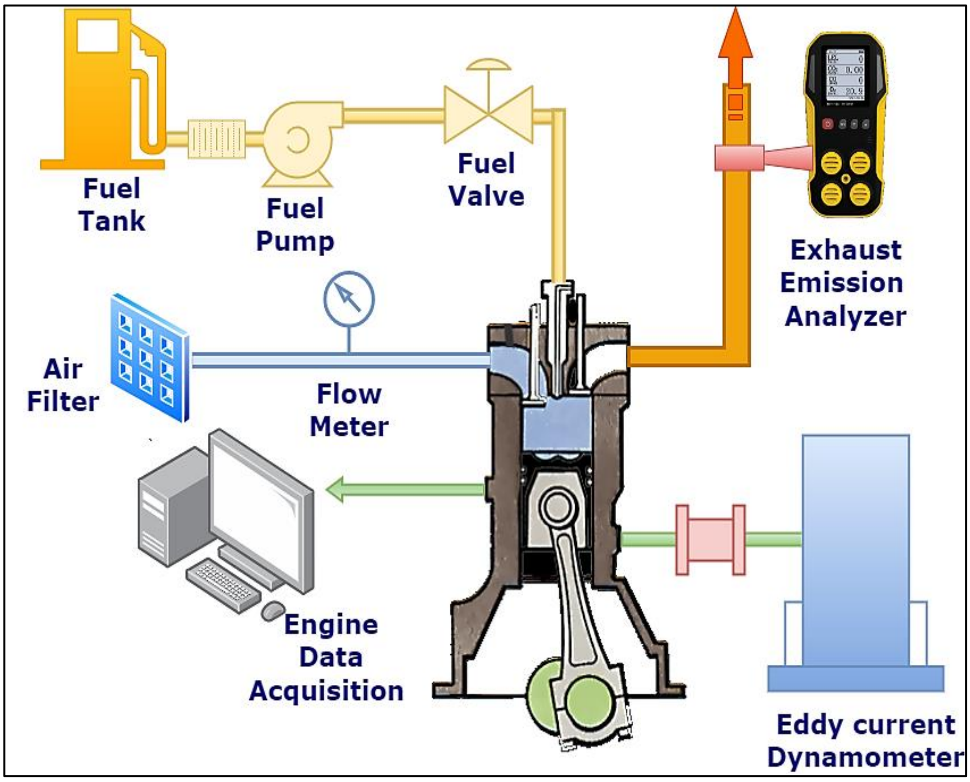

Figure 1: Schematic diagram of bioethanol experimental setup

A constant-speed engine, single-cylinder, direct-injection, with a coated piston was used to test diesel and bioethanol mixes. The speed of a diesel engine is unaffected by the amount of bioethanol in the fuel. The eddy current dynamometer subjected the engine to loads ranging from 0% to 100%. Each test mixture is exerted 25% further than its limits by the engine's 4.4 kW power output. The experimental setup is depicted in Figure 1. An eddy current dynamometer allows for the manual adjustment of engine loads. A calibrated burette was used to monitor airflow, and a calibrated aperture on an air drum was used to measure fuel flow. The fuel flow data also included the amount of diesel and bioethanol mixtures used. With the help of AVL software, the test rig's readings were able to obtain a wide range of metrics and results in real time. The parameters and instruments utilized for the investigation are tabulated in Table 3.

Table 3: Parameter measurement and instrumental details

Measurement	Range	Resolution	Accuracy	Instrument
Load	-	0.25 kg	+0.1 kg to −0.1 kg	Load cell
Speed	0- 10000 rpm	0.1 rpm	± 10 rpm	Digital tachometer
Fuel Quantity	0-50 cm^3	0.1 cm^3	± 0.1 cm^3	Burette Measurement
Hydro Carbon Emissions	0 to 20000 ppm	1 ppm	± 10 ppm	AVL DI GAS Analyser, FID technique
Carbon Monoxide Emissions	0 to 15%	0.1% vol	± 0.03%	AVL DI GAS Analyser, NDIR technique
Nitrogen Oxides Emissions	0 to 5000 ppm	1 ppm	± 10 ppm	AVL DI GAS Analyser, Electro-Chemical Sensor

