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Influence of Fuel Blends on Performance, Combustion, and Emission Characteristics of CI Engines

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Abstract

Depletion of conventional fuels, as well as continuous price hike, is prime reasons for the requirement for alternative fuel. In order to overcome such situations, blending diesel fuel is one of the promising techniques to create alternative fuels with the aid of conventional fuels. The present work deals with the experimental investigation of carbodiesel fuel blends in single cylinder 4 stroke diesel engines to examine the utilization of carbodiesel fuel blends as an alternative fuel in diesel engines. Four different types of fuel blends such as carbodiesel5, carbodiesel10, carbodiesel15, and carbodiesel20 fuel blends were employed for experimental purposes. Experiments were conducted by using different equipment for the recording of experimental readings of engine characteristics and then these data were linked with a data acquisition system for further processing. An increment in carbon black content in diesel fuel resulted in an increment in ignition delay and combustion duration, but it resulted in decrement in other combustion parameters such as maximum pressure, maximum rate of pressure rise, maximum heat release rate, and combustion efficiency. Maximum brake specific energy consumption increases but on the other hand maximum brake thermal efficiency decreases with increment in carbon content within the fuel blends of carbo-diesel. It was noticed that reference diesel fuel has got the least amount of exhaust gas temperature due to the fact that it has got maximum rate of pressure rise for diesel fuel as compared to other fuel blends of carbodiesel. It was gathered that CO (carbon monoxide), HC (hydrocarbon), and smoke emission content increases with increment in carbon content in carbodiesel fuel blends and NO_x (nitrogen oxides) decreases with increment in carbon content within fuel blends. Out of all experimental findings, carbodiesel5 was found to be the most efficient fuel blend as compared to other fuel blends which matches quite well with diesel fuel in performance, combustion, and emission characteristics.

Keywords

Pyrolysis, Engine, Carbodiesel, Fuel blend, Combustion, Performance, Emission, Diesel

Introduction

Depletion in fossil fuels had led to price hike of oil, and due to introduction of new standards for emission, measures are being launched globally to substitute gasoline and diesel fuel [1-3]. The pursuit of alternative fuels is supported by massive financial investments [3-5]. At the same time, the process for getting rid of used tires from automobiles is getting more complicated [3, 6, 7]. Waste to energy conversion tries to displace traditional fuels [3]. For internal combustion engines, alternative fuels include ethanol, biodiesel, and liquid plastic fuel [1-7]. Recycling of rubber obtained from waste tires was found to be a feasible process for generation of energy in order to prevent environmental damage, especially with regard to discarded car tires [8, 9]. On the contrary, a very less portion of tire produced worldwide annually is recycled each year [9-12]. There was a chance to use fewer natural resources by switching to tire oil obtained through pyrolysis in place of diesel fuel [9-12]. The pyrolysis of used car tires has been the subject of numerous investigations [9-12]. Pyrolysis is the heat degradation of a material into more simple, smaller molecules [9-12]. Char, oil, and gas were the byproducts of tire pyrolysis process [6-9]. The temperature and design of the reactor have an impact on the quantity and quality of these products [6-9]. Large HC chains disintegrate during the pyrolysis process at specific temperatures without presence of oxygen, creating final products that typically contain all forms of states [6-9]. One of the byproducts of pyrolysis process obtained at a temperature of 550 °C in the form of liquid mixture of various HCs. Gas becomes the main product at temperatures above 700 °C as a result of the continued cracking of liquids [6-9]. The main component of the gas is methane, with smaller amounts of ethane, ethene, ethyne, and other chemical compounds [9]. The design and temperature of the reactor determine the quantity and quality of these products. In the current work, vacuum pyrolysis was used to extract pyrolysis oil from used tires [9, 10]. In the initial liquid is formed during production of gas produced by pyrolysis and carbon black [9].

