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Efficiency Augmentation And Emission Abatement- A Characteristics And Time Study On Utilization Of Alum Powder In A Di Diesel Engine

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A research work was done to study the efficacy and emission attributes of a Diesel engine while consuming 100 grams of Potassium Alum Inorganic Salt(PAIS) as additive in neat Diesel. In the first stage of this experiment, various quantity (50gm, 100gm, 150gm, 200gm, 250gm) of PAIS was added to Diesel to find the optimum quantity of PAIS at which the performance and emission was good. It was found that 100gm of PAIS gave better performance and emission characteristics. In the next phase, having 100gm of PAIS as the reference, the fuel was made to stay for 1 to 5 days and the properties of the fuel were measured along with efficacy and emission characteristics. It was seen that the Diesel blended with 100gm PAIS for 3 days found to give better results when associated to other fuel mixtures. The PAIS functions as an oxygen donor, providing oxygen for CO oxidation or absorbing oxygen for NOx reduction. PAIS's activation energy reduces hydrocarbon emissions by burning off carbon deposits inside the barrel of engine at wall temperature and preventing the buildup of non-polar chemicals on the cylinder walls. The results reveal that 100gm of PAIS blended with Diesel and retained for 1,2,3 days offered better outcomes in terms of efficiency and emission reduction. Beyond 3 days, for 4^{th} and 5^{th} days the fuel quality tends to decrease and the efficiency and emission attributes also seems to be deteriorating. The BTE for Diesel was 25 % and for Diesel blended with PAIS and retained for 3 days gave better BTE of 26.3 % when compared to pure Diesel. The NOx emanation for Diesel was 912 ppm at full load, for Diesel blended with 100gms of PAIS and retained for 3 days gave NOx emission of 1165 ppm and for 5 days gave NOx emission was 952 ppm.

Key words: Alum powder; Five days retention; DI diesel engine; Efficiency Enhancement and Emission Reduction

1.Introduction

Diesel engines, despite their general efficiency over spark ignition engines, often face higher emissions, which has hindered their widespread acceptance, particularly in automotive applications. Recently, stringent global emissions regulations have targeted nitrogen oxides (NOx), Smoke, and particulate matter emitted by automobiles using diesel engines. Fuel properties like volatility, density, and sulphur content significantly influence particulate emissions and can be modified using fuel additives and few other techniques. One such promising strategy involves incorporating inorganic salts and Alum-treated diesel fuel into Internal combustion (IC) engines. This approach is being explored to potentially enhance engine performance, reduce emissions, and improve fuel economy.

Achugasim et al., 2013 suggested that Crude oil represents the most abundant natural source of hydrocarbons, with its content reaching up to 90%, depending on its type. These hydrocarbons encompass a diverse range, including aliphatic and aromatic compounds. Aromatic hydrocarbons can be classified as simple, featuring a single benzene ring, or complex, incorporating two or more benzene rings. Okoye et al, 2009 studied how the unique formation of crude oil influences the variations in length of chain and size of ring of various hydrocarbons. These hydrocarbons are separated during the refining process of petroleum according to their chain length and subsequent boiling temperatures, producing valuable products or fractions. Hyne et al, 2001 discussed on cracking the diesel range aliphatics (DRA) which can transform them into aliphatic hydrocarbons available in premium motor spirit (PMS) or kerosene, which boil at lesser temperatures. Jimoh et al., 2004 investigated the breakdown of large or long hydrocarbons into simpler ones can be obtained through various techniques. One approach involves high-temperature processes known as thermal cracking, while another method utilizes catalysts at optimum temperatures, known as catalytic cracking. Ayhan et al , 2008 studied on Double salts are particularly notable for their strong catalytic capabilities. These salts consist of two different cations and anions within their crystalline structure. They are formed by combining 2 or more different salts, resulting in a single ionic lattice. Double salts typically crystallize into larger crystals more readily than single salts and exhibit characteristics from their component salts. Unlike complex salts, which dissociate to yield complex ions that remain intact in solution, double salts dissolve or dissociate in water to release simple ions. Examples of double salts include Ammonium cobalt (II) sulphate hexahydrate ($(NH_4)_2CO(SO_4)_2$ $6H_2O$), Potassium aluminium sulphate dodecahydrate ($KAl(SO_4)_2$ $12H_2O$), and Ammonium nickel sulphate hexahydrate ($(NH_4)2Ni(SO_4)_2$ $6H_2O$), among others.

Numerous studies have explored the effects of nano additives in Diesel, Diesel-Biodiesel blends, but drawing generalized conclusions remains challenging due to inconsistent and conflicting results. This paper thoroughly discusses research findings regarding the use of Inorganic salt in Diesel applications. Specifically, the impact of Potassium Alum Inorganic

Salt(PAIS) on performance, and emissions parameters. The study covers crucial aspects such as the selection of right quantity of PAIS, details for preparing PAIS blended Diesel, enhancements in engine efficiency, potential emissions effects on human health, as well as the advantages and disadvantages associated with blending of PAIS.