This study investigate the effect of bioethanol on a diesel engine with a piston that has been coated with nano materials. Bioethanol, derived from the water hyacinth, was mixed with diesel in varying proportions of 10%, 20%, 30%, and 40% by volume, resulting in blends referred to as BE10D90, BE20D80, BE30D70, and BE40D60. The bioethanol fuel blends are formulated as BE10D90, consisting of 10% bioethanol and 90% diesel, and BE20D80, including 20% bioethanol and 80% diesel. Similarly, BE30D70 refers to a fuel blend consisting of 30% bioethanol and 70% diesel, while BE40D60 denotes a fuel blend containing 40% bioethanol and 60% diesel. Examining the potential of water hyacinth bioethanol as a diesel engine fuel substitute is the primary goal of this research. This research work investigates the efficiency and environmental impact of a diesel engine powered by a mixture of water hyacinth bioethanol and diesel fuel. The engine utilises a piston that has been coated with partially stabilised zirconia nanoparticles.

Results and Discussion

Study on brake thermal efficiency

An effect of Brake Thermal Efficiency (BTE) on the power output of the engine is shown in Figure 2. When subjected to the conditions of maximum load, the BTE of the bioethanol blends were, in order, 28.62%, 28.52%, and 28.22%, respectively. Brake thermal efficiency was found to be roughly 3.3% lower for BE10D90, 3.6% lower for BE20D80, 4.6% lower for BE30D70, and 4.7% lower for BE40D60 when compared to base diesel at higher loads. If there is table a larger concentration of oxygen in the bioethanol, then it will burn more effectively, which will lead to improved thermal performance. The higher percentage of bioethanol in the mixture causes the mixture to have a higher viscosity, which in turn causes the combustion rate to be lower. As a result, the BTE is less than that of diesel (12).

