Journal of Mines, Metals and Fuels, *73(2): 385-400; 2025. DOI: 10.18311/jmmf/2025/47502*

Print ISSN : 0022-2755

Journal of Mines, Metals and Fuels

Contents available at: *www.informaticsjournals.co.in/index.php/jmmf*

An Experimental Investigation of CI Engine using Environmentally Friendly Waste Plastic Fuels and its Blends with Diesel and Nano Additive

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Abstract

The continuing rise in transportation, especially attributed to the emergence of vehicles, has been driven by significant technological innovations in Internal Combustion (IC) engines. Environmental concerns, particularly the substantial waste created by plastics, are a significant issue in India. A substantial discrepancy exists between plastic manufacturing and the development of plastic garbage. Consequently, the necessity for alternative fuels sourced from municipal plastic waste has arisen to improve the efficiency of internal combustion engines, reduce emissions, and address further environmental issues by the "Swachh Bharat Mission of India." The experiments were carried out at a constant speed of 1500 rpm at different load conditions fuelled with diesel, waste plastic fuel and its blends with Silicon dioxide (SiO_2) nano additive to investigate IC engine performance and emissions parameters. The overall result shows that compared with diesel, waste plastic fuel blend with nano additive SiO_2 (SiO280DWPO20-220) showed superior performance in terms of brake thermal efficiency and reduced the fuel consumption at 40-80 % load at 220 MPa pressure.

Major Findings: *From the findings the Plastic 220 emerges as a promising alternative with superior combustion efficiency and power generation capabilities, while SiO280DWPO20-220 demonstrates a reduction in friction losses. SiO2WPO100-200 and SiO2WPO100-220 exhibit higher emissions of HC, CO, and NOx. Overall analysis from the study demonstrates the potential of SiO2 nanoparticles as additives in enhancing the performance and reducing emissions of diesel engines using waste plastic blends with nano additive, contributing to the development of sustainable transportation and suggesting its potential as an environmentally friendly alternative fuel.*

Keywords: *Alternative Fuels, Diesel Engine, Emissions, Performance, Waste Management, Waste Plastic Fuel, Plastic Oil, Nano Additive, Silicon Dioxide (SiO_2)*

1.0 Introduction

The historical roots of internal combustion engines stretch back to 1876 when Otto pioneered the spark-ignition engine, followed by Diesel's revolutionary invention of the compression-ignition engine in 1892. Over the years, these engines have evolved alongside our deepening understanding of engine processes, the introduction of new technologies, the demand for novel engine types, and the evolving environmental constraints on engine usage. Internal combustion engines, and the industries surrounding their development, manufacturing, and support, now stand as dominant forces in the power, propulsion, and energy sectors. Despite the vast technical literature on engines, the need for comprehensive organization and summarization persists. The primary

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objective of internal combustion engines remains the conversion of chemical energy stored in fuel into mechanical power. Unlike external combustion engines, internal combustion engines release this energy through the internal combustion or oxidation of fuel within the engine. The actual working fluids are the fuel-air mixture before combustion and the products post-combustion. As highlighted by Heywood JB, the work transfers providing the desired power output take place directly between these working fluids and the mechanical components of the engine. The simplicity, robustness, and high power-to-weight ratio of Spark Ignition (SI) and Compression Ignition (CI) engines have rendered them extensively applicable in transportation (land, sea, and air) and power generation[1]. Pulkrabek WW, research highlighted that SI engines initiate combustion through a spark plug, which generates a high-voltage electrical discharge, igniting the air-fuel mixture in the combustion chamber. On the other hand, CI engines rely on self-ignition due to the high temperature resulting from compression igniting the air-fuel mixture in the combustion chamber surrounding the plug. In the early days of engine development, external flames and a torch were used to initiate the combustion. The combustion starts in a Compression Ignition engine (CI) when the air-fuel mixture is self-ignited due to the high temperature in the combustion chamber caused by high compression. The major emissions produced by internal combustion engines include hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NOx), and solid particulates. Hydrocarbons represent unburned fuel molecules and smaller equilibrium particles of partially burned fuel. Carbon monoxide arises from insufficient oxygen for complete carbon-to-CO_2 conversion or incomplete air-fuel mixing due to the brief engine cycle time. Oxides of nitrogen form when high combustion temperatures cause stable N_2 to dissociate into monatomic nitrogen N, subsequently combining with reacting oxygen. Solid particulates, visible as black smoke in the exhaust of compression ignition engines, constitute another emission. Additional emissions found in engine exhaust include aldehydes, sulfur, lead, and phosphorus. Two approaches are employed to curb harmful engine emissions: enhancing engine and fuel technology to promote better combustion and fewer emissions and after-treatment of exhaust gases using thermal or catalytic converters to convert harmful emissions into acceptable CO_2, H_2O, and N_2 [2] Hochgreb and Sher have highlighted, in their studies done in the 1950s in Los Angeles that automobile emissions were significant contributors to urban air pollution. This led to the identification of volatile organic compounds (HC or VOC) and oxides of nitrogen (NOx) as major culprits in smog formation. Vehicles, including light trucks, heavy trucks, and off-road vehicles, alongside stationary combustion systems, emerged as dominant sources of carbon monoxide (CO) and lead. Beginning in the late 1960s, the developed world saw increasing regulatory measures for vehicle emissions, with recent focus extending to the fuels used by spark ignition and diesel engines, such as gasoline/petrol and diesel, aiming to further reduce emissions[3]. Banerjee *et al.* found that economic development significantly contributes to improvements in life standards, making it a key focus for the 21st century alongside environmental conservation. Striking a delicate balance between the two is imperative, requiring concurrent and essential support. However, the pursuit of economic prosperity, while enhancing life standards, often leads to environmental degradation with lasting repercussions for nature[4]. Sharma *et al.*, the research has demonstrated the accumulation of waste plastic grocery bags presents a significant environmental challenge. Pyrolysis, a thermochemical conversion process, offers a promising pathway for converting this waste into valuable resources, including alternative diesel fuels. The research has investigated the influence of pyrolysis parameters on product yield and composition. Characterization techniques, such as gas chromatography-mass spectrometry and nuclear magnetic resonance spectroscopy, are employed to analyze the properties of the pyrolysis-derived fuel. The fuel properties of the alternative diesel, including cetane number, density, and viscosity, are then compared to conventional diesel standards. This study investigates the production of alternative diesel fuel from waste plastic grocery bags via pyrolysis. It focuses on the characterization of the produced fuel and its suitability as a replacement for conventional diesel[5].

