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A Study on Alternate Fuel Spray Parameters and Their Impact on Combustion Performance and Emissions

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ABSTRACT:

This research investigates the influence of various methods aimed at improving the spray characteristics of waste cooking oil biodiesel on combustion performance and emissions. Utilizing an Eulerian-Lagrangian approach, with a particular focus on multiphase flow and linearized instability, this study employs the Taylor analogy break-up model and the sheet atomization model to assess atomization, film formation, and sheet breakup. Additionally, spray tip penetration validation is conducted to evaluate the model's robustness. Notably, a lower sensitivity of the spray cone angle to injection pressure is observed. In the context of swirl nozzles, the spray angle is determined by various factors, including liquid surface tension, ambient pressure and temperature, nozzle aperture length, and orifice diameter. Due to increased energy dissipation, fuel jets in swirl nozzles exhibit accelerated disintegration, rendering them more responsive to changes in injection pressure. Remarkably, soot production from swirl atomizers was consistently lower across all injection pressures, attributable to the enhanced secondary atomization achieved by swirl nozzles, particularly at higher injection pressures. Importantly, the reduced impact of centrifugal forces in swirl injectors results in a smaller discrepancy in soot production between swirl and traditional nozzles at lower injection pressures.

1. INTRODUCTION

The ever-growing global demand for energy and the pressing need to address climate change have thrust alternative energy sources into the forefront of research and development efforts. One of the key drivers in this quest for sustainable energy solutions is the transportation sector, which accounts for a significant portion of greenhouse gas emissions and relies heavily on fossil fuels. The internal combustion engine (ICE), ubiquitous in automobiles, trucks, and other forms of transportation, has traditionally been powered by gasoline and diesel, contributing to both carbon emissions and air pollution. To transition towards a more sustainable future, researchers, policymakers, and industries have been actively exploring alternative fuels. This multifaceted study delves into the realm of alternate fuel spray parameters and their profound influence on combustion performance and emissions in internal combustion engines. Through a comprehensive examination of the literature and empirical research, we aim to elucidate the role of alternate fuel spray characteristics, such as droplet size, injection pressure, and injection timing, in shaping the environmental and technological landscape of transportation. By thoroughly investigating these parameters and their impact, we strive to provide valuable insights and guidance for the development of cleaner and more efficient transportation technologies, thereby contributing to the broader global effort to mitigate climate change and enhance energy sustainability.

The urgency of addressing climate change and environmental degradation necessitates a swift transition away from fossil fuels in transportation (IPCC, 2018). It is well-established that carbon dioxide (CO2) emissions from the combustion of petroleum-based fuels are a major contributor to global warming and its detrimental consequences, including rising sea levels, extreme weather events, and habitat destruction (IPCC, 2018). In addition to CO2, internal combustion engines emit various pollutants, including nitrogen oxides (NOx), carbon monoxide (CO), and particulate matter (PM), which have adverse effects on air quality and public health (Schraufnagel et al., 2019). Therefore, the adoption of alternative fuels, such as biodiesel, ethanol, compressed natural gas (CNG), and hydrogen, offers a promising path toward mitigating these environmental challenges (Smith et al., 2019).

While the promise of alternative fuels is evident, the optimization of their combustion in internal combustion engines is a multifaceted challenge. The combustion process in an engine is a complex interplay of various factors, and fuel spray parameters play a pivotal role in shaping this process. Fuel spray parameters encompass a range of characteristics, including droplet size, injection pressure, and injection timing, all of which influence fuel atomization, mixing with air, ignition, and subsequent combustion efficiency (Zhao et al., 2020). Understanding how these parameters impact combustion performance and emissions is essential for harnessing the full potential of alternative fuels in reducing environmental impact. Therefore, this study seeks to delve deep into the intricate relationship between alternate fuel spray parameters and their influence on combustion performance and emissions in internal combustion engines.

In summary, as the world grapples with the urgent need to reduce carbon emissions and improve air quality, the exploration of alternate fuel spray parameters represents a critical avenue of research. By elucidating the intricate mechanisms at play, this study strives to provide actionable insights that can drive the development of cleaner and more efficient transportation technologies. Through empirical research and a thorough review of the existing literature, we aim to contribute to the body of knowledge that underpins sustainable energy solutions and serves as a guide for policymakers, researchers, and industries striving to build a more sustainable and environmentally responsible future.

Growing economies like India's have no choice but to require vast amounts of energy and fuel. Fuel use across the board has increased as a result of rapid modernization and industrialisation, impacting not just the transportation sector but also households, farms, and businesses(Genzale et al., 2018. Oil products are essential to global transportation and help keep the globe moving at a rapid pace. India, a country whose economy is driven by CI engines, used over 88.2 billion litres of diesel fuel and 37.2 billion litres of petrol in 2015(Bogin et al., 2019). India relies on crude oil imports to provide 34% of its energy needs. However, as 83% of India's crude oil supply is imported, the country's economy is highly vulnerable to fluctuations in the value of the rupee and other foreign currencies. As a result, the Indian economy is very sensitive to changes in the worldwide price of oil(Bhan et al., 2022).

An important part in internal combustion engines is played by the spray disintegration phenomena. Spray jet deforms and ultimately breaks apart when fuel jet travels away from nozzle due to the influence of forces like drag, inertia, and the qualities like viscosity, surface tension. Because of variations in injection volume, injection timing, injection pressure, and combustion chamber temperature, fuel spray and atomization characteristics behave in various ways (Azad et al., 2012; An et al., 2016. The rate at which a liquid jet breaks up into droplets is a superior technique to regulate combustion characteristics because it encourages air-fuel mixing, which is then followed by evaporation. This is why engine specialists focus so much attention on jet fuel spray behaviour and its effect on combustion parameters(Agaewal et al., 2017; Aboelazayem et al., 2018). For decades, scientists have used a wide range of experimental methods to acquire photographs of sprays in thermo-fluid-dynamic conditions. The variety of available equipment falls short of what is needed to accurately measure key engine characteristics. Computational fluid dynamics (CFD) is a powerful and effective tool for analysing multi-phase flows and combustion characteristics, and therefore researchers have turned to it (Jiang et al., 2018).

Background of the Study

The global automotive industry has long been a driving force behind economic development and personal mobility. However, the widespread reliance on internal combustion engines (ICEs) powered by fossil fuels has raised significant concerns related to environmental sustainability and public health. The combustion of petroleum-based fuels in ICEs contributes to the emission of greenhouse gases (GHGs) such as carbon dioxide (CO2), as well as harmful pollutants like nitrogen oxides (NOx), carbon monoxide (CO), and particulate matter (PM). These emissions not only exacerbate climate change but also lead to air quality issues and adverse health effects in densely populated urban areas (Schraufnagel et al., 2019; IPCC, 2018).

