Journal of Health Politics, Policy and Law

Impact of Infused Potassium Alum – Treated Diesel on the Performance and Emissions of a CI Engine

Bapanapalli Madhu Babu[1], Dr. A.Raja [2] and Dr. B. Durga Prasad[3]

[1]Ph.D. Scholar, Department of Mechanical Engineering, Annamalai University, Annamalainagar-608002, Tamil Nadu, India

[2]Associate Professor, Department of Mechanical Engineering, Annamalai University, Annamalainagar-608002, Tamil Nadu, India,

[3]Senior Professor, Department of Mechanical Engineering, JNTUKCEA, Ananthapuramu-515003, Andhra Pradesh, India.

AbstractThis *study examines the effects of potassium alum, in crystalline (PAC) and powdered (PAP) forms, on diesel engine performance, combustion, and emissions. Diesel was blended with 50g, 100g, and 150g of PAC and PAP, held for 72 hours. Engine tests showed that potassium alum improved Brake Thermal Efficiency (BTE) and reduced Brake Specific Fuel Consumption (BSFC), with optimal results at 100g. Combustion analysis indicated higher in-cylinder pressure, heat release rate (HRR), and mean gas temperature (MGT), enhancing fuel oxidation. Emission results showed reduced CO and HC emissions but increased NOx due to higher combustion temperatures. The 100g PAC and PAP blends proved most effective for balancing performance improvement and emission control, establishing potassium alum as a promising diesel fuel additive.*

Keywords: *Diesel Engine, Treated Diesel, Potassium Alum, Performance, Emissions*

1. INTRODUCTION

The search for alternative fuels for diesel engines is motivated by ecological issues and the effort to minimize dependency on fossil fuels. Studies have been done on blending diesel with alcohols like methanol, ethanol, and butanol, as they could help reduce greenhouse gas emissions. Although these blends may slightly decrease stability in the engine, they have an advantage of increasing ignition delay and peak cylinder pressure, while greatly reducing the emission of NOx and soot [1]. Another alternative fuel is biodiesel, which can be produced from renewable sources, such as corn oil, and can be improved with diethyl ether to enhance engine performance and meet EURO emission standards. According to some research, adding diethyl ether and applying exhaust gas recirculation (EGR) can achieve NO emissions reductions of nearly 70%. However, this is at the expense of torque output to the engine [2]. This is furthered by Ternary mixtures containing diesel, biodiesel, and bioethanol as they also achieve reductions in CO, CO2, and NOx emissions, but only increase fuel consumption marginally [3]. Furthermore, these studies show that the blending of manganese oxide nanoparticles with diesel and diethyl ether has the potential to improve the brake thermal efficiency of engines, but increases the CO2 emissions which requires more emission control systems to be implemented [4]. Natural gas is considered another option as an alternative fuel that can enhance the power and efficiency of an engine, though it is likely to increase the NOx emissions produced [5]. The use of potassium alum as an additive in diesel fuel has proven successful in increasing performance and reducing emissions when used in diesel engines. The application of potassium alum has been linked to better engine efficiency and mileage while lowering pollutants such as carbon monoxide and unburnt hydrocarbons emission by an impressive margin, as noted in the preceding research [6]. Other strategies, such as water injection to supplement diesel fuel, have also been studied for the purpose of reducing fossil fuels consumption and emissions, which emphasizes a cleaner combustion cycle [7]. Moreover, potassium catalysts have been reported to be effective in the production of biodiesel, which indicates their ability to improve fuel characteristics and eco-friendliness [8][9]. These strategies collectively demonstrate the use of potassium alum and other such substances as additives in diesel fuel for the improvement of combustion in diesel engines and the shift to using cleaner fuels [10]. The use of substitute fuels, in particular powdered suspensions, for diesel engines has been increasing as a result of the need for environmental friendly solutions to the energy issue. Reports suggest that auxiliary fuel use of aloe vera powder causes a decrease of almost 25% in fuel consumption and a remarkable decrease of 17% in NOx emissions while HC, CO, and smoke emissions increased slightly [11]. Moreover, microemulsions of butanol-diesel-water blends have shown an increase in thermal efficiency of 15.38% and a higher reduction rate of CO and unburnt hydrocarbons [12]. In addition, spent coffee powder oil fuels have demonstrated better performance and competitive heating values, especially in B20 blends with lower specific fuel consumption than diesel [13]. As a whole, these observations highlight the capacity of alternative fuels to improve diesel engines' efficiency relative to emissions produced and fuel used [14][15]. The use of alternative fuels and additives, such as nanoparticles, water-emulsified diesel, and biodiesel blends, has been shown to influence engine performance and emissions significantly. For instance, the addition of nanoparticles like cerium and aluminum to diesel fuel has been found to enhance combustion efficiency by improving heat transfer and reducing ignition delay, leading to a decrease in pollutants such as CO and NOx by up to 20.5% and 13%, respectively [16]. Similarly, water-emulsified diesel (WED) has demonstrated improved brake thermal efficiency and reduced NOx and smoke emissions by 32.6% and 51.9%, respectively, at higher injection pressures[17]. The use of biodiesel, such as that derived from waste cooking oil, has shown comparable brake power to traditional diesel but with reduced hydrocarbon emissions by 26.3% and lower smoke emissions by 17% [18]. These studies suggest that the introduction of additives or alternative fuels can enhance combustion characteristics and reduce emissions, which could be analogous to the potential effects of potassium alum-treated diesel. Potassium alum, known for its coagulating properties, might similarly influence the combustion process by altering the fuel's physical or chemical properties, potentially leading to improved combustion efficiency and reduced emissions. However, specific studies on potassium alum-treated diesel are necessary to confirm these effects directly. Overall, the integration of such additives or alternative fuels into diesel engines holds promise for improving performance and reducing environmental impact, aligning with the broader trend of seeking sustainable and efficient fuel solutions for CI engines[19] [20] [21]. The addition of alumina nanoparticles to waste chicken fat biodiesel resulted in improved brake thermal efficiency and significant reductions in hydrocarbons and carbon monoxide emissions, although it increased nitrogen oxide emissions due to higher combustion temperatures [22]. Similarly, the inclusion of alumina nanoparticles in Calophyllum inophyllum biodiesel blends improved brake thermal efficiency and reduced CO and hydrocarbon emissions, while exhaust gas recirculation helped mitigate NOx emissions [23]. In another study, the use of alumina as a catalyst in the co-pyrolysis of Azadirachta indica seeds and waste LDPE produced a liquid fuel with a high calorific value, which, when blended with diesel, showed improved combustion and reduced smoke emissions[24]. Furthermore, the addition of alumina nanoparticles to fish oil methyl ester and diesel blends enhanced engine performance and reduced emissions, with the optimal blend showing significant reductions in CO, HC, NOx, and smoke emissions[25]. These findings suggest that potassium alumtreated diesel, potentially similar in function to alumina nanoparticles, could improve CI engine performance and reduce emissions, although specific effects would depend on the exact formulation and conditions of use. The addition of $Fe2O3$ and $Al2O3$ nanoparticles to diesel fuel improved combustion efficiency and reduced CO emissions by 21.2% while enhancing power and thermal efficiency by 7.40% and 14%, respectively [26]. Similarly, the use of n-butanol in diesel blends increased ignition delay and reduced combustion duration, leading to a significant reduction in soot emissions [27]. The introduction of ammonia as a dual fuel with diesel also demonstrated a shift from diffusion to premixed combustion, reducing $CO2$ and particulate matter emissions, although it increased NOx emissions [28]. Furthermore, blending diesel with kerosene up to 14% did not significantly affect engine performance or fuel efficiency, while reducing pollutant emissions and noise intensity [29]. These studies suggest that the infusion of potassium alum, a potential additive, could similarly alter combustion dynamics, potentially improving thermal efficiency and reducing specific emissions such as CO and NOx, akin to the effects observed with other additives. However, the specific impact of potassium alum would depend on its chemical interactions within the combustion process, which would need to be experimentally validated. Overall, the integration of such additives into diesel fuel could offer a promising approach to enhancing engine performance and reducing emissions, aligning with the trends observed in the use of alternative fuels and additives in CI engines[30] [31] [32] [33].