2.0 Literature Survey

Chintala *et al.,* studies on increasing the generation of municipal mixed plastic waste necessitate sustainable disposal and resource recovery strategies. Converting

plastic waste into plastic oils through pyrolysis offers a promising avenue for producing alternative fuels. Research has investigated the use of plastic oils in diesel engines, examining their impact on engine performance, combustion characteristics, and emissions. Studies have also explored the effects of different plastic waste compositions on the properties of the derived plastic oils and their subsequent performance in engines. This study presents a comparative assessment of single-cylinder diesel engine characteristics using plastic oils derived from municipal mixed plastic waste. The performance of the plastic oils is compared to that of conventional diesel fuel, providing insights into their potential as a sustainable alternative[6]. Lin *et al.,* the search for alternative fuels and strategies to reduce emissions from diesel engines has led to the investigation of diesel emulsions. Emulsifying diesel fuel with water and other additives can influence combustion characteristics and potentially reduce emissions. Ultrasonic emulsification has emerged as an effective method for preparing stable and homogenous diesel emulsions. Research has explored the effects of emulsion composition and preparation parameters on engine performance, combustion, and emissions. This study investigates the engine performance and emission characteristics of three-phase diesel emulsions prepared using an ultrasonic emulsification method. The effects of parameters on engine performance and emissions are also analysed[7]. Panda *et al.,* from the findings *i*n the realm of emulsions, a W/O emulsion signifies a dispersion where water droplets are distributed within the surrounding oil phase. Conversely, an O/W/O emulsion denotes an arrangement where oil droplets serve as the inner phase, encapsulated within dispersed water droplets distributed in the outer oil phase. The preparation of W/O two-phase emulsions involves the addition of the emulsifier Span 80 into the oil phase, ensuring homogeneous stirring. Subsequently, distilled water is introduced into the oil and emulsifier mixture using a metering pump. The resulting solution, comprising water, oil, and emulsifier, undergoes ultrasonic vibration in a tank with a capacity of 4.5 litres. After 5 minutes of vibration, the preparation of W/O two-phase emulsion is deemed complete. Throughout engine performance testing, the W/O emulsion is continuously stirred at a speed of 600 rpm using a mechanical agitator. For the formulation of O/W/O three-phase emulsions, the emulsifier Tween 80 is employed in the creation of O/W two-phase emulsions. A metering pump is then employed to introduce the O/W two-phase emulsions into the oil phase, already blended with Span 80. The solution mixture is vibrated for 5 minutes, finalizing the preparation of the three-phase emulsion[8]. Bridjesh *et al.,* the utilization of different resins and varying process temperatures yields distinct products[9]. Sathyamurthy *et al.,* research on various strategies is employed to enhance the combustion, performance, and emission characteristics of Compression Ignition (CI) engines. Experimental approaches such as altering the combustion chamber design, employing different fuel blends, and adjusting injection timing have been explored, yielding promising results. Notably, the utilization of Waste Plastic Oil (WPO) as a fuel in CI engines has captured researchers' interest, prompting experiments to assess its impact as either a neat plastic fuel or a blend with other fuels. To mitigate the aromatic content of WPO, oxygenated additives like alcohols, esters, or ethers are introduced. Alcohols exhibit a propensity to improve spray characteristics, thereby aiding in smoke reduction[10]. In a study conducted by Sundar *et al.,* the research investigated the effects of pyrolysis parameters on the yield and quality of the derived fuel. The addition of nanoparticles to fuels has been shown to improve combustion characteristics and reduce emissions in diesel engines. Furthermore, optimizing injection timing can enhance engine performance and efficiency. This study investigates the potential of pyrolysis-derived fuel from disposed plastic food containers in diesel engines, focusing on the effects of nanoparticle doping and injection timing optimization. The findings contribute to a better understanding of the potential of waste plastic as a sustainable fuel source and the role of nanoparticles in enhancing engine performance and reducing emissions[11]. Mani *et al.,* The depletion of fossil fuel reserves and the environmental impact of conventional diesel engines have motivated research into alternative fuels and emission reduction strategies. Waste plastic oil, derived from the pyrolysis of plastic waste, presents a promising alternative fuel source for diesel engines. Exhaust gas recirculation is a well-established technique for reducing nitrogen oxide emissions in diesel engines. Studies have investigated the effects of using waste plastic oil on engine performance and emissions. Further research has explored the combined effects of waste plastic oil and EGR on engine combustion characteristics and emissions. This study experimentally

investigates the performance and emission characteristics of a direct injection diesel engine fuelled with waste plastic oil and utilizing EGR. The findings contribute to a better understanding of the potential of waste plastic oil as a sustainable fuel and the effectiveness of EGR in mitigating emissions[12]. Damodharan *et al.,* the research has investigated the effects of waste plastic oil on engine performance, combustion characteristics, and emissions. Exhaust gas recirculation is a well-established technique for reducing nitrogen oxide emissions in diesel engines. Studies have explored the independent effects of injection timing and EGR on engine performance and emissions. However, the combined influence of these two parameters on engines fuelled with neat waste plastic oil requires further investigation. This study experimentally investigates the combined effects of injection timing and EGR on the combustion, performance, and emissions of a direct injection diesel engine fuelled with neat waste plastic oil. The findings contribute to a better understanding of how to optimize engine operation with this alternative fuel to minimize emissions and maximize performance[13]. Mani *et al.,* Studies have investigated the use of waste plastic oil in diesel engines, examining its impact on engine performance, combustion characteristics, and emissions. These studies have explored various aspects, including the effects of different plastic feedstocks, pyrolysis conditions, and engine operating parameters. This study investigates the performance, emission, and combustion characteristics of a direct injection diesel engine using waste plastic oil. It focuses on contributing to a better understanding of the potential of waste plastic oil as a sustainable fuel for diesel engines[14]. Kalargaris *et al.,* the research has investigated the influence of pyrolysis parameters on the properties of the produced oils. Studies have also explored the use of these pyrolysis oils in diesel engines, examining their impact on engine performance, combustion characteristics, and emissions. This study presents an experimental evaluation of a diesel engine fuelled by pyrolysis oils produced from LDPE and EVA. It aims to contribute to a better understanding of the potential of these pyrolysis oils as sustainable fuels for diesel engines[15]. Hoseini *et al.,* The use of biodiesel-diesel blends has emerged as a promising strategy for reducing reliance on fossil fuels and mitigating emissions from compression ignition engines. However, challenges remain in optimizing the performance and emission characteristics of these blends. Nanomaterials, such as graphene oxide, have shown potential as fuel additives for enhancing combustion and reducing emissions. Studies have investigated the effects of GO additives on various fuel properties, including viscosity, surface tension, and cetane number. This study investigates the performance and emission characteristics of a CI engine using GO nanoparticles as additives in biodiesel-diesel blends. The research aims to contribute to a better understanding of the potential of GO nanoparticles for improving the performance and reducing emissions of CI engines fuelled with biodiesel-diesel blends[16]. Muruganantham *et al.,* Growing concerns about environmental pollution and the depletion of fossil fuels have spurred research into alternative fuels for diesel engines. Biodiesel, derived from renewable sources like vegetable oils, has emerged as a promising alternative. Nanoparticle additives, such as cerium oxide, have shown potential for enhancing the combustion characteristics and reducing emissions of biodiesel blends. This study analyzes the performance and emission characteristics of a diesel engine fuelled with COME blended with diesel and cerium oxide nanoparticles. The research aims to contribute to a better understanding of the potential of COME and cerium oxide nanoparticles for improving engine performance and reducing emissions[17]. Das *et al.,* studies have investigated the use of waste plastic oil-diesel blends in diesel engines, focusing on their impact on engine performance, combustion characteristics, and emissions. Exergy analysis provides a valuable tool for evaluating the efficiency and sustainability of energy conversion processes. This study conducts an energy, exergy, and emission analysis of a DI single-cylinder diesel engine using a pyrolytic waste plastic oil-diesel blend. The research aims to contribute to a better understanding of the potential of pyrolytic waste plastic oil as a sustainable fuel for diesel engines[18]. Rao *et al.,* the relationship between economic growth and environmental pollution has been a subject of extensive debate and research. The Environmental Kuznets Curve hypothesis posits an inverted U-shaped relationship, suggesting that environmental degradation initially increases with economic growth but eventually declines after a certain income threshold. However, the validity and universality of the EKC have been questioned, with empirical evidence providing mixed results. This study investigates the interactive influence between economic growth and