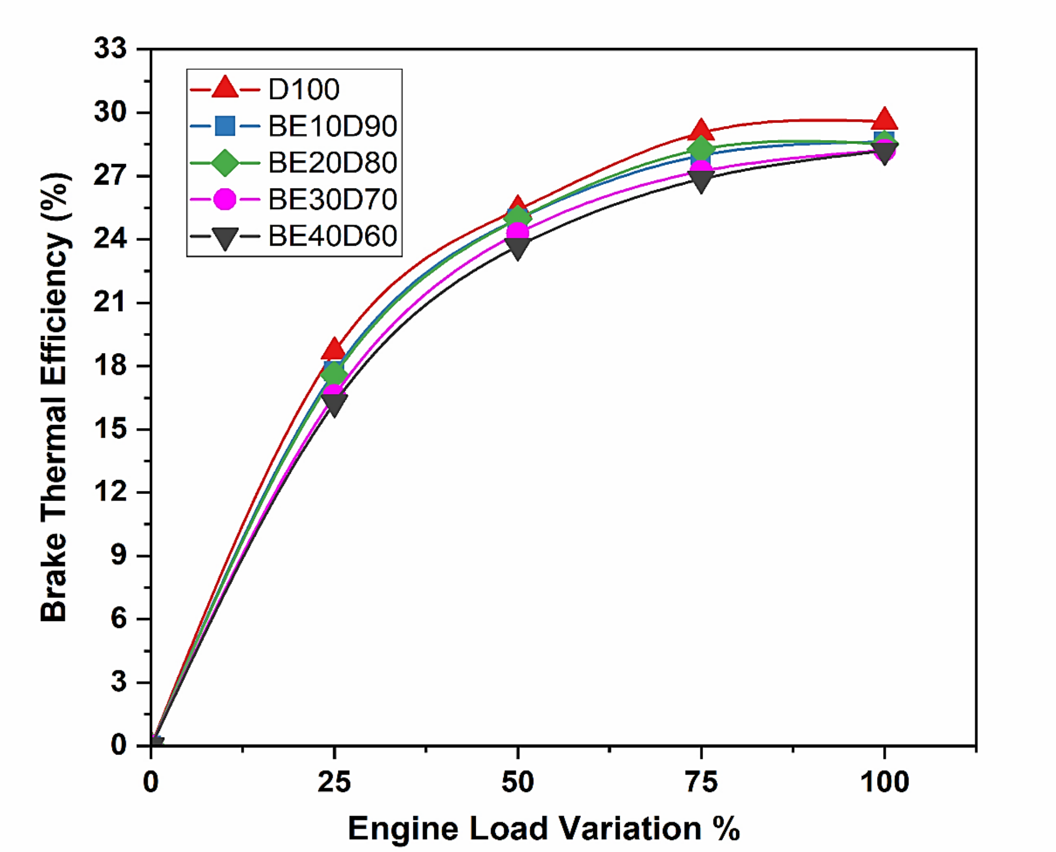

Figure 2: Study of bioethanol blends on brake thermal efficiency

Study on specific energy Consumption

As can be seen in Figure 3, the specific energy consumption (SEC) rises along with an increase in the engine load when bioethanol ratios are present. The BE10D90, BE20D80, BE30D70, and BE40D60 blends all had SEC values that were higher than diesel. Fuel consumption for oil blends is much higher than that of diesel oil for producing the same amount of power. Reduced oil mixture viscosities directly translated to reduced fuel droplet sizes upon injection into the combustion chamber, which resulted in worse fuel penetration, incorrect fuel-air mixing, and a decrease in the efficiency of the combustion process (15). The highest levels of bioethanol blends came out between 1.1% and 11.3% higher than diesel under a variety of load circumstances.

