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Development of synthesized fuels based on diesel by incorporating zinc oxide nanoparticles, surfactant and ethyl acetate

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ABSTRACT

A study investigated the performance effects of non-stabilized and surfactant-stabilized nanoparticles (NPs) in the presence and absence of ethyl acetate to optimize diesel fuel attributes. Various concentrations of NPs were added to diesel as the base material, with Nephelometric Turbidity Unit (NTU) used to assess nanofuel stability. Results showed that diesel containing modified 15–20 nm NPs, along with blended diesel fuel (BDF) with a Hydrophilic-Lipophilic Balance (HLB) value of 7.9, exhibited the highest stability over 48 h. The inclusion of NPs positively impacted parameters like calculated cetane index (CCI), initial boiling point (IBP), flash point, density, and viscosity. However, it reduced volatility and pour point. Tween 80 and Span 80 reduced CCI, volatility, and pour point while increasing flash point, density, and kinematic viscosity. Ethyl acetate did not notably affect volatility, density, or viscosity but improved cold-cranking index (CCI) and pour point during combustion by acting as an oxygen buffer. It also showed potential in reducing carbon monoxide (CO) and unburned hydrocarbons (HC) in exhaust emissions

1. Introduction

Because of the increased need for energy, researchers have been investigating several new energy sources as well as methods to make current energy sources more efficient. As a consequence, the development of improved fuels is a major problem. Diesel fuel, which is produced by refining crude oil, is widely utilized in commercial and industrial applications. The technology utilized in its production, as well as the quality of the oil, have an influence on the composition of diesel fuel. Diesel fuels provide a few issues when used in an engine owing to their higher carbon content and heavier weight, both of which make them less attractive. One of the most major concerns is a high freezing point, which causes the filters to get clogged over time; as a consequence, utilizing them in cold conditions poses some obstacles. Following the refining process, roughly 100 parts per million (ppm) of paradine is added to diesel fuel to reduce its freezing point. Diesel fuel is characterized by the fact that it has a low combustion efficiency and a large pollutant content, both of which contribute to the pollution of the air. Because of this, various research has centered on discovering strategies to increase the properties of diesel fuel [1–4].

Furthermore, the exploitation of fossil fuels for use in the transportation and energy sectors has had a severe impact on the surrounding environment, resulting in an increase in gas emissions such as CO2, CO, NOx, SOx, and others [5]. As a result, researchers are investigating alternative fuel sources in order to lessen our reliance on fossil fuels and the quantity of pollutants emitted into the environment [6,7]. As a

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result, there has been a significant surge in research on commercial biodiesel production and applications across Asia, namely in India, Malaysia, and Indonesia [8–10]. The direct use of biodiesel in typical diesel engines has a few drawbacks, including poor fuel atomization, piston ring sticking in cold weather conditions, somewhat increased density, and a minor decrease in fuel efficiency [11]. The constraints of biodiesel may be overcome by adjusting the properties of the fuel by the use of nanoadditives with a high energy content [12–14]. A number of researchers have recently investigated the impact of nano additions on biodiesel, and they discovered that the base fluid's properties have significantly enhanced. The introduction of nanoparticles into biodiesel results in complete combustion of the fuel, which enhances catalytic activity, the micro explosion phenomenon, and eventually results in lower emissions [15,16]. According to the findings of Fazliakmetov and Shpiro [17] the use of additives with high quantities of iron, manganese, and cerium may help reduce the quantity of particulate matter (PM) released by diesel engines. Peroxides with 0.2–0.5% Mn concentration reduce smoke by 22–25% [18]. It is critical that HC emissions be reduced as a result of the decrease of aromatics in Diesel. Yang et al. [19] performed an experiment in which they added Mn-based additives to diesel fuel and discovered that the quantity of aromatic HC in the fuel was decreased by half. It is not possible to avoid being exposed to pollutants if the diesel contains Ca, P, K, Zn, or Pb. Numerous studies have demonstrated that various additives affect combustion and emissions by altering the cetane number [20–24]. Karthikeyan et al. [25] explored a diesel engine cylinder kinetics utilizing a canola oil methyl ester containing ZnO nanoadditive. The usage of canola oil containing a ZnO nanoadditive reduced nitrogen oxides (NOx), carbon monoxide (CO), and hydrocarbons (HC) emissions by about 18.7%, 14.0%, and 50%, respectively. Vellaiyan and Amirthagadeswaran [26] studied the combustion characteristics of a diesel engine by emulsifying diesel fuel in water and adding a ZnO nanoadditive to the mixture. When ZnO nanoparticles were added to the emulsion fuel, the testing revealed that NOx, CO, and HC emissions could be decreased by 32.5%, 25%, and 9.9%, respectively. Because of the presence of ZnO nanoparticles, this decrease was feasible. The same authors discovered that a mass fraction of 100 ppm ZnO nanoparticle in water emulsified diesel fuel promotes enhanced combustion, performance, and emissions levels [27]. This mass fraction was shown to be the best state for improving combustion, performance, and emissions levels.