Many researchers in the past contributed a lot to finding the solutions for conversion of tire oil into usable form for CI engines. Tire oil was prepared by blending Cao and NZ by varying its weight percentage from (2 to 10 percent) which yielded in fuel sample that can used as fuel to burn in standard CI engines [1]. Karagoz et al. [2] realized that upon increment in percentage quantity of oil produced through pyrolysis as well in engine load consequently led to pressure increment inside cylinder and in rate of thermal energy. This phenomenon was cited since the tire pyrolysis oil content has got less cetane number in contrast to basic diesel fuel. Murugan et al. [3] experimentally realized that WTP010 blend found to be superior oil through pyrolysis which resembles diesel in terms of performance as well as environmentally friendly too. Critical review work was done for reviewing various aspects of oil found through pyrolysis process and found that this oil resembles the behavior of diesel in terms of all parameters [4, 7, 12]. Frigo et al. [6] found that sulfur content was crucial parameter during pyrolysis of oil and found greater than diesel whereas cetane index for diesel was higher than that of pyrolysis oil. Koc and Abdullah [7] found experimentally that blending of tire pyrolysis oil which yielded in considerable decrement in brake specific fuel consumption. Murugan et al. [3] found that blending of distilled tire pyrolysis oil and diesel yielded an increased rate of formation of smoke. Murugan et al. [9] again realized experimentally that formation of smoke had increased by 7% for tire pyrolysis oil (TPO-50) in contrast to diesel. Murugan et al. [10] found experimentally that in distilled tire pyrolysis oil (DPTO-90) blends resulted in increased rate of heat release as well as in pressure rise in early stages of combustion in contrast to diesel fuel. Hussain et al. [11] found that according to emission characteristics, unburnt HC emissions from electrical pyrolysis oil and microwave pyrolysis oil were, respectively, 7% and 15% greater than those from diesel. Tire pyrolysis oil produced by vacuum pyrolysis had lower thermal efficiency than diesel operation [12]. Experiments were conducted for determination of significance of carbon black content addition for formation of carbodiesel (5, 10, 15, and 20) upon engine characteristics of diesel engine and found that carbodiesel10 version had outlined all other fuel blends [13]. In the recent past, researchers also worked on tribological analysis of waste tire pyrolysis oil. Yaqoob et al. [14] outlined that DT10 outperformed diesel gasoline in terms of wear behavior. Yaqoob et al. [15] found that the wear scar diameters of tires pyrolysis oil, BT10, and BT20, respectively, were 23.99%, 8.37%, and 32.62% smaller than those of biodiesel gasoline with an 80 kg load. Yaqoob et al. [16] realized that diesel has the best results in terms of wear, whereas waste tire pyrolysis oil has the best results in terms of friction. It was found that still relatively less work was conducted on the fuel blends of diesel engine and as well as upon determination of performance characteristics of diesel engines. Research in the past also investigated the role of nanoparticles in the improvement of performance, emission, and combustion characteristics of the diesel engine. In this context Khan et al. [17-18] rigorously reviewed the exceptional properties of the diesel emulsion upon addition of nanoparticles and found that nanomaterials contain a higher percentage of surface atoms, and this percentage rises as the size of the material decreases. Nanomaterials are endowed with extraordinary properties due to the increase of surface atoms and large surface area [17-18]. Nanoparticles are employed in catalytic converters and as fuel or lubricant additives in internal combustion engines [17-18]. The addition of nanoparticles to the fuel has the advantages of better combustion characteristics, faster energy release, and a shorter ignition delay [17-18]. Nanoparticles added to lubricants greatly reduce the amount of friction between contact surfaces [17-18]. The performance of the catalytic converter was improved by the high reactivity of the nanoparticles [17-18]. In addition to this, the addition of cerium oxide in neat diesel promotes the process of atomization of fuel and yields in increment in thermal efficiency of fuel blends as well as reduces emission levels too [19]. It was found that the emission levels of HC and CO have reduced upon addition of nanoparticles with liquid based fuel except NO_x emission level [20]. Thus, the objective of current work is to experimentally determine influence of carbodiesel content on the associated maximum characteristics of diesel engine for engine characteristics.