environmental pollution, focusing on specific pollutants, countries/regions, periods, and econometric techniques. The research aims to contribute to a better understanding of the complex dynamics between economic development and environmental quality[19]. Brand *et al.,* delved into the health implications of air pollution emanating from cars and vans[20]. Sekar *et al.,* This study investigates the combustion and emission characteristics of a diesel engine fuelled with pyrolysis oil produced from solid plastic waste using a screw reactor, with the addition of a nanocatalyst. The investigation aims to contribute to a better understanding of the potential of this integrated approach for sustainable waste management and alternative fuel production[21]. Kumar *et al.,* Several studies have investigated the performance, combustion, and emission characteristics of diesel engines fuelled with WPO and its blends with conventional diesel fuel. This study presents an experimental evaluation of waste plastic oil and its blends on a single-cylinder diesel engine. The study objectives to contribute to a better understanding of the potential of WPO as a sustainable alternative fuel for diesel engines[22]. Ananthakumar *et al.* studied the dual challenges of plastic waste management and the need for sustainable fuels has led to increasing interest in waste plastic oil as a potential alternative fuel. Variable compression ratio engines offer the flexibility to optimize engine performance and efficiency under varying operating conditions and fuel types. Several studies have investigated the use of WPO and its blends with conventional diesel in internal combustion engines, examining their impact on performance, emissions, and combustion characteristics. This study investigates the performance, emission, and combustion characteristics of a VCR engine fuelled with diesel, WPO, and their blends. The study attentions to contribute to a better understanding of the potential of WPO as a fuel for VCR engines and its impact on engine performance and emissions[23]. Parthasarathy *et al.,* this study investigates strategies to enhance the performance and combustion characteristics of HCCI engines powered by WPO. The research focuses on and aims to contribute to a better understanding of how to optimize HCCI engine operation with WPO for improved efficiency and reduced emissions[24]. Ghanati *et al.,* Growing concerns about dwindling fossil fuel reserves and the environmental impact of combustion emissions have driven research into improving engine efficiency and reducing emissions. Nanomaterials, with their unique properties, have emerged as potential fuel additives to enhance combustion and engine performance. Specifically, SiO_2 and TiO_2 nanoparticles have shown promise in improving various engine characteristics. This review examines the effects of using SiO_2 and TiO_2 nanoparticles as fuel additives on diesel engine characteristics. The review analyzes the impact of these additives on performance, combustion, and emissions and discusses the underlying mechanisms responsible for the observed effects. The review also addresses the potential benefits and challenges associated with using these nano-additives in diesel engines[25]. Shelat *et al.,* critically reviewed the effects of nano-additives on the performance and emission characteristics of CI engines, with a focus on health impacts. The author indicates that incorporating nano additives can enhance the physicochemical properties of waste plastic, such as density, viscosity, and cetane number, leading to improved performance, combustion efficiency, and emission characteristics in diesel engines[26]. The one promising solution is to convert waste plastics into fuel for internal combustion engines, which not only helps to manage the waste problem but also provides a sustainable energy source. This study aims to investigate the performance, emission, and combustion characteristics of a compression ignition engine using waste plastic-derived fuels and their blends with diesel, as well as the impact of nano additives on engine operation. As a part of the "Swachh Bharat Mission of India", this research work aims to use an alternative fuel that is produced from municipal mix waste plastics with nano additive to improve the IC engine performance, and combustion and correspondingly reduce emissions without modification of the diesel engine.

3.0 Methodologies

In the experimental investigation, a systematic approach was employed with a total of 70 runs to comprehensively evaluate the performance, combustion, and emission characteristics of the Compression Ignition (CI) engine. The experiments were designed with various fuels, each serving distinct purposes in the study. These fuels included conventional Diesel200 and Diesel220, representing standard diesel formulations. Plastic200 and Plastic220 denoted the neat Waste Plastic Oil (WPO) samples, exploring the engine's behaviour with

untreated plastic oil. Additionally, SiO_2WPO100-200 and SiO_2WPO100-220 encompassed waste plastic oil doped with silicon dioxide (SiO_2) nanoparticles at concentrations of 100 ppm and 200 ppm, respectively. Further variations were introduced with 80DWPO20-200 and 80DWPO20-220, signifying blends of 80% Diesel with 20% WPO, providing insight into the impact of Diesel-WPO mixtures. Similarly, $SiO_2$80DWPO20-200 and $SiO_2$80DWPO20-220 represented blends of Diesel, WPO, and SiO_2 nanoparticles, examining the synergistic effects of these components. The selected test conditions were maintained at a constant engine speed of 1500 RPM, ensuring consistent rotational performance throughout the experiments. Load conditions varied systematically, ranging from 0% to 1.1%, allowing for a comprehensive assessment across different operational loads.