Al, Al_2O_3, CeO_2, Mn, CuO, FeO, and CoO are some of the most often utilized NPs in diesel fuel additives [28]. By synthesizing organic compounds including manganese, magnesium, copper, and calcium and then employing those compounds in their study, Guru et al. [29] were able to increase diesel fuel attributes such as freezing point, crisis point, viscosity, and cetane rating. Soudagar et al. [30] employed Sr@ZnO nanoparticles in the diesel variation process. This inquiry was hampered by the volatility of the new fuel.To make the nanocrystals in the diesel more stable over time and less susceptible to deterioration, they incorporated trimethyl sodium halide. Lian et al. [31] described a solvothermal technique that comprised a mixed solvent solution for the production of ZnO NPs with regulated size. The NPs were generated using this way. The average diameter of the NPs may be modified to fall anywhere between 15 and 25 nanometers by adjusting the percentage of ethanol to ethylene glycol in the mixture. Wang et al. [32] were the first to report on the solvothermal fabrication of tunable-size ZnO microstructures. Water was introduced to the organic solvent at the appropriate moment throughout the procedure to achieve this outcome. The reaction's precursor was an aqueous solution of zinc acetate dissolved in methanol. The resultant ZnO microstructures, however, were not homogenous and included imperfections. Bitenc and Crnjak Orel [33] presented a procedure for the manufacture of nano- and sub micrometer-sized ZnO that only needed a single step and took place in the solution phase. Another paper demonstrating the capacity to vary the size of ZnO NPs by changing the water content in the precursor suspension formed by mixing Zn (CH3COO)2 + NaOH + tetradecane in EG is the one alluded to in the preceding sentence by Li et al. [34].

Researchers have shown that nanoparticles have the ability to act as a catalyst in the combustion of diesel fuel. One of the key aims of this study is to assess the effectiveness of nanoparticle additions to commercial diesel fuel produced using ethyl acetate as a cetane improver. Before going on to the next stages, we combined Tween 80 and Span 80 to determine if it was necessary to scatter nanoparticles. The predicted cetane indices, condensation and instability, pour point, energy content, density, and kinematic viscosity were utilized to assess the impact of ethyl acetate on the diesel fuel's integrity. This examination was carried out in line with the ASTM's standard testing protocols. Finally, an exhaust scientific experiment was conducted to evaluate the performance of regular diesel fuel to that of the modified fuel.

2. Experimentation

2.1. Materials

An Indian refinery was responsible for the delivery of the grade IV petroleum diesel. The characteristics that were studied for unblended diesel fuel are shown in Table 1. TCI Chemicals was the supplier for the ethyl acetate, NPs, Tween 80, and Span 80 that were used in this experiment. Tween 80, also known as polysorbate 80, is a nonionic surfactant that is often used to stabilize emulsions and improve solubility of hydrophobic substances in aqueous solutions. Span 80, or sorbitan monooleate, is another nonionic surfactant frequently employed as an emulsifier and dispersing agent. Both Tween 80 and Span 80 play crucial roles in enhancing the stability and performance. Ethyl acetate, with a molar mass of 88.1 g/mol, is characterized by several key properties. Firstly, it appears as a colorless liquid, distinguishing it visually. Additionally, it emits an ether-like, fruity odor, which is often noted when handling the compound. Ethyl acetate's physical state is defined by its melting and boiling points; it solidifies at −83.6 °C and transitions to a liquid state upon reaching a boiling point of 77.1 °C. These properties collectively contribute to ethyl acetate's distinct characteristics and utility in various industrial and laboratory applications.

2.3. Synthesis of nano-fuels

Experiments on nanofuel production were devised and carried out in line with a strategy that involved four separate steps. The initial phase in the process of generating nano-fuels was disseminating the nanoparticle in diesel fuel using a bath ultrasonic bath for thirty minutes at temperatures ranging from70 to 80^{0}C. This technique step was completed at the start of the procedure. We will be able to predict the appropriate nanoparticle concentrations after we have examined the stability of the nanofluid. Second, you will sonicate the fuel for fifteen minutes at 70 °C with a combination of the surfactants Tween 80 and Span 80 to boost its nano-stability. Third, compute the hydrophilic-lipophilic balancing number. Fourth, you will calculate the range of hydrophilic-lipophilic

Table 1
Attributes of relatively pure diesel fuel.

Characteristics	Unit	Value
Compactnessabout 200C	kgm-3	893
Viscosity about 50^{0}C	mm^{2}s	2.9
Cetane index	–	59.22
Solubility at 65^{0}C	μm	433
Ignition Point	^{0}C	68
Virtualized Point	^{0}C	−3.9
Pour Juncture	^{0}C	−12
ash proportion	w/w%	893
Aromatic proportion	w/w%	2.9
Concentration of Particles in Perpetual Movements	mgkg^{-1}	59.22
Dependent carbon	w/w%	433
Quantity of Sulphur	w/w%	68
Quantity of water and sand particles	v/v%	−3.9

balance. Fifth, you will choose an HLB range those accounts for the fuel's nano-stability. The hydrophilic-lipophilic balance number may be preconceived using the mathematical Eq. (1) (Foo et al., [35]).

$$HLB_{mix} = (X)HLB_{Tween80} + (1 - X)HLBSpan_{80} * 100 \quad (1)$$

Where and x are the hydrophilic-lipophilic equilibrium ratio of the mixture and, roughly, the proportion of ammonium lauryl detergent included in the grand total of Prepubescent. Whereas and x denote the hydrophilic-lipophilic balance number of the combination, respectively. Table 2 displays the HLB values of the samples generated, as well as the amounts of Span 80 and Tween 80 utilized. The focus in the last stage of the technique is on precise hydrophilic-lipophilic balance number optimization within the preoperational range of the hydrophilic-lipophilic balance number based on differences in nano-fuel stability. This is the last phase in the procedure. In the fourth step of the process, the ethyl acetate is dissolved in the diesel fuel by rotating the mixture for five minutes to generate a homogeneous solution. Following that, the physicochemical properties of the nano-fuels are examined. Each experiment was done three times to guarantee that the findings were accurate and dependable.