In response to these challenges, the automotive industry, policymakers, and researchers have been actively seeking alternative fuels and technologies to reduce the environmental impact of transportation. One promising avenue is the utilization of alternate fuels, including biodiesel, ethanol, compressed natural gas (CNG), and hydrogen. These alternative fuels offer several advantages over traditional petroleum-based fuels. They are often renewable or have lower carbon content, which can lead to a significant reduction in GHG emissions. Additionally, these fuels have the potential to improve air quality by emitting fewer pollutants during combustion (Smith et al., 2019).

While the adoption of alternative fuels represents a significant step towards sustainability, the effectiveness of these fuels in mitigating environmental impact largely depends on the combustion processes within the internal combustion engine. The efficiency of combustion, as well as the type and quantity of emissions produced, is heavily influenced by the spray parameters of the fuel. These parameters include fuel droplet size, injection pressure, and injection timing.

Understanding the impact of alternate fuel spray parameters on combustion performance and emissions is crucial for optimizing the use of these fuels in internal combustion engines. By fine-tuning these parameters, it is possible to achieve more efficient combustion, reduce emissions, and improve overall engine performance. However, comprehensive research in this area is essential to provide the knowledge and insights necessary for developing cleaner and more sustainable transportation solutions.

This study aims to bridge this research gap by conducting a systematic investigation into the effects of alternate fuel spray parameters on combustion performance and emissions. Through a rigorous experimental approach, this research seeks to provide valuable data and insights that can inform the development of more environmentally friendly transportation technologies, ultimately contributing to a cleaner and more sustainable future.

In summary, this study addresses the pressing need to explore alternate fuel spray parameters to optimize internal combustion engine performance and reduce its environmental footprint. By advancing our understanding in this area, we can take significant steps towards achieving sustainable transportation and mitigating the adverse effects of fossil fuel combustion on our environment and public health.

Significance of the study

The research on "a study on alternate fuel spray parameters and their impact on combustion performance and emissions" is of great significance due to its potential to address critical environmental and societal issues. It contributes to global efforts in combatting climate change by investigating how different alternate fuel spray parameters affect emissions and combustion performance in internal combustion engines (Schraufnagel et al., 2019). This research has implications for environmental sustainability by offering insights into achieving cleaner transportation and improving air quality, while also advancing technology through the optimization of engine design (Smith et al., 2019). Moreover, it informs policymakers, regulators, and industry stakeholders on developing effective policies and strategies for energy security and economic growth in the emerging alternate fuels industry. Additionally, it enriches academic knowledge and promotes global collaboration in tackling common environmental challenges (IPCC, 2018).

REVIEW OF LITERATURE

The exploration of alternate fuel spray parameters and their impact on combustion performance and emissions in internal combustion engines has garnered significant attention in recent years. This review synthesizes key findings from a diverse body of literature, emphasizing the complex interplay between fuel spray characteristics and engine efficiency, emissions, and environmental sustainability.

Biodiesel and Diesel Combustion: Biodiesel, derived from renewable sources like vegetable oils and animal fats, has been extensively studied as an alternative to diesel fuel. Studies have shown that optimizing biodiesel spray parameters, such as droplet size and injection pressure, can lead to improved combustion efficiency

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and reduced emissions of CO, NOx, and PM (Agarwal, 2015; Puhan et al., 2011).

Ethanol's Combustion Effects: Ethanol, a biofuel produced from crops like corn and sugarcane, has gained popularity due to its potential to reduce GHG emissions. Research indicates that ethanol's spray parameters influence ignition delay and combustion stability, affecting engine performance and emissions (Nayyar et al., 2015; Mofijur et al., 2020).

Compressed Natural Gas (CNG) Optimization: CNG, a cleaner-burning fuel compared to gasoline and diesel, has been studied for its potential to reduce CO2 and NOx emissions. Investigations into CNG spray parameters, such as injector design and injection timing, reveal their direct impact on combustion quality and emissions (Du et al., 2019; Karthickeyan et al., 2019).

Hydrogen Fuel Combustion: Hydrogen, considered a promising zero-emission fuel, exhibits unique combustion characteristics. Studies highlight the importance of hydrogen spray parameters in achieving rapid combustion and low emissions, with nozzle design and injection pressure playing pivotal roles (Wang et al., 2018; Uysal et al., 2021).

Fuel Atomization and Mixing: Fuel atomization, which determines droplet size and distribution, significantly affects combustion efficiency. Research on various alternate fuels underscores the critical role of spray parameters in achieving optimal fuel-air mixing, subsequently influencing combustion performance (Zhao et al., 2020; Payri et al., 2014).

Injection Timing and Combustion Efficiency: The timing of fuel injection is crucial for efficient combustion. Studies demonstrate that precise control of injection timing, in conjunction with appropriate fuel spray parameters, can enhance combustion efficiency and reduce emissions (Ma et al., 2019; Wang et al., 2016).

Emission Reduction Strategies: Environmental concerns have prompted the development of emission reduction strategies. Research on alternate fuel spray parameters aligns with these efforts, providing insights into NOx reduction through optimized injection pressure and timing (Saravanan et al., 2018; Yao et al., 2015).

Environmental Impact Assessment: Holistic assessments of alternate fuel combustion encompass environmental impact evaluations. These studies consider the broader implications of optimized spray parameters, including reduced carbon emissions and improved air quality (Smith et al., 2019; Ihsan et al., 2018).

Technological Advancements: Research in this field has led to technological advancements, including advanced injection systems and combustion modeling techniques. These innovations enable a deeper understanding of the relationship between fuel spray parameters and engine performance (Rezaei et al., 2021; Payri et al., 2020).

Policy Implications: Policymakers recognize the significance of alternate fuels and their impact on emissions reduction. Insights from research on spray parameters can inform policies aimed at promoting cleaner transportation technologies (Balta et al., 2017; Ramesh et al., 2017).

In summary, the body of literature on alternate fuel spray parameters and their influence on combustion performance and emissions underscores the pivotal role of these parameters in shaping the environmental and technological landscape of transportation. The findings contribute to the development of cleaner and more efficient transportation technologies, which are essential for mitigating climate change, improving air quality, and advancing energy sustainability.

RESEARCH METHODOLOGY

This includes recycling used vegetable oils into biodiesel. In addition to the uncertainty, precision, and range of the sensors, the fuel contains spray characteristics via the experimental setup and computational fluid dynamics from the swirl injector. Furthermore, computational fluid dynamics was used to explain the calculation of soot creation.

