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Influential Investigation of Alumina Nano-additives on the Alternative Energy Recovered from Waste Materials for Engine Applications

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Abstract

Fossil fuels like crude oil or natural gas must be saved in order to support current economic development. In addition to traditional sources of energy like coal and oil, there are several renewable options available, such as biomass, hydroelectricity, and wind power. Another significant consideration is the use of an effective approach for disposing of garbage. There has been a massive growth in the manufacture of all types of goods, which in turn generates garbage. Plastics have long been a popular material for a variety of products because of their high adaptability and cheap cost. Plastic waste disposal and a lack of conventional fuel are two issues that this article aims to solve in an effort to promote a more sustainable environment. The waste plastic fuel recovered from different grade of waste plastics with alumina (Al_2O_3) was not investigated for potential use in diesel engines. In this analysis, a combination of 20% plastic fuel with standard diesel forms a base fuel as WME20 blend. Alumina additives at concentrations of 20 ppm, 40 ppm, and 60 ppm were combined with WME20 waste plastic fuel as an alternative fuel source in order to improve the engines' performance.

Keywords

Energy recovery, Waste plastics, Diesel engine, Alumina, Emission, Nano additives

Introduction

Due to fast industrialization and an increasing population, the main issues of today are the energy crisis and environmental degradation. Nature takes a long time to break down solid debris like plastic bottles, supermarket bags, and the like. In addition, plastic disposal techniques like landfilling, recycling, and burning pose serious health and environmental dangers to people and the natural world. As a result, plastic pollution must be curbed to prevent further harm to the ecosystem [1]. Pyrolysis is a cost-effective and ecologically responsible approach to disposing of hazardous waste. A better option would be to produce gasoline from polymers that have a calorific value equivalent to that of fuel. Catalytic pyrolysis was tested on a variety of recycled plastics to see whether it might be used to turn plastic into fuel [2, 3]. Materials made from synthetic plastics are non-biodegradable and often include a hydrogen chain along with carbon. Many researchers have examined the use of oil generated from plastic waste as a potential source of energy. The machinery working on pyrolytic oil with additives was studied to determine its operating parameters and efficiency potential [4].

Researchers evaluated the operating characteristics and efficiency of a diesel engine using plastic fuel mixes without modifying the engine, and their findings indicate that post-consumer synthetic plastic fuel might be a viable alternative. Scientists conducted laboratory tests in conjunction with a diesel engine that ran on neat waste plastic fuel. It was observed that the engine's efficiency was diminished, and emissions were higher than with a conventional diesel-fueled engine [5, 6]. Over the past few years, the plastics sector has seen a dramatic increase in the manufacturing of synthetic polymers such as polypropylene (PP), polyethylene (PE), polystyrene, polyethylene terephthalate (PET), and polyvinyl chloride (PVC). All of these recycled plastics were evaluated in terms of energy conversion. It was discovered that waste plastic pyrolysis oil might be used as a fossil fuel substitute. Indirect injection was used in the engine tests for the combustion experiments. The engine experiment results revealed decreased performance but increased fuel consumption. Due to the low volumetric fuel rating, there was a noticeable decrease in performance [6].

Post-consumer plastics pyrolysis oil was used to perform diesel engine tests. The plastic waste oil blends are evaluated for combustion and emissions in various percentages. Using synthetic plastic pyrolysis oil resulted in a greater ignition delay. Combustion peak pressures were greater, and heat release rate was higher, as a result of this. Increased blending ratios lead to an increase in emissions [7]. Researchers aimed to investigate the combustion and emission effects of an engine using compression ignition and a combination of post-consumer plastic pyrolysis oil. Engine vibration and exhaust pollutants were exacerbated with higher mixes. Late combustion and unsaturated HC (Hydrocarbon) have been blamed for the higher levels of emitted greenhouse gases. Blends more than 30% demonstrated combustion performance considerably above diesel values [8].

Exploring the effects of variable compression ratio diesel engine performance and emissions on variable parameters such as injection pressure and time. Various proportions of ethanol and diesel are mixed with waste plastic fuels to make test fuels. The experimental analysis shows the maximum thermal efficiency, increasing by 16 and 38% over pure diesel and pure waste plastic fuel [9]. The performance and emissions of a diesel engine utilizing waste plastic fuel generated by pyrolysis using Zeolite-A as a catalyst are being investigated. Using 20% waste plastic fuel-diesel enhances thermal efficiency and decreases brake specific fuel consumption (SFC). The NO_x (Nitrogen oxides) and HC emissions are lower at low loads and increase with load [10]. Waste plastic fuel blends, and its distilled derivatives may be used to power the engine without requiring modification. However, both raw waste plastic fuel and distilled waste plastic fuel had a significant negative impact on engine performance and emission levels. A greater density and viscosity, lower cetane number, higher sulphur content, and acid value were all factors contributing to this [11].