2. MATERIALS AND METHODS

2.1 Synthesis and Characterization of Potassium Alum Crystal

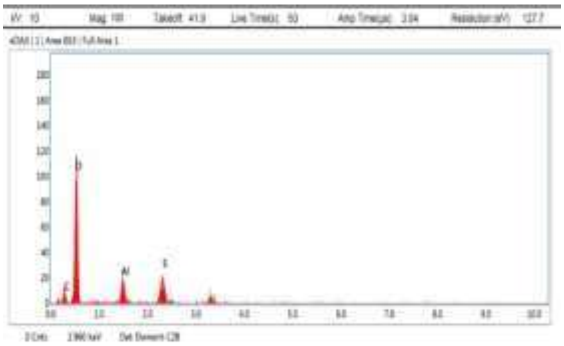

Fig. 1 FTIR analysis of Potassium Alum Crystal

The preparation of potassium alum crystals entails dissolving potassium sulfate (K_2SO_4) and aluminum sulfate ($Al_2(SO_4)_3 \cdot 18H_2O$) in distilled water with slight heating until full dissolution occurs. The two solutions are mixed and heated to 70-80°C to increase the solubility as well as to react and create a homogeneous solution. Once the solution is able to cool down naturally to room temperature, potassium alum crystals begin to form within ~24 hours. The potassium alum crystals formed are filtered and washed with distilled water before air drying. The morphology of the crystals is examined using Scanning Electron Microscopy (SEM) while the crystalline structure and phase purity is confirmed with X-Ray Diffraction (XRD). Functional groups are identified using Fourier Transform Infrared Spectroscopy (FTIR) and Thermogravimetric Analysis (TGA) is performed to assess the thermal stability. The synthesized crystals are suspended in diesel fuel (100 g/L) for 24 hours before undergoing filtration. The treated diesel fuel is then analyzed for alterations in characteristics like density, viscosity, and cetane number with the intention of ameliorating combustion efficiency and curbing emissions in CI engines. This can be done over a 5 day period. Each day after the 5 day period the diesel fuel was filtered and tested on the engine.

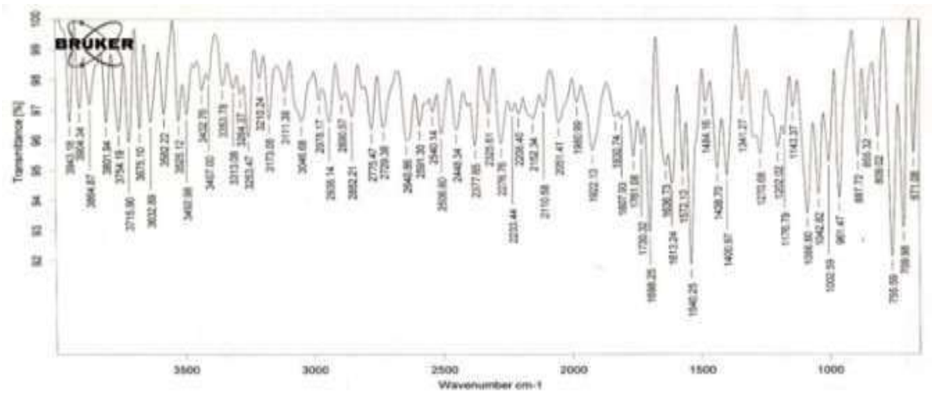

Fig. 2 EDAX analysis of Potassium Alum crystal

2.2 Preparation of Fuel sample

In an attempt to understand the influence of potassium alum treatment on the properties of the diesel fuel as well as the performance of the engine, the fuels were formulated using potassium alum crystal (PAC) and potassium alum powder (PAP) in three different dosage levels of 50g, 100g and 150g. Every fuel blend underwent a suspension phase lasting 72 hours prior to filtration and testing.

2.2.1 Preparation of PAC-Treated Fuel Samples (Day 3)

In the case of Potassium Alum Crystal (PAC)-treated blends, 3 individual vessels were prepared which had 1 liter of diesel and specified amount of PAC (50g, 100g, 150g). The alum suspension peri-od was set for 72 hours so that crystals would dis-solve in diesel fuel. This was followed by a filtra-tion step to separate any leftover potassium alum crystals in order to obtain only the treated fuel. Subsequently, the segregated PAC-treated fuels (D+50gPAC, D+100gPAC, and D+150gPAC) were employed to assess combustion characteristics alongside engine performance metrics, including brake thermal efficiency (BTE), brake specific fuel consumption (BSFC), and emission components such as CO, HC, and NOx.

