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Influence of Laser light on Specific Physical and Chemical Characteristics of Diesel fuel

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ABSTRACT

This study investigates the potential of laser light as a non-chemical method to modify the molecular structure of diesel fuel, with the objective of enhancing key performance properties such as viscosity, density, and Cetane number (CN). Sudanese diesel fuel sourced from the Khartoum refinery was analyzed before and after laser exposure to evaluate the extent of property enhancement. Using a calibrated viscometer and ASTM standard procedures, the kinematic viscosity and density were measured, while CN was determined using the bracketing hand wheel method with a test engine and reference fuels. A 10 mL sample of diesel was irradiated with laser light for 60 min under controlled laboratory conditions at the Central Petroleum Laboratories in Khartoum. Post-exposure results revealed a significant reduction in kinematic viscosity (from 3.571 mm^2/s to 1.40 mm^2/s) and density (from 0.927 g/cm^3 to 0.78 g/cm^3), alongside an increase in CN from 57.2 to 62.4. These enhancements suggest molecular restructuring-primarily the transformation of cyclic and branched hydrocarbons into linear chains-resulting in improved combustion characteristics. The findings demonstrate the feasibility of laser-based treatment as a novel technique for refining diesel fuel quality.

Keywords: Laser, Physicochemical properties, Diesel fuel, Enhance properties, Cetane number.

INTRODUCTION

The modification of diesel fuel properties through physical and chemical treatment methods has attracted significant research interest, with laser light exposure emerging as a promising non-invasive technique. The interaction of laser radiation with diesel fuel can induce changes in its molecular structure and microphysical characteristics, potentially enhancing combustion performance and emission profiles. Kinematic viscosity is a critical parameter influencing fuel atomization, spray behavior, and combustion efficiency in diesel engines. Studies have demonstrated that laser irradiation can lead to a reduction in diesel fuel viscosity by altering intermolecular interactions. According to Kumar, *et al.,*[1] exposure to pulsed laser beams causes partial cracking of long-chain hydrocarbons, thereby lowering the average molecular weight and viscosity of the fuel. This viscosity reduction enhances fuel atomization, improving combustion efficiency and reducing soot formation[2].

Density, closely linked to fuel energy content, is another physicochemical property affected by laser treatment. Experimental investigations by Singh and Verma[3]. revealed that diesel fuel subjected to continuous-wave laser exposure exhibited a marginal decrease in density, attributed to thermal effects and slight molecular rearrangements. The decrease in density was correlated with the breakdown of heavier hydrocarbons into lighter fractions, which contributes to improved ignition characteristics[4]. Cetane number (CN) is an essential parameter representing the ignition quality of diesel fuel. Increasing the CN leads to shorter ignition delays and smoother combustion. Laser treatment has been reported to enhance the cetane number by promoting isomerization and fragmentation reactions within the fuel composition. Patel, *et al.,*[5] observed an increase of up to 5 CN units in diesel samples exposed to nanosecond laser pulses, which was linked to the formation of more reactive hydrocarbon species and reduced aromatic content. The ignition quality of diesel fuel is measured through the cetane number (CN), a standard assessment conducted using a conventional engine test as outlined by ASTM guidelines[6]. The ignition delay, defined as the duration between fuel injection and the onset of combustion (ignition), serves as a critical metric for evaluating ignition quality[7]. A fuel characterized by a high cetane number (CN) exhibits a notably short ignition delay, leading to combustion initiation almost immediately following its injection into the engine[8]. The ignition quality of diesel fuel is influenced by its molecular composition. In diesel engines, various molecular components exhibit differing ignition characteristics. For instance, n-paraffins tend to ignite readily due to their simpler molecular structure. Conversely, compounds such as aromatics, which possess more complex ring structures, require higher temperatures and pressures for ignition to occur[9]. Sudan relies heavily on diesel fuel for transportation, agriculture, and power generation. However, local diesel often suffers from high viscosity, low cetane number, and variable density, leading to poor combustion efficiency, higher emissions, and engine wear. Investigating the impact of laser light treatment offers a novel, non-chemical method to enhance fuel quality without adding additives or changing the refining process. The current research aimed to evaluate the impact of laser light on the physicochemical and combustion properties of diesel fuel. Diesel fuel quality is largely defined by its kinetic viscosity, density, and cetane number (CN), all of which influence engine performance and emissions. Enhancing these properties can lead to more efficient combustion and lower pollutant output Also, conducting this research promotes local scientific advancement, capacity building, and technological innovation, supporting national development and academic contributions to energy science.

MATERIALS AND METHODS

Materials

All reagents and chemicals used in this study were of analytical reagent (AR) grade and were obtained at the highest available purity. The diesel sample was collected from the Khartoum Refinery Station and was determined to contain n-heptane, iso-cetane, iso-octane, and cetane.