When the load rises, the thermal efficiency improves, and the fuel consumption decreases due to the greater concentration of waste plastic fuel in the mix. High in-cylinder pressure is caused by waste plastic fuel's high heat release and delayed ignition. Oxygenated chemicals in waste plastic fuel also aid to reduce emissions from burning. Diesel engines may utilize up to 50% waste plastic fuel in the mix with just a minor increase in CO (Carbon monoxide) emissions at higher loads [12]. The combustion and performance study of the engine and the pyrolysis oil may serve as a substitute for conventional fuel. The addition of pyrolysis oil does not result in outstanding performance like diesel fuel, as shown by combustion studies such as the fuel consumption and efficiency. Adding nanoparticles to them, on the other hand, improves their performance [13].

A 20% waste plastic fuel blended diesel with 50, 70, and 100 ppm of nanographene was compared to the performance of a diesel in the supercharged engine at different compression ratios. At a compression ratio of 17:1, the thermal efficiency of waste plastic fuel combined with 100 ppm graphene dispersed diesel fuel rose by 1.2%. The addition of 100 ppm nanographene to plastic reduced CO, HC, and NO_x emissions considerably compared to the other blends [6]. Individual fuel blends of 80% diesel, 20% WPO with 25 ppm, 50 ppm, 75 ppm, and 100 ppm cerium oxide nano-additive were created and evaluated in a diesel engine for combustion, performance, and emission tests. Less than one percent increase in BTE and a considerable decrease in CO, HC, and smoke emissions were seen in diesel WPO (Waste plastic oil) mixed with 75 ppm nano-additive [14].

Waste plastics are being investigated for their potential to be used as a source of renewable energy in place of traditional fossil fuels. Waste plastic fuel derived from HDPE (High density polyethylene), and LDPE (Low density polyethylene) using the pyrolysis method will be tested in a single-cylinder diesel engine to establish its emission and performance properties. The addition of alumina nano additive as an oxygen enhancer for better combustion. The plastic fuel recovered from different grades of waste plastics with alumina was not investigated for potential use in diesel engines. In this analysis, a combination of 20% waste plastic energy (WME) with standard diesel (SD) forms a base fuel as WME20 blend. Alumina additives at concentrations of 20 ppm, 40 ppm, and 60 ppm were combined with WME20 waste plastic fuel as an alternative fuel source in order to improve the engines' performance.

Materials and Method

Materials

The pyrolysis technique may convert around 80 weight percent of plastic into oil. Furthermore, the amount of energy required to generate useful goods and oil from one unit weight of PE is 1.047 MJ/kg. Various research projects have been conducted to determine the feasibility of using pyrolysis liquid oil as an alternative fuel. Pyrolysis oil is combined with diesel in a percentage ranging from 10 percent to 40 percent, and it has been tested in a range of compression ignition engines in a number of scientific investigations. These studies were conducted to determine the influence of pyrolysis liquid oil as a mix fuel with commercial diesel and to investigate the combustion and exhaust pollutants produced by the engine [15].

Saturated and unsaturated components are found in pyrolysis oil, but saturated bonds make up the majority of the diesel oil makeup. A saturated bond of carbons has a dissociation energy of 347 kJ/mol, whereas an unsaturated bond of carbons has a dissociation energy of 611 kJ/mol, as discovered by kinetic studies. A higher dissociation energy for alkene components results in a longer ignition delay time. An ignition delay has a detrimental impact on combustion, making pyrolysis oil inappropriate. Non-biodegradable synthetic plastics often include a hydrogen chain and carbon atoms. Many specialists have looked at the possibility of using plastic waste oil as a fuel. There has been investigation into the operation and efficiency of a diesel engine utilizing diesel blends with plastic fuel, and their evaluation concludes that post-consumer synthetic plastic fuel might be a potential substitute. Scientists used a diesel engine in a laboratory to conduct tests on waste plastic fuel. When compared to a regular diesel-fueled engine, this one's efficiency was found to be lower and its pollutants higher. Alkanes, alkenes, and aromatics make up the vast majority of the chemicals found in synthetic polymers [16].