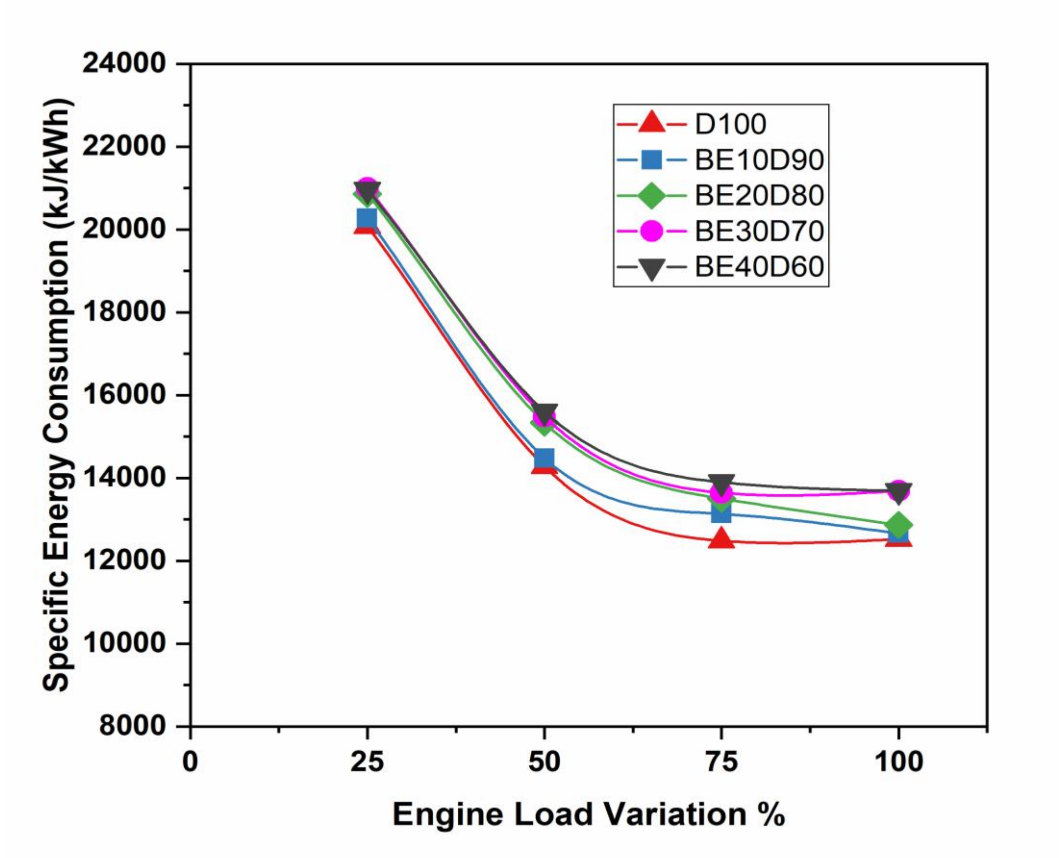

Figure 3: Study of bioethanol blends on specific fuel consumption

Study on carbon monoxide emissions

Figure 4 shows the effects of engine load on carbon monoxide (CO) emissions from blends BE10D90, BE20D80, BE30D70, and BE40D60. Fuel consumption rises in response to greater loads, leading to an oxygen deficit and, in turn, higher carbon monoxide levels in the air. It was discovered that bioethanol blends increased CO production significantly under both starting and full load conditions. Carbon monoxide emissions from all bioethanol mixes drop sharply from idle to half load, then spike dramatically from half load to full load. At different loads, all bioethanol blends were shown to produce higher carbon monoxide emissions than the diesel engine. The increase ranged from 2.4% to 15%. Reduced carbon dioxide emissions were the direct effect of a lower H/C ratio (38).