2.Materials and Methods

2.1 Characterization of Potassium Alum Inorganic Salt

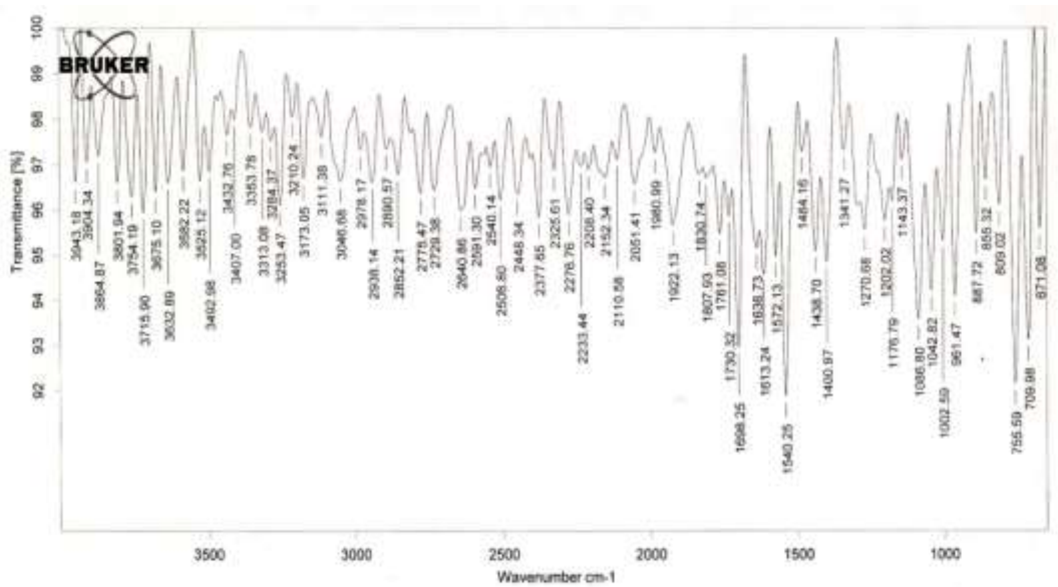

Fig. 1 FTIR analysis of Potassium Alum Inorganic salt

The FTIR spectra of Potassium Alum Inorganic Salt was recorded and presented in the above figure 1. It is seen from above graph that Transmittance is inversely proportional to Absorption. The strong absorption frequencies at 1698.25, 1540.25, 1002.59 and 755.59 indicates as a representation of the C-H stretching for Diesel added with Potassium Alum Inorganic Salt. The presence of aldehydes or ketones was suggested by the C=O stretching indication at the absorbance peak of 1540.25 cm-1indicating C-H stretching. A marginal variation in spectra can be noticed due to the blending of Potassium Alum Inorganic Salt to Diesel.

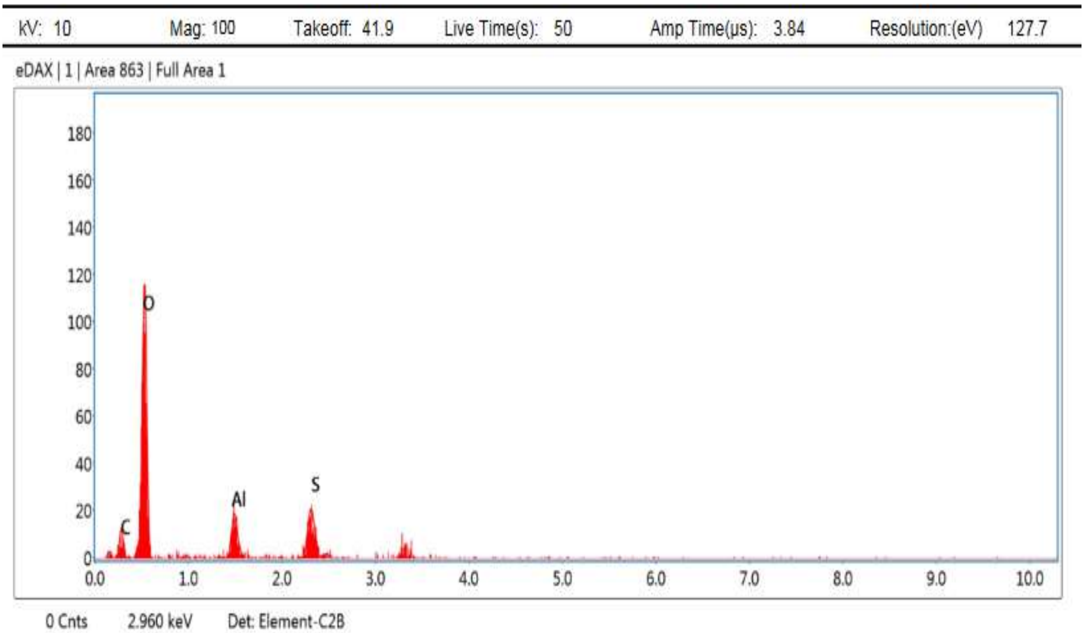

Fig. 2 EDAX analysis of Potassium Alum Inorganic salt

The elemental composition of Potassium Alum Inorganic Salt was measured using EDAX. The JEOL scanning Electron Microscope was used to study the morphological studies. Here EDAX is attached with SEM. The obtained elemental composition of Potassium Alum Inorganic Salt is found to be C:O:Al:S. The obtained results confirms that the atomic % of O2 is more which confirms that the Potassium Alum Inorganic Salt is favourable for high quality combustion.