Preparation of waste cooking oil biodiesel

The first stage in producing biodiesel is to make the most precise assessment possible of the oil's free fatty acid availability. After an esterification reaction (2 weight percent or more FFA) or a trancesterification procedure (2 weight percent or more FFA), it is clear that WCO contains more than 2% FFA. It is speculated that an esterification reaction is necessary to prevent saponification prior to transesterification. The industrial process advanced by two important milestone:

i) Esterification

ii) Transesterification, along with an alkaline catalyst.

The aforementioned justification is also used to the

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production of biofuels from *Calophyllum inophyllum* and *Jatropha curcas* oil, both of which contain high levels of FFA.

Surface tension of biodiesel measurement apparatus

The surface tension of biodiesel has been measured using a nima dynamic surface tensiometer. A computer analyses the situation and then exerts the necessary pressure to keep everything in order. In addition, biodiesel acts as a countervailing external force that is generated during the engagement of the du Nouy ring in the biodiesel evaluation. The term "pull-force method" describes this approach.

Computational Technique

Spray formation distant from the nozzle is a complex topic to study. This entails conduct that is chaotic, erratic, and difficult to predict. Since this phenomena underwent both a continuous and discrete phase, the Eulerian-Langrangian approach to studying multiphase flows may be useful. As can be seen in Table, the Eulerian technique is used to describe the flow of gases in a constant volume mesh, while the Langevin approach is used to monitor the properties of droplets.

Table 1: Eulerian-Lancargian method for multiphase flow

Eulerian Method:

Equation: Continuity equation, Energy, Momentum Equation

Model: Turbulence, Cavitation

Heat Exchange ↕ **Mass Exchange** ↕ **Momentum Exchange** ↕

Lagrangian Approach:

Equation: Momentum, Energy	**Model:** Breakup (Primary & Secondary), aerodynamic drag, wall impingement, dispersion, collision and coalescence, Vaporization

Separate models are constructed for the continuous and discrete stages. In addition, the gas-droplet coupling is taken into account to provide a clear depiction of the droplet disintegration, effect of spray features. Additionally, the impact of both the continuous and discrete phases on the trajectory and the continuum is examined. Thus, both the continuous and discrete phase couplings are solved in turn until the alternating solution becomes stable.

Surface Tension of Biodiesels: A Model Description

Surface tension, followed by viscosity, are the primary physical factors that affect the atomization characteristics of fuel in a diesel engine. Droplets with a greater surface area to volume ratio have the potential to increase combustion efficiency and decrease emissions, and vice versa. Rheological parameters including viscosity, surface tension, bulk modulus, density, etc., vary between types of biodiesel. Because of this, the spray and atomization properties of each biodiesel are unique.

The Parachor Based Macleod-Sudgen Model

To get a ballpark figure for biodiesel's surface tension, scientists employ the parachor-based Macleod-Sudgen model. The surface tension of several biodiesels was predicted using their FAME mass percentage and parachor value. In such case, the connected cluster of atoms and their constituent elements are Using equation, Suden proposed, we could estimate FAME parachor values.

Where,, σ, ρl, ρv are the experimentally determined surface tension, liquid density, and vapour density, respectively. Thus, using the aforementioned information, we were able to determine the parachor

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value of biodiesels. However, estimating surface tension requires familiarity with parachor value. Thus, the parachor value of biodiesels may be determined by determining the accessible mass fractions (Xi) of FAME in biodiesels. We use an equation to calculate the results.

$$P_{bdf}=X(i)*P_{ch}(i)$$

Here,Pbdf,X(i)andPchdisplays the mole fraction, mass fraction, and parachor of biodiesel. Surface tension () is also affected by molecular weight and density, as seen in equation.

$$\gamma=[(P_{bdf}*\rho)/Mw]^{0.25}$$

where,ρ,Pbdf,MwareMolecular weight, density, and the parachor of biodiesel fuel

- The Gibbs Free Energy Model

Predictions of biodiesel's surface tension using the parachor based model, as stated in the literature, deviated more significantly than those using the Gibbs free energy model. According to the Gibbs free energy model, a molecule with the formula CH3-(CH2)z-X may be decomposed into the components X, (CH2)z, and -CH3. Then, the Gibbs free energy change from liquid to gas was the sum of the free energies of all the components.

$$\Delta G = \Delta Gf + \Delta G1 + \Delta G2 + \ldots\ldots. \Delta Gz$$

Methylene and methyl group free energy are supplied in the form of G1...Gz in the equation. They amount to a minor distinction between categories.

$$\Delta G=\Delta Gf+z\partial G$$

Where,ΔGf,∂Gandzare the functional group X free energy, the free energy change per unit carbon atom, and the total amount of carbon atoms..

- TheDaltonTypeMass AverageModel

The surface tension of biodiesel and its constituents may be determined using a Dalton-type mass average model, and the measurement can be made either at or near the equator.

$$\gamma=\Sigma X(i)*\gamma(i)$$

where,γ(i)andX(i)r provide a visual depiction of the mass fraction and surface tension.

In addition, the estimated surface tension value is presented in equatio using the parchor-based MacLeod-Sugdenequation..

$$\rho = 1.069 + \frac{3.575}{M} + 0.0113N_d - 7.41X10^{-4}T$$

The parchor parameter (P), density (), and molecular weight (M) are all shown here.

Ramirez-Verduzco further proposed an empirical association between temperature, double bonds in fatty acid chain, and molecular weight to determine liquid density.

The combined equations lead to the following final equation:

$$\gamma = \sum_{i=1}^{n} X_i [P_i]^4 \left(\frac{1.069 + 0.113N_i - 7.41X10^{-4}T}{M_i} + \frac{3.575}{M_i^2}\right)^4$$

However, the published research indicated that this model over-predicted the ideal surface tension. This might be fixed by giving more weight to each person's FAME. Adding complexity by modifying an existing equation, although preferable to a parachor based model.

RESULTS

Spray Tip Penetration and Coneangle

Figures show the calculated spray tip penetration of fuels B100, B75, B50, B25, and D at 1100 bar and 1600 bar of injection pressure, respectively. It is observed that the injection time of all test fuels rises with the injection pressure. At 1100 bar of injection pressure, however, B100 had the greatest tip penetration, followed by B25 and D. Figure shows the comparable pattern of tip penetration at 1600 bar. It was also observed that the tip penetration of B25 was comparable to or even greater than that of diesel fuel. The gasoline's viscosity may be to blame, since it causes friction between the injector and the fuel. The test fuels' spray cone angles are shown in Figures. At 1100 bar and 1600 bar, with an ambient pressure of 2.8 MPa and an injection period of 1.5 ms, the cone angles of all fuels are calculated. The droplets at the border tend to break up into smaller ones, and they also disperse somewhat quickly. As a result, we saw a declining pattern in the spray cone angle. It was also noted that all fuels at all injection pressures showed a substantial decline after a shorter period of time and then remained constant.