Test parameters were categorized into three main groups: Combustion Parameters, Performance Parameters, and Emission Parameters. Combustion Parameters involved the analysis of key combustion characteristics, shedding light on the engine's internal processes. Performance Parameters focused on overall engine performance metrics, while Emission Parameters delved into the composition and quantity of emitted pollutants. This systematic and multifaceted approach aimed to provide a holistic understanding of the CI engine's behaviour under diverse fuel formulations and operational conditions, contributing valuable insights to the ongoing research in this domain.

3.1 Materials

The nanoparticles employed in the study were Silicon Dioxide (SiO_2) with the following specifications: minimum assay purity of 99.5%, an Average Particle Size (APS) of 15nm, a Specific Surface Area (SSA) of 650m^2/g, hydrophilic nature, and a spherical to irregularly shaped particle morphology. The blending process of the fuel with nanoparticles involved a meticulous two-step procedure to ensure homogeneity and effective dispersion. Initially, the blending commenced with a Magnetic Stirrer, where the nanoparticles were introduced to the fuel at a proportion of 100mg per litre. This step, lasting 30 minutes, aimed to initiate the blending process and achieve an initial level of particle-fuel integration. Subsequently, the blending process was further refined using an Ultra Sonicator. This advanced equipment was employed to enhance the mixing efficiency and achieve a more uniform distribution of nanoparticles within the fuel. The Ultra Sonicator process facilitated improved intermolecular interactions and ensured that the nanoparticles were uniformly dispersed throughout the fuel. This meticulous blending methodology was crucial to maintaining the desired concentration and characteristics of SiO_2 nanoparticles in the fuel for subsequent experimental investigations.

3.2 Experimental Setup

The Photographic view of the experimental setup is shown in Figure 1. The experimental setup for the conducted



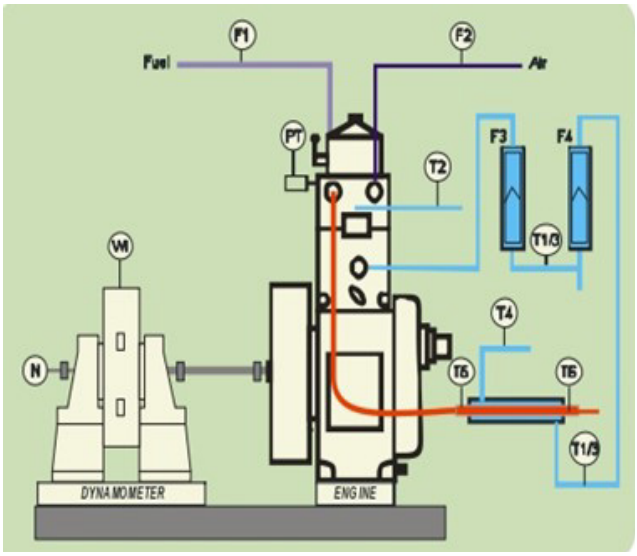


Figure 1. Photographic view of the experimental setup.

investigations comprised several essential components to ensure comprehensive data collection and analysis. At the core of the setup was the engine, serving as the primary test bed for assessing the performance and combustion characteristics of various fuel blends. The engine's operation was meticulously controlled and monitored through the integration of a dynamometer, which allowed for precise manipulation of load conditions and RPM settings.

To gauge the emissions produced during the engine's operation, a five-gas analyser was incorporated into the setup. This analytical tool enabled real-time measurement and monitoring of critical gases such as carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxides (NOx), and other relevant components. Simultaneously, a smoke meter was employed to quantify the particulate matter in the exhaust, providing valuable insights into the combustion efficiency and environmental impact of the tested fuels.

Ensuring accurate and synchronized data acquisition was a Data Acquisition (DA) system, seamlessly integrated into the experimental setup. This system played a pivotal role in capturing, recording, and processing various parameters related to combustion, performance, and emissions throughout the experimental runs. Software used in the DA system is Engine-Soft which is a LabVIEW-based software package meticulously crafted by Apex Innovations Pvt. Ltd., specifically tailored for the comprehensive monitoring of engine performance systems. This sophisticated software, Engine-Soft, adeptly addresses a multitude of engine testing requirements, encompassing monitoring, reporting, data entry, and logging. Offering a robust suite of functionalities, the software excels in the evaluation of crucial parameters such as power, efficiencies, fuel consumption, and heat release.

The versatility of Engine-Soft is underscored by its ability to generate various graphs corresponding to different operating conditions, providing a nuanced understanding of engine behaviour. During online testing in the RUN mode, Engine-Soft scans, stores, and presents a plethora of essential signals in graphical form. The stored data files are easily accessible, allowing users to visualize data in both graphical and tabular formats. Additionally, the software facilitates further analysis by exporting data in Excel format, enhancing its utility for in-depth examination and interpretation.

The synergistic operation of these components within the experimental setup not only facilitated a comprehensive understanding of the combustion and performance characteristics but also allowed for a thorough assessment of the engine's overall performance and its environmental implications.

The specifications of the test engine are in Table 1, the Dynamometer Specifications in Table 2, the Specification of the Smoke meter in Table 3 and the Specification of Gas Analyzer Table are below.

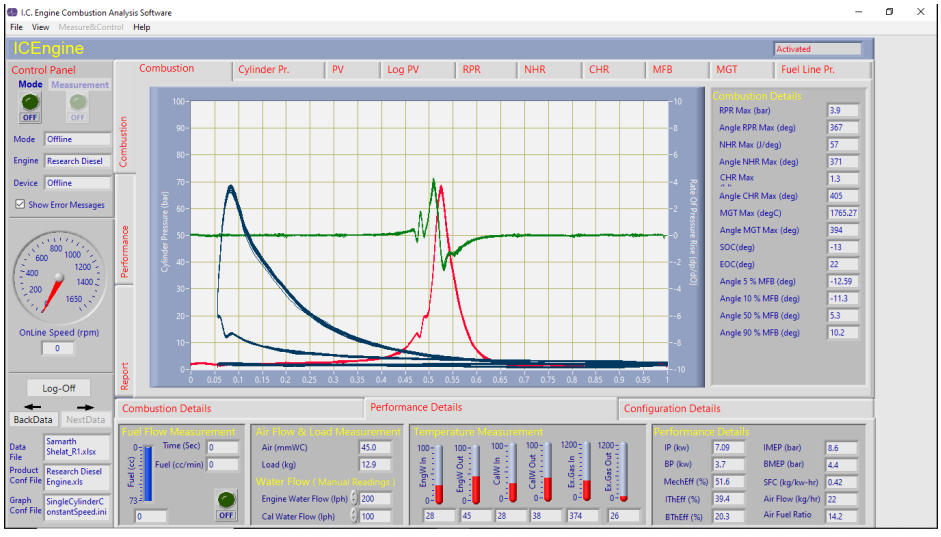


Figure 2. DA system software monitoring.