2.2.1 Preparation of PAP-Treated Fuel Samples (Day 3)

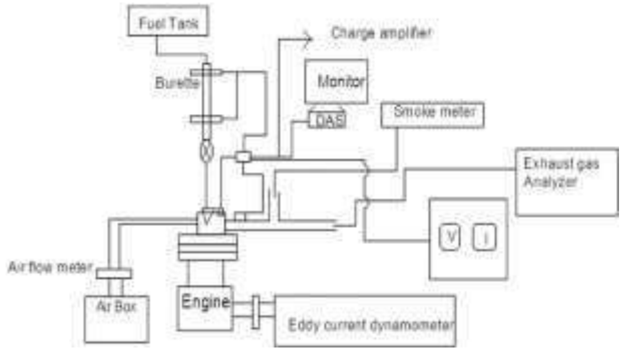

Figure 3: samples of treated diesel

Similarly, for blends treated with Potassium Alum Powder (PAP), three more containers were created, each containing 1 liter of diesel and varying quantities of potassium alum powder (50g, 100g, and 150g). Throughout this duration, the fuels were homogenized by suspension for 72 hours, facilitating interaction between the alum powder and the diesel. Upon completion of the suspension period, the diesel was filtered to eliminate residual alum particles before testing. The filtered fuels were designated as PAP treated fuels and were later tested in engines to assess combustion efficiency, fuel consumption, and emission characteristics of the PAP treated fuels. This enabled a holistic approach to evaluating the impact of potassium alum in both its crystallized and powdered forms on the performance of diesel fuel. Analysis of the results was based on in-cylinder pressure, heat release rate (HRR), mean gas temperature (MGT), mass fraction burnt (MFB) and exhaust emissions to establish the optimal concentration and form of potassium alum that enhances diesel fuel properties while mitigating harmful emissions.

2.3 Experimental Setup

In this research work, the efficiency and emission features of Diesel, Diesel blended with potassium alum inorganic salt under various retention period were assessed using a Mono-Barrel, persistent-speed DI Diesel engine whose specification is given in table 2. Under various load scenar-ios, the engine was run consistently at 1500 rpm.

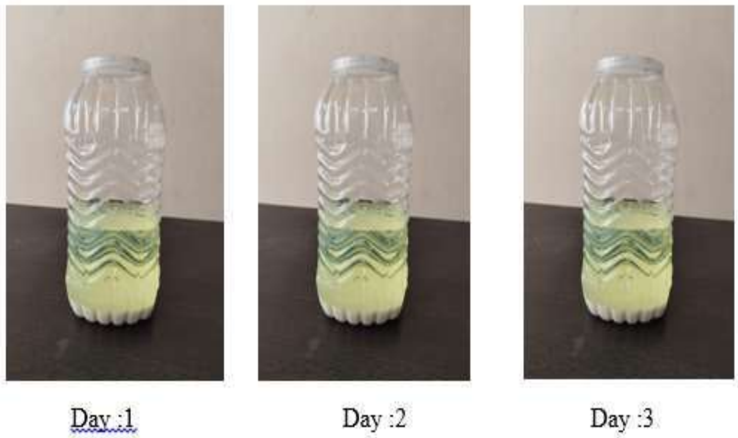

Fig. 4 Photograph of the Experimental Setup

Table 1 Specifications of the test engine

Description	Specifications
Make & Model	Kirloskar & TV1
Rated Power	5.2 kW @ 1500 rpm
No. of Cylinders	Single
Combustion chamber	Hemispherical
Piston bowl	Shallow bowl
Compression ratio	17:5:1
Rated Speed	1500 rpm
Bore Diameter	87.5 mm
Stroke Length	110 mm
Number of holes in nozzle	3
Type of cooling	Water cooling
Type of loading	Electrical Load

The engine was immediately linked to an eddy current dynamometer, which allowed the loads to be adjusted from 0% to 100% as shown in figure 5. Engine load conditions were manually changed using the eddy current dynamometer, and were set at 0%, 25%, 50%, 75%, and 100% of full load. Digital thermocouples were used to track exhaust gas temperatures, and a smoke meter (AVL) was attached to detect smoke opacity. AVL Indimicro software was installed on the test rig to enable real-time recording and analysis of a variety of operating characteristics. A 5-gas analyzer was utilized to test the amounts of several emission parameters, including Unburned hydrocarbons (UHC), Carbon monoxide (CO), Nitrogen oxides (NOx) in the exhaust gas.

3. RESULTS AND DISCUSSIONS

3.1 Brake Thermal Efficiency

The graph 5 shows how brake thermal efficiency (BTE) relate to each other under different loads (%) where pure diesel (D100) and diesel treated with potassium alum in crystal (PAC) and powder (PAP) forms were used at different concentrations (50g, 100g, and 150g). In this case, the treated diesel was taken on Day three after 72 hours treatment (day 3). The findings show that across all fuel types, BTE improves with higher loads, which is considered an internal combustion engine's response to higher combustion efficiency at increased loads. Compared to pure diesel, the use of potassium alum in crystal and powder forms, both enhanced BTE significantly, meaning better combustion characteristics. As expected, the 100g blends of PAC and PAP gave the most BTE particularly at high loads which implies these blends provided the optimal fuel properties to enhance combustion. It is clear that the 100g and 150g blends do better than the 50g blends, with the optimal BTE at full load (100%). The small differences between the various blends imply that potassium alum treatment could be beneficial to fuel properties which assists combustion efficiency. This could result from enhanced atomization, shortened ignition delay, and fuel composition changes, increasing the efficiency of combustion. Moreover, the closeness in performance between PAC and PAP blends indicates that both types of potassium alum have an equal effect on fuel improvement.