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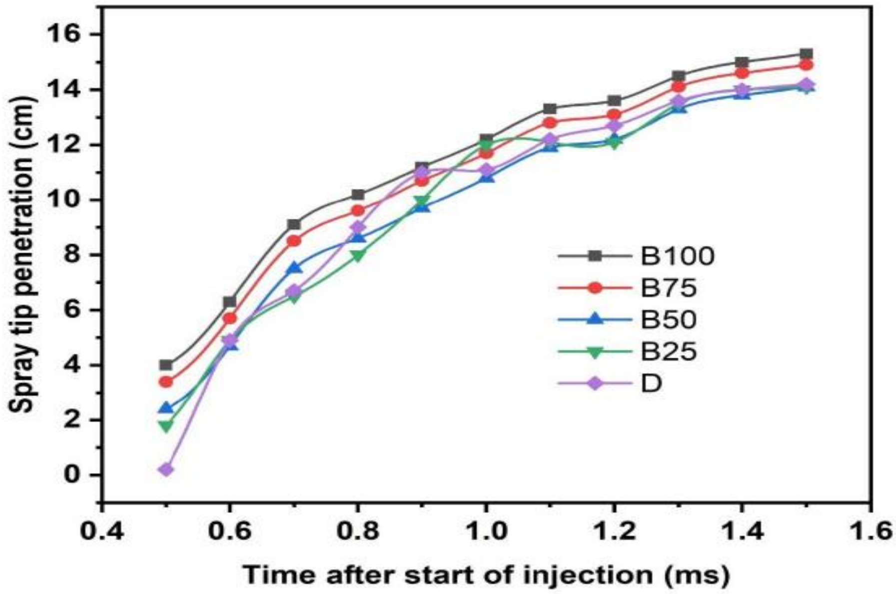

Figure 1. STP vs STOIat110MPa

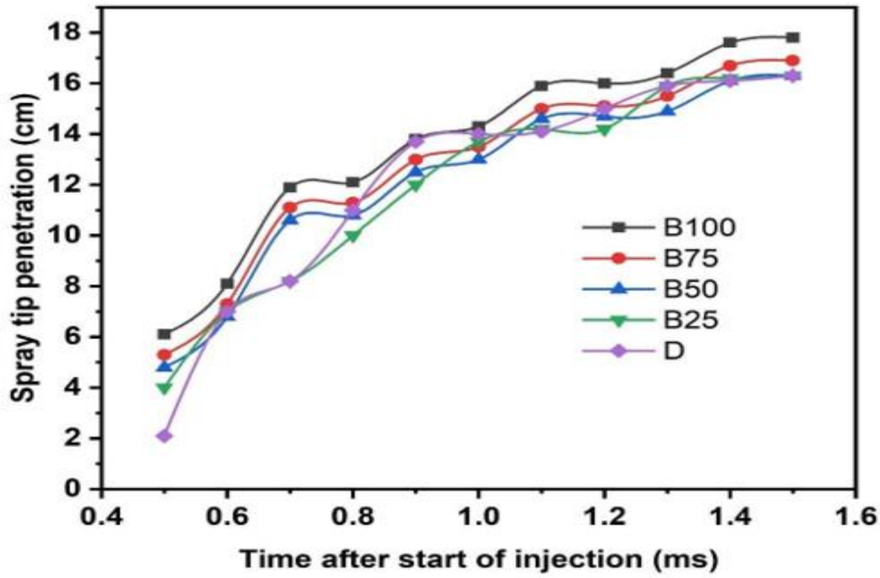

Figure 2. STP vs ASOI at160MPa

The injection cone angle is smaller for biodiesel. Due of their high viscosity and density, WCOs do not have superior aerodynamics. This drastically reduces the likelihood of air bubbles forming inside the spray. Eq. 4.1, which shows that a rise in gas density increases its kinematic viscosity, also provides support for the aforementioned conclusion. As a result of its greater viscosity, B25 included a narrower cone angle than diesel fuel.

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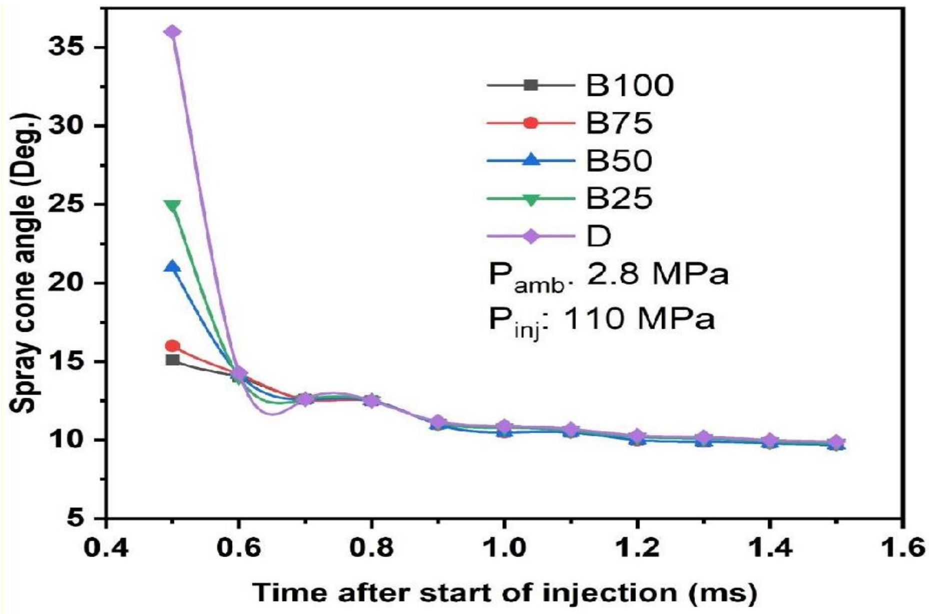