Methods of analysis

Diesel fuel characteristics were regulated by governmental standards that specified both their required properties and the methods for testing them. In the United States, various federal and state agencies defined these characteristics and, in some cases, modified the minimum quality standards established by organizations such as the American Society for Testing and Materials (ASTM). Relevant information on diesel fuel specifications and testing procedures was available in resources such as publications from the Society of Automotive Engineers (SAE) and the Annual Book of ASTM Standards[6].

Standard protocol for assessing the kinematic viscosity of Diesel fuel

In this experiment, the time required for a specified volume of liquid to flow by gravity through the capillary tube of a calibrated viscometer was carefully measured. The procedure was carried out under controlled temperature conditions and with a constant driving head to ensure the reproducibility of results. The kinematic viscosity was calculated using the viscometer's calibration constant in combination with the recorded flow time, in accordance with ASTM (2005)[6].

Standard testing methodology for evaluating the cetane number (CN) of Diesel fuel

The combustion properties of the diesel fuel were evaluated using a test engine, in which its performance was compared with that of reference fuel blends with known cetane numbers (CN). This comparative approach allowed for the accurate determination of the cetane number under standardized operating conditions. The bracketing hand wheel method was employed to calibrate the compression ratio based on hand wheel readings for the test sample and two reference fuels representing the upper and lower cetane limits. This procedure was implemented to achieve a precise ignition delay, thereby enabling interpolation of the cetane number using data obtained from the hand wheel measurements (ASTM, 2005).

Exposure of Diesel fuel Sample to laser light

Prior to the experiment, the sample tube was thoroughly cleaned and dried. Approximately 10 mL of the diesel fuel sample was then introduced into the instrument tube. The sample was subsequently exposed to ultraviolet (UV) gas laser light generated by a flash lamp (powered by electrical current) for a controlled duration of 60 minutes.

RESULTS AND DISCUSSION

In the course of this research, a diesel fuel sample was analyzed prior to and following the sample's exposure to laser light, a comprehensive evaluation of various physicochemical properties is conducted using multiple tests. These assessments adhere to the guidelines established by the American Society for Testing and Materials (ASTM). The physicochemical parameters that were assessed, including density, kinematic viscosity, and cetane number (CN).

The results of this study reveal a significant enhancement in diesel fuel quality following exposure to laser radiation. This improvement is substantiated by notable reductions in both density and kinematic viscosity, as shown in Table 1 and illustrated in Fig. 4 and 5, alongside an observed increase in the Cetane Number (CN), as presented in Table 3. Because a lower density and viscosity result in a higher cetane number, the density and viscosity of diesel fuel were deemed to be crucial characteristics[10]. The density and dynamic viscosity data are recorded in Table 1.

Table 1: Kinematic viscosity and density of Diesel samples pre- and post-laser radiation exposure

Property	Pre-exposing	Post-exposing
Viscosity (mm^2/s)	3.46	1.48
` Density (g/cm^3)	0.92	0.792

After laser exposure, the density of the diesel fuel decreased from 0.92 g/cm^3 to 0.792 g/cm^3, and the kinematic viscosity dropped from 3.46 mm^2/s to 1.48 mm^2/s. These changes are considerable and suggest a molecular restructuring in the diesel sample, possibly due to the breakdown or conversion of higher molecular weight, branched, or cyclic hydrocarbons into lighter, more linear chains. As established by Riazi and Al-Otaibi[11], lower density and viscosity typically correlate with higher cetane numbers, thereby indicating improved combustion characteristics. The Khartoum Refinery's permissible limits, consistent with ASTM standards, specify acceptable viscosity ranges of 1.9–4.1 mm^2/s (summer) and 1.5–3.8 mm^2/s (winter) at 40°C, and density limits of 0.8063–0.9 g/cm^3. The pre-exposure values of viscosity (3.46 mm^2/s) and density (0.92 g/cm^3) were within or marginally exceeded these ranges, whereas the post-exposure values (1.48 mm^2/s and 0.792 g/cm^3, respectively) fall slightly below the specified lower limits. Although these post-treatment values are just under the standard threshold, the reductions still imply enhanced ignition and combustion efficiency. The slight drop in density and viscosity below standard values may be beneficial for cold climate applications, where lower viscosity fuels are preferred to reduce gelling and improve flow characteristics[12]. However, this would require further study on long-term engine compatibility and lubricant interactions. Table 2, presents the acceptable range established by the Khartoum refinery, aligned with the standards set forth by the American Society for Testing and Materials (ASTM). The results obtained from the density and kinematic viscosity tests are illustrated clearly in Fig. 1 and 2, respectively.