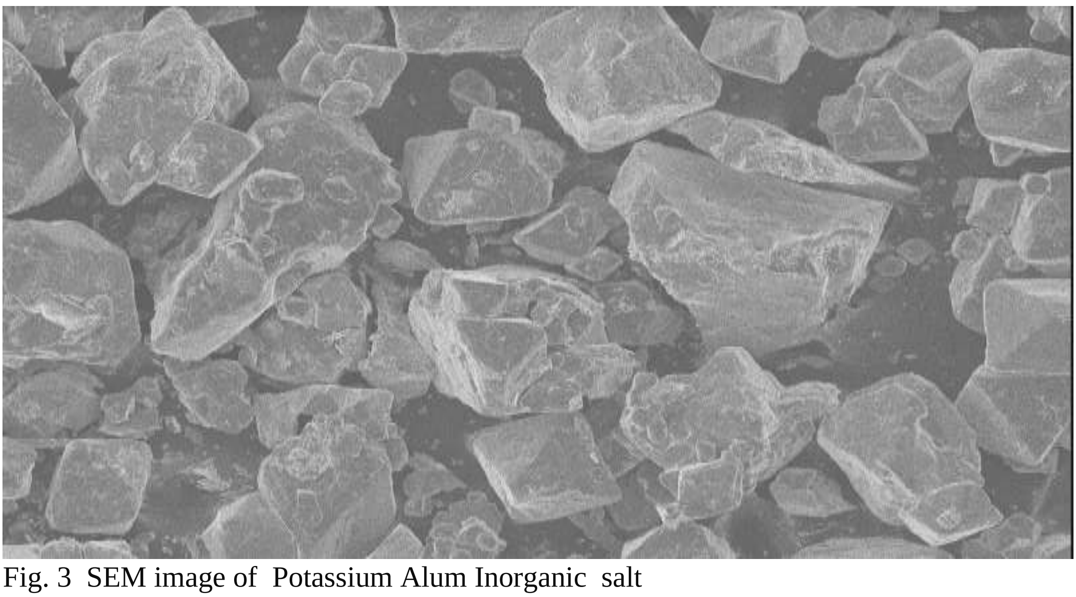

Fig. 3 SEM image of Potassium Alum Inorganic salt

The SEM image of Potassium Alum Inorganic salt is shown in figure 3. It is found that the crystalline salt consists of uniform grain morphology. This is a favourable condition for complete combustion which means that the entire Potassium Alum Inorganic salt is involving to liberate more amount of heat energy during combustion.

2.2 Preparation of Fuel sample

Initially 100 grams of Potassium Alum Inorganic Salt in powder form was accurately quantified into a separate dry 1000 ml conical flask. Later, 1 litre of commercial diesel was added to flask, and the mixture was stirred for 30minutes. After stirring, the flask was allowed to stay for 24 hours to ensure no separation and complete mixing happened as shown in figure 4. Samples were extracted from flask and sent to the laboratory for FTIR to find Transmittance and Absorption potential of the Inorganic salt , EDAX to determine the elemental composition of Potassium Alum Inorganic Salt , SEM tests to determine their uniform grain morphology. The GC investigation was conducted using an Agilent machine, following the conditions and procedures described in previous studies (Achugasim et al., 2013; Osuji and Achugasim, 2010).

Day :1 Day :2 Day :3 Day :4 | Day :5

Fig. 4 Potassium Alum Inorganic Salt retained in Diesel for 1 to 5 days

Table 1 Properties of Diesel and PAIS added fuel

	Diesel	**Diesel + 100grams IS (INORGANIC SALT)**	**Diesel + 100grams IS(Day 1)**	**Diesel + 100grams IS(Day 2)**	**Diesel + 100grams IS(Day 3)**	**Diesel + 100grams IS(Day 4)**	**Diesel + 100grams IS(Day 5)**
Heating value (kJ/kg)	41,597	41,791	41,795	41,810	41,823	41,825	41,832
Density (kg/m^3)	820	860	861	865	865	865	865

Viscosity at 40°C (10^{-4} m^2/s)	4.2	4.2	4.2	4.2	4.2	4.2	4.2
Flash point ºC	51	56	58	58	59	59	59
Fire point ºC	62	62	63	62	62	63	62