Experimentation

First of all, in the present carbon black is utilized after carrying out pyrolysis of waste tires. Secondly the obtained carbon black after pyrolysis was dried and crushed to convert it into powder form and after that it was further compacted to bring to the size of 4 micron. After that diesel was mixed with fine particles of carbon black in order to form carbodiesel fuel blends for the present investigation to become an alternative fuel for diesel fuel. Figure 1 shows the three-dimensional experimental set-up of test rig for conducting tests and schematic illustration of experimental setup was depicted in figure 2. The experimental setup of the current investigation is based on diesel engines having single cylinder and four stroke. The engine make is by Kirsloskar which runs at 1500 rpm and develops 4.4 kW power. A load cell and a dynamometer based on

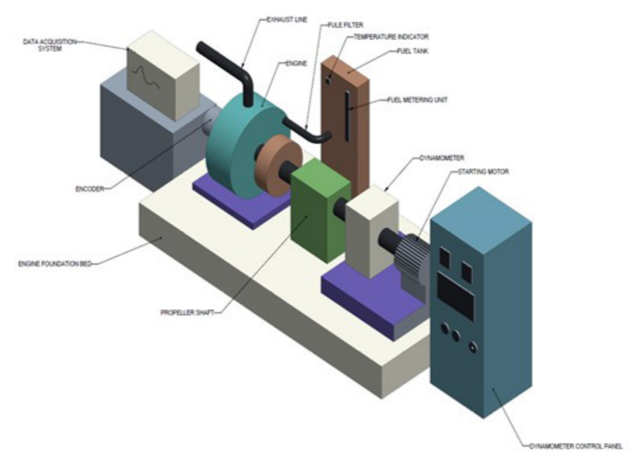

Figure 1: Three-dimensional experimental set-up of engine.

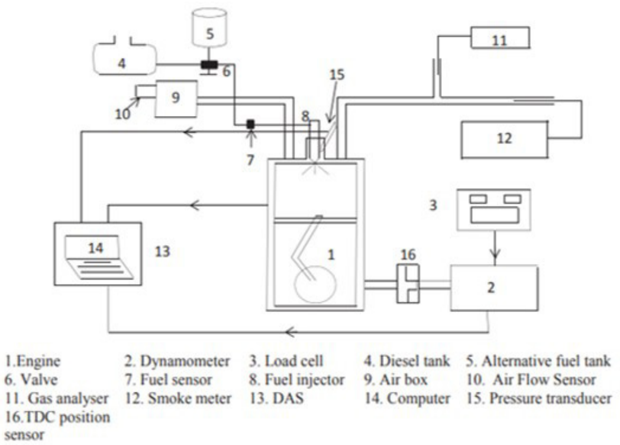

Figure 2: Representation of experimental setup utilized in present work [13].

electric powered driven were connected to the engine. With the aid of the dynamometer, the engine received the appropriate load. A digital controller included with dynamometer to manage load associated with engine. Two separate fuel tanks held diesel and alternate fuel. Supply of fuel through tanks was actuated through a connecting valve. The gasoline measurement system comprises of a burette equipped with optical sensor for measurement of fuel levels. Signal was sent to data acquisition system as gasoline pass after the sensor at upper level in order to initiate counter time. On the contrary another signal was sent to another optical sensor placed at lower level for refilling burette as well as for stopping halt time. This allowed for the calculation of the amount of time needed to use a certain amount of fuel. The system's existing injector was used to inject diesel or an alternative fuel. To ensure a continuous supply through inlet passage and to dampen engine's pulsations, an air box was installed.

For measurement of air flow, the air box was equipped with pressure sensor. A thermocouple (K-type) was attached within exhaust pipe for sensing temperature of exhaust gas. To start, diesel fuel was used to run the engine and collect reference data. Pressure transducer, position sensor, amplifier was connected to data acquisition system. Pressure measurement was actuated by employment of pressure transducer on cylinder head whereas position sensor was connected to shaft for reading of TDC position. To measure speed, a contactless sensor was linked close to the engine's flywheel. On the computer's monitor, information gathered through data acquisition system via each sensor for associated loads was shown. Emissions content of HC, CO, and NO_x through exhaust of engine were measured using exhaust gas analyzer. Every time a measurement was taken, the analyzer's probe was introduced into the exhaust.