Conversion in the catalytic process is facilitated by using a catalyst. For example, temperature, heating rate, catalyst use, particle size, retention duration, and moisture content are the variables that will influence while on pyrolysis of plastic waste. It was shown that this method, when compared to traditional thermal pyrolysis, yielded higher yields of oil from synthetic waste and better-quality oil at shorter reaction times and lower temperatures. It is possible to minimise energy usage while improving pyrolysis technique output using these settings. Many catalysts, including aluminium hydroxide, calcium hydroxide, and natural zeolite, are used in the process of making plastic fuel conversion. There are several different forms of plastic pyrolysis that create compounds with low carbon numbers, such as polystyrene and PP, as well as HC in the gasoline range. Catalytic conditions outperformed thermal pyrolysis in terms of conversion rate, even at lower temperatures [17].

Polymers found in plastic trash included PP, PE, polystyrene, PET, and PVC and their properties are tabulated in table 1. All the plastic had to be carefully separated and shredded into pieces that were between 2 and 5 mm. The catalytic pyrolysis method was used to convert each type of polymer and properties like reaction time, reaction temperature, oil yield, wax formation, and gas formation were studied and compared [19]. Pyrolysis is a process that happens when there is no air around. The shredded plastic waste is put into the muffle furnace, which can reach a maximum temperature of 600 °C and run for a long time. The digital controller and thermocouple work together to keep an eye on and control the temperature. When pyrolysis is done, a vacuum pump was added to help. People who used waste plastics got the most out of them when the ZSM (zeolite) to plastics ratio was 1:4. The catalyst used in this process makes sure that no dioxins are made at all.

Table 1: Properties of different types of plastic materials [18].

Type	Moisture (Wt.%)	Fixed carbon (Wt.%)	Volatite (Wt.%)	Ash (Wt.%)
PET	0.46 0.61	7.77 13.17	91.75% 86.83%	0.02 0.00
PE	0.10	0.04	98.87	0.99
HDPE	0.00 0.00	0.01 0.03	99.81 98.57	0.18 1.40
LDPE	0.30 -	0.00 -	99.70 99.60	0.00 0.40
PP	0.15 0.18	1.22 0.16	95.08 97.85	3.55 1.99
PVC	0.80 0.74	6.30 5.19	93.70 94.82	0.00 0.00

It is possible to recover energy by the pyrolysis process of converting waste plastics to liquid fuel. The shredded HDPE and LDPE were taken in the ratio of 50:50 as the source of waste plastic fuel extraction. According to this research, an input energy needs of 1.5 kW is provided by the furnace (Figure 1). On average, pyrolysis requires 8 MJ/kg of material processed when run at its highest rate. Assuming the pyrolysis product has a calorific value of 43 MJ/kg, this means there is a net energy gain of 35 MJ/kg. The composition of the feedstock material has an impact on the reaction time and temperature. While the reaction times for polypropylene was 30 min, high- and low-density polyethylene were 60 min. Specific heat of HDPE and LDPE is 2.3 kJ/kg.K. Specific heat is a measure of the amount of energy needed to raise a materials temperature. The chemicals in styrene are mostly aromatic, it required less time and heat to react than HDPE and LDPE [13].

Recent advancements in nanotechnology have opened the door for the development of nanoscale energetic materials, which provide significant benefits over materials that are just a few microns in size or larger. For a diesel engine to function well and emit low emissions, ignition temperatures and ignition delay are crucial characteristics to measure. Using the hot experiment, researchers aimed to enhance the igniting qualities of diesel fuel by incorporating alumina nanoparticles into the fuel. It was discovered that the ignition possibility for the nanoparticle combination was greater than the ignition probability for pure diesel in all of the scenarios investigated [21].