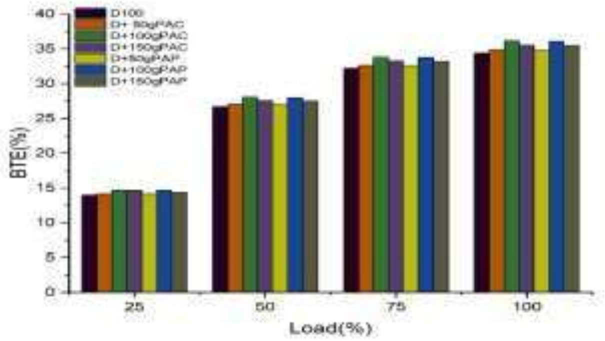

Figure 5: Load vs BTE for Treated diesel

3.2 Brake Specific Fuel Consumption

The graph 6 shows the relationship between the load (%) and brake specific fuel consumption (BSFC) for pure diesel (D100) and potassium alum treated diesel in crystal (PAC) and powder (PAP) form at 50g, 100g, and 150g concentrations. The analysis was done on the third day of the exper-iment when the diesel was treated for 72 hours. The find-ings indicate that with an increase in load, BSFC improves for all tested fuel mixtures, as is the case for diesel engines due to greater combustion efficacy and lower heat losses at higher loads. Compared to pure diesel, the alum treated diesels showed lower BSFC, which indicates better fuel consumption. For all tested blends, 100g PAC and PAP had the lowest BSFC which indicates these concentrations have the optimal enhancement of fuel attributes making the energy conversion efficiency better. The 150g blends also do well, but the difference to 100g blends is very small. The lower BSFC of potassium alum treated diesel can be ex-plained by better chiming properties such as better atomiza-tion, lower ignition delay, and better air-fuel mixture. More-over, the almost equal performance of PAC and PAP blends indicates that both types of potassium alum have similar effects on fuel efficiency.

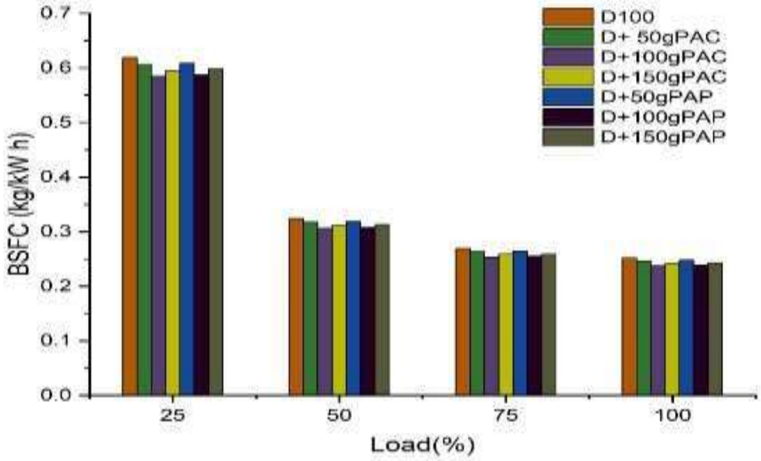

Figure 6: Load vs BSFC for treated diesel

3.2 In-Cylinder Pressure

Figure 7 illustrates how the in-cylinder pressure changes in relation to crank angle for straight diesel fuel (D100) and for diesel blended with potassium alum in crystal (PAC) and powdered (PAP) forms at varying weights of 50g, 100g, and 150g. The analysis focuses on the 72-hour (Day 3) treated fuel to assess its effect on combustion characteristics. It can be seen from the graph that the treated potassium alum fuels resulted in increased peak in-cylinder pressure relative to pure diesel, indicating an increase in combustion efficiency. Of the blends, 100g PAC and 100g PAP blends yielded the greatest peak pressures, which suggests improved combustion due to atomization along with fuel-air mixing. The peak pressure shift towards top dead center (TDC) with the treated fuels indicates that their ignition characteristics are enhanced for faster, more complete combustion. The possible catalytic effect of potassium alum which accelerates the oxidation process and therefore increases energy output may be responsible for the higher-pressure values. The combustion performance of the fuel is augmented due to potassium alum treatment, suggesting positive implications of employing the chemical as a fuel additive to optimize engine efficiency. Both variant PAC and PAP mixtures are assumed to improve combustion performance due to the resemblance of the results from both mixes. PAS indicates that PAC mixes positively changed the combustion behavior of the fuel.