Measurement of amount of smoke via exhaust manifold was carried out through smoke meter. In the beginning, diesel was utilized for measurement of engine characteristics. Operational parameters utilized in the work were CR = 17.5 and working pressure of 200 bar with 1500 rpm. The engine was operated via both fuels with and without changes to the engine. Information for engine operations was gathered, saved, and compared to data for the diesel operation for analysis. The following subsections provide a description of each instrument.

Results and Discussion

Influence of carbodiesel variations on combustion characteristics

Maximum pressure attained during combustion within diesel engines is one of the driving factors for making of efficient diesel engine. It was gathered from figure 3 that maximum pressure was certainly achieved by using reference diesel fuel. Besides this it was found that out of various fuel blends the carbodiesel5 fuel blend attains maximum pressure after the reference diesel fuel which appears to be to exhibit similar characteristics like diesel fuel. It was also noticed that by upon increasing percentage of carbon with fuel blend results in the decrement in maximum pressure.

Influence of carbodiesel variations on maximum pressure

Maximum pressure attained during combustion within diesel engines is one of the driving factors for making of efficient diesel engine. It was gathered from figure 3 that maximum pressure was certainly achieved by using reference diesel fuel. Besides this it was found that out of various fuel blends the carbodiesel5 fuel blend attains maximum pressure after the reference diesel fuel which appears to be to exhibit similar characteristics like diesel fuel. It was also noticed that by upon increasing percentage of carbon with fuel blend results in the decrement in maximum pressure.

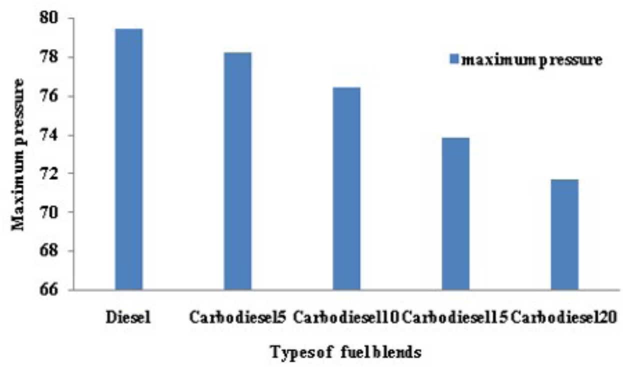

Figure 3: Influence of carbodiesel variations on maximum pressure.

Influence of carbodiesel variations on ignition delay

Variation of ignition delay by using various types of fuel blends was given in figure 4. It was noticed that the ignition delay obtained during experiments for diesel engine was found to be 9.31° for reference diesel fuel. It was also noticed that by using other fuel blends i.e., carbodiesel fuels, ignition delay increases by approximately 4% through increment in carbodiesel content. The similar pattern for maximum ignition delay was obtained for carbodiesel5 which can replace diesel based on this criterion.

Influence of carbodiesel variations on maximum heat release rate

Figure 5 shows influence of carbodiesel variations on maximum heat release rate by employing various types of carbodiesel fuel blends. It is one of the important factors for combustion in diesel which mainly dependent upon the calorific value of fuel, injection timings as well as on ignition delay. Reference diesel fuel has recorded with the case of peak rate of heat release. Again, this rate of heat release diminishes due to increment in carbon content in carbodiesel. Reduction in heat release rate (max.) for carbodiesel was attributed the increment in ignition delay of carbodiesel fuels. Besides this again calorific value of carbodiesel fuel blends also plays an important role for achieving maximum heat release rate.

Influence of carbodiesel variations on combustion duration

The influence of carbodiesel variations on combustion duration was depicted in figure 6. It was realized that reference diesel fuel has least amount of combustion duration. It was also recognized that combustion duration increases with increment in content of carbon. A similar behavior was again attained for carbodiesel5 fuel blend which matches with reference diesel fuel.