The physiochemical features of nanoparticles are significantly influenced by their dimensions and size (Figure 2). The arrangement of atoms within nanoparticles is influenced by the unique structural characteristics of the nanoparticles, re-

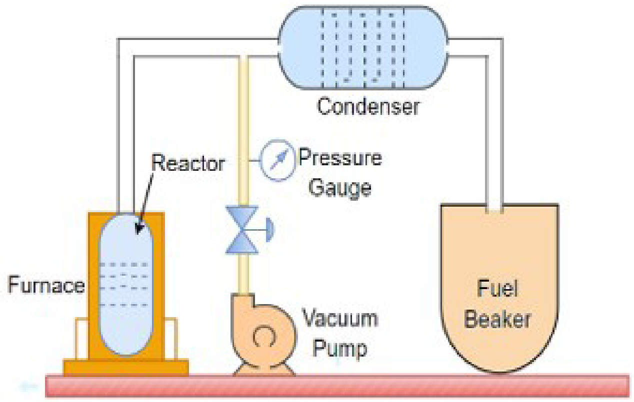

Figure 1: Experimental pyrolysis setup [20].

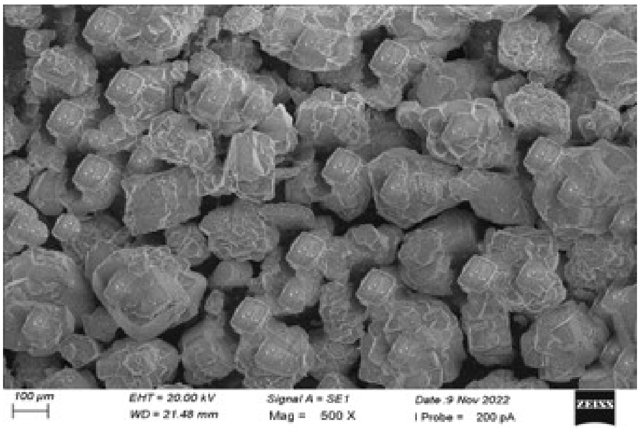

Figure 2: SEM analysis of alumina nanoparticles.

sulting in variations in their configuration as the size of the nanoparticles changes. Nanoparticles possess two discernible layers and exhibit a non-pointed morphology. The surface layer of a nanoparticle refers to the outermost and first layer that consists of metal ions or molecules, which play a crucial role in determining the surface properties and functionality of the nanoparticle. The shell layer, being the second stratum, exhibits distinct characteristics that set it apart from the remaining layers [22]. Materials Research and Innovation Centric Solution (Vellimalai, Kanyakumari, India) is where the nanoparticle was purchased. Alumina particle size ranges from 80 to 100 nm, while the pH level falls within the range of 8 to 10. The substance exhibits a density of 0.78 g/cm^3 at a temperature of 25 °C. The mechanical strength of the material falls within the range of 320 to 620 MPa, while its compressive strength ranges from 2,000 to 4,000 MPa. Additionally, the thermal conductivity of the material is estimated to be between 20 and 30 W/mK [23].

When the bulk density of nanoparticles varies, so does the attraction force between the nanoparticles and the fuel's surface tension. As the size of the nanoparticles grows, so does their surface tension in nanoparticles. The surface charge density of bigger nanoparticles is increased by the presence of smaller nanoparticles. Due to their high heat conductivity and mechanical qualities, alumina nanoparticles may influence biodiesel combustion. Alumina is toxicologically volatile and irritating to the respiratory system. It quickly interacts with water to form hydrogen. The size and form of alumina nanoparticles affect the combustion of blended nanoparticle fuels. In this way, water molecules can be split into hydrogen and oxygen [24].

Experiment details

In this study a single-cylinder direct injection water-cooled diesel engine with a maximum power output of 4.4 kW was used for investigation (Figure 3). The Eddy current dynamometer was coupled with the engine to ensure the loading of an engine from zero to maximum load with four loading conditions.

The test engine was permitted to operate as long as to reach the steady state at 210 bar of pressure and 21° bTDC injection timing during the trail run with standard diesel. The

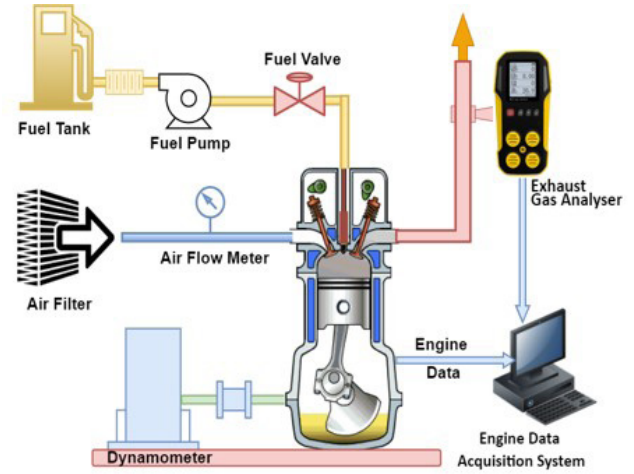

Figure 3: Single cylinder DI diesel engine experimental setup.

emission gas analyser and smoke metre were used to measure out exhaust emission parameters. Engine data acquisition system will collect the data from the engine parameters and from the gas analyser to examine the engines' performance.