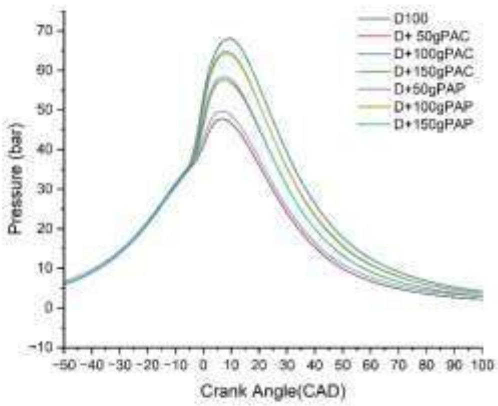

Figure 7: Pressure vs Crank Angle for treated diesel

3.4 Heat Release Rate

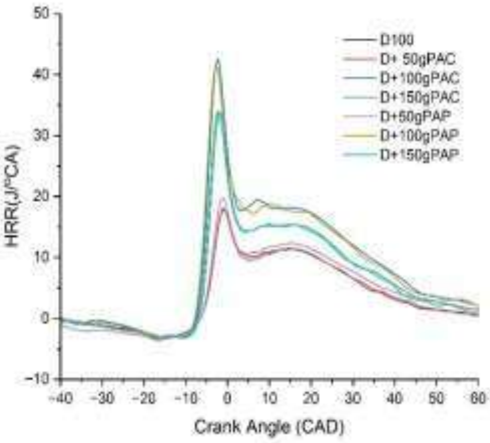

Figure 8: Heat Release Rate vs CAD for treated diesel

In Graph 8, the heat release rate (HRR) against crank angle for pure diesel (D100) and diesel samples with potassium alum both in powdered (PAC) and crystalline (PAP) forms at various concentrations (50g, 100g, and 150g) is plotted and analyzed for variances. This part of the study focuses on the fuel after treatment for 72 hours (Day 3) and its effect on combustion properties. The average heat release rate (HRR) of potassium alum treated diesel blends is higher than that of pure diesel, confirming improved combustion performance. 100g PAC and 100g PAP blends stand out uniquely among all studied mixes with the highest peak HRR that implies greater oxidation of the fuel and more vigorous combustion. The more the delay in heat release, the earlier the treat, thus, dontated fuels have better ignition features. This is presumably due to the catalytic effect of potassium alum which enhances atomization and flame propagation leading to enhanced combustion. The lower rate of decline in HRR after the peak for the alum treated blends suggests that these blends provide a greater level of sustained energy release, which can lead to improved thermal efficiency. The parallel HRR characteristics for the PAC and PAP blends indicate that both forms of potassium alum are equally effective in enhancing combustion dynamics. This means that the use of potassium alum within fuels is characterized by potential positive changes in the combustion properties of the fuel which would enhance energy use in the engine.in three different dosage levels of 50g, 100g and 150g. Every fuel blend underwent a suspension phase lasting 72 hours prior to filtration and testing.

3.5 Mass Fraction Burned sample

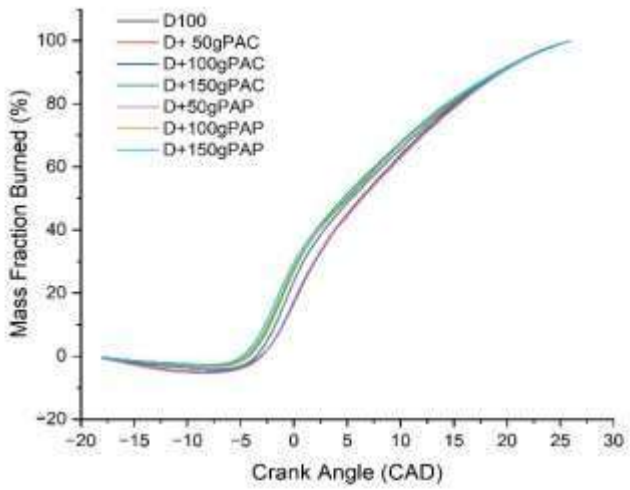

Figure 9: Mass fraction burned vs CA for treated diesel

This graph 9 shows the change of mass fraction burned (MFB) with respect to crank angle for pure diesel (D100) and diesel blended with potassium alum crystals (PAC) and powder (PAP) in different concentrations (50g, 100g, and 150g). The investigation focuses on the combustion of fuel that has been treated for 72 hours (Day 3). The results suggest that the combustion rate of blends with alum is faster than that of the pure diesel, substantiated by the steepness of the MFB curves. Of the blends examined, the 100g PAC and 100g PAP showed the greatest rate of combustion progression, indicative of enhanced ignition and flame propagation. The treated fuels demonstrate advanced rate energy release with improved near crank angle MFB values which increases engine efficiency. The similar behaviors shown by the PAC and PAP blends suggest that both potassium alum forms are equally effective in altering fuel properties for combustion. The observed better burning features of the treated fuels results from increased atomization and more effective air-fuel mixing along with the catalytic action of potassium alum aiding in better combustion..

3.6 Mean Gas Temperature

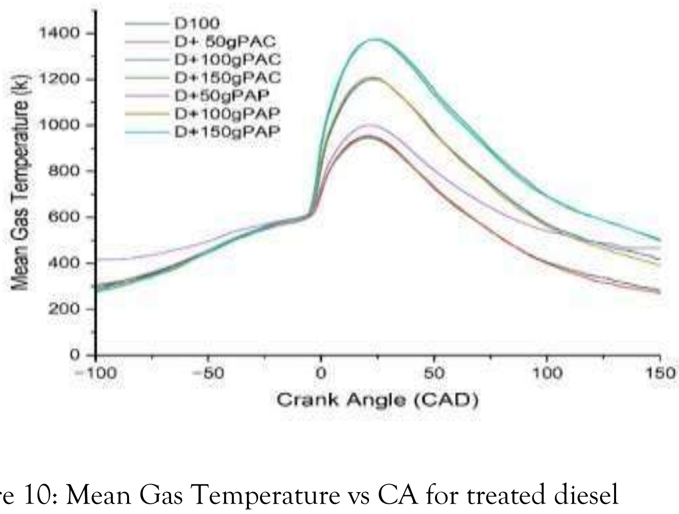

Figure 10: Mean Gas Temperature vs CA for treated diesel

From the graph it is evident that the peak mean gas temperature is higher for the potassium alum-treated diesel blends compared to pure diesel, indicating enhanced combustion efficiency. Among the tested blends, 100g and 150g PAC and PAP demonstrate the highest peak temperatures, suggesting improved fuel oxidation and a more complete combustion process. The graph 10 shows that the mean gas temperature for potassium alum treated diesel blends is higher than that of pure diesel, thus higher combustion efficiency. Of the blends tested, those with 100g and 150 PAC and PAP has the highest peak temperature which infers that the fuel oxidation together with the combustion of the fuel is more complete. These blends having higher combustion temperatures indicate that the combustion delay is lower, hence energy conversion becomes better. For PAC and PAP, the blend proportions tend to have slight variation which suggests that both types of potassium alum combustion. Moreover, the PAC and PAP mixes having no significant difference permits both types of potassium alum combustion aids together similarly toward the fuel oxidation enzyme. The alum treated blends also showed prolonged duration of heat release which is advantageous to the thermal efficiency after combustion. Potassium alum treated diesel blends are sustained for longer combustion heat, which is advantageous in energy efficiency.