2.4. Modified fuel composition

The turbidity of the modified fuels was assessed in accordance with ASTM D1655, which allowed for an investigation into the long-term viability of the newly developed diesel fuels. The CCI is an indicator that may be used for measurement, and it can also be used to assess the quality of diesel fuel. It was developed as a measuring index for the purpose of assessing the invasion and ignition reliability of Nano-fuels, in addition to the amount of time required for ignition [36]. In spite of the fact that ASTM D976 is the approach that is used the vast majority of the time, various other methods have been used to show CCI. Two examples of these techniques are the ASTM D976 and the ASTM D4737 standards. These processes are determined by employing the physical characteristics of diesel fuel in the calculation process. When calculating CCI using this method, both the API gravity and the mid-boiling point (T50) are taken into consideration. Lokesh et al. [37] Throughout the duration of this experiment, the CCI was determined by using an Eq. (2) that was based on ASTM D976.

$$\text{CCI} = 467.74 - 1743.416D + 794.74D^2 - 0.654B + 99.904(logB)^2 \quad (2)$$

Where D and B are the expected densities at 15^0C and the threshold of boiling, appropriately, using ASTM D1298 and test method D86 are used. Both of those numbers came straight from the ASTM guidelines. Nano-fuels produced in line with the ASTMD86 standard were put through their paces in a distillation device and their volatility and distillation behavior were evaluated using a Distillation by force technique based on the test method D86 standard. The extraction mechanism of Nano-fuels was the focus of this analysis. Using the Pensky-Martens shuttered receptacle method, which is in line with the requirements of the American Society for Testing and Materials (ASTM) D93 standard, we were able to determine the flash points of the nano-fuels. In addition, the ASTM D 6749 standard was used in order to conduct an analysis of the sample pour points. A viscometer was also utilized in order to determine the amount of viscosity that the newly developed Nano-fuels had in line with the standard that was set by ASTM D7042. This was done in order to ensure that the results were accurate.

Table 2
Surfactants used in the modified Diesel fuel.

HLB_{mix}	Tween 80 (%)	Span 80 (%)
10	91.90	8.10
9	75.81	24.19
8	59.68	40.32
7	43.55	56.45
6	27.42	72.58
5	11.29	88.71

3. Materials and methods

3.1. NP, SEM, XRD and FTIR

In Fig. 1a, the structure of nano- admixtures is shown. Using a transmission electron microscope, we were able to establish that the particles have a spherical shape and are grouped together (SEM). In addition to this, it is quite important to comprehend that the sizes fluctuate anywhere from 15 to 20. The XRD profile of the NPs was constructed by analyzing X-rays in a method that was compatible with the cubic fluorite structure that was described on the Joint Committee for Diffraction Data Specifications (JCPDS) card. This allowed for the creation of the XRD profiling that is shown in Fig. 1b. Crystalline plates could be detected in the data at the spectrum's peaks 121, 210, 230, and 321. The most prevalent NP functional groups may be seen in the FTIR spectrum shown in Fig. 1c. While the numbers around 130 depict the strain that builds within the bands, the numbers around 560 reflect the bands themselves.

3.2. Engine experimental setup

A diesel engine equipped with a fixed bed underwent a series of tests to assess the efficacy of diesel-biodiesel blends, with experiments involving both the presence and absence of nanoparticles. The experimental arrangement included fitting an eddy current dynamometer onto the engine's shaft, enabling a diverse range of tests involving manipulation of engine loads and fuel mixtures. The engine's rotational speed was consistently maintained at 1300 rpm. It operated in a steady and continuous mode, with data collected at every power output level. Throughout the experimental procedure, a designated fuel storage tank was employed for housing both the created samples and the petroleum-based fuel. The quantity of fuel used was measured employing a conventional burette, a precise method widely utilized for volume measurement. A timer was used to record the duration between each injection of 5 mL of the petroleum-based fuel and biodiesel mixture into the conventional burette. Subsequent to the engine evaluation, the fuel underwent an examination in accordance with ASTM criteria. Table 3 highlights the most notable discrepancies identified within the considered variables. The experiment was conducted thrice, once for each of the distinct tests, to ensure the utmost accuracy of results.

To gather acoustic data, an audiometer analog was positioned approximately 0.80 m away from the power source of engine test bed. The statistics provided earlier demonstrated the magnitude of the sound pressure level originating from external sources. To facilitate the experimental process, a portable microphone was employed. The movement of the diaphragm, or the fluctuation in sound pressure measured in Pascal units, resulted in the generation of an electrical signal. This variation in sound pressure was quantified and subsequently transformed into the corresponding, intensity of pressure from sound expressed in decibels (dB).

3.2. Assessing the resilience of nanofuels

To conform to the specifications of the amended fuel solidification process, the results of mixing nanoparticle concentrations in the range of 20–60 are presented in Fig. 2a. These results demonstrate that the modified fuel is stable. A study of fuels manufactured with varied concentrations of nanoparticles revealed that the turbidity of modified fuel developed with increasing concentrations of nanoparticles. This was shown in the comparison of the fuels. However, after 60 min, the nanoparticles begin to cluster together considerably more firmly, which results in the precipitation of dense colloids in a very short amount of