The data on engine performance, combustion, and emission characteristics were used to evaluate the possibility of using waste plastic fuel generated by pyrolysis in a diesel engine in an experimental setting. WME as fuel was created by extracting oil from three different types of waste plastics HDPE, and LDPE. The properties of fuel blend are tabulated in table 2. The trial runs and basis study were conducted using just pure diesel fuel. The WME20 were developed using a volume-based technique, with 80 percent diesel and 20 percent WME being used in the formulation. Using the addition of alumina for further experiments, WME20A20 was made using 80 percent diesel and 20 percent WME on volume with 20 ppm of alumina added. WME20A40 and WME20A60 were created in a similar manner by combining 40 ppm and 60 ppm with WME20. It was performed on a single-cylinder thermal barrier coated piston diesel engine that was loaded at a 25 percent incremental load from zero percent to one hundred percent of its maximum capacity. The brake thermal efficiency (BTE) and the SFC are being examined. The exhaust gases generated by engines, which include HC, NO_x, CO, and smoke, are now being investigated for their composition.

Table 2: Physicochemical properties of diesel, HDPE, LDPE, and WME.

Properties	Diesel	HDPE	LDPE	WME
Density@15 °C, g/ml	0.5	0.799	0.795	0.789
Kinematic viscosity at 40°C, centistokes	2.61	10.12	4.98	6.1
Gross calorific value, kcal/kg	10897	11042	11507	11090
Flash point, °C	72	24	20	21
Fire point, °C	82	34	30	31
Cetane index	52	65	68	64

Results and Discussion

Brake thermal efficiency

The BTE of WME20A40 was found to be about 2.6

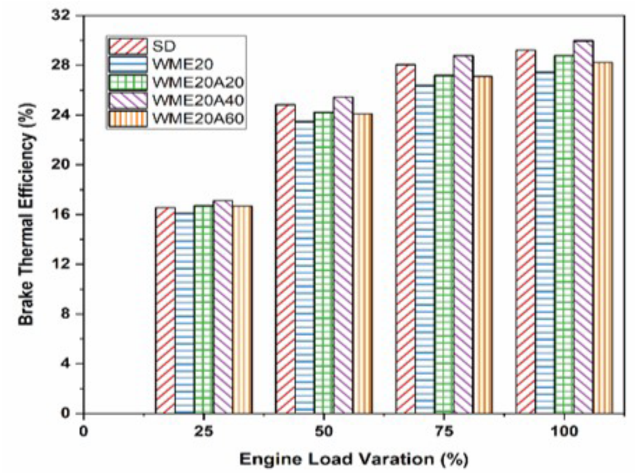

Figure 4: Variation of BTE on engine load.

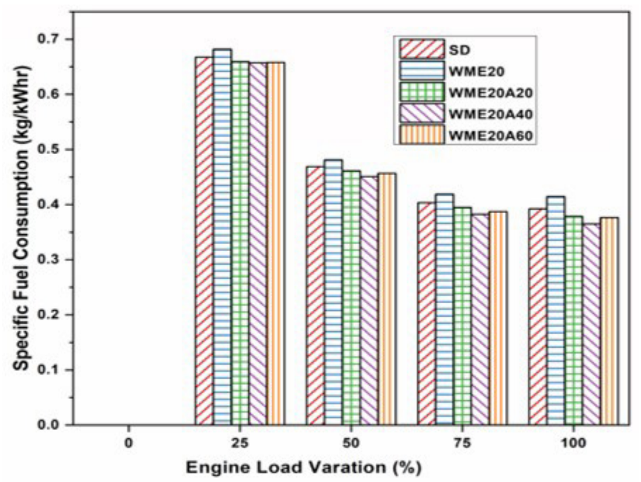

Figure 5: Variation of SFC on engine load.