Influence of carbodiesel variations on maximum combustion efficiency

Variation of maximum combustion efficiency was plotted for different fuel blends of carbodiesel and shown in figure 7. Again, reference diesel fuel has got maximum combustion efficiency as compared other carbodiesel fuels. Out of all fuel blends of carbodiesel, carbodiesel5 matches quite well in terms of combustion efficiency as it is comparable to reference diesel fuel case. Combustion efficiency diminishes with increment in percentage of carbon content with fuel blends.

Influence of carbodiesel variations on peak pressure rise rate

A plot for assessment of influence of various carbodiosel variations on peak pressure rise rate was depicted in figure 8. Peak rate of pressure rise was obtained for diesel fuel. It was also found that after diesel fuel, carbodiesel5 fuel has got maximum pressure during whole operation. It was found that peak rate of pressure rise decreases with increment in carbon content within fuel blends of carbodiesel.

Influence of carbodiesel variations on maximum 90 % mass burned

Influence of fuel blends on maximum 90% of mass burned was depicted in figure 9. Maximum 90% of mass burned was obtained highest for diesel fuel. It was also found that after diesel fuel, maximum 90% of mass burned has attained

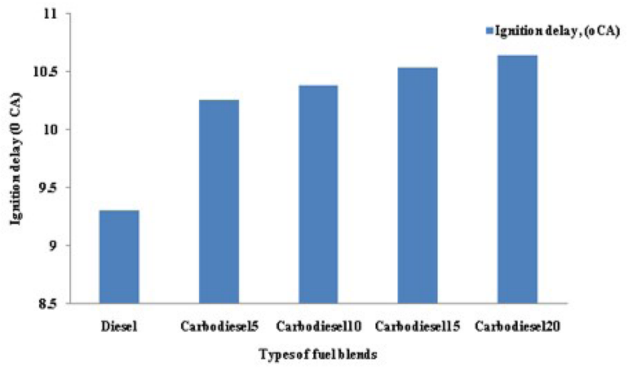

Figure 4: Influence of carbodiesel variations on ignition delay.

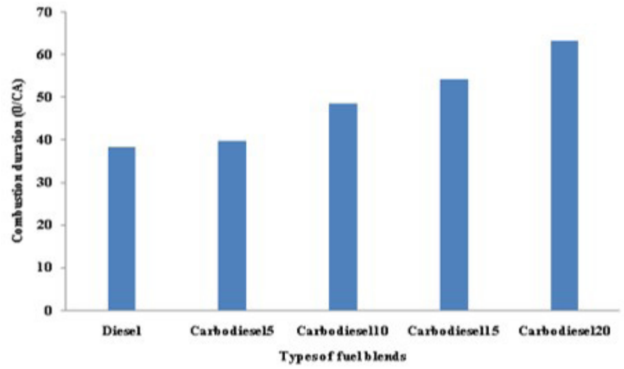

Figure 6: Influence of carbodiesel variations on combustion duration.

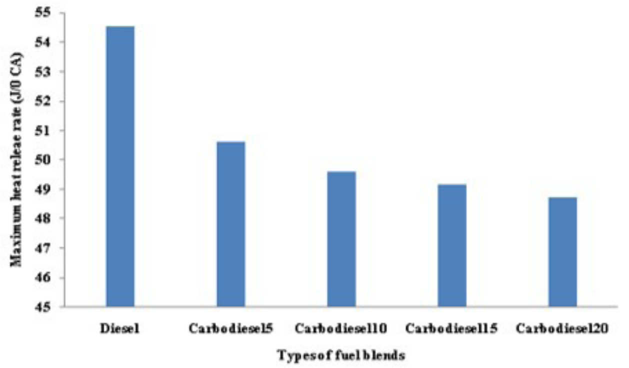

Figure 5: Influence of carbodiesel variations on maximum heat release rate.