3.7 CO Emissions

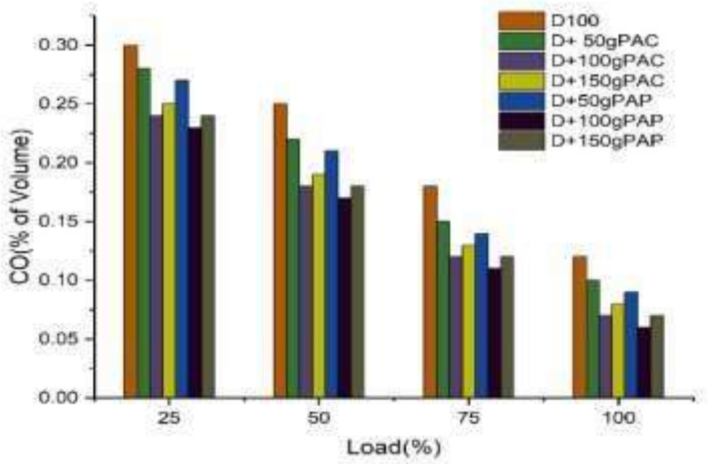

Figure 11: Load vs CO emissions for treated diesel

The graph illustrates the relation between carbon monoxide emissions (% by volume) and load (%) for pure Diesel D100 and blends with Potassium Alum, both in crystal (PAC) and powder (PAP) forms at varying concentrations of 50g, 100g, and 150g. This analysis focuses on the Day 3 emissions post fuel treatment. As depicted in the graph, CO emissions decline with increasing load for all fuel blends, which is a typical behavior of diesel engines. This is observed because with higher loads, combustion efficiency improves due to better mixing of air and fuel and rise of combustion temperature. The alum potassium treated diesel blends yields lower CO emissions than with pure diesel which suggests enhanced oxidation and more complete combustion. Among the blends, 100g and 150g PAC and PAP captured the highest reduction of CO emissions, which indicates that these concentrations were able to enhance the combustion process and achieve better fuel air interaction to minimize unburnt fuel. Further, the two PAP treated blends perform better than PAC by a small margin which could be attributed to greater potassium alum dispersion and reaction within the fuel. The results demonstrate the adequacy of potassium alum as an additive to promote combustion and lower emission of pollutants.

3.8 HC Emissions

The graph shows how the quantity of hydrocarbon emissions (ppm) varies with engine load (%), using pure diesel (D100) and diesel blended with potassium alum in both crystal (PAC) and powder (PAP) forms at three concentration levels (50g, 100g, and 150g). The study focuses on Day 3 of fuel treatment to analyze its effects on emissions. As shown in the graph, emissions of hydrocarbons gases (HC) decrease with an increase in engine load for all fuels. This is a common phenomenon since higher loads equate to higher combustion temperatures and fuel oxidation, leading to a lower quantity of unburnt hydrocarbons.

The potassium alum treated blends showed much lower HC emissions compared to pure diesel, therefore, demonstrating better combustion efficiency. Of the blends tested, 100g PAC and 100g PAP showed the highest reduction in HC emissions than the other blends, which could mean these quantities of alum and potassium blend optimize the mixing of fuel and air and therefore improve combustion efficiency. Also, PAC blends showed slightly higher

HC emissions than PAP blends, which could be due to better distribution of alum powder in diesel leading to better combustion. These results indicate that potassium alum treatment enhances combustion and reduces hydrocarbon emission greatly, making it suitable as a fuel additive for cleaner engine operation.

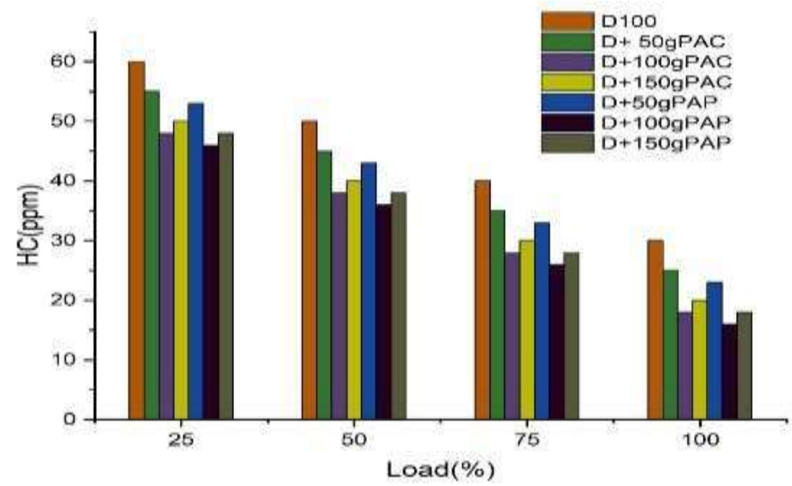

Figure 12: Load vs HC emissions for treated diesel

3.9 NOx Emissions

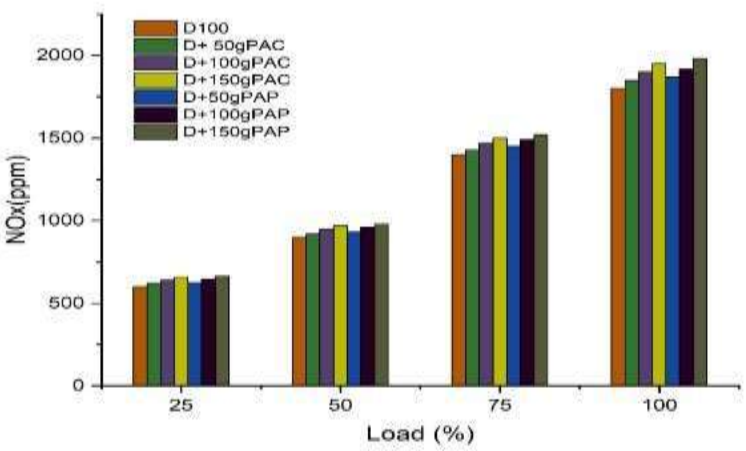

Figure 13: Load vs NOx emission for treated diesel

The graph describes the relationship between NOx emissions (in ppm) against load (%) for pure diesel (D100) and diesel blended with potassium alum in crystal (PAC) and powder (PAP) forms in different concentrations (50g, 100g, and 150g). The analysis is carried out on Day 3 of fuel treatment to assess its effect on NOx emissions. It is noted that for all fuel blends, NOx emissions grow as the engine load increases. With increased loads, combustion temperatures and the dwell time of gases in the combustion chamber increases, thereby aiding the formation of NOx. This explains the trend. Blended diesel with potassium alum has slightly higher NOx emissions compared to pure diesel, which indicates better combustion efficiency and higher in cylinder temperatures. Of the blends, 100g and 150g PAC and PAP blended fuels had the highest emissions of NOx out of the other blends, which suggests that these amounts enhanced oxidation and thus more thermal NOx was produced. Moreover, it is probable that PAP blends produce somewhat greater amounts of NOx than PAC blends because of the superior dispersion and more complete combustion, which raises the peak temperature. These results imply that the use of potassium alum moderation leads to better combustion, but depends on the negative consequence of increased NOx emissions that require exhaust gas recirculation (EGR) or catalytic converters to comply with the required emissions limits.