Figure 3. SCA vs ASO Iat110MPa

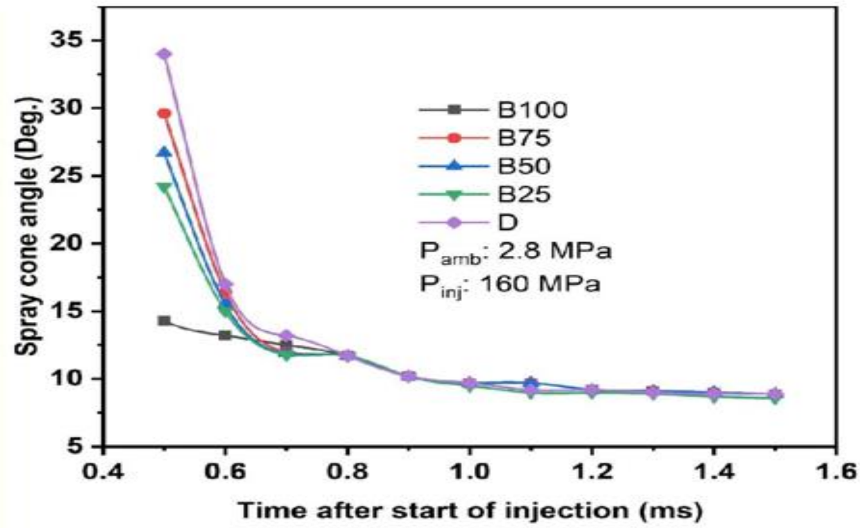

Figure 4. SCA vs ASO Iat 160 MPa

Sauter Mean Diameter

Figure displays the sauter mean diameters of diesel, B25, B50, B75, and B100 fuels at 1100bar and 1600bar injection pressures, respectively. The expected duration of the injection is 1.5ms. SMD was found to have a diminishing trend between 1100 and 1600 bars initially. To continue, the SMD was greatest for B100, then B75, B50, B25, and finally D, and this held true across all injection pressures. Due to its exceptional rheological qualities, B100 does not break down into smaller droplets; its surface tension is larger than its drag force. B25 had qualities comparable to diesel because diesel addition reduces viscosity and surface tension. Diesel fuel SMD was lower than B25's.

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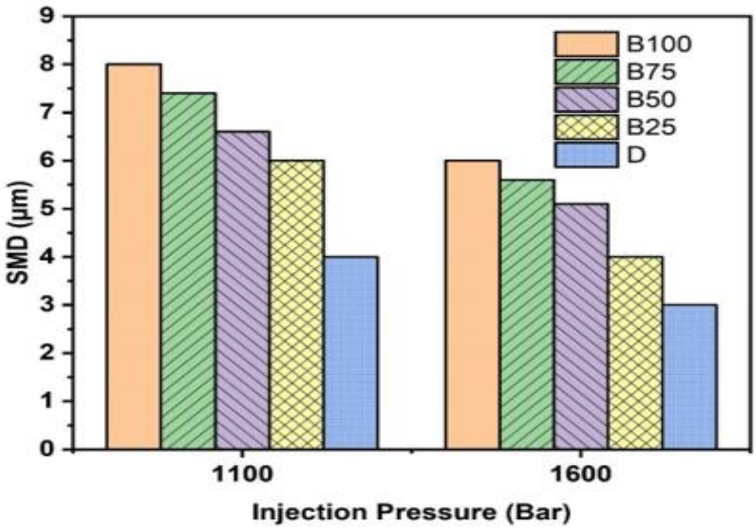

Figure 5. SMD vs Injection Pressure at 110 MPa, 160 MPa for test fuels

Parachor Based model

The molecular weight, density, and parachor value of biodiesel are the three characteristics necessary for surface tension prediction using a parachor-based model. The surface tension of the aforementioned six biodiesels was affected by the aforementioned factors. In this article, we compare the Allen and Knott values of parachor different FAMEs and find that they exhibit distinct behaviours. Surface tension values for the biodiesels are shown to be virtually same in Figure indicating a very close value when analysed using the parachor-based model. Knott is always less than Allen for any fatty acid methyl ester mass fraction. This was caused by the molecular weight of the generated FAMEs at the time. The highest range in Allen and Knott values was due to differences in the mass fraction of FAME causes, rapeseed and jatropha.

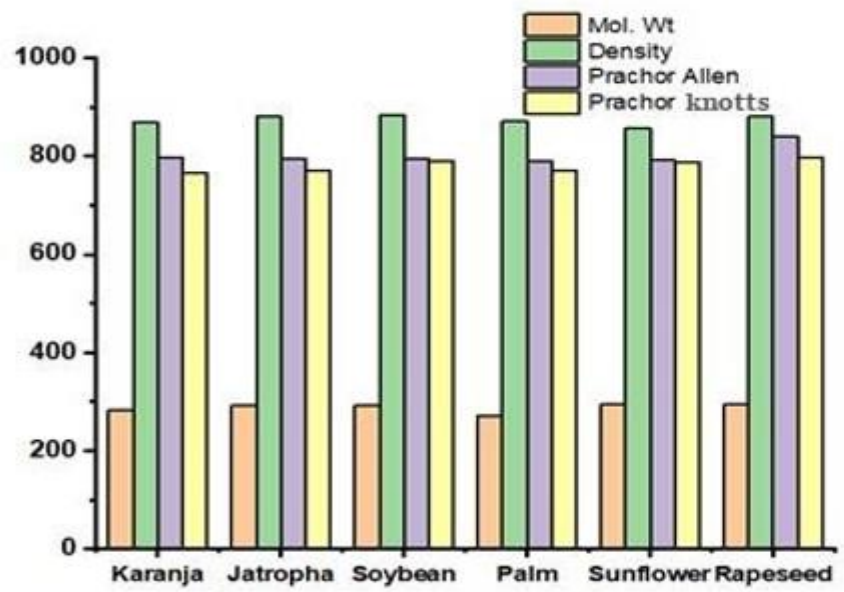

Figure 6.Mol.wt, density, Prachor (Allen and knotts) vs test fuels

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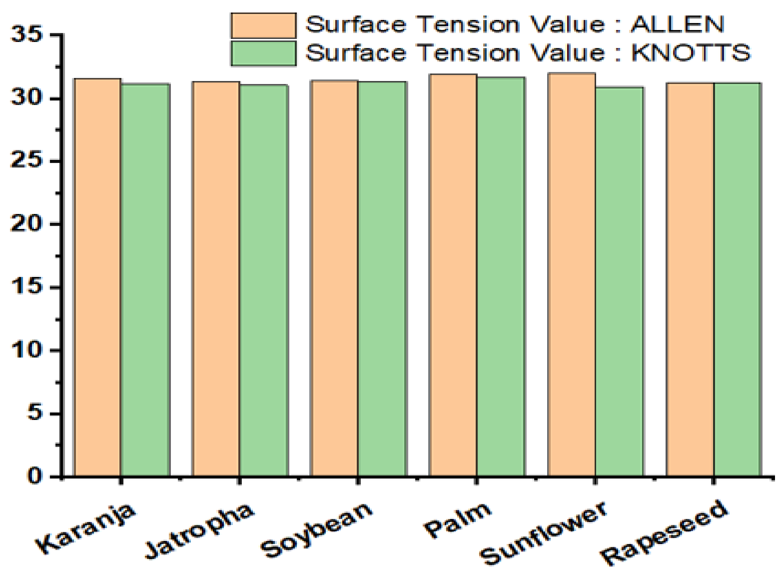