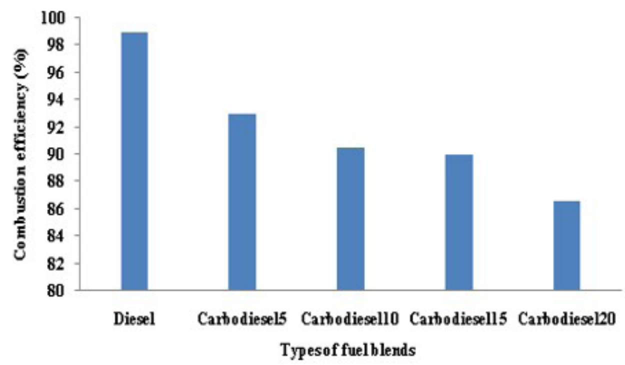

Figure 7: Influence of carbodiesel variations on combustion efficiency.

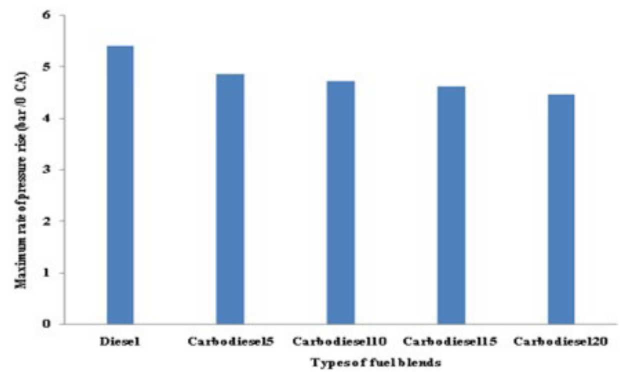

Figure 8: Influence of carbodiesel variations maximum rate of pressure rise.

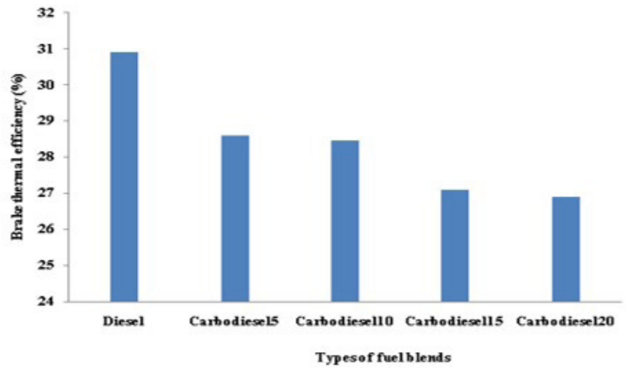

Figure 10: Influence of carbodiesel variations on brake thermal efficiency.

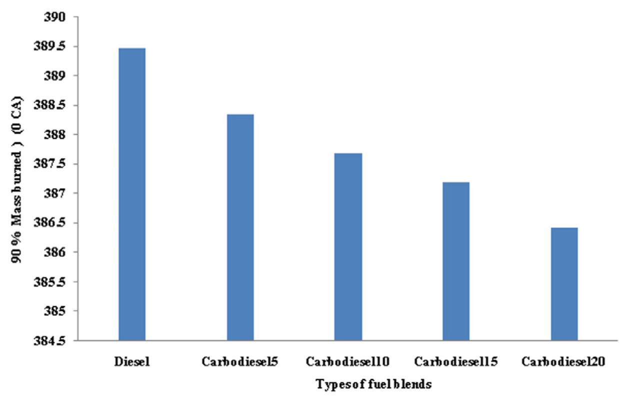

Figure 9: Influence of carbodiesel variations on 90% of mass burned.

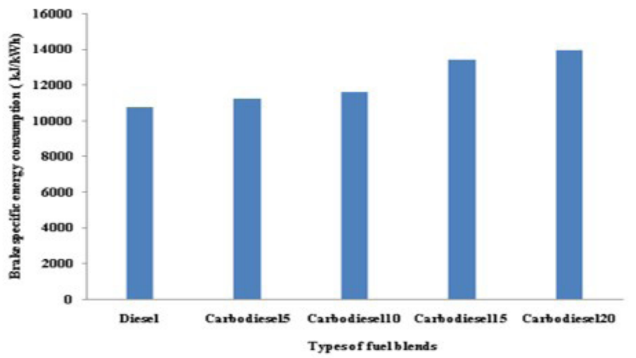

Figure 11: Influence of carbodiesel variations on maximum brake energy consumption.