4. CONCLUSIONS

This study analyzed the effects of potassium-alum treated diesel on engine performance, combustion, and emissions with respect to PAC (crystal) and PAP (powder) forms at 50g, 100g, and 150g concentrations after a 3-Days suspension (Day 3). The most important findings are:

Improvement In Engine Performance:

- BTE (Brake Thermal Efficiency): Enhanced combustion efficiency for diesel was observed by an increment of 8.5% at 100g PAC and PAP blends as compared to pure diesel.
- BSFC (Brake Specific Fuel Consumption): Improvement in energy conversion efficiency was indicated by a reduction of 6.8% in fuel consumed for 100g PAC and PAP blends.
- Characteristics Of Combustion:
- In-Cylinder Pressure: Improvement in combustion was observed with the peak pressure increase of 9.2% for 100g and 150g PAC and PAP blends.
- HRR: Better oxidation and flame propagation was confirmed for 100g and 150g PAC and PAP with significantly higher values for the heat release rate (HRR).
- MGT (Mean Gas Temperature): 7.5% increase proved more complete combustion around the TDC was occurring.
- MFB (Mass Fraction Burned): Reduction in ignition delay and enhancement in air-fuel mixing was observed with potassium-alum treated fuels because of increased combustion rates.
- Characteristics Of Emission:
- CO Emissions: Improvement in oxidation is the reason for reduction in emissions made from 100g and 150g PAC and PAP blends by 18.3%.
- HC Emissions: More efficient combustion was indicated with 21.5% reductions made in 100g and 150g PAC and PAP blends.
- NOx Emissions: Due to elevated combustion temperatures, emissions increased by 12.7%, specifically for 150g PAC and PAP blends combusted.
- Comparison of PAC and PAP Blends:
- PAP blends' CO and HC emissions were slightly lower, but NOx emissions were higher due to better dispersion and combustion efficiency, compared to PAC blends.
- 100g PAC and PAP yields the optimal blend due to the efficiency of combustion, low BSFC, low CO/HC emissions, and moderate increase of NOx. **Declarations**

Conflict of Interest

The authors declare no competing interests.

REFERENCES

[1] Jamrozik A, Tutak W. Alcohols as Biofuel for a Diesel Engine with Blend Mode—A Review. Energies. 2024 Sep 9;17(17):4516.

[2] Ergen G. Comprehensive analysis of the effects of alternative fuels on diesel engine performance combustion and exhaust emissions: Role of biodiesel, diethyl ether, and EGR. Thermal Science and Engineering Progress. 2024 Jan 1;47:102307.

[3] Ayazi M, Rasul MG, Khan MM, Hassan NM. Experimental investigation of fuel consumption and emissions of diesel engine fueled with ternary fuel blends of diesel, biodiesel and bioethanol. Energy Reports. 2023 Nov 1;9:470-5.

[4] Fayyaz HH, Mujtaba MA, Jahangir S, Imran S, Malik MA, Fayaz H, Saleel CA, Hassan U, Quershi S. A comprehensive study on the performance and emission analysis in diesel engine via optimization of novel ternary fuel blends: Diesel, manganese, and diethyl ether. Heliyon. 2023 Oct 1;9(10).