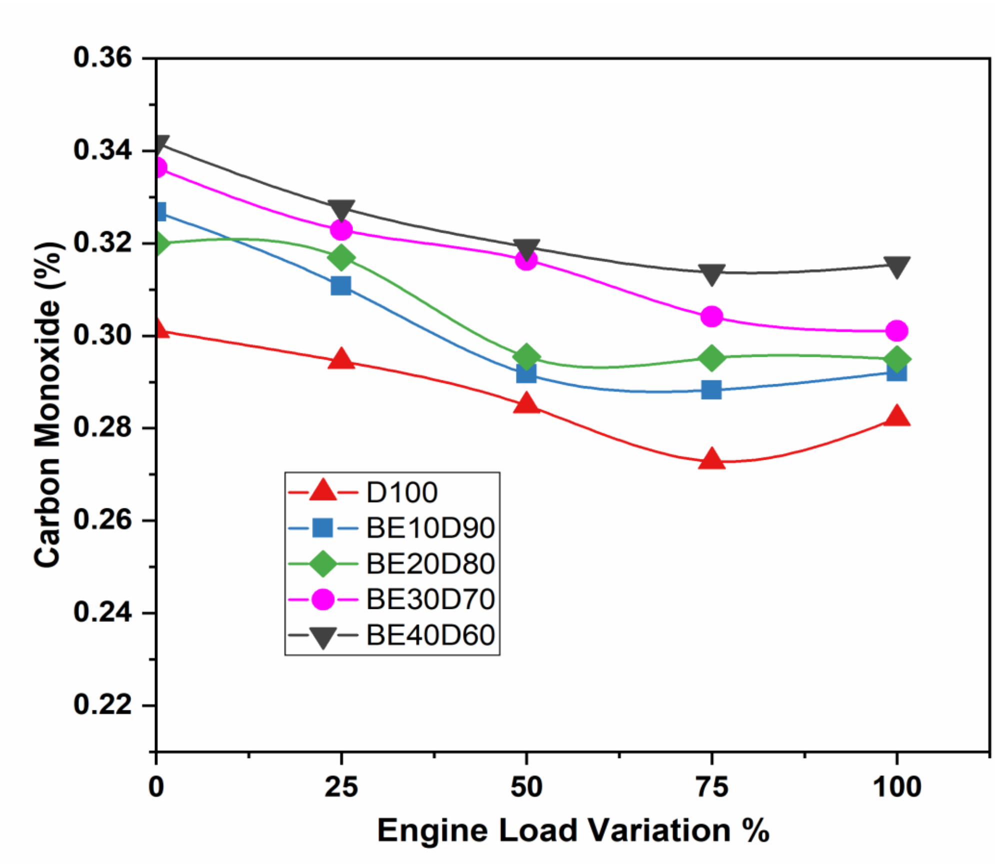

Figure 4: Study of bioethanol blends on carbon monoxide emissions

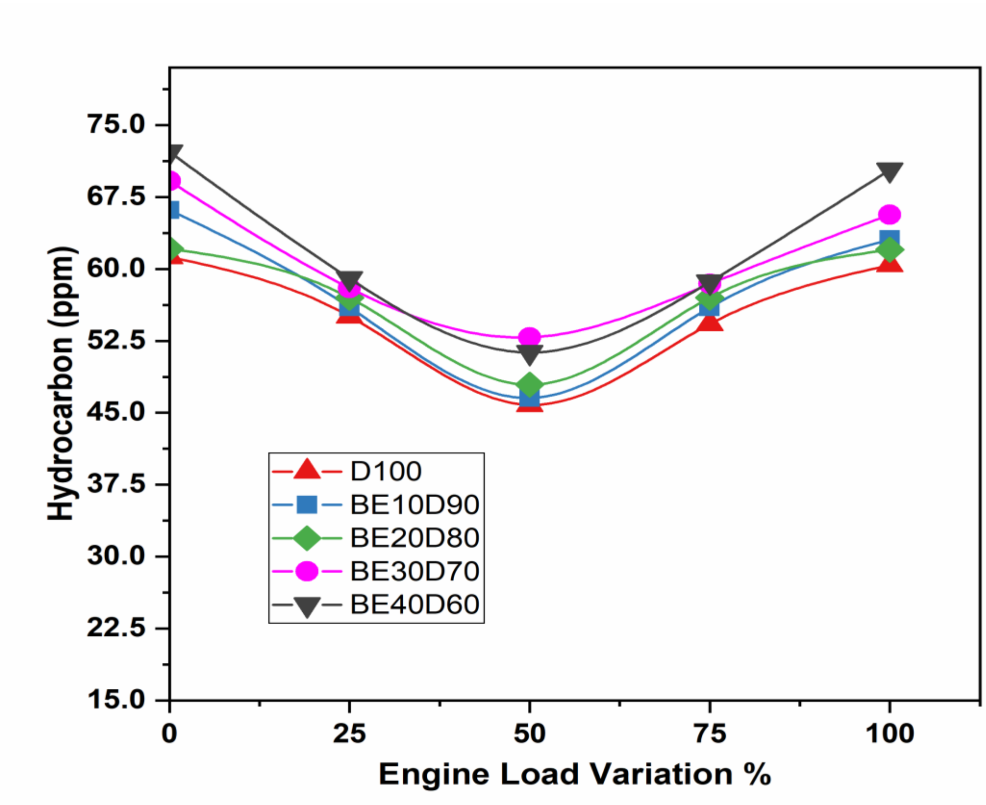

Figure 5: Study of bioethanol blends on hydrocarbon emissions

Study on hydrocarbon emissions

The graph in Figure 5 shows how the amount of unburned hydrocarbon (HC) emissions from bioethanol mixes changes as the engine is loaded. Higher HC emissions with increased engine load can be explained by a higher fuel volume being introduced into the engine, regardless of the mixing ratio. At full throttle, HC emissions were found to be 4.4% higher for BE10D90 blends than for pure diesel, 2.6% higher for BE20D80 blends, 8.7% higher for BE30D70 blends, and 16.4% higher for BE40D60 blends, respectively. As cylinder temperatures have risen, the flame quench has increased, leading to this. On the other hand, due to the oil's exceptionally low viscosity, which led to smaller droplet sizes and lower diffusion as the blending ratio increased, HC concentrations increased (10).

Study on nitrogen oxides emissions

At full throttle, Nitrogen Oxides (NOx) emissions from BE30D70 and BE40D60 mixes are 1.2% and 9.6 % higher, respectively, than those from diesel. Figure 6 displays the relationship between engine load and bioethanol NOx emissions. Engine load increased from fuel use, which led to a spike in NOx emissions, as recorded.