Table 1. Test engine specifications

Specifications	
Make and model	Kirloskar, Research Diesel Engine240PE.
No. of cylinder	Single
No. of stroke	4 T
Injection type	Direct injection.
Type of cooling	Water cooling
Stroke length	110 mm
Bore diameter	87.5 mm
Connecting rod length	234 mm
Compression ratio	18:1
Clearance volume	38.91 cubic centimetre
Swept volume	661.45 cubic centimetre
Rated speed	1500 rpm
Rated output	3.5 kW at 1500 rpm
Fuel injection timing	0-25° BTDC

Table 2. Dynamometer specifications

Dynamometer Specifications	
Make	Technomech
Model	TMEC10
Maximum power	10 BHP / 7.46 KW
Voltage Supply	230 V
RPM	1500-5000

Table 3. Specification of smoke meter

Smoke Meter	
Type and make	437, AVL
Display	LCD
Operating Voltage	220 V AC, 50 Hz
Power supply	11.5 – 360 V DC
Dimensions (w×h×d)	570×1250×500 mm
Weight	50 Kg

Table 4. Specification of gas analyzer

Gas Analyser	
Type and make	DIGAS444, AVL
Display	LCD
Operating Voltage	100-300 V AC, 50-60 Hz
Power Consumption	10 W
Dimensions (W×H×L)	270×85×320 mm
Weight	4.5 Kg
Approval	ARAI, Pune

4.0 Uncertainty Analysis

Significant errors and uncertainties in experiments may occur from factors such as the selection, condition, calibration, and environment of the instruments used, as well as the observation, reading, and planning of the tests. Conducting uncertainty analysis is crucial for verifying the accuracy of the experimental findings. The difference between the true value (known) and the result (best experimentally obtained value) is the error. Uncertainty is the best estimate of the magnitude of the known error. The error limits for the measured variables or parameters and the error limits for the calculated result are represented as R ± ΔR. To determine the accurate error boundaries for the calculated outcome, Holman adopted the root-mean-square method to find out the error[26].

R = f (x1, x2, ..., xn)

x1 ± n1, x2 ± n2, ..., xa ± Δxa

Where, `R" is the computed result function of the independently measured variables x1, x2, x3, ... xn, as per the relation.

An uncertain analysis was performed using Equation 1.

$$\Delta R = \sqrt{\left\{\left(\frac{\delta R}{\delta x1} * \Delta x1\right)^2 + \left(\frac{\delta R}{\delta x2} * \Delta x2\right)^2 + \cdots \ldots \ldots \ldots \ldots + \left(\frac{\delta R}{\delta xn} * \Delta xn\right)^2\right\}} \quad 1$$

Using the above equation, the uncertainty in the computed values such as BP, BTE and fuel flow measurements were estimated. The % uncertainties of parameters such as load, BTE, and BSFC were determined by utilizing the percentage uncertainties of several instruments. Given in Table 5

Table 5. Evaluation of experimental apparatus uncertainties

Instruments	**Measurement**	**Accuracy**	**Uncertainty (%)**
Gas Analyzer	CO: 0-15 % Vol. HC: 0-20000 ppm Vol. CO_2: 0-20% Vol. O_2: 0-25% Vol. NO: 0–5000 ppm Vol.	±0.001%Vol. ±0-2000 ppm ±0.1 %Vol. ±0.01% Vol. ±1 ppm Vol.	±0.2 ±0.2 ±0.15 ±0.20 ±0.2
BP	-	-	±0.10
BTE	-	-	±2.46
BSFC	-	-	±0.07

The observed data, including voltage, current, fuel duration, and speed were calculated using their respective uncertainties according to the Gaussian distribution equation-1. The errors in the observed parameters, RPM (N) and Load (Kg) and pressure (MPa) found using the Gaussian technique, are ± 2 RPM and ± 0.05 torque respectively. Fuel consumption, the uncertainties are taken as ± 0.1 Kg/h (ΔFC)[26].

5.0 Results and Discussion

The results were derived and categorized into three distinct parameters: Analysis of basics performance, IC engine performance and emission analysis. The observation table detailing these outcomes is presented in the forms of charts in Figure 3, Figure 4 and Figure 5.

5.1 Analysis of Basic Performance Parameters at Different Load Conditions

1. Torque (Nm):
   Torque generally increases with an increase in load for all fuels. Higher torque values are observed with an increase in load, with Plastic 220 consistently showing the highest torque.
2. Brake Power (BP, kW):
   Brake power follows a similar trend, increasing with the load. Plastic 220 consistently exhibits higher brake power, indicating its effectiveness in generating useful power.
3. Friction Power (FP, kW):
   Friction power tends to rise with the load. While Plastic 220 has higher friction power, $SiO_2$80DWPO20-220 shows a noticeable reduction in frictional losses.
4. Indicated Power (IP, kW):
   Indicated power generally increases with load. Plastic 220 consistently displays higher indicated power, suggesting enhanced combustion efficiency.
5. Brake Mean Effective Pressure (BMEP, bar):
   BMEP increases with the load, with Plastic 220 consistently exhibiting higher BMEP values, indicating improved engine efficiency and performance.
6. Indicated Mean Effective Pressure (IMEP, bar):
   IMEP values also rise with the load. Plastic 220 consistently demonstrates higher IMEP, indicating improved combustion efficiency.

5.2 Analysis of Performance Parameters at Different Load Conditions

1. Brake Thermal Efficiency (BTHE, %):
   BTHE generally increases with load for all fuels. Plastic 220 exhibits a notable increase in efficiency as the load rises, indicating its ability to utilize energy effectively.
2. Indicated Thermal Efficiency (ITHE, %):
   ITHE shows varied trends across fuels and load conditions. Plastic 220 consistently demonstrates high ITHE, suggesting efficient conversion of heat into useful work.
3. Mechanical Efficiency (%):

Mechanical efficiency tends to decrease with increasing load for most fuels. Plastic 200 and Plastic 220 maintain relatively stable mechanical efficiency, indicating consistent mechanical performance.