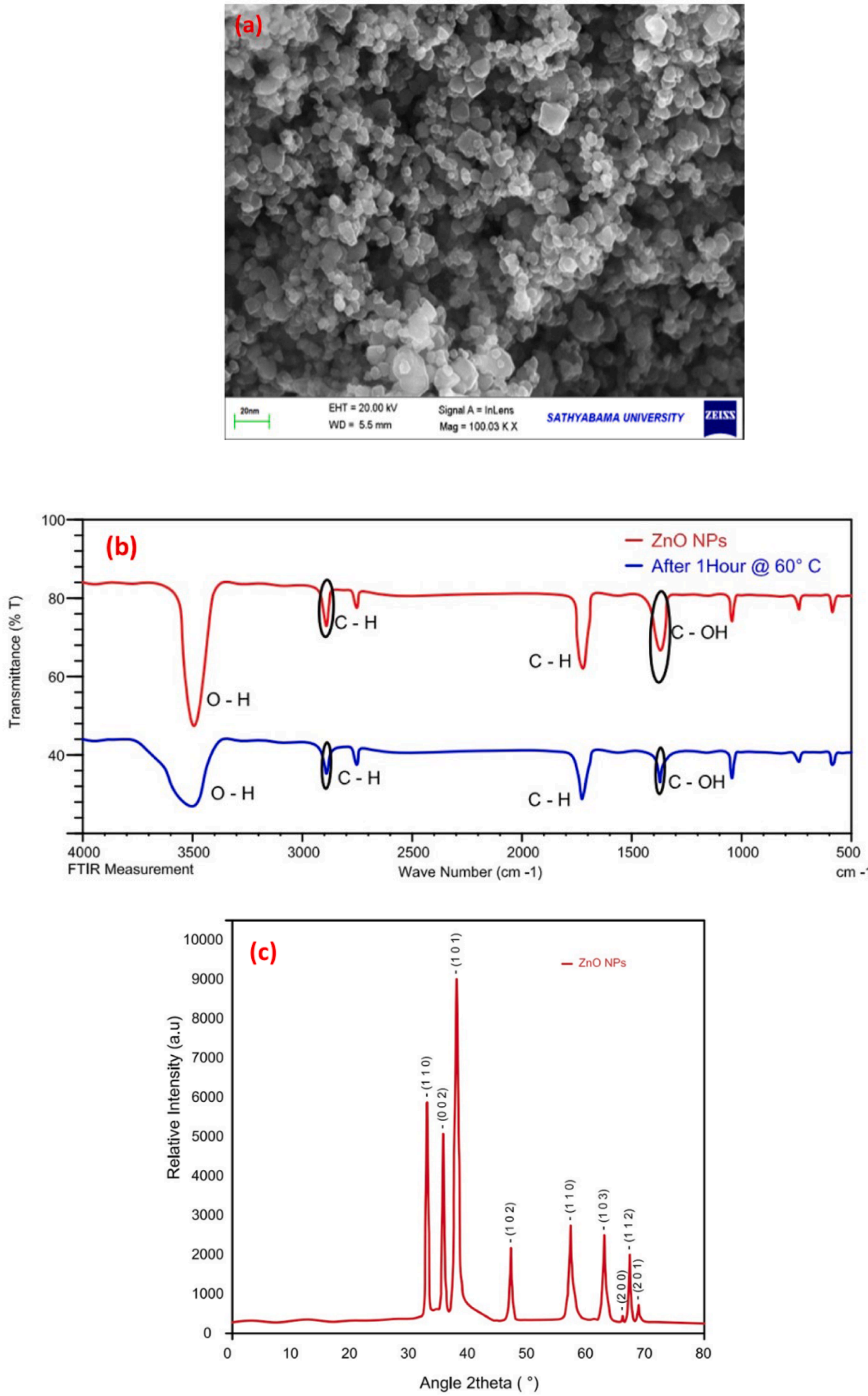


Fig. 1. (a)SEM (b) FTIR spectrum (c) XRD pattern.

time. The change in turbidity was used as a measurement of the nano-level fuels of stability throughout these experiments. The reliability of the nano-fuel deteriorated as the accumulation of NPs elevated [14]. This was due to the fact that the NPs, which are what keep the particles in suspension thanks to their buoyancy, fell to the bottom as gravity triumphed over buoyancy. When compared to the other concentrations, the NPs at a concentration of 20 were found to have the best dispersion and stability. As a result, this level was chosen as the ideal one at which to continue the research.

During the second stage of the experiment's design procedure, surfactants such as Tween 80 and Span 80 were incorporated to the enhanced fuels. This was done to augment the nano- consistency of the fuels. Tween 80 and Span 80 were incorporated to the enhanced fuels in predetermined proportions to obtain HLB values between 5 and 10. The

Table 3
Instrument catalog featuring known uncertainty values.

Instruments	Accuracy	Range	%uncertainties
Gas analyzer	±0.02%	CO 0–10%	±0.1
	±0.02%	CO_2 0–20%	±0.10
Smoke meter	±0.1	HSU 0–100	±1.0
Temperature indicator	±1 °C	0–1100 °C	±0.1
Stopwatch (digital)	±0.1s	–	±0.2
Pressure sensor	±1 bar	0–120 bar	±0.1
Crank angle encoder	±1°	–	±0.2
Speed sensor (proximity type)	±10 rpm	0–1000 rpm	±1.0
Torque indicator	±0.1 N m	0–100 Nm	±0.1

turbidity of the nano-fuels was then measured after 2, 24, and 48 h. The NTU consistency of enhanced fuels with HLB values in the extend of 6–8 is superior to that of fuels with lower HLB numbers, as illustrated in Fig. 2b. This is shown by comparing the NTU predictability of the two fuel sets. This is because the quasi proportion of the substances in the changed fuel channel is substantially less than the polar component. However, in step three, we tested the resilience of the changed fuel by taking the close proximity of the HLB values into account. This enabled more precise findings. As a consequence, in order to improve the stability of the nano-fuel, the turbidity variations for the newly enhanced fuel were tested multiple times with a difference of <0.2 between each attempt. The turbidity of the diesel fuel was measured two, twenty-four, and forty-eight hours following the addition of surfactants such as Tween 80 and Span 80 in particular amounts to create HLB values between 5 and 10 to assess how much of an influence the surfactants had on the fuel. The changed fuels yielded HLB values ranging from 5 to 10. The nano-stability fuel may be enhanced by combining it with other fuels, as illustrated in Fig. 2b. This is shown in the image. The turbidity of nano-fuels was tested 2, 24, and 48 h after surfactants were applied to modified fuels to achieve HLB values in the extend of 5–10. This was done to get the necessary degree of HLB. Fig. 2b shows that modified fuels with HLB values in the range of 6–8 have better NTU stability than modified fuels with lower HLB numbers. This is shown by the decreased NTU stability of changed fuels with lower HLB levels. This is because the non-polar proportion of the molecules in the changed fuel medium is substantially less than the polar component. The stability of the altered fuel was investigated; however, for more exact findings, the consideration of narrower HLB number spacing, which was incorporated in the third phase, was taken into account. As a consequence, the turbidity tests for the newly adjusted fuel were repeated until the difference was less than 0.2.