3.Experimental procedure

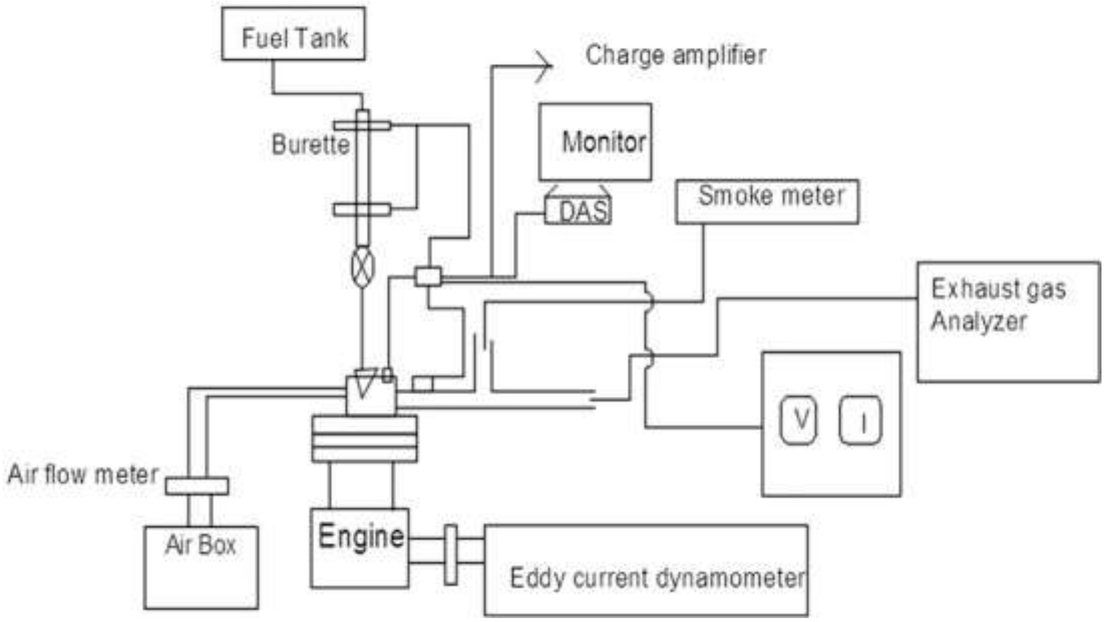

Fig. 5 Photograph of the Experimental Setup

Table 2 Specification of the test engine

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
Injection Pressure	220 bar
Injection Timing	23 deg CA BTDC
Fuel Injection type	Direct
Number of holes in nozzle	3
Spray hole diameter	0.25mm
Spray cone angle	110
Cubic Capacity	661.45 cc
Type of loading	Electrical Load
Type of cooling	Water cooling
Type of ignition	Compression Ignition

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 scenarios, the engine was run consistently at 1500 rpm. 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), Carbon dioxide (CO_2), and Oxygen (O_2) in the exhaust gas.

3.1 Uncertainty analysis

The uncertainties of the parameters are calculated by sequential perturbation. Some of average uncertainties of measured and calculated parameters are air flow rate(0.2 %), liquid fuel flow rate(0.1 %), gas flow rate(0.2 %), load on engine (0.1%), speed of engine (0.3 %), pressure inside the cylinder (0.5 %), temperature(0.4 %), Lower Calorific Value of fuel (0.7 %). Based on these parameters, the calculated accuracy of the performance and emission studies of the engine is found to be within ± 2.5%. However, the accuracy of emission study is found to be ± 2.5 %. The maximum values of coefficient of variance of the performance parameters, viz., BTE and BSFC are 3 and 4% respectively. Whereas, the combustion emission parameters namely, Peak Cylinder Pressure, Ignition Delay, CO, HC and NOx have shown COVs of 5, 4, 2, 2 and 6% respectively.

Instruments and uncertainties

Instrument	Measured parameter	Measuring range	Accuracy	Percentage uncertainties
AVL Digas 444 analyzer	NOx	0 - 5000 ppm	±10 ppm	±0.53
	HC	0 -20,000 ppm	±10 ppm	±0.11
	CO	0 -10% vol	±0.03%	±0.32
	CO2	0-100% vol	±0.5%	±1.0
AVL 437C smoke meter	Smoke opacity	0 -10 FSN	±1%	±1.1
Speed sensor	Engine speed	0 -10,000 rpm	±10 rpm	± 0.1
Stop watch	Time	-	±0.6 s	±0.2
Burette	Fuel quantity	0 -50 cc	±0.1 cc	±1.0
Thermocouple	Temperature	0-1000 deg C	±1°C	±0.1
\Crank angle encoder		±0.5 CA		±0.2

4.Results and Discussion

The efficiency, emission test of engine using Diesel, Diesel with 100gm of Potassium Alum Inorganic Salt under various retention time were tested and assessed for diverse load situation.