Table 2: The permissible limits established by the Khartoum refinery, in accordance with ASTM standards

Properties	Temperature (°C)	Summer	Winter
Viscosity (mm^2/s)	40	1.9 – 4.1	1.5 – 3.8
Density (g/cm^3)	40	0.8063 – 0.9	0.8063 – 0.9

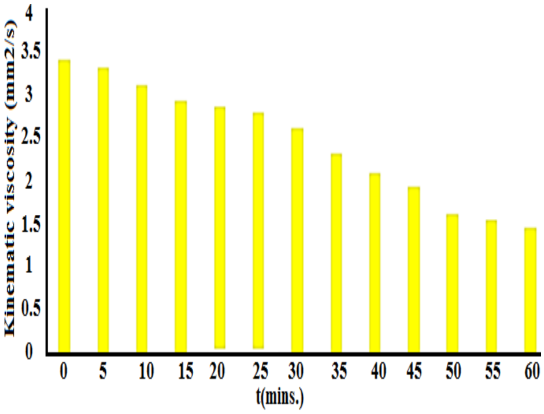

Fig. 1. Kinematic viscosity of Diesel samples pre- and post-laser radiation exposure

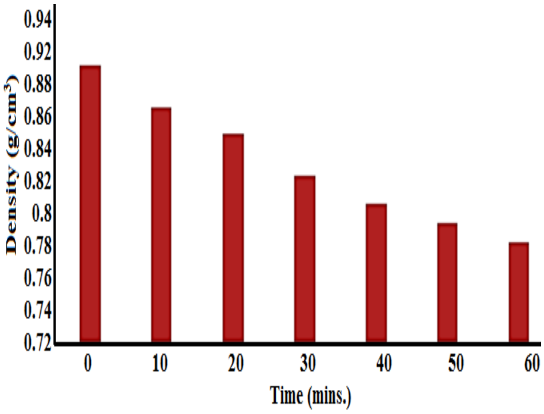

Fig. 2. Density of Diesel samples pre- and post-laser radiation exposure

Cetane number assessment of Diesel fuel sample

The quality of diesel fuel is primarily assessed through its Cetane Number, which is regarded as a crucial characteristic. The cetane number increased significantly from 57.2 to 62.4 after laser exposure (Table 3). This rise supports the argument that molecular reformation towards more linear hydrocarbons occurred, enhancing ignition delay and combustion quality. As higher cetane fuels are associated with reduced NOx and particulate emissions[13], this transformation is highly beneficial from an environmental and engine performance perspective. This aligns with prior findings where various upgrading methods, including hydrotreatment and isomerization, have shown similar effects in increasing CN while lowering density and viscosity[14]. Moreover, laser-based techniques for fuel refinement have been suggested as a cleaner and more targeted approach, minimizing the need for chemical additives. The result from the CN test is also, shown in Figure 3.

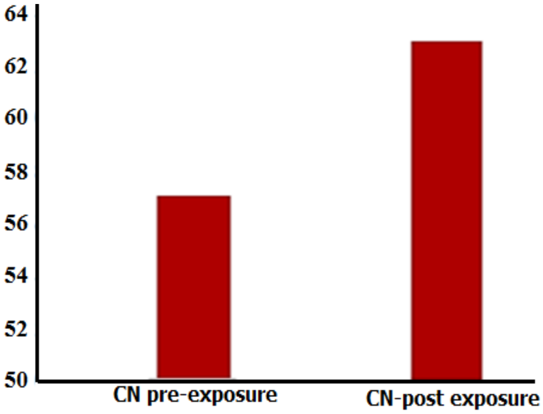

Fig. 3. Cetane number of the diesel fuel sample pre- and post-laser radiation exposure

The results presented in the table above suggest a notable improvement in diesel quality after exposing the sample to laser light. This enhancement is reflected in the increase of the Cetane Number. A higher Cetane Number typically translates to enhanced ignition efficiency, subsequently leading to a reduction in the volume of emissions generated by diesel engine exhaust. The observed increase in the cetane number of the diesel fuel sample following exposure to laser light can be attributed to the impact of laser radiation on the molecular structure of the compounds within the diesel fuel. Specifically, laser radiation has the potential to transform certain cyclic, branched, and aromatic compounds into linear chain hydrocarbons. This conversion is significant because linear chain hydrocarbons are known to exhibit higher cetane numbers.

The findings of this study are consistent with those of Elamin, *et al.,*[15], who observed reductions in density and viscosity of petroleum diesel after photolytic treatments, coupled with an increased cetane number. Similarly, Farooq, *et al.,*[16] reported molecular restructuring of hydrocarbon chains under UV laser exposure, leading to improved fuel ignition characteristics. These studies corroborate the results obtained in this work, reinforcing the viability of laser exposure as an alternative refining technique. The observed improvements in CN and reductions in density and viscosity after laser treatment strongly support the potential of this approach for enhancing fuel performance and emissions characteristics.

CONCLUSION

Drawing from the experimental findings

previously elaborated upon, a number of conclusions can be inferred. Significantly, the cetane number (CN) of the diesel fuel sample used in this study, before being subjected to laser light, was measured at 57.[20] The cetane number of the analyzed diesel fuel sample increased to 62.4. Laser technology substantially improves the properties of the diesel fuel sample obtained from the Khartoum Refinery by lowering its viscosity and density while increasing its cetane number. These modifications suggest enhanced combustion efficiency, making laser light treatment a promising approach for improving diesel fuel performance within ASTM and refinery standards.

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Conflict of interest

Authors declare there is no conflict of interest

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