Fig. 2c demonstrates that increasing the from 7 to 8.6 and subsequently lowering it to 9 enhanced the turbidity of nano-fuels. As a result, an HLBmix value of 8.6 provided the greatest degree of consistency throughout the trial. Increased intermolecular interactions between the surfaces of the NPs and the molecules of fuel around them may help them resist the gravitational pull of their surroundings. When Tween 80, Span 80, and 20 NPs were added to the mixture, a modified fuel with an 8.6 number was generated. This fuel was taken into account in the ensuing studies. It was determined if the modified diesel sample could survive high temperatures. Fig. 2c demonstrates that increasing the from 7 to 8.6 and subsequently lowering it to 9 enhanced the turbidity of nano-fuels. As a result, a value of HLB mix equal to 8.6 provided the maximum degree of consistency. The improved intermolecular interactions between the NPs' surfaces and the fuel molecules around them are most likely what permits them to defy gravity [38]. This is one possible reason. As a consequence, the modified diesel contained therein was heated for one hour at a temperature of sixty degrees Fahrenheit. The nanoparticles were exposed to an FTIR evaluation for study after being separated by centrifugation at 5500 rpm for 15 min. The high temperatures have no effect on the functional groups of the nanoparticles, as illustrated in Fig. 1b.

3.3. Impact of admixtures on CCI

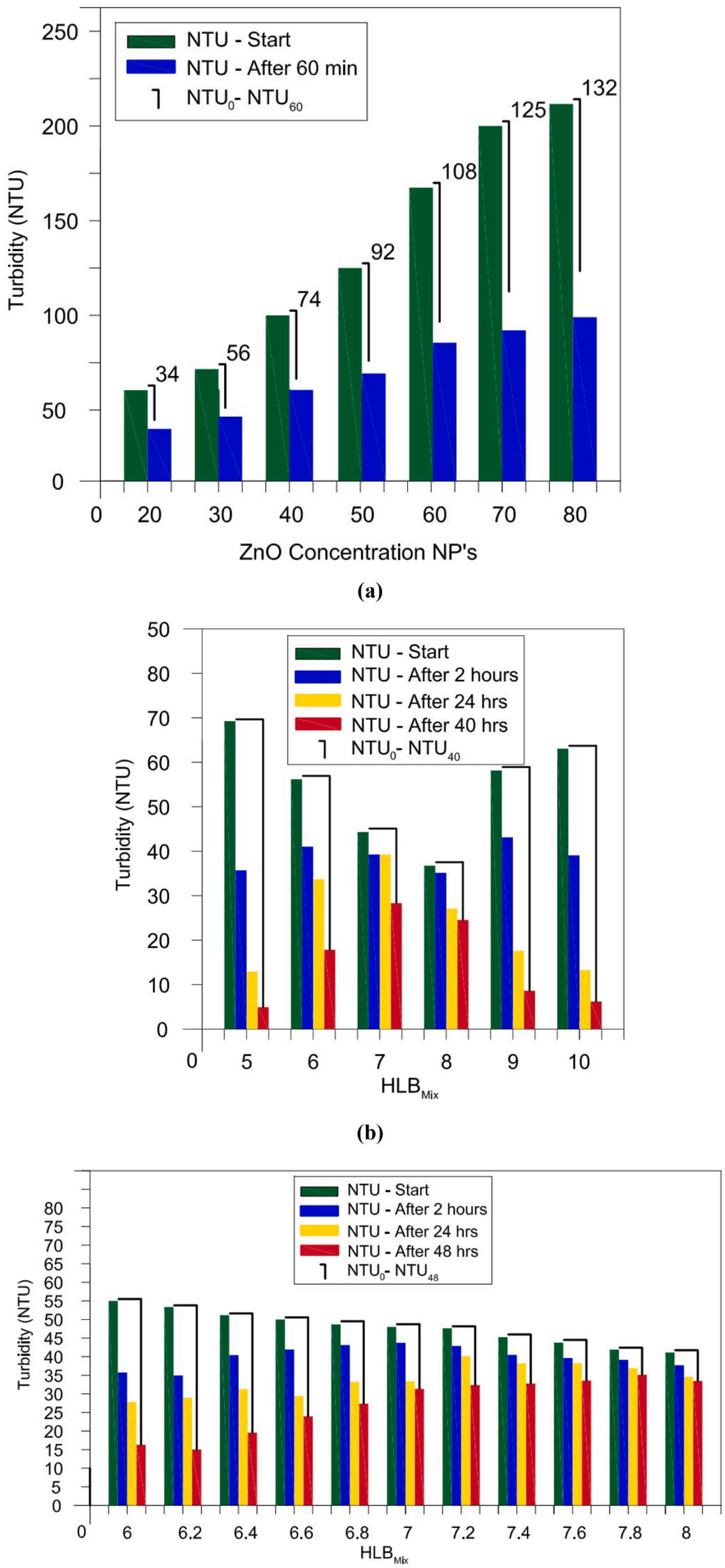
CCI was measured and compared for diesel, enhanced diesel (Diesel fuel addition NPs), adapted diesel with irritants (BDF: Octane booster plus NPs plus Emulsifiers), and enhanced diesel with ethyl acetate. As shown in Fig. 3, the incorporation of nanoparticles to petroleum diesel tends to increase CCI, whereas the inclusion of surfactants tends to decrease CCI. Furthermore, it was demonstrated that ethanolic extract has the capacity to restore the CCI of the blended modified petrol while also enhancing it. Both contain an abundance of hydroxyl functional groups, which enables them to react rapidly with the oxygen molecules that are provided by the Nanoparticles that develop naturally in the fuel medium [39,40]. In a nutshell, surfactants have the potential to lower the quantity of oxygen that is present in the fuel medium, which in turn slows down the process of ignition [41]. However, the inclusion of ethyl acetate enhanced the CCI of the nano fuel because to the oxygen that it generated during the reaction. In other words, surfactants have the potential to decrease the quantity of oxygen that is available in the fuel medium, which in turn slows down the ignition process [42]. The CCI of the nano fuel was improved as a result of the addition of ethyl acetate, which has a function that improves CCI as a result of the oxygen that it releases.