4.1 Performance features

4.1.1 Brake Thermal Efficiency

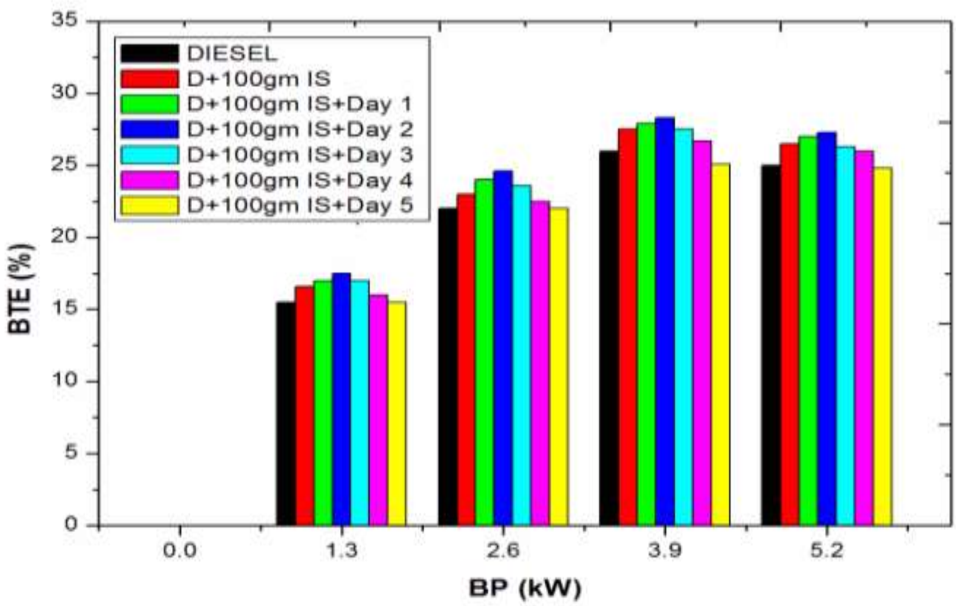

Fig. 6 Variation of BTE against BP

Figure 6 illustrates the change in Brake Thermal Efficiency (BTE) across loads while utilizing Diesel and Diesel blended fuels that has 100gm Potassium Alum Inorganic Salt mixed and retained for 1 to 5 days. The blend is noteworthy for having brake thermal efficiency numbers that are more than Diesel. Nevertheless, the combined fuel's reduced viscosity intensifies the BTE. At maximum load conditions for Diesel the BTE was 26.5 %, for blend with 100gm of Potassium Alum inorganic salt immediately after blending the BTE was 26.9 %, for blend with day 1 the BTE was 27 %, for blend with day 2 the BTE was 27.3 %, for blend with day 3 the BTE was 26.3 %, for blend with day 4 the BTE was 26 % and for blend with day 5 the BTE was 24.8 %. This study attributes to rise in BTE to the advantageous features of the Potassium Alum Inorganic Salt. In addition, the inorganic catalyst's activation energy assistances scald off carbon deposits inside the engines cylinder by the side of top temperature, which thwarts non-polar molecules from depositing on the cylinder wall and lowers the amount of greenhouse gases released into the atmosphere[11,12].

4.1.2 Brake Specific Fuel Consumption

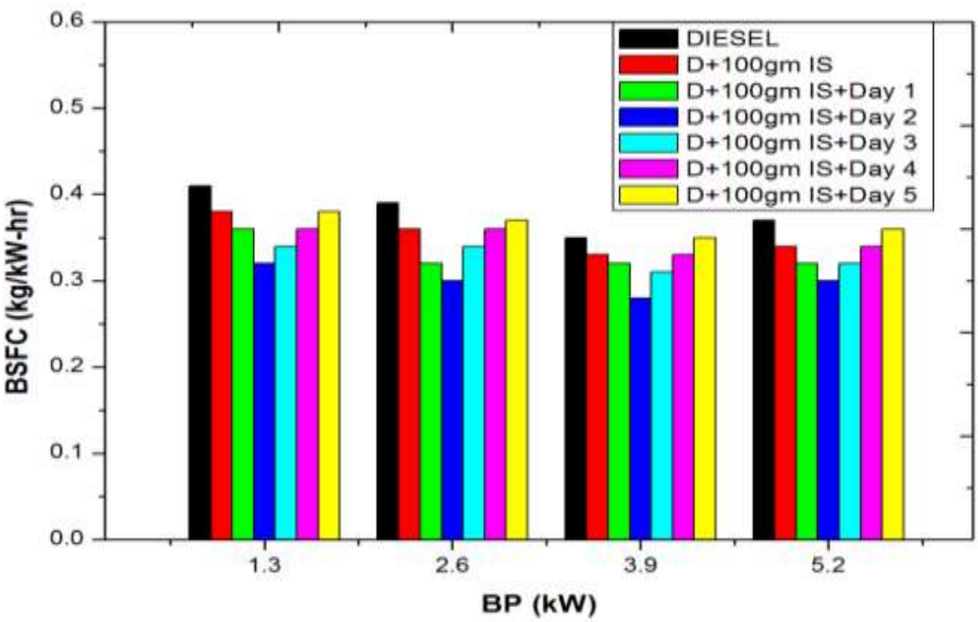

Fig. 7 Variation of BSFC against BP

The deviation of BSFC across various engine loads (kW) for blends of is depicted in Figure 7. The graph shows that the SFC of blended oils are slightly higher when equated to pure diesel. This difference is primarily attributed to diesel's higher calorific value. Blends like E5 and E10 show SFC values that are very similar but slightly larger than those of pure diesel because of lower heating value and larger viscosity of PAIS blended Diesel. The incorporation of Potassium Alum inorganic salts in these blends serves several purposes. It helps increase viscosity to confirm enough lubrication of the injection pump and alleviates the mixture in the presence of high-water content, ensuring homogeneity of the fuel under all situations. Additionally, it possesses worthy detergent assets that keep fuel injection device clean and promote effective atomization. The primary benefits of using this additive include enhanced power of the engine and torque output, enhanced cetane number, reduced carbon dioxide emissions, decreased corrosion, and minimized engine noise. At maximum load conditions for Diesel the BSFC was 0.37 kg/kW hr, for blend with 100gm of Potassium Alum inorganic salt immediately after blending the BSFC was 0.34 kg/kW hr, for blend with day 1 the BSFC was 0.32 kg/kW hr, for blend with day 2 the BSFC was 0.3 kg/kW hr, for blend with day 3 the BSFC was 0.32 kg/kW hr, for blend with day 4 the BSFC was 0.34 kg/kW hr and for blend with day 5 the BSFC was 0.36 kg/kW hr.