percent higher than that of diesel and 9 percent higher than that of WME20 when tested at maximum load situation (Figure 4). Because waste plastic fuel has a higher concentration of aromatic compounds than diesel fuel, a high proportion of waste plastic fuel in the mix results in a lower BTE than diesel fuel. This is because WME has a lower combustion rate due to the higher concentration of aromatic compounds. This is due to the high aromatic content of WME, which necessitated the use of additional energy to break the chain. An increase in exhaust temperature indicates that less heat is wasted during combustion, resulting in an increase in thermal performance. A higher boiling point and self-igniting temperature in WME mixes, similar to diesel, enhanced their performance and efficiency. The plastic fuel reaction is defeated as a result of greater WME spray atomization and faster fuel vaporisation. Because of improved vaporisation and air-fuel atomization, alumina improves thermal performance while also improving combustion efficiency and maintaining constant ignition timing. Improved fuel air mixing is promoted by the additive's longer ignition delay, which enhances WME mixes and results in closer BTE [10].

Specific fuel consumption

The SFC value varies based on the speed at which the engine is operated, and the loads placed on the engine. When compared to diesel, the WME fuels WME20A20, WME20A40, and WME20A60 resulted in fuel consumption reductions of 3.4 percent, 7 percent, and 4 percent, respectively. According to (Figure 5), when comparing WME20 at various load levels, the WME20A40 was reduced by around 3 to 11 percent. The use of a nanoadditive mix enables for quicker fuel vaporization and higher spray atomization than with regular diesel [25]. A good fuel spray, on the other hand, leads to a good combustion, which is beneficial. As a result of the combination of a high cetane rating and an alumina addition on fuel blends, the SFC rating is lower than that of a conventional diesel engine. WME20 to diesel fuel exhibits a percentage increase in SFC ranging from 2 to 5%. The combined impact of increased viscosity and lower magnitude of heating value for WME results in a higher level of consumption of fuel. The amount of WME produced rises in proportion to the amount of SFC present in the mix. In this case, it is because of inadequate atomization of WME, which is produced by increased viscosity and density of the material [3].

Carbon monoxide emission

WME20 blends were determined to have the lowest CO emissions of all the fuels that were evaluated (Figure 6). WME20A40 demonstrated a 3.9 - 6.2 percent decrease in CO when compared to diesel, and an approximately 8 percent reduction when compared to WME20. In the course of the combustion of HC, CO is created as a byproduct as an intermediate product. CO creation is dependent on the equivalency ratio proportions, which are critical in the process. Increased loads result in increased fuel consumption, which results in a shortfall in oxygen content and, as a consequence, an increase in CO concentrations. Low CO emissions are produced by using a lower equivalency ratio in conjunction with greater in-cylinder temperatures [9]. When operating at maximum load, the CO emissions from the WME20 fuels were decreased by about 1.5 to 6.2 percentage points. The generation of CO was found to be high at both the start and full load conditions, which was attributed to the rich fuel combination. Alumina has more oxygen molecules than other materials, and the combination of fuel and air with correct spray atomization results in a reduction in CO emissions [26].

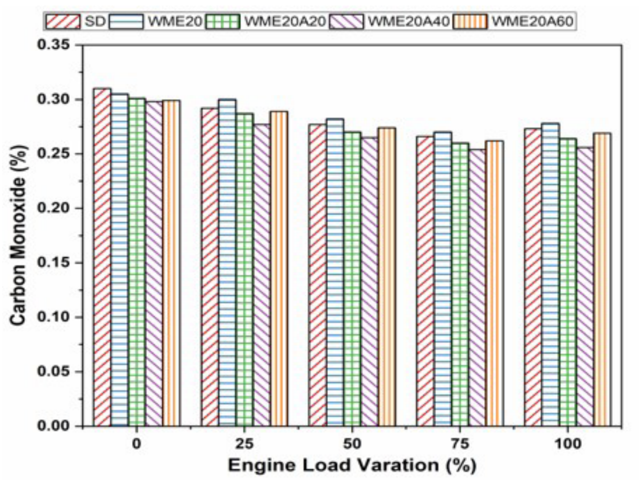

Figure 6: Variation of CO emission on engine load.

When operating at half load, CO emissions increase significantly, which may be connected to the consumption of more fuel and the shorter time period permitted for the fuel to burn completely. WME has around 4 - 5 percent oxygen, which assists in the full combustion of the fuel and results in a decrease in CO emissions than other fuels [6].