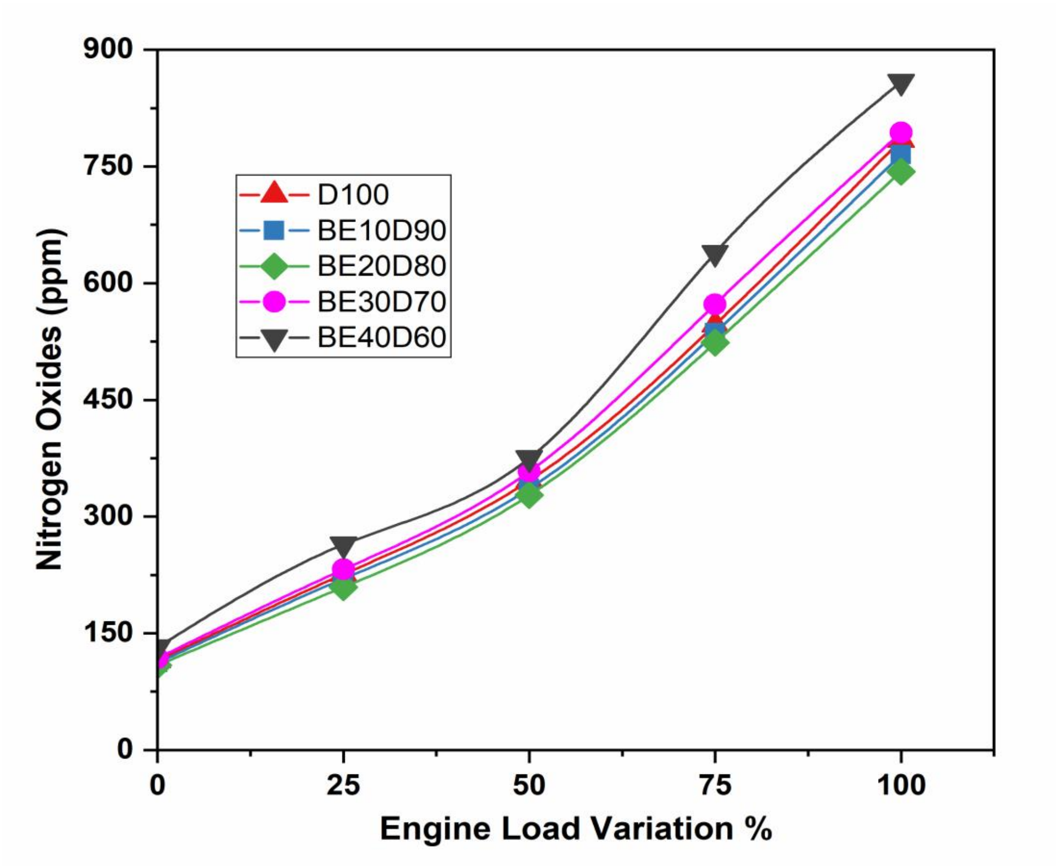

Figure 6: Study of bioethanol blends on nitrogen oxides emissions

Emission levels of nitrogen oxides are affected by a number of factors, including the oxygen and nitrogen content of the surrounding air, the combustion temperature, and the time span of the reaction (39). Increases in oxygen content, as shown in blends of BE10D90 and BE20D80, lead to lower NOx production and thus greater combustion temperatures. Because more oxygen was available during combustion, the amount of NOx produced fell by 1.9% to 7.4% compared to diesel.

Study on smoke emissions

The increased engine load due to the higher fuel usage was blamed for the increase in smoke emissions. Smoke emissions from BE30D70 and BE40D60 mixtures are 2.7% and 5.3% higher than base diesel, respectively, at full load condition, as shown in Figure 7. The amount of smoke produced depends on several factors, including the oxygen content of the bioethanol, the carbon content of the fuel, the combustion temperature, and the duration of the process. Smoke, formed from the combustion of organic materials, is a major contributor to the pollution problem (13). Blends of BE10D90 and BE20D80 demonstrate that increasing the oxygen concentration results in less smoke generation and consequently higher combustion temperatures. Reduced smoke emissions of 4–9.3 percent compared to diesel were attributed to the increased availability of oxygen during combustion.