3.4. The influence of compositions on distillate, volatile, pour point, and flammability

The outcomes of distillations carried out in accordance with ASTM D86 on both the standard diesel fuel and the modified fuels are shown in Table 4. Because the addition of NPs strengthens the intermolecular interactions between the particles of diesel fuel and the characteristics of the NPs' surfaces, there is an increase in both the enthalpy of unburned fuel as well as the surface tension of diesel fuel [43]. This can be attributed to the fact that diesel fuel has a higher surface tension. In addition, the incorporation of surfactants into the modified fuel medium resulted in increased hydrophilic and hydrophobic interactions, which resulted in a strengthening of the diesel fuel/NPs bindings [44]. In addition, it has been shown that including a surfactant in the fuel causes a rise in the concentration of esterified fatty acids, which have a higher boiling point and may intensify the contacts between molecules [45]. The fuel's changing latent heat of vaporization enthalpy as the temperature was increased may be responsible for the boiling point disparities that were seen at higher percentages [46]. These inconsistencies were observed between basic diesel fuel and modified fuels.

The information shown in Table 4 demonstrates that the IBP of BDF with ethyl acetate has a lower value than the IBP of BDF, and that this difference is effectively maintained until half the dieselhas been evaporated, after which the simmering points and volatile substances fuel rise. It's possible that the polar chains in ethyl acetate are what enable it to create covalent bonds with surfactant molecules at ambient temperature as opposed to higher ones [47]. Because the temperature at which ethyl acetate decomposes is very low, the boiling point of BDF that has been supplemented with ethyl acetate is lower than that of pure BDF. However, owing to the low percentage of ethyl acetate that was added to the BDF, there was hardly any noticeable change in the boiling point at all.

The results of the tests performed on modified fuels with varied concentrations of NPs in order to determine their flashpoints are shown in Fig. 4a. After adding 20 NPs to the fuel, the flashpoint rose to 5, and each further increase in NP concentration resulted in a rise of just 3.5 °C. Another point in favor of employing lower dosages of NPs is the fact that doing so reduces the amount of PM that is emitted as a consequence of combustion. Fig. 4b depicts the changes in diesel fuel's flashpoint that occur as a result of the addition of NPs, surfactants, and ethyl acetate. The inclusion of catalytic NP considerably enhances the flashpoint of altered fuels and lowers their volatility, making these fuels much safer to handle and transport [48]. The addition of surfactants to the fuel



(a)

(b)

(c)

Fig. 2. A comparison of the 60-minute NPs stability in the various modified fuels (a). After 2, 24, and 48 h, the turbidity of the ready nano-fuels varies by (b) a constant factor and (c) a range of values from 7 to 8.6.

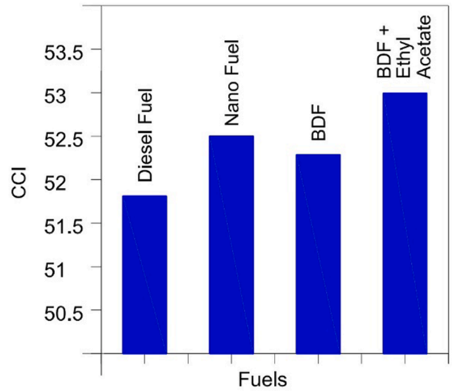
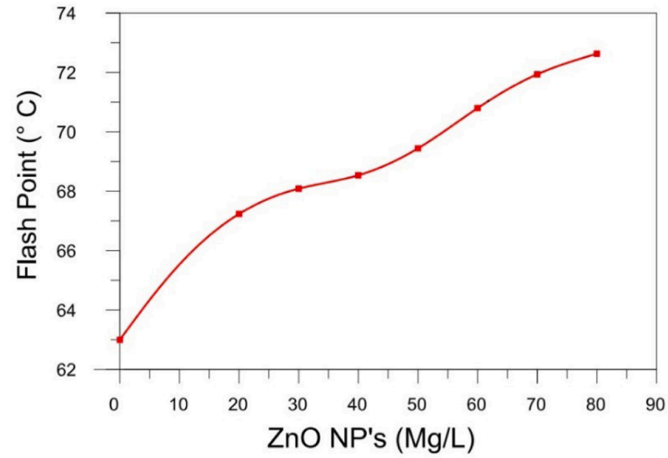
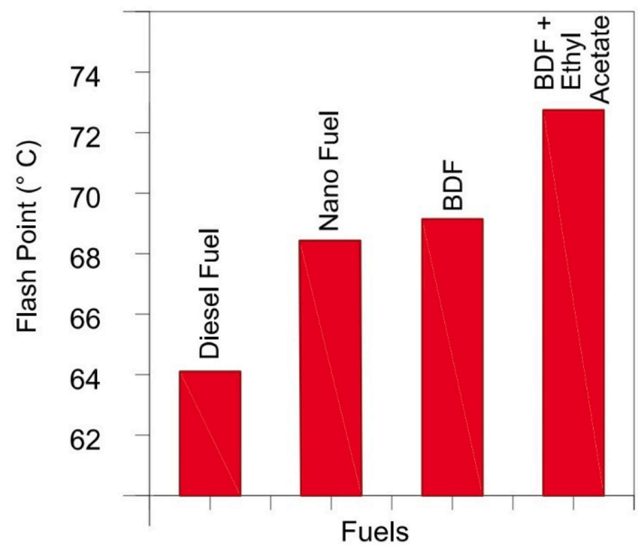


Fig. 3. Effects of ZnO NPs, surfactants, and ethyl acetate on fuel CCI.