4. Air Flow (kg/h):
   Airflow generally increases with load. SiO2WPO100-220 shows a significant decrease in airflow at higher loads, suggesting potential limitations in the air intake.
5. Fuel Flow (kg/h):
   Fuel flow increases with load, and Plastic 220 consistently exhibits higher fuel flow. This aligns with the observed higher power and efficiency for Plastic 220.
6. Specific Fuel Consumption (SFC, kg/kWh):
   SFC tends to decrease with load for most fuels, indicating improved fuel efficiency at higher loads. Plastic 220 consistently demonstrates lower SFC, suggesting efficient fuel utilization.
7. Volumetric Efficiency (%):
   Volumetric efficiency varies across fuels, with Plastic 200 and Plastic 220 maintaining relatively high volumetric efficiency. $SiO_2$80DWPO20-220 shows a decline in volumetric efficiency at higher loads.
8. Air-Fuel Ratio (A/F Ratio):
   The A/F ratio remains relatively stable across different load conditions for each fuel. Plastic 220 consistently exhibits a lower A/F ratio, indicating a well-balanced air-fuel mixture.

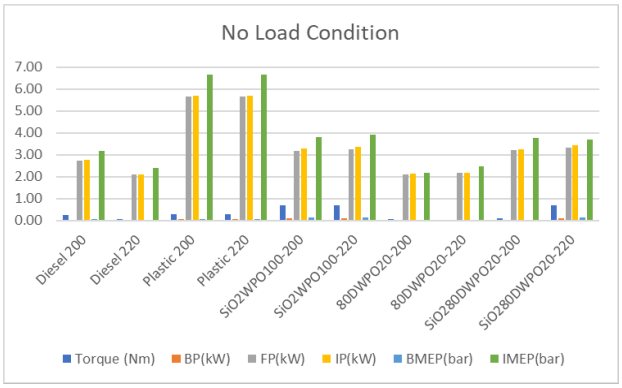
5.3 Analysis of Emission Parameters at Different Load Conditions

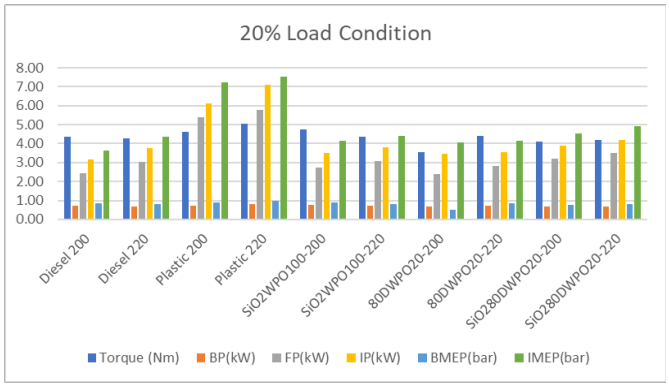
1. Carbon Monoxide (CO) (%vol):
   CO emission generally increases with the load for all fuels. Diesel 220 exhibits a notable increase in CO emission at higher loads, indicating a potential issue in combustion efficiency.
2. Hydrocarbon HC (ppm):
   Hydrocarbon (HC) emissions show varied trends across fuels and load conditions. Plastic 220 consistently demonstrates higher HC emissions, suggesting incomplete combustion.
3. Carbon Dioxide CO_2 (%vol):
   CO_2 emission tends to increase with load, reflecting the higher fuel consumption at higher loads. Plastic 200 and Plastic 220 exhibit relatively lower CO_2 emissions compared to other fuels.
4. Oxygen O_2 (%vol):
   Oxygen (O_2) levels decrease with load, indicating more efficient combustion at higher loads. Diesel 220 consistently shows lower oxygen levels, suggesting a richer fuel mixture.
5. Nitrogen Oxide NO (ppm):
   Nitrogen Oxide (NO) emissions generally increase with load. SiO_2WPO100-200 and SiO_2WPO100-220 show higher NO emissions, indicating potential challenges in controlling nitrogen oxide formation.
6. Smoke:
   Smoke levels vary across fuels and load conditions. Diesel 200 and Diesel 220 exhibit significant smoke levels, suggesting incomplete combustion. Plastic 200 and Plastic 220 also show increased smoke at higher loads.

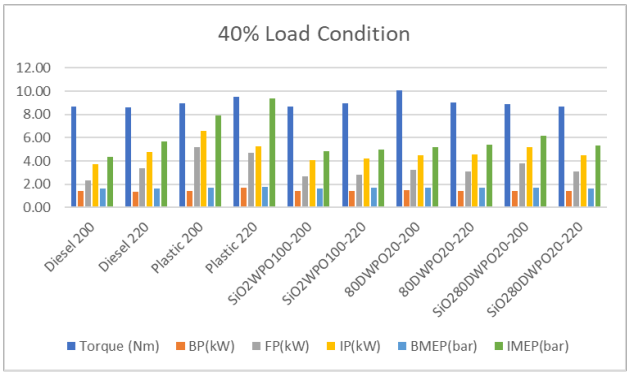
6.0 Discussion

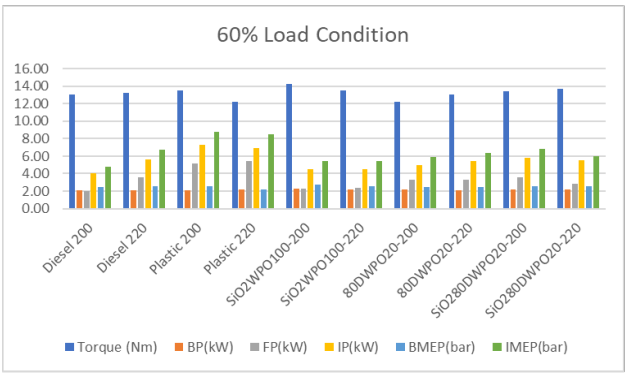
In the comprehensive analysis of fuel performance and emission parameters, several key insights emerge. Diesel 200 and Plastic 200 share similar injection pressures, and their performance characteristics vary. Both fuels exhibit competitive performance, particularly in achieving lower CO_2 emissions. It is crucial to note that load-specific considerations play a pivotal role in determining optimal and poor performance conditions. At a higher injection pressure of 220 MPA, Diesel and Plastic showcase distinct strengths and challenges. Plastic fuel consistently outperforms Diesel in torque, brake power, indicated power, and mean effective pressures. However, higher friction losses are associated with Plastic 220, emphasizing the importance of balancing its unique advantages with inherent trade-offs. Blends of Plastic and diesel combine the characteristics of diesel and 80% WPO. While exhibiting competitive performance, the optimal load condition is observed at approximately 0.6 load.