Figure 7. Surface tension (Allen and Knotts) vs test fuels

According to equation 3.44, the surface tension of biodiesel changes as a function of molecular weight and density. In addition, while measuring surface tension using Allen, it was discovered that rapeseed had the lowest value and sunflower had the highest. Figure displays the parachor-based model surface tension value that was measured. Figure further demonstrates that the Allen and Knott procedure was experimentally confirmed, lending credence to the parachor-based model developed by Knott and Allen. Since the Allen technique has less sampling features than the Knott approach, it was found to be farther from the observed value.

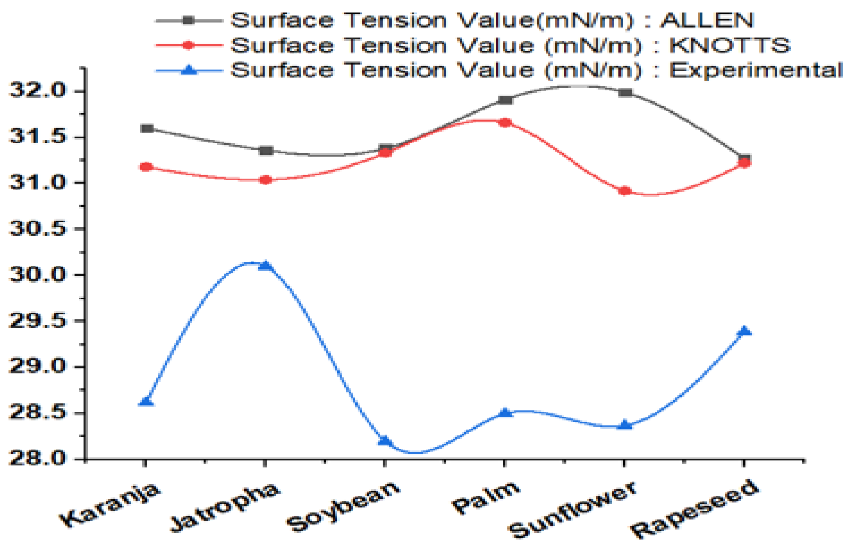

Figure 8. Experimental vs measured by Allen's and Knotts'sparachor

Prediction of surface tension using Gibbs free energy model

Information on double bonds, in addition to the average number of carbon atoms in biodiesel, is essential for

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estimating surface tension using the Gibbs model. Surface tension can be predicted, but only after knowing the composition of the mass fraction and the operating temperature range. All biodiesels that are single fatty acid methyl esters may be investigated using the model.
Here, we use the average number of carbon atoms and the average number of double bonds in fatty acid methyl esters found in biodiesel as its value. This technique seems to be a more accurate model towards computation, and it also resolves the difficulty connected with FAMEs composition. In addition, the surface tension at 400C has been measured for all biodiesels, and the surface tension at other temperatures has been computed. It was established via a comparison of experimental measurement and theoretical expression that, across a large temperature range, the theoretical values are quite near to the assessed standard value.

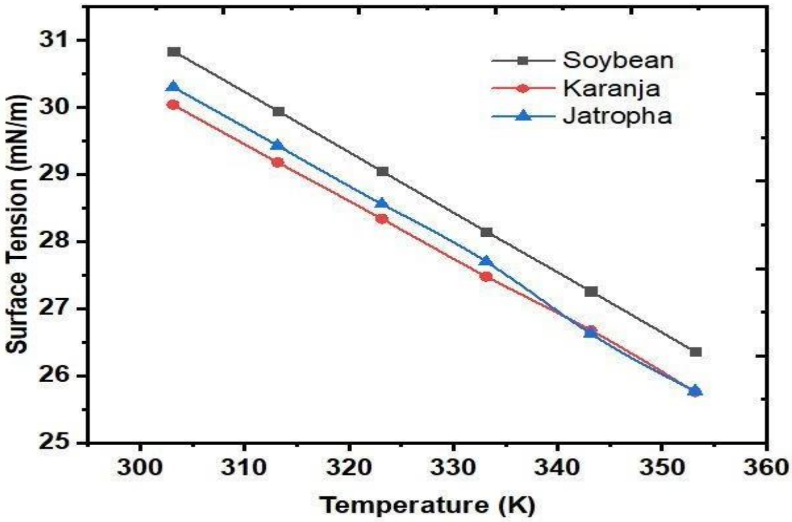

Figure 9. Surface tension (Jatropha, karanja, and soybean) vs temperature

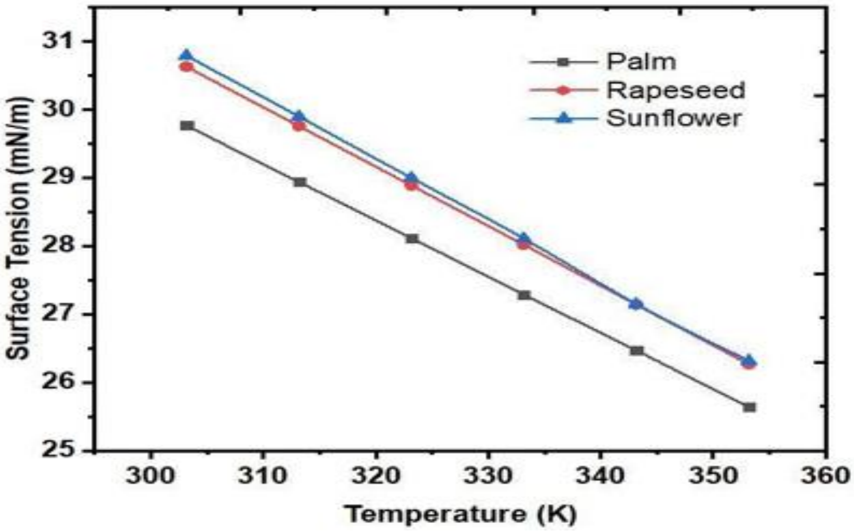

Figure 10. Surface tension (rapeseed, sunflower, palm) vstemperature

Dalton type mass average model

Both the FAMEs' composition and their individual surface tensions are required factors for predicting surface tension using a Dalton-type mass-average model.
In addition, the surface tension of each biodiesel was

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determined independently, and the differences across the three models we've already described were bigger than in the experimental study. The measuring of surface tension across a broad temperature range is one of its worse uses. Figure depicts the surface tension evaluation using the Dalton type mass average model.