4.2 Emission characteristics

4.2.1 Variation of NOx Emission

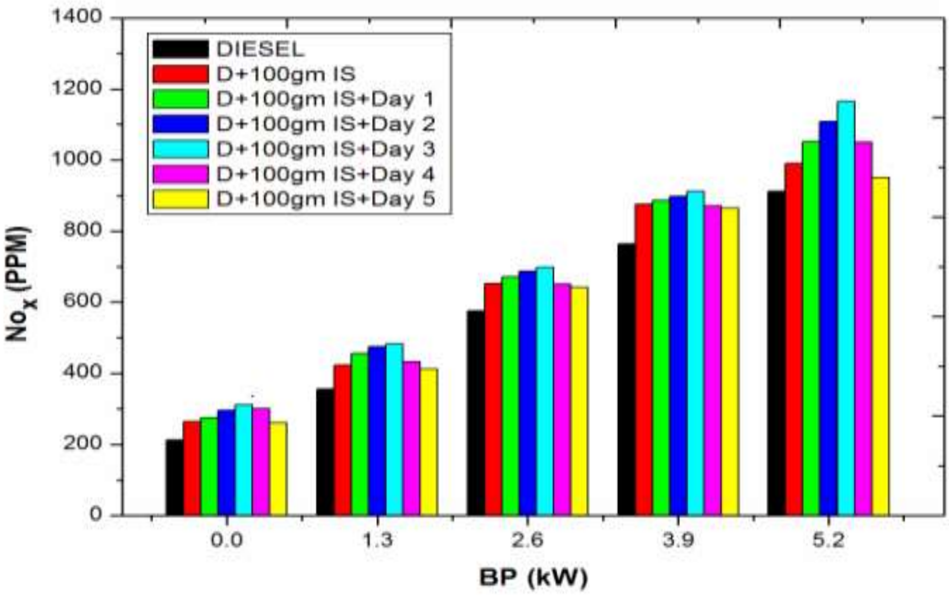

Fig. 8 Change of NOx emission against BP

The variation of NOx emission against BP across different engine loads for Diesel and blends PAIS with Diesel in figure 8. The graph shows that the NOx pollution for blend mixture is slightly higher compared to pure diesel. This difference is primarily attributed to diesel blends oxidation potential. The incorporation of Potassium Alum inorganic salts in these blends serves several purposes. It helps increase viscosity to confirm enough lubrication of the injection pump and stabilizes the blend in the existence of high-water content, ensuring homogeneity of the fuel under all conditions. Additionally, it possesses good detergent properties that keep fuel injection equipment clean and promote effective atomization. The primary benefits of using this additive include improved engine power and torque, enhanced cetane number, reduced carbon dioxide emissions, decreased corrosion, and minimized engine noise. At maximum load conditions for Diesel the NOx emission was 912 ppm, for blend with 100gm of Potassium Alum inorganic salt immediately after blending the NOx was 990 ppm, for blend with day 1 the NOx emission was 1052 ppm, for blend with day 2 the NOx was 1108 ppm, for blend with day 3 the NOx emission was 1156 ppm, for blend with day 4 the NOx was 1050 ppm, and for blend with day 5 the NOx from engine was 952 ppm. The notable rise in NOx pollution at peak load circumstances for Diesel blended with 100 grams of PAIS may be caused by high-quality combustion, which raises the temperature of the combustion chamber.

4.2.2 Variation of CO emission

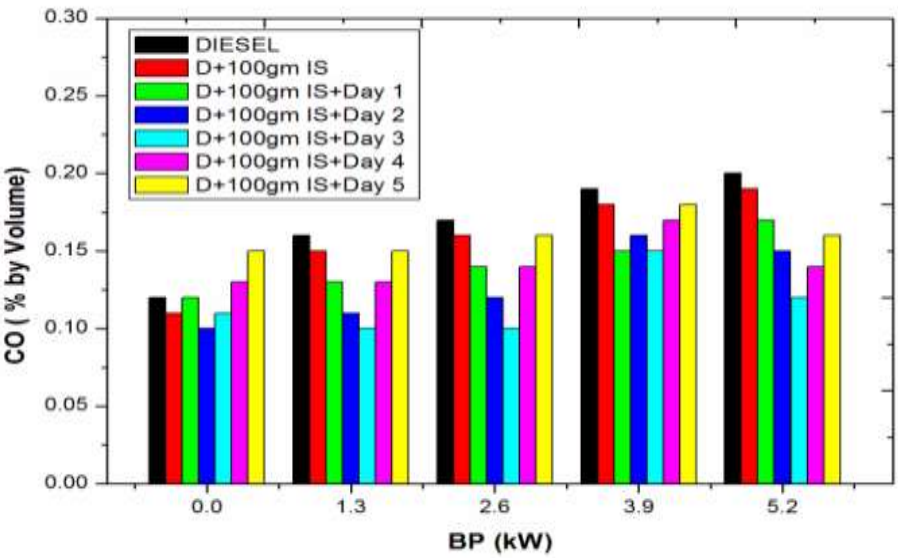

Fig. 9 Variation of CO emission against BP

Figure 9 displays the different levels of carbon monoxide for different mixtures. Based on the measurements, it can be deduced that carbon monoxide emissions tend to decrease by up to 60% while pure diesel emissions tend to increase. By supplying the combustion chamber with excess oxygen, the CO emission can be decreased. Complete combustion makes it feasible to transform CO into CO_2. At full load, carbon dioxide will be visible in the diesel engine's exhaust. The CO concentrations for Diesel was 0.2 % by volume, for blend with 100gm of Potassium Alum inorganic salt immediately after blending the CO emission was 0.19 % by volume, for blend with day 1 the CO was 0.17 % by volume, for blend with day 2 the CO was 0.15 % by volume, for blend with day 3 the the CO emission was 0.12 % by volume, for blend with day 4 the CO emission of 0.14 % by volume and for blend with day 5 the CO emission was noted to be 0.16 % by volume. This higher CO emissions may be because of a weak flow pattern, insufficient quantity of oxygen, inadequate mixture development and ineffective burning.