(a)



(b)

Fig. 4. (a)The influence of nanoparticles on the enhanced fuel threshold (b)The flashpoints of diesel fuel.

Table 4
Shows the distillation date of ethyl acetate in BDF.

Portion (%)	Point of boiling (°)			
	Diesel Fuel	Enhanced fuel	BDF	BDF + Ethyl Acetate
0	169	171	176	172
5	189	194	195	192
10	199	203	204	203
20	213	215	215	215
30	224	226	226	226
40	234	238	238	238
50	248	252	255	250
60	267	269	271	269
70	288	295	294	291
80	316	319	324	317
90	348	349	351	348
95	360	363	364	362
100	371	371	370	371

improved the dispersion of NPs, which in turn enabled more productive interactions and a more efficient catalytic function. As a consequence, the flashpoint of BDF was much greater when compared to that of nano-fuel. ZnO nanoparticles are introduced as the more reasonable nanoparticles because of their increased viscosity index, decreased flash point and ignition delay, decreased emissions, and improved combustion [49]. Ethyl acetate is added to diesel fuel to increase its flashpoint. This is because ethyl acetate breaks down into more polymer blends capable of supplying oxygen for chemical initiation. After adding 100 ppm of surfactants to diesel fuel, researchers found that they were able to generate a larger nanoparticle scattering in the fuel, and the fuel's flash point was found to be 50 °C.

The pour point is a very important property to have if you are going to be carrying diesel fuel or storing it in areas where the temperature is lower. The pour point of each and every one of the prepared specimens was measured. As can be shown in Fig. 5a, the expansion of NPs, surfactants, and ethyl acetate nitrate to a solution may, respectively, reduce the solution's pour point by about 35%, 52%, and 69%. It's possible that this is due to the intermolecular bonds between the molecules of paraffin becoming less stable with time. When the aforementioned materials are included into the fuel medium, the pour point experiences a significant decrease. This is because the paraffin molecules prefer to establish bonds with the aforementioned materials rather than with smaller-sized paraffin compounds [50].

3.5. Additive impacts on density and viscosity

Refer to Fig. 5b to show how the inclusion of NPs, surfactants, and ethyl acetate affects the density. The density of diesel fuel containing NPs is hardly affected, however the density of diesel fuel with Tween 80 and Span 80 may be greatly improved. When ethyl acetate was added to the mixture, the density of the modified diesel decreased even more. Because the product data sheet specifies that the bulk density of the NPs varies from 0.2% to 8.6%, adding the NPs to the mix may result in a higher overall density. Furthermore, Tween 80 and Span 80 have substantially greater densities than diesel fuel, despite the fact that they may be trapped inside the larger molecules that make up diesel fuel. Furthermore, in comparison to diesel fuel, ethyl acetate molecules are substantially bigger; as a consequence, they occupy less space in the fuel, resulting in the modified diesel having a lower density [51].

To evaluate the kinematic viscosity of the samples, a standard test methodology known as ASTM D4052 was employed. Fig. 5c demonstrates the kinematic viscosity differences that occur as a direct result of the varied additive concentrations. Small changes in fuel viscosity were found at low NP concentrations; however, these changes may be attributable to the NPs' proclivity to produce resistance between fluid layers [52]. When Tween 80 and Span 80 were both added to the mixture, the viscosity of the modified diesel increased significantly. Surfactants have a propensity to enhance kinematic viscosity when added to diesel because they strengthen the interlayer forces of the fuel, making it more difficult to move the fluid around. However, adding a little quantity of ethyl acetate to the modified diesel resulted in a slight

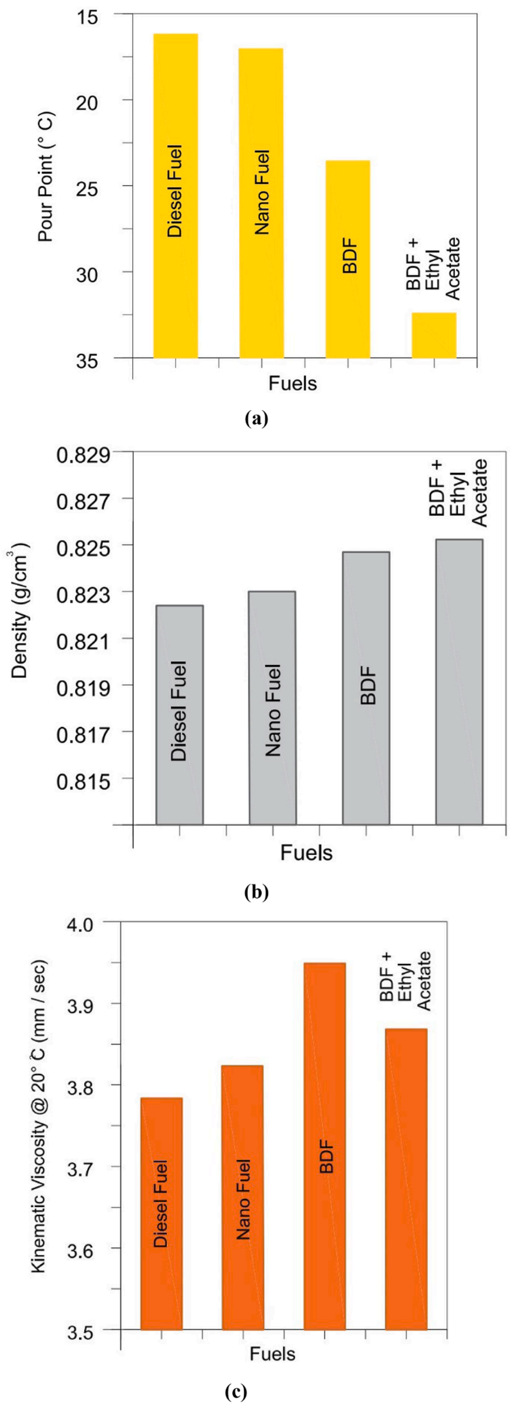


Fig. 5. (a)The influence of various additives on changed fuel pour point, (b) improved fuel density, and (c) improved fuel kinematic viscosity.