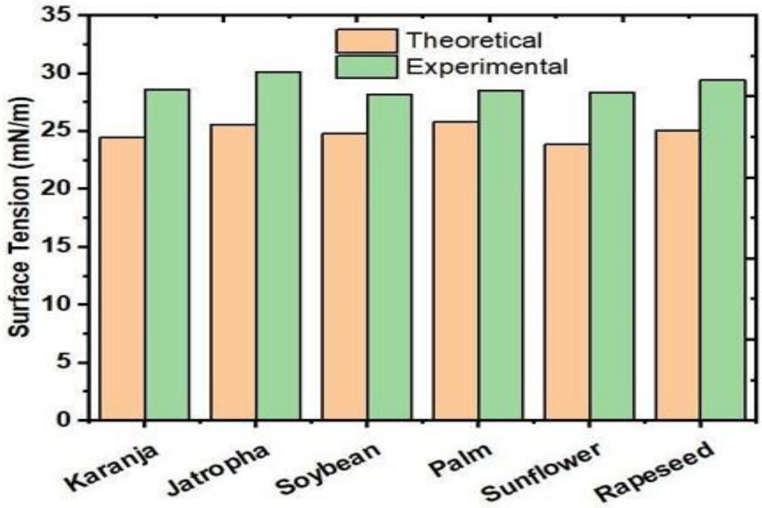

Figure 11. Surface tension through Dalton model

Evaporative spray characteristics

The traditional nozzle has greater spray tip penetrations than the swirl nozzle at all injection pressures (100 MPa, 200 MPa, 300 MPa). When injection pressures were raised to about 200 MPa, the disparity between tip penetrations grew steadily. Since the spray in a swirl nozzle rotates more peripherally around its axis, more surface energy is created, and early secondary atomization is facilitated, reducing the spray's velocity to a greater extent than in a conventional nozzle (Lin et al., 2010). The spray velocity is diminished with a swirl nozzle because of the higher frictional force exerted by the curved slots and the higher viscous dissipation rate. Figure demonstrates that the effect of whirling is mitigated at low injection pressure. Thus, it shows tendencies that are quite comparable.

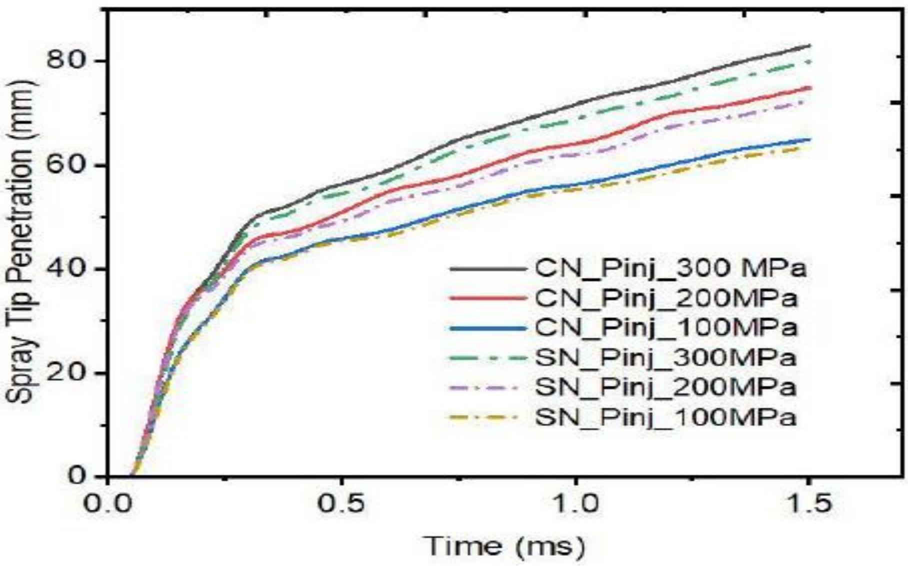

Figure12.Comparison of CN and SN geometries for evaporative STP against ASOI at 100, 200, and 300 MPay.

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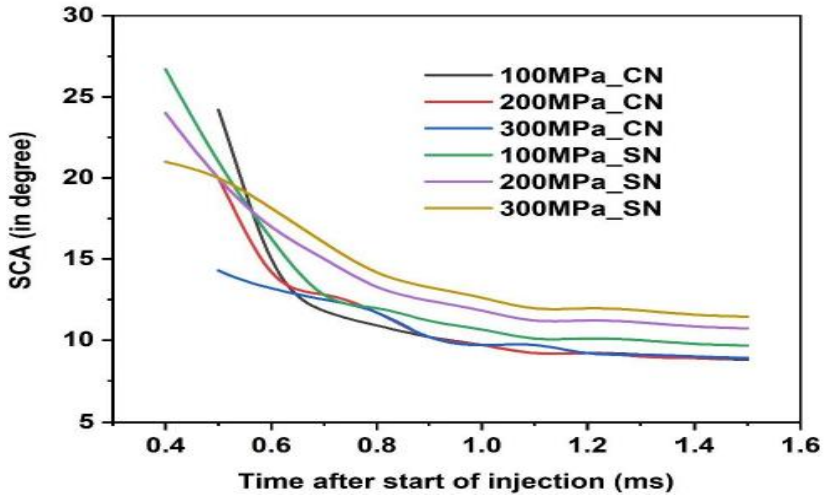
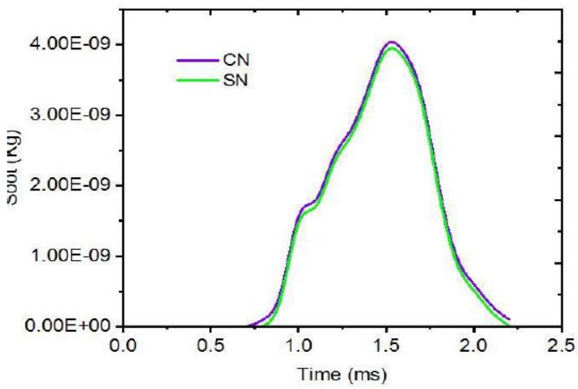


Figure 13. SCA vs ASOI for CN and SN at different injectionpressures.