4.2.3 Variation of HC Emission

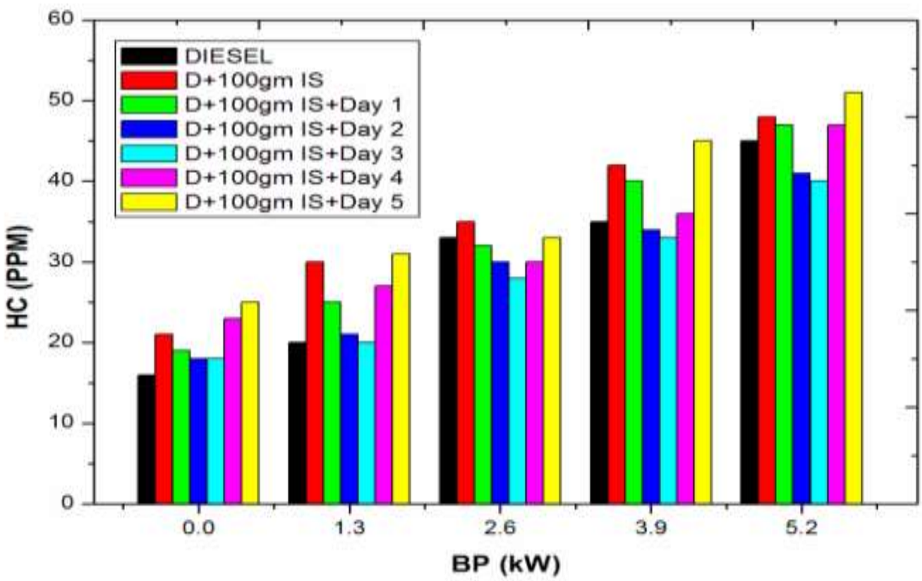

Fig. 10 Change of HC emission against BP

Figure 10 illustrates the hydrocarbon emissions for different blends, showing that, except at larger loads, emissions are slightly lesser than those from diesel. Across various load situations, HC emissions were lesser for Diesel compared to blends E5 to E15. This difference is attributed to diesel's higher calorific value, resulting in less fuel injected and enabling the engine to operate in a leaner state. In an oxygen-enriched environment, combustion is more complete, leading to lower HC emissions with diesel fuel. The incorporation of Potassium Alum inorganic salts in these blends serves multiple purpose like enhanced power of engine and torque, enhanced cetane number, reduced carbon dioxide emissions, minimized corrosion, and reduced engine noise. At maximum load conditions for Diesel the HC emission was 45 ppm, for blend with 100gm of Potassium Alum inorganic salt immediately after blending the HC was 48 ppm, for blend with day 1 the HC emission was 47 ppm, for blend with day 2 the HC emission was 41 ppm, for blend with day 3 the HC emission was 40 ppm, for blend with day 4 the HC emission was 47 ppm, and for blend with day 5 the HC from engine was 51 ppm. This study highlights the fact that the use of Inorganic salts reduces HC emissions significantly, even at a moderate level.

4.2.4 Variation of Smoke Emission

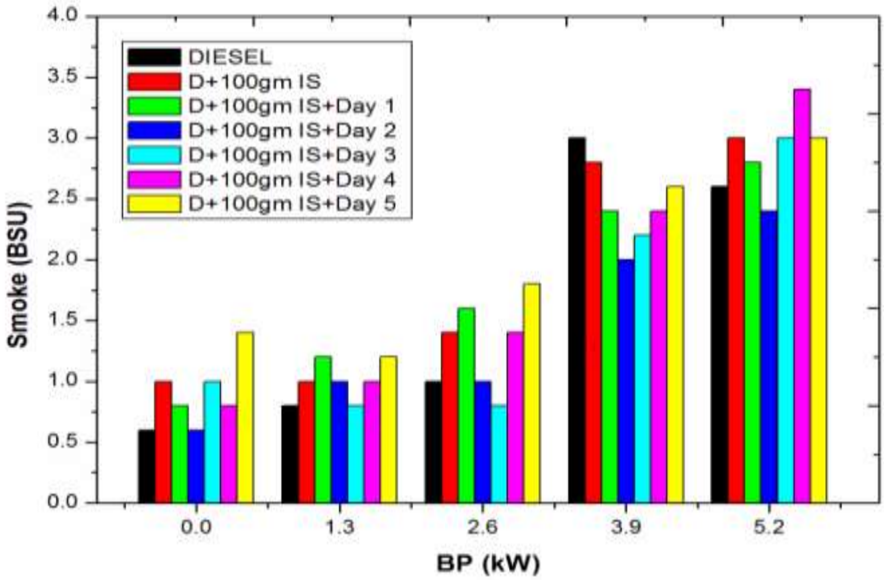

Fig. 11 Variation of Smoke emission against BP

The smoke opacity remains consistent at both high and low power settings but decreases at intermediate power levels as shown in figure 11. Increased smoke opacity is typically attributed to incomplete combustion of fuel hydrocarbons. Moreover, higher proportions of DEE in diesel can escalate smoke opacity, possibly due to phase separation in the blend. The incorporation of Potassium Alum inorganic salts serves several beneficial purposes. For Diesel the Smoke Emission was 2.6 BSU, for Diesel blended with 100gm of Potassium Alum inorganic salt immediately after blending the smoke level was 3 BSU, for blend with day 1 the Smoke emission was 2.8 BSU, for blend with day 2 the Smoke emission was 2.4 BSU, for blend with day 3 the smoke emission was 3 BSU, for blend with day 4 the smoke emission was 3.4 BSU and for day 5 the smoke emission was 3 BSU. When comparing neat Diesel fuel, Potassium Alum Blended fuel has showed lower smoke emissions. This phenomena is brought about by the fast dissipation of water droplets in fuel-rich areas, enhanced OH radicals that efficiently oxidize soot precursors, and increased spray momentum. This reduction is probably the result of better reactant mixing and less soot formation, which were made possible by the quick secondary atomization effects of the IS added diesel.