Hydrocarbons emission

The variance in HC emission generation as a function of the test fuel used in the experiment. Comparing the WME fuels WME20A20, WME20A40, and WME20A60 to diesel resulted in HC reductions of 3.2 percent, 4.8 percent, and 1.6 percent, respectively when compared with diesel (Figure 7). In order for the fuel to burn more fully and cleanly as a result of the higher concentration of oxygen in alumina, it may be essential to ignite the unsaturated HC contained in the fuel. Lower vaporisation, a slower oxidation rate, and a fast rate of fuel consumption are all important factors in the creation of HC emissions. Therefore, the additional oxygen contributes to the completion of combustion, resulting in a decrease in HC emissions [23]. When compared to raw WME20, WME20A40 showed a 12 - 15 percent reduction. HC emissions are marginally enhanced when the fraction of WME in the mix increases from 4 - 11 percent, owing to the accumulation of new particles in crevice volume and their escape from the combustion [27].

Because of the WME's low cetane number and diminished auto-ignition capabilities, the quenching effect causes the HC emissions to be increased. Because of unsaturated aromatic compounds in waste plastic, HC emissions are increasing. Unreactive HC do not break down into saturated compounds when burned, resulting in the generation of exhaust gases rather than HC when burned [12].

Nitrogen oxides emission

In accordance with the data in (Figure 8), all tested fuels had a tendency to increase NO_x emissions as the load range increases. In the presence of diesel at maximum load, the NO_x emissions from the WME20, WME20A20, WME2040, and WME20A60 increased by 13.9 percent, 7.5 percent, 8.2 percent, and 9.6 percent, respectively. NO_x is largely produced as a byproduct of the interaction between oxygen and nitrogen in the atmosphere. Increased NO_x production occurs when oxygen molecules reach a lean mixing scale, which is shown in greater combustion temperatures as a result [28].

The Zeldovich process also controls the kinetics of NO_x generation; however, many factors influence NO_x production,

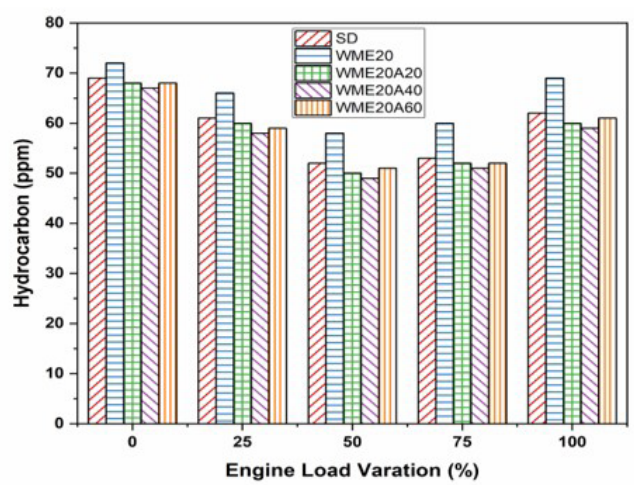

Figure 7: Variation of HC emission on engine load.

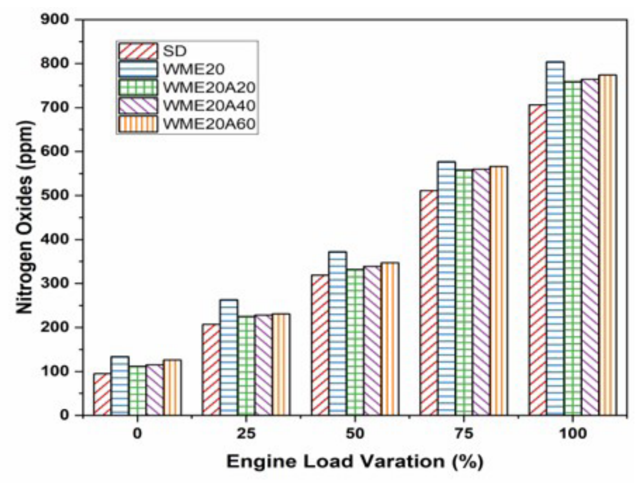

Figure 8: Variation of NO_x emission on engine load.