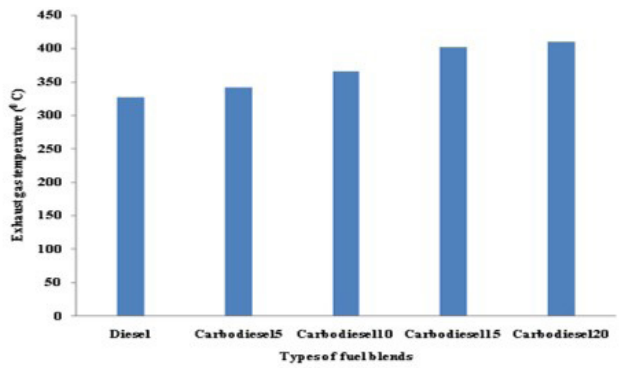

Figure 12: Influence of carbodiesel variations on temperature of exhaust gas.

greatest value of peak pressure. Additionally, it was found that peak pressure increment decreases upon increment for carbon content within fuel blends of carbodiesel.

Influence of carbodiesel variations on performance characteristics

Influence of carbodiesel variations on maximum brake thermal efficiency (%)

Brake thermal efficiency (max.) variation versus content of carbodiesel was plotted and shown in figure 10. Maximum thermal efficiency (maximum) was found to be highest for diesel. It was also found that after diesel fuel, maximum 90% of mass burned has got maximum efficiency. In addition to this, brake thermal efficiency (max.) diminishes with increment in carbon within fuel blends of carbodiesel.

Influence of carbodiesel variations on maximum brake energy consumption (%)

Plot of energy consumption (maximum) versus variety of carbodiesel content was shown in figure 11. Least $bsec_{max}$ was obtained for diesel in comparison to other variations of carbodiesel. Increment in $bsec_{max}$ was found with increment in carbon content in carbodiesel.

Influence of carbodiesel variations on temperature of exhaust gas

Variation of exhaust gas temperature due to utilization of different carbodiesels was plotted and depicted in figure 12. It was noticed that reference diesel fuel has least amount of exhaust gas temperature due to the fact that it has got peak pressure rise for diesel fuel in comparison to other fuel blends. Carbodiesel5 has got similar behavior like diesel fuel and matches quite well with the diesel fuel for exhaust gas temperature.

Influence of carbodiesel variations on emission characteristics

Influence of carbodiesel variations on maximum CO emission (%)

Figure 13 shows influence of variety of carbodiesel on CO emission (%). Out of all fuel blends, reference diesel fuel has exhibited minimum amount of CO emission. Besides this it was also gathered that the carbodiesel5 emission content matches quite well with reference diesel fuel. It was also no-

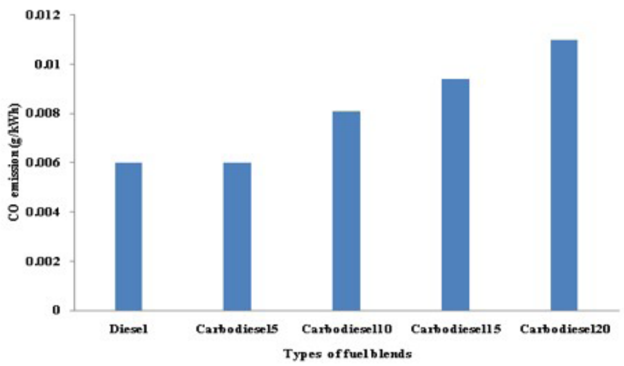

Figure 13: Influence of carbodiesel variations on CO (%) emission.

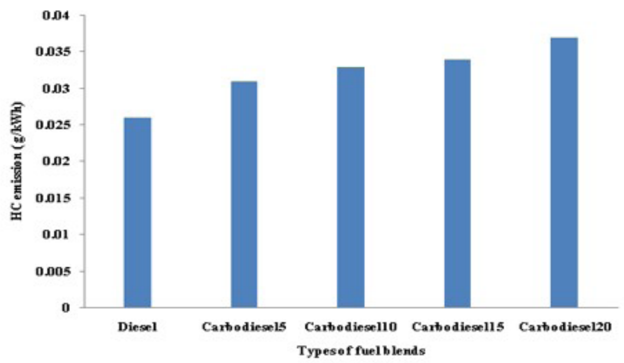

Figure 14: Influence of carbodiesel variations on HC emission (%).

ticed that CO emission content increases with increment in CO content within fuel blends.