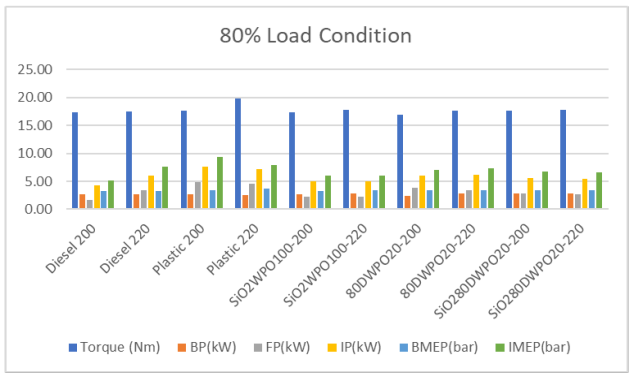
These blends contribute to the spectrum of alternatives, each with its unique performance, and emission characteristics. The SiO_2WPO100 fuels, distinguished by the inclusion of SiO_2 nanoparticles, exhibit unique characteristics. SiO_2WPO100-220 shows the potential to reduce friction losses, highlighting the benefits of nanoparticle additives. However, this comes

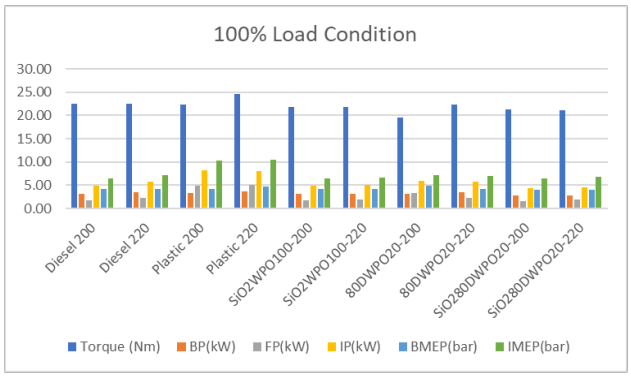












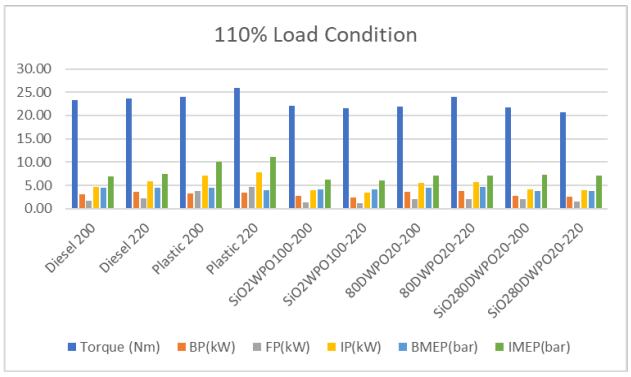
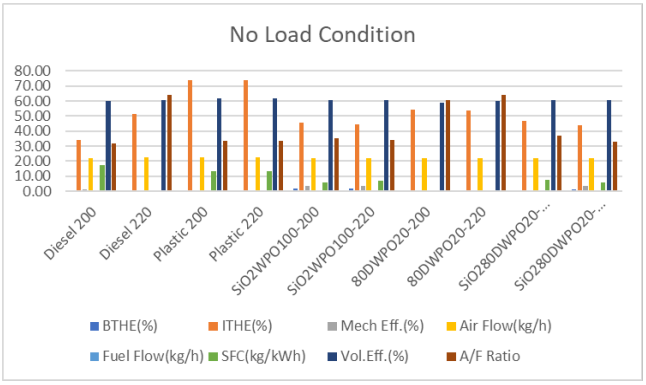
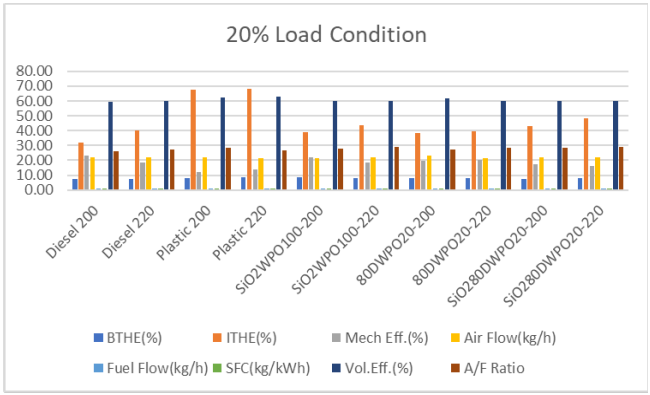
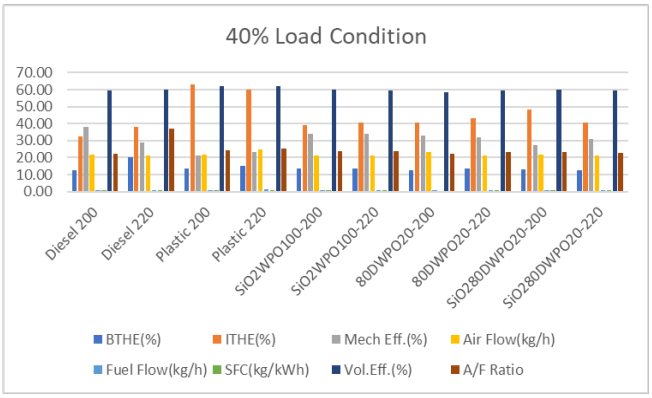
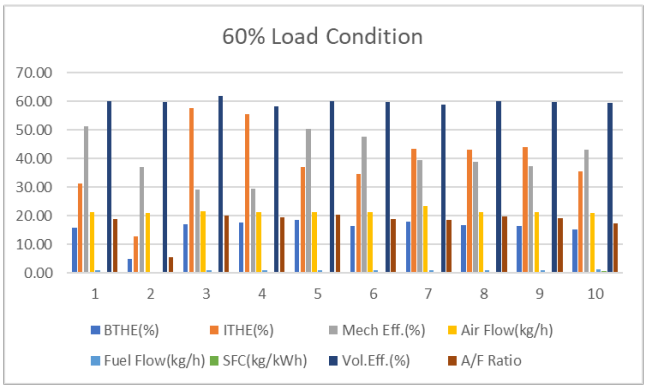


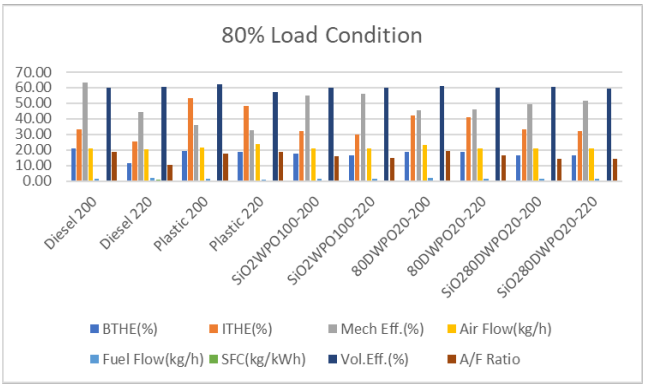
Figure 3. Analysis for basic performance parameters showing the results of testing at different load conditions and constant RPM of 1500.