drop in the viscosity of the resultant combination. Because bulk property is utilized to calculate kinematic viscosity, adding a little amount of ethyl acetate to the modified diesel is unlikely to significantly change its viscosity. This is due to the fact that bulk property is employed to calculate kinematic viscosity. There's also a chance that the complicated structure of ethyl acetate, which has a high potential for being introduced into the diesel fuel and surfactant linkages, is causing this little drop in kinematic viscosity.

3.6. CO and emission

Researchers observed that adding 50 ppm of nano to diesel fuel increased firmness, viscidity, and thermal transfer; decreased specific fuel consumption; and reduced carbon monoxide, unburned hydrocarbons, and all kinds of particle particulates emissions. Furthermore, the researchers noticed that the specific fuel consumption of the diesel fuel decreased. Increased as a direct result of the increased heat produced inside the combustion chamber. According to Mei et al.'s [53] study, CNT-diesel is preferable because it improves combustion efficiency and reduces pollutants in a variety of ways. Fig. 6 shows both the pollutants and the basic diesel fuel (BDF) containing ethyl acetate. In accordance with the outcome, there was a 27% increase in combustion efficiency and a 45% decrease in emissions (mostly of HC) to the exhaust gas. The catalytic activity of NPs is principally responsible for increased combustion efficiency and reduced emissions. This action speeds up the oxidation process by delivering oxygen molecules, which accelerates the transformation of carbon into carbon dioxide. As a result, shown in Fig. 6, customized fuel may be used instead of standard diesel to reduce the environmental effect of automobiles reduced pollutant levels [54, 55].

4. Conclusion

The findings of the research indicated that the modified diesel fuel including nanoparticles (NPs) and surfactants achieved optimal stability of roughly 60% after 48 h, with particle sizes between 15 and 20 nm being pivotal to this stability. The use of nanoparticles markedly improved many essential characteristics of diesel fuel, such as the cetane combustion index (CCI), initial boiling point (IBP), ignition point, density ratio, and relative viscosity. The improvements concurrently led to a significant decrease in gasoline volatility and pour point, signifying enhanced fuel performance and adaptability to diverse settings.

The collaboration between Tween 80 and Span 80 surfactants improved the characteristics of the modified gasoline. This combination resulted in an elevation in ignition point, hardness, and apparent viscosity, concurrently decreasing the CCI, volatility, and pour point by up to 20%. These modifications demonstrate that the surfactant combination enhanced the fuel's combustion attributes while also optimizing its flow and thermal properties, making it more appropriate for practical use in various environmental circumstances.

The use of ethyl acetate, although not affecting instability, density, or viscosity, significantly improved the fuel's CCI and pour point. This enhancement is ascribed to ethyl acetate's role as an oxygen buffer,

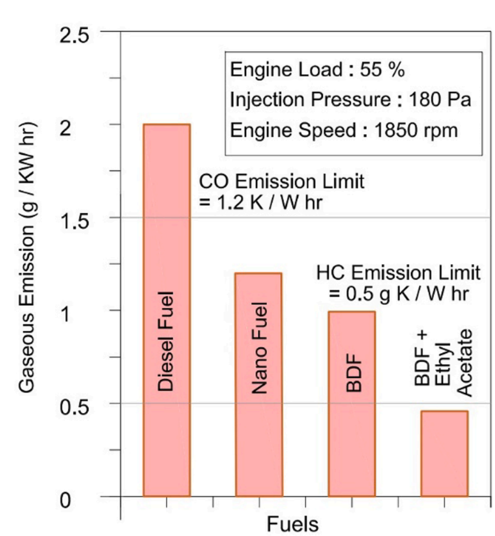


Fig. 6. Exemplifies the imbalance in HC and CO emissions.

which promotes more efficient ignition in diesel fuel. These advances indicate that ethyl acetate may significantly contribute to enhancing fuel performance, especially in situations necessitating better igniting properties and operational dependability at reduced temperatures.The modified diesel, a combination of diesel fuel and ethyl acetate, was assessed for its real-world applicability under simulated practical situations. The testing findings were encouraging, demonstrating a 40% decrease in carbon emissions relative to traditional diesel fuels. This notable reduction highlights the improved fuel's capacity to enhance cleaner combustion and diminish environmental impact. The alterations made to diesel fuel by including nanoparticles, surfactants, and ethyl acetate resulted in a product with improved stability, greater ignition and flow characteristics, and significant environmental advantages. These results underscore the potential for more innovation in fuel compositions to satisfy the increasing demand for clean and efficient energy solutions.

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CRediT authorship contribution statement

S. Baskar: Conceptualization. **Mohd. Majid:** Formal analysis. **Arasu Raman:** Data curation. **L. Ganesh Babu:** Investigation. **Mahalingam Selvaraj:** Methodology. **Padmanabhan Sambandam:** Project administration. **N. Punitha:** Resources. **S. Vijayaraj:** Software. **M. Anish:** Validation, Conceptualization. **J.R. Deepak:** Visualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

The authors confirm that the data supporting this research are accessible inside the paper itself.

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