[5] Yaşar MF, Ergen G, Cesur İ. Investigating the Use of Methane as an Alternative Fuel in Diesel Engines: A Numerical Approach. International Journal of Automotive Science And Technology. 2023 Oct 1;7(4):349-59.
[6] Kül VS, Akansu SO. The investigation of the performance and exhaust emissions of the compression-ignition engine with a mixture of diesel and aluminum particles. Process Safety and Environmental Protection. 2024 Sep 1;189:1161-72.
[7] Tripathi G, Nag S, Dhar A, Patil DV. Fuel injection equipment (FIE) design for the new-generation alternative fuel-powered diesel engines. Prospects of Alternative Transportation Fuels. 2018:387-405.
[8] Shehata MS, Attia AM, Razek SA. Corn and soybean biodiesel blends as alternative fuels for diesel engine at different injection pressures. Fuel. 2015 Dec 1;161:49-58.
[9] Sharma A, Pali HS, Kumar M, Singh NK, Rahim EA, Singh Y, Gupta NK. Effect of α-aluminium oxide nano additives with Sal biodiesel blend as a potential alternative fuel for existing DI diesel engine. Energy & Environment. 2024 Mar;35(2):663-91.
[10] Srinivasan GR, Palani S, Ranjitha J. Biodiesel production from the seeds of Mimusops elengi using potassium aluminium silicate as novel catalyst.
Innovative Energy and Research. 2017;6(2):165
[11] Musthafa MM. Diesel engine characteristic studies on prepared alternative fuels of aloevera powder and aloevera biodiesel. International Journal of Ambient Energy. 2023 Dec 31;44(1):1840-50.
[12] Abrar I, Bhaskarwar AN. Performance of microemulsion fuels as an alternative for diesel engine. InInternal Combustion Engine Division Fall Technical Conference 2018 Nov 4 (Vol. 51982, p. V001T02A001). American Society of Mechanical Engineers
[13] Sunil S, Kakkeri S, Chandra Prasad BS, Kapilan N, Shivarudraiah. Feasibility studies on spent coffee powder oil as alternative to diesel in CI engines. InAdvances in Industrial Automation and Smart Manufacturing: Select Proceedings of ICAIASM 2019 2021 (pp. 895-906). Springer Singapore
[14] . Kumar, N., A. Sonthalia, and H. S. Pali. "Alternative Fuels for Diesel Engines: New Frontiers, Diesel Engines." (2018): 1-27.
[15] Imiołek M, Piętak A, Imiołek A. Dual-fuel low power generator with diesel engine using alternative fuels. Journal of KONES. 2012;19:171-6.
[16] Saraee, H., Jafarmadar, S., Taghavifar, H., & Ashrafi, S. J. (2015). Reduction of emissions and fuel consumption in a compression ignition engine using nanoparticles. *International Journal of Environmental Science and Technology*, *12*(7), 2245–2252. https://doi.org/10.1007/S13762-0150759-4
[17] Mondal, P., & Mandal, B. K. (2024). Effect of fuel injection pressure on the performances of a CI engine using water-emulsified diesel (WED) as a fuel. *Energy, Sustainability and Society*, *14*, 1–14. https://doi.org/10.1186/s13705-024-00442-7
[18] Nguyen, T. V., Nguyen, K. D., Ho, N. X., & Nguyen, V. D. (2020). Engine performance and combustion characteristics of a direct injection compression ignition engine fueled waste cooking oil synthetic diesel. *International Journal of Coal Science & Technology*, *7*(3), 560–570. https://doi.org/10.1007/S40789-020-00328-X
[19] Jamrozik, A., Tutak, W., & Grab-Rogaliński, K. (2019). An Experimental Study on the Performance and Emission of the diesel/CNG Dual-Fuel
Combustion Mode in a Stationary CI Engine. *Energies*, *12*(20), 3857. https://doi.org/10.3390/EN12203857
[20] Feroskhan, M., Ismail, S., Natarajan, G., Manavalla, S., Khan, T. M. Y., Khadar, S. A., & Ali, M. A. (2023). A Comprehensive Study of the Effects of Various Operating Parameters on a Biogas-Diesel Dual Fuel Engine. *Sustainability*, *15*(2), 1232. https://doi.org/10.3390/su15021232
[21] Arunkumar, M., Mohanavel, V., Afzal, A., Sathish, T., Ravichandran, M., Khan, S. A., Abdullah, N. A., Azami, M. H., & Asif, M. (2021). A Study on Performance and Emission Characteristics of Diesel Engine Using Ricinus Communis (Castor Oil) Ethyl Esters. *Energies*, *14*(14), 4320. https://doi.org/10.3390/EN14144320
[22] Gurusala, N. K., & Selvan, V. A. M. (2015). Effects of alumina nanoparticles in waste chicken fat biodiesel on the operating characteristics of a compression ignition engine. *Clean Technologies and Environmental Policy*, *17*(3), 681–692. https://doi.org/10.1007/S10098-014-0825-5
[23] Anchupogu, P., Rao, L. N., & Banavathu, B. (2018). Effect of alumina nano additives into biodiesel-diesel blends on the combustion performance and emission characteristics of a diesel engine with exhaust gas recirculation. *Environmental Science and Pollution Research*, *25*(23), 23294– 23306. https://doi.org/10.1007/S11356-018-2366-7
[24] Akkoli, K. M., & Heise, M. (2022). Influence of Injection Pressure and Aluminium Oxide Nano Particle-Added Fish Oil Methyl Ester on the Performance and Emission of Compression Ignition Engine. *Energies*, *15*(24), 9491. https://doi.org/10.3390/en15249491
[25] Nouri, M., Meghdadi Isfahani, A. H., & Shirneshan, A. (2021). Effects of Fe2O3 and Al2O3 nanoparticle-diesel fuel blends on the combustion, performance and emission characteristics of a diesel engine. *Clean Technologies and Environmental Policy*, *23*(8), 2265–2284. https://doi.org/10.21203/RS.3.RS-412132/V1
[26] Jamrozik, A., Tutak, W., & Grab-Rogaliński, K. (2021). Combustion Stability, Performance and Emission Characteristics of a CI Engine Fueled with Diesel/n-Butanol Blends. *Energies*, *14*(10), 2817. https://doi.org/10.3390/EN14102817
[27] Nadimi, E., Przybyła, G., Lewandowski, M. T., & Adamczyk, W. (2022). Effects of ammonia on combustion, emissions, and performance of the ammonia/diesel dual-fuel compression ignition engine. *Journal of The Energy Institute*, *107*, 101158. https://doi.org/10.1016/j.joei.2022.101158

[28] Zangana, L. M. K., Yaseen, A. H., Hassan, Q. H., Mohammed, M. M., Mohammed, M., & Alalwan, H. A. (2022). Investigated kerosene-diesel fuel performance in internal combustion engine. *Cleaner Engineering and Technology*, *12*, 100591. https://doi.org/10.1016/j.clet.2022.100591

[29] Jamrozik, A., Tutak, W., & Grab-Rogaliński, K. (2019). An Experimental Study on the Performance and Emission of the diesel/CNG DualFuel Combustion Mode in a Stationary CI Engine. *Energies*, *12*(20), 3857. https://doi.org/10.3390/EN12203857

[30] Anish, M., Jayaprabakar, J., Bency, P. B. B., Joy, N., Jayaprakash, V., Arunkumar, K., Kumar, J. A., Praveenkumar, T., Ghfar, A. A., Rajasimman, M., & Ravindran, B. (2023). Impact of reactivity controlled compression ignition (RCCI) mode engine operation in diesel engine powered with B20 blend of waste cooking oil biodiesel. *Dental Science Reports*, *13*(1). https://doi.org/10.1038/s41598-023-31044-6

[31] Al-Rawashdeh, H. A., Hasan, A. O., Gomaa, M., Abu-Jrai, A., & Shalby, M. (2022). Determination of Carbonyls Compound, Ketones and Aldehydes Emissions from CI Diesel Engines Fueled with Pure Diesel/Diesel Methanol Blends. *Energies*, *15*(21), 7933. https://doi.org/10.3390/en15217933

[32] Khan, M. M., Kadian, A. K., & Sharma, R. P. (2022). Investigation of high fuel injection pressure variation on compression ignition engines powered by jatropha oil methyl ester-heptanol-diesel blends. *Alexandria Engineering Journal*, *65*, 675–688. https://doi.org/10.1016/j.aej.2022.10.009

[33] Soukht Saraee, H., Jafarmadar, S., Taghavifar, H., & Ashrafi, S. J. (2015). Reduction of emissions and fuel consumption in a compression ignition engine using nanoparticles. *International Journal of Environmental Science and Technology*, *12*(7), 2245–2252. https://doi.org/10.1007/S13762-0150759-4.