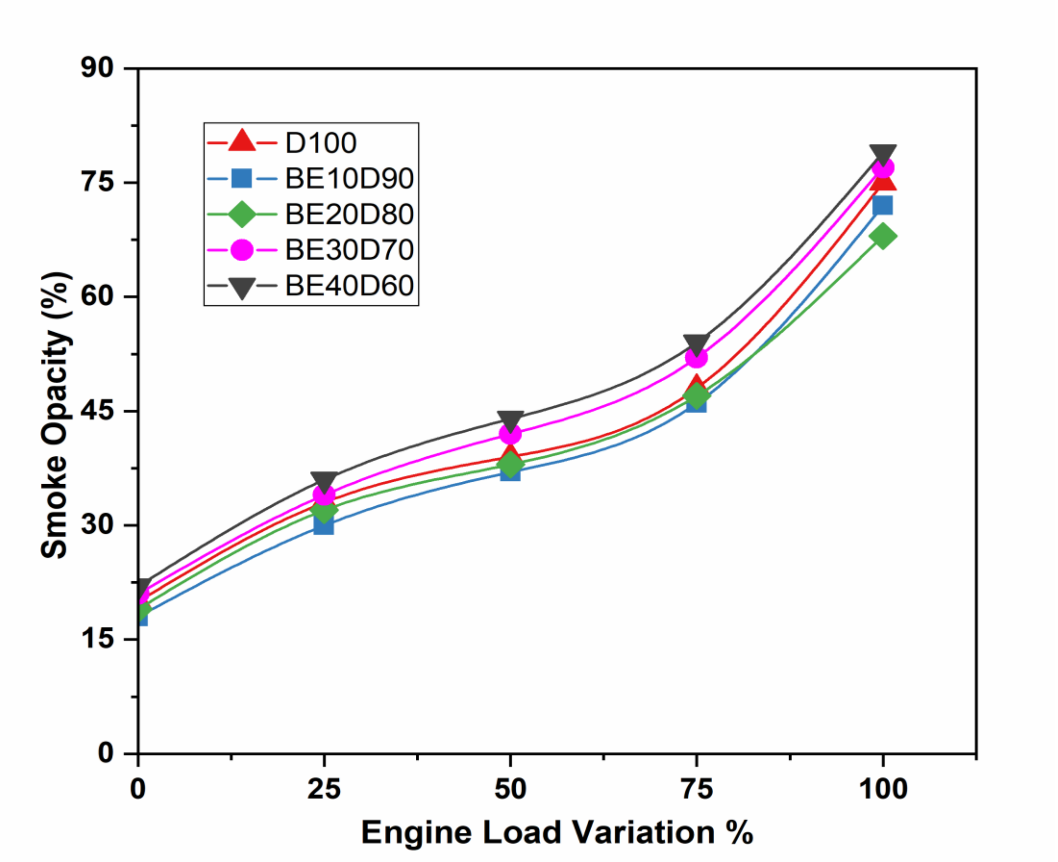

Figure 7: Study of bioethanol blends on smoke emissions

Conclusion

Renewable energy sources have recently attracted the attention of scientists due to rising environmental concerns. One potential solution that could address both economic and environmental issues is bioethanol. The purpose of this research is to determine whether diesel engines can utilize bioethanol, which is energy recovered from water hyacinth. Bioethanol blends made from water hyacinth are examined in this research for their effects on diesel engine performance and emissions. The fuel consumption of bioethanol blends came out to be between 1.1% and 11.3% higher than diesel under a variation of load conditions. At different loads, all bioethanol blends were shown to produce higher carbon monoxide emissions than the diesel engine, which ranged from 2.4% to 15%. Also, hydrocarbon emissions were recorded to be around 2.6% to 16% higher than diesel engine for bioethanol blends. Blends of BE10D90 and BE20D80 demonstrate that increasing the oxygen concentration results in less smoke generation and less NOx. When compared to diesel, the production of NOx decreased by 1.9% to 7.4% and smoke emissions decreased by 4-9.3%. The social impact of bioethanol is predominantly favourable as it generates employment opportunities, particularly in rural regions, where the agricultural sector employs around 20 times more individuals compared to petrol production. This has the potential to enhance local economies and increase incomes. Moreover, it can serve as a means for countries to achieve energy self-sufficiency, thereby decreasing their dependence on imported petroleum. In order to accomplish energy recovery goals, this study thoroughly investigates bioethanol as an alternative fuel in diesel power generators and industrial boilers.

Abbreviation

BE10D90: 10% bioethanol and 90% diesel
BE20D80: 20% bioethanol and 80% diesel
BE30D70: 30% bioethanol and 70% diesel
BE40D60: 40% bioethanol and 60% diesel
BTE: Brake Thermal Efficiency
C5: Arabinose and xylose
C6: Galactose, glucose, and mannose
CO: Carbon monoxide
E10: Ethanol 10%
E20: Ethanol 20%
H/C: Hydrogen to Carbon ratio
HC: Hydrocarbon
NOx: Nitrogen Oxides
SEC: Specific Energy Consumption
TBC: Thermal barrier coatings

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Author contributions

All authors contributed equally to bringing out this research article.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this article.

Ethical approval

This research article is the authors' own original research work, which has not been previously published elsewhere. This research article is not currently being considered for publication elsewhere. The results are appropriately placed in the context of prior and existing research. All data and sources used are properly disclosed. No animal or human' studies were involved.

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