Influence of carbodiesel variations on maximum HC emission (%)

Figure 14 shows influence of variety of carbodiesel on HC emission (%). Out of all fuel blends, reference diesel fuel has exhibited minimum amount of HC emission. Besides this it was also gathered that the carbodiesel5 emission content matches well with reference diesel fuel. It was also noticed that HC emission content increases with increment in CO content within fuel blends.

Influence of carbodiesel variations on maximum NOx emission

Figure 15 shows influence of variety of carbodiesel on NO_x emission (%). Out of all fuel blends, reference diesel fuel has exhibited maximum amount of NO_x emission. Besides this it was also gathered that the carbodiesel5 emission content matches well with reference diesel fuel. It was also noticed that NO_x emission content decreases with increment in carbon content within fuel blends.

Influence of carbodiesel variations on maximum smoke emission

Figure 16 shows the effect of variety of fuel blends on smoke emission (%) characteristics. Out of all fuel blends, reference diesel fuel has exhibited minimum amount of smoke emission (%). Besides this it was also gathered that the carbodiesel5 has got least smoke emission content out of other fuel blends, which matches well with reference diesel fuel. It was also noticed that smoke emission content increases with increment in carbon content within fuel blends.

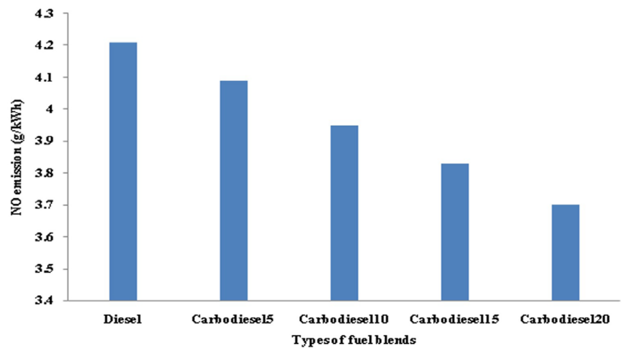

Figure 15: Influence of carbodiesel variations on NO_x emission (%).

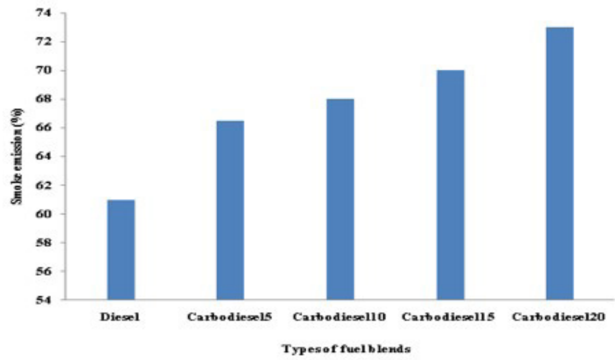

Figure 16: Effect of fuel blends on smoke emission (%).

Conclusion

The need for alternative fuel is mostly driven by the depletion of conventional fuels and ongoing price increases. Blending diesel fuel is one of the promising methods for producing alternative fuels from conventional fuels in order to overcome such circumstances. Carbodiesel5, carbodiesel10, carbodiesel15, and carbodiesel20 fuel blends were employed for experiments using single four stroke diesel engine. Engine characteristics in terms of performance, emission, and combustion were studied experimentally. It was discovered that increasing the amount of carbon black in diesel fuel causes an increase in the igniting delay duration. While combustion time increased, other characteristics such as maximum pressure, combustion efficiency, maximum heat release rate, and maximum heat release rate decreased. Maximum brake specific energy consumption was discovered to be rising. Maximum brake thermal efficiency declines as carbon content in carbo-diesel fuel blends rises.

Acknowledgements

None.

Conflict of Interest

None.

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