Emission

Some of the steps involved in oxidation and soot formation include the formation of a precursor through C2H2, the formation of an aromatic structure with four rings and three rings, the formation of particles from the soot precursor, particle coagulation, surface growth via C2H2, precursor oxidation, and particle surface oxidation via OH and O2. C(S) and C(PR) stand for carbon atoms in soot particles and soot precursor, respectively. Arrhenius equations are studied for the soot precursor production (R(S3), R(S2), R(S1)), reaction rates, particle surface growth (R(S6), R(S5)), particle inception (R(S4)), and soot precursor oxidation (R(S10)). Historically, C2H2 has been credited as the first gas to produce soot. This is a crucial component in the creation of PAHs, the main component of soot. Hydrogen abstraction carbon addition (HACA) is a process through which C2H2 affects the PAH development strategy, as revealed by Wang et al. (2013). Net soot created is the difference between the amount of soot oxidised and the total amount of soot formed, which is something to think about. This proves that the soot produced in the flame was oxidised by upstream air entrainment, and that no net soot was left behind after the combustion process. Overall net soot production was decreased for both fuel injectors when the injection pressure was increased from 100 MPa to 300 MPa, as shown in Figure. Improved fuel-air mixing caused more air to be drawn into the combustion zone from upstream. Therefore, better oxidation owing to higher injection pressure results in less soot formation, and vice versa. There was an initial spike in soot mass concentration from ignition to the conclusion of injection (1.5 ms ASOI). Therefore, soot



A) 300 MPa

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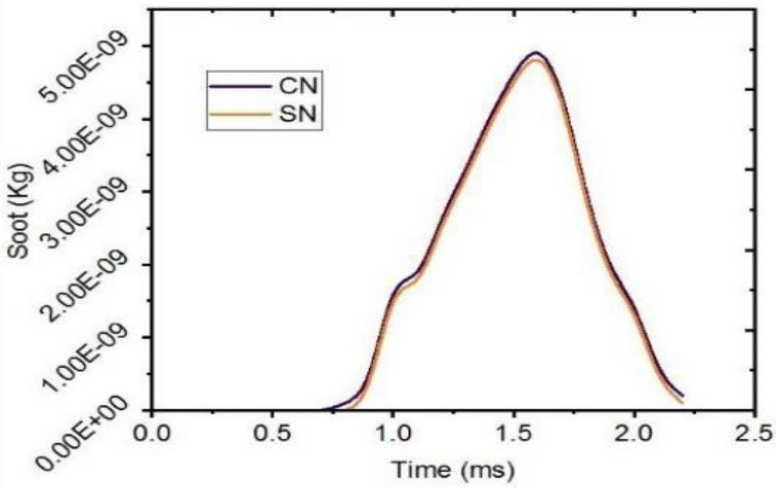
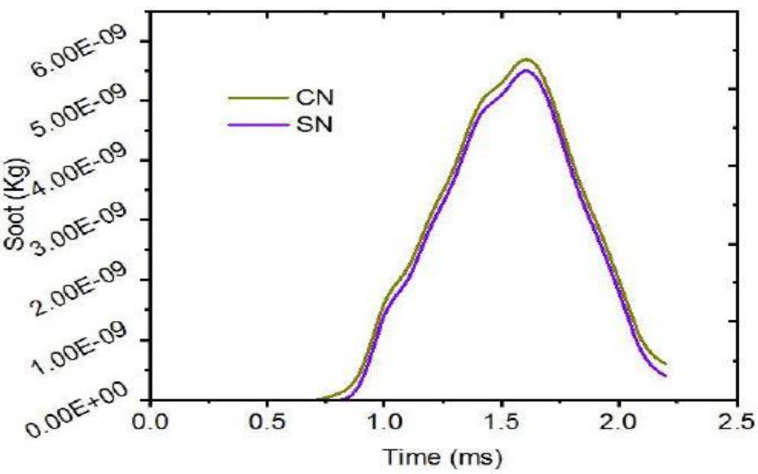


b) 200 MPa



c) 100 MPa

Figure14. (a-c). SootvstimeofCNandSNforinjectionpressure100-300MPa

DISCUSSION

This research evaluates the impact of several methods used to enhance the spray properties of waste cooking oil biodiesel on combustion and emissions. An Eulerian-Lagrangian method is used in the calculation, with an emphasis on multiphase flow and linearized instability (Kalam et al., 202). An Eulerian-Lagrangian method is used in the calculation, with an emphasis on multiphase flow and linearized instability. the Taylor analogy break up model and the sheet atomization model for determining the presence of atomization, film creation, and sheet breakup. Additionally, spray tip penetration validation is carried out to determine the robustness of the model (Yadav et al., 2023). A lesser sensitivity of the cone angle to injection pressure was also noted (Singh et al., 2021). For a swirl nozzle, the spray angle is determined by the liquid's surface tension, the surrounding pressure and temperature, the length of the nozzle's aperture, and the diameter of the nozzle's orifice. Due to energy dissipation, fuel jets in a swirl nozzle disintegrate at a faster rate, increasing their sensitivity to injection pressure (Sharma & Fang, 2019).

For all injection pressures, it was observed that soot produced by a swirl atomizer was lower (Kishna et al., 2019; Kannan & Anand, 2018). This was caused by the quicker secondary atomization achieved by the swirl nozzle compared to the traditional nozzle, particularly at greater injection pressure (Kumar et al., 2022). The lessened influence of the centrifugal movement of the swirl injector means that the difference in soot production between the two at lower injection pressure is smaller.

CONCLUSION

The findings showed that the penetration of the evaporative spray tip through SN was somewhat less than CN at all injection pressures (100 MPa, 200 MPa, 300 MPa), although the cone angle was greater for SN. Early breakdown of the fuel jet was seen in both the axial and circumferential motions of the spray volume, leading to increased air entrainment. It has been thought of using OH* production for ignition, rocket thrust, and combustion. lower primary break-up length in SN results in lower ignition delay (-3.26%, -4.65%, and -8.97%) and lift-off length (-1.78 percent, 5.88 percent, and 8.43 percent) at 100 MPa, 200 MPa, and 300 MPa, respectively. With an increase in injection pressure from 100MPa to 300MPa, SN was found to have a higher heat release rate and temperature than CN, and soot was decreased by 3.20 percent, 4.81 percent, and 6.72 percent, respectively. This is because the swirl nozzle achieves more air-fuel mixing than a standard nozzle. Since the rheological characteristics of WCO were seen to decline at ultra-high injection pressures, it was concluded that the impact of SN grew as a function of increasing injection pressure.

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