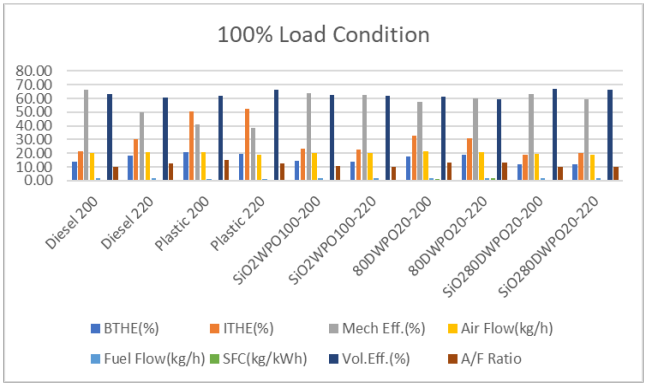












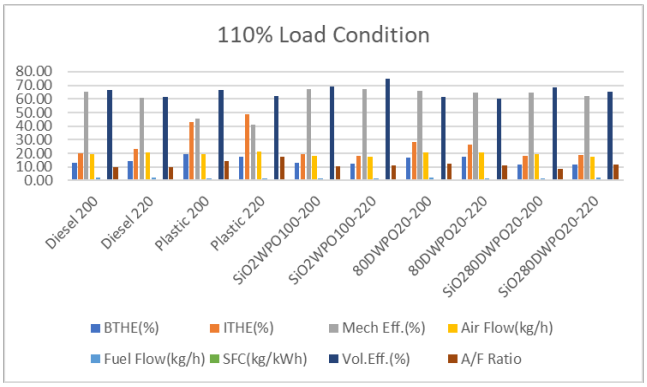


Figure 4. Analysis for performance parameters showing the results of testing at different load conditions and constant RPM of 1500.



Figure 5. Analysis for emission parameters showing the results of testing at different load conditions and constant RPM of 1500.

at a slight compromise in overall engine performance. Optimal performance is observed at approximately 0.6 load, underlining the importance of load-specific considerations. Like SiO_2WPO100, $SiO_2$80DWPO20 fuels emphasize the impact of injection pressure 220 Mpa, showcasing reduced friction losses and marginal compromises in overall performance. The optimal load condition is also around 0.6 load, suggesting a consistent trend across nano-doped fuels.

7.0 Conclusion

From experimental investigation with different fuels and different blends at different loads, there are some points which can be summarized and concluded concerning performance and emission characteristics which are described below;

1. Plastic 220 consistently stands out as a promising fuel, displaying superior torque, brake power, indicated power, and mean effective pressures across all load conditions. This suggests efficient performance characteristics and power generation capabilities.
2. On the other hand, $SiO_2$80DWPO20-220 showcases reduced friction power, indicating lower internal engine losses. However, a trade-off is observed, with slightly compromised torque and power, emphasizing the complexity of balancing friction losses and overall engine performance. Plastic fuel injected at 220 MPa excels in combustion efficiency, reflected in higher BMEP and IMEP values. Optimal load conditions vary across fuels and 0.6 load which is 60% gives optimal performance in most fuels. The 0.6 load condition represents a delicate equilibrium between heightened engine performance and mitigated friction losses. Conversely, suboptimal conditions are identified at the load extremes lower loads for Plastic 220, where its inherent advantages are not fully harnessed, and higher loads for $SiO_2$80DWPO20-220, where challenges in airflow may adversely affect combustion efficiency.
3. In terms of efficiency, Plastic 220 outperforms in thermal efficiency, mechanical efficiency, and fuel utilization, positioning it as a promising fuel. SiO_2WPO100-220 faces challenges in maintaining airflow at higher loads, hinting at potential combustion limitations that require further investigation and optimization.
4. The discussion on emission parameters highlights the need for combustion optimization in Diesel 220, addressing challenges in CO and HC emissions. Plastic 200 and Plastic 220 exhibit lower CO_2 emissions, indicating better fuel efficiency, while SiO_2WPO100-200 and SiO_2WPO100-220 show higher NO emissions, suggesting the need for emission control measures. Finally, addressing performance analysis in Diesel 200 and Diesel 220 is crucial to reduce smoke emissions. These results confirm that WPO with nano additives may be utilized as a fuel without requiring any changes to the engine, making it a viable and eco-friendly option.

8.0 Acknowledgment

The author would like to thank CVM University Innovation and Startup Centre (CVMUISC), SSIP 2.0 for providing financial support.

9.0 Author Designation

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Dr. Sanjay Maganlal Patel- Assistant Professor and Head

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Nomenclature

WPO	Waste Plastic Oil	NOx	Nitrogen oxides
PPO	Pyrolysis Plastic Oil	CO	Carbon Monoxide
Diesel 200	Diesel injected at 200 MPa pressure	CO_2	Carbon Dioxide
Diesel 220	Diesel injected at 220 MPa pressure	UHC	Unburned Hydrocarbons
Plastic 200	Plastic fuel injected at 200 MPa pressure	BTE	Brake Thermal Efficiency
Plastic 220	Plastic fuel injected at 220 MPa pressure	ITE	Indicated thermal efficiency
SiO_2WPO100-200	Neat Waste plastic oil with SiO_2 nano additive injected at 200 MPa pressure	Mech Eff.	Mechanical Efficiency
SiO_2WPO100-220	Neat Waste plastic oil with SiO_2 nano additive injected at 220 MPa pressure	SFC	Specific fuel consumption
80DWPO20-200	80% Diesel and 20% WPO injected at 200 MPa Pressure	BP	Brake Power
80DWPO20-220	80% Diesel and 20% WPO injected at 220 MPa Pressure	FP	Friction Power
$SiO_2$80DWPO20-200	80% Diesel and 20% WPO doped with SiO_2 nano additive injected at 200 MPa Pressure	IP	Indicated Power
$SiO_2$80DWPO20-220	80% Diesel and 20% WPO doped with SiO_2 nano additive injected at 220 MPa Pressure	IMEP	Indicated means effective pressure
SiO_2	Silicon Dioxide Nano Particle	BMEP	Brake mean effective pressure