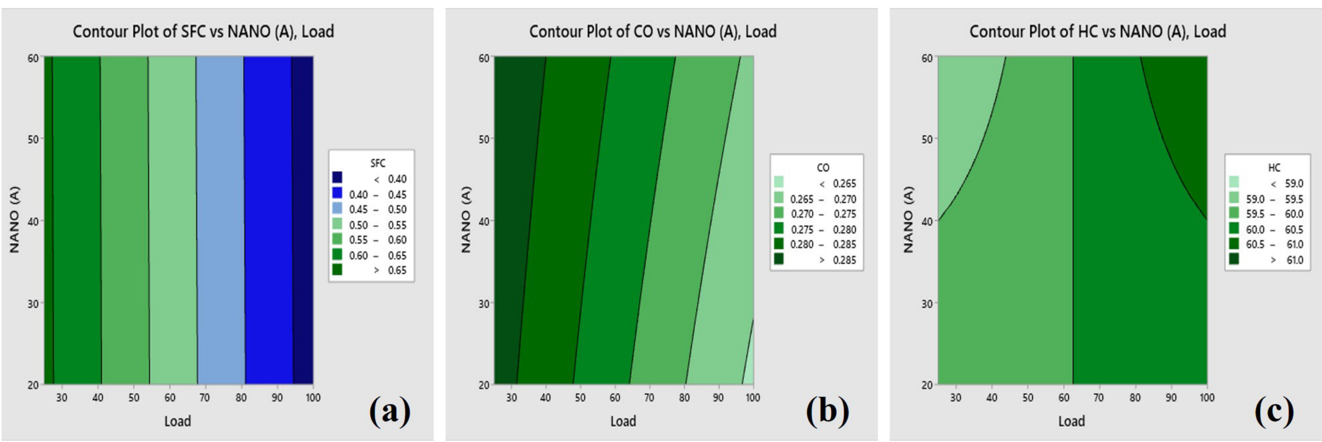

Figure 9: Influential study of nano on **(a)** SFC, **(b)** CO, and **(c)** HC emissions.

including the amount of oxygen present in the combustion chamber as well as the temperature and excess air coefficient of the combustion chamber and the length of time spent inside the combustion chamber. NO_x emissions were higher when comparing WME to pure diesel at maximum load. The increasing temperature inside the cylinder, as well as the total peak temperature throughout the combustion cycle, are the key contributors to NO_x emissions. Because nitrogen readily combines with oxygen at high temperatures, NO_x formation occurs only at the point of combustion temperature. In order to compensate for the higher oxygen content in alumina, which plays an important role in the formation of NO_x, the higher temperature inside the cylinder and combustion temperature throughout the cycle resulting in the lean fuel charge are the primary components responsible for the production of NO_x during the combustion cycle [29].

Influential study of alumina

The contour plots presented in figure 9 illustrate the influence of the lowest attainable alumina ratio and the highest engine load on the engine's ability to function with reduced levels of CO, HC emissions, and SFC [30-32]. Conversely, the rise in the blending ratio resulted in heightened levels of HC concentrations as a consequence of the fuels' reduced viscosity, which in turn caused a reduction in droplet sizes and diffusion [33-36]. Moreover, the utilization of waste plastic as a fuel source exhibits a notable escalation in carbon emissions in comparison to the combustion of pure diesel fuel. The lowest SFC was observed under maximum engine load conditions when utilizing the lowest alumina content.

Conclusion

A great supply of energy is provided by HC, which are present in plastic. There is a significant likelihood that energy may be recovered during the disposal of waste plastic. In the waste plastic recycling industry, the ability to convert waste plastic into energy is the most difficult aspect to overcome. This paper investigates the possibility of waste energy recovery from the various grades of used plastics into an energy source for diesel engine applications. Plastic fuel's performance and emission characteristics are enhanced by the addition of alumina nano-additive in different blended ratios. The BTE of WME20A40 was found to be about 2.6% higher than that of diesel and 9% higher than that of WME20 when tested at maximum load situation. The SFC of WME2040 falls by about 3 to 11% compared to WME20 and 7% fuel saving with diesel. This due to alumina blend allows for faster fuel vaporization and greater spray atomization than pure diesel and a good fuel spray leads to a good for improved combustion. WME20A40 demonstrated a 3.9 - 6.2 percent decrease in CO when compared to diesel, and an approximately 8 percent reduction when compared to WME20. Also, compared to diesel, WME20A40 resulted in HC reductions of 5%. This research examines the prospect of using waste plastics as a source of fuel in the future. According to the conclusions of this research, waste plastic materials as fuel has the potential to be employed as an alternative energy source.

Acknowledgements

None.

Conflict of Interest

None.

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