5. Conclusion

Alternative fuels should ideally be readily available, cost-effective, environmentally friendly, and capable of meeting energy security demands without compromising engine performance. Comprehensive performance tests were conducted on a compression ignition (CI) engine using

Diesel, Blends of Diesel and Potassium Alum Inorganic Salt. The objective was to identify the optimal retention time of blend that offered the best combination of engine performance and emission characteristics. For Diesel the BTE was 26.5 %, for Diesel with 100gm PAIS the BTE was 26.9 %, for day 1 the BTE was 27 % and for day 2 the BTE was 27.3 %, for day 3 the BTE was 26.3 %. The trend of BTE shows that for day 1 and 2 the BTE increases than Diesel and after day 2 the BTE tends to decrease.

Declaration

The authors declare that none of their financial or competitive interests might have an impact on the work that is the topic of this paper.

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Author Contributions

All authors contributed equally to bringing out this research article.

Conflict of Interest

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

Ethics Approval

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

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References

1.Achugasim,O, Ojinnaka,C, Osuji,LManagement of petroporphyrins in a crude oil polluted environment. European Chemical Bulletin, 2(10), 2013, pp 794-796.
2.Ayhan, D Biodiesel : A realistic fuel alternative for diesel engines. Springer, Berlin, 2008 pp 74-83.
3.Hyne,N JNontechnical guide to petroleum Geology, exploration, drilling and Production. RennWell, Alexandria. 2001, pp 1-4.
4.Harris, D C Gas chromatography: Quantitative chemical analysis. Freedman and company, London, (1999), pp675-712.
5.Jimoh,A The use of diesel oil treated with inorganic salts: an alternative to kerosene. Aust. J. Tehnol. 8(1), 2004, 27-37.
6.Leahy,J.G, Colwell,R R Microbial degradation of petroleum in the environment. Microb. Rev. 53(3), 1990, 305-315.
7.Ojinnaka,C, Osuji,L, Achugasim, O Remediation of hydrocarbons in crude oil contaminated soil using fenton's reagent. Environ. Monit. Assess. 184(11), 2012, pp. 6527-6540.

8.Ojinnaka,C M An introduction to principles of organic chemistry. Kemispect Associates, Port Harcourt, 2012, pp 169-178.
9.Okoye, I P fundermentals of petroleum and hydrocarbon chemistry. Allwell Publishers, Port Harcourt. 2009, pp 30-46.
10.Osuji,L C, Udoetok,I A, Ogali,R E Attenuation of Petroleum Hydrocarbons by Weathering: A case study. Chem. Bio. Div. 3: 2006, pp 422-433.
11.Osuji,L C, Achugasim,O trace metals and volatile aromatic hydrocarbon content of ukpeliede-I oil spillage site, Niger Delta Nigeria. J.Appl. Sc.Environ. Mgt. 14(2), 2010, pp. 17-20.
12.Osuji, L C Petroleum Chemistry and Toxicology: In theory and practice. Jeso International, Owerri, pp71-90. Wellinton, B F, Asmus, A F (1995) Diesel engines and fuel systems. Longman, Sydney, 2011, pp56-69.
13. Wellinton, B F, Asmus, A F Diesel engines and fuel systems. Longman, Sydney, 1995 pp56-69.
14. American Encyclopedia of Science and Technology, Vol. 2, 1985, pp. 408-9. McGraw-Hill, New York, USA.
15American Society for Testing Material, Vol.5. 1985, Easton, Philadelphia, USA.
16.Bajah, T.S. A New Chemistry Approach, New Ed., 1975, pp. 94-5, Atmam Press, Ibadan, Nigeria.
17.Dyroff, G.V. Manual on Significance of Tests for Petroleum Products, Chapter 5, 6th ed. Wiley & Sons, New York, NY, USA. 1993.
18.Innocent, S. Possibility of Chemical Conversion of Diesel Fuel to Kerosene, pp. 4-8, 1997. Bachelor of Engineering Thesis, Federal University of Technology, Minna, Niger State, Nigeria.
19.Joseph, O. Production of Bio-fuel Using Palm Kernel Oil, 2001, pp. 11-25. Bachelor of Engineering Thesis, Chemical Engineering Department, Federal University of Technology, Minna, Niger State, Nigeria.
20.Leffler, W.L. Petroleum Refining for Non-Technical Mind, 2nd ed., 1987, pp. 3 and 32. Viscas, New Delhi, India.
21.Liotta, F.J. Jr. Modelling a Dual-fuelled Cylinder (HCCL) Engine Using a PDFbased Engine Cycle. ARCO Chemical SAE Paper, 2004, Vicas Publ., New Delhi, India