Influence of Nozzle Hole Geometry of CI Engines Performance and Emission Parameters Fuelled by Diesel and Biodiesel—A Review

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Abstract: In the quest to reduce hazardous pollutant emissions and environmental impact, various renewable alternative fuels derived from bio-based sources have entered the market. Biodiesel, a vegetable oil ester, has gained a lot of popularity and attention for diesel engine applications. The performance of diesel engine and emission characteristics are closely linked with fuel atomization and spray pattern of fuel injection nozzles. In modern engines various orifices with different designs are used. In a diesel engine, the shape of the diesel fuel injection nozzle and the fuel flow parameters in the nozzle have a considerable impact on the processes of fuel atomization, combustion, and exhaust emissions. The main focus of this study is to explore how number of nozzle hole and shape affects the performance of diesel engine, combustion, and emissions for both Biodiesel and diesel fuels.

Keywords: carbon monoxide, oxides of nitrogen, hydrocarbons.

I. Introduction

The demand for alternate fuels are increased day by day due to the increased number of vehicles. Recent days the ultimate objective of engine design is to reduce the hazardous gases such as carbon monoxide (CO), oxides of nitrogen (NOx), hydrocarbons (HC), and particulate matter (PM) emissions into the atmosphere. Given the challenges of properly controlling the combustion process, several actions aimed at mitigating its impacts, such as cleaning exhaust gases, have been attempted. The fuel injection system is the furthermore important part in the engine and it regulates the supply of fuel depends on the needs of the load and also maintain the injection pressure and fuel atomization, air-fuel mixing etc. Subsequently, it considerably disturbs engine performance and emissions. The mechanisms of the fuel injection system need exact plan measures, material determination, and manufacturing methods. Along with traditional pump-line nozzle arrangements, new ideas arose, such as distributing pumps,
accumulation systems, common-rail systems, unit pump and unit injectors and so on. Attempts are made to reuse the waste cooking oil to use as a fuel in diesel engines rather than to dispose it. [14] According to the application's requirements, combustion may be tuned for the highest performance, emissions, and smooth operation. Exhaust emissions such as HC, CO, NOx, and ash are the maximum genuine worries about the diesel engines, because of non-uniform fuel appropriation, which makes the ignition blend be non-stoichiometric. Accordingly, the DI diesel engines ignition interaction is heterogeneous. It leads to an increase in air emissions. At the completion of the compression stroke the fuel is injected in to the cylinder in the form of liquid through the nozzle and blend with air present in the cylinder. The liquid jet exit the nozzle gets turbulent and expands out. The droplets are formed from fuel jet's outer skin. Once the in-cylinder fluids temperature reaches beyond the self-ignition temperature, the ignition started spontaneously and begin burning at a variety of areas when the appropriate conditions are present. Spray contact becomes a significant occurrence in high-speed Direct injection diesel engines as a result. Spray pattern has a significant impact on fuel jet distribution and evaporation. The spray patterns of fuel inside the cylinder are generated by the injection system which influence the performance and emission controlling processes. The main issue is the small size of the nozzle channel flow regions, which are smaller than one millimetre in diameter and can withstand the pressures of up to 200 bars. Increasing the nozzle holes inturn increases the atomization during combustion. [16,17] This makes quantities and other interpretations of the flow in the nozzle really challenging. The estimations are generally bound to consistent state estimations of nozzle stream coefficients or observations and estimations of stream in increased direct models .Due to the introduction of bio diesel and design changes of diesel engines powers more than the conventional fossil fuels. [18,19]

2. Methodology

2.1. Transesterification Reaction

The process of trans esterification is replacing the ester of an organic group R′′ with the organic group R′ of an alcohol in organic chemistry. An acid or basic catalyst is frequently used to catalyse these reactions. It is the most popular and effective method for reducing the viscosity of vegetable oils. A blend of unsaturated fats, alkyl ester, and glycerol is created when fatty oil consolidates with three atoms of liquor within the presence of a catalyst. In the presence of a catalyst, esterification is a method for completely removing glycerol and unsaturated lipids from a vegetable oil.

![Figure 2.1 Transesterification process](image-url)
3. Results And Discussion

3.1. Performance Parameters

3.1.1. Brake Thermal Efficiency (BTE)

Sangeetha krishnamoorthi et al (2021) conducted experiments fuelled by preheated Spirulina methyl ester in VCR engine using 1-hole nozzle and 3-hole nozzle. When compared to Diesel and Preheated Spirulina, the BTE for unheated Spirulina was low. The main reason is that increased viscosity causes poor atomization and more fuel droplets owing to incorrect fuel and air mixing. Complete combustion happens in biodiesel due to the presence of oxygen, resulting in an increase in BTE value. The BTE of B20 Preheated Spirulina with a single or three-hole nozzle was found to be greater than unheated Spirulina and ordinary diesel. This might be because to the warmed Spirulina B20's improved viscosity, which allows for greater atomization and combustion. The BTE of unheated spirulina with a 3-hole nozzle is 26.3 percent, whereas plain diesel has a BTE of 28.73 percent and Spirulina B20 (preheated) at 60°C has a BTE of 29.32 percent. At maximum load circumstances, with a 3-hole nozzle, the BTE of B20 Preheated Spirulina was found to be higher than diesel [1].

J. Deokar et al (2019) did experiments with 3, 4 and 5 hole nozzle. Because the B0 blend has a larger calorific value than the other blends evaluated, it has a enhanced brake thermal efficiency. Since the diameter of nozzle holes declines, the nozzle hole area also likewise reduces, the 5 hole nozzle has the highest braking thermal efficiency of all the nozzles examined. As a result, less fuel is used and the thermal efficiency is improved. Additionally, on the grounds that splash example of the 4-hole nozzle was uneven, the highest amount of fuel was encroached on the cylinder wall, bringing down BTE. [2]

C. Nandakumar et. al (2020) did experiments with different hole nozzles for a B50 blend. As number of hole increases in nozzle, the brake thermal efficiency also increases for B50 and its maximum for 5-hole nozzle. BTE may have increased as a result of finer fuel atomization, leading by improved air/fuel mixing and combustion. Also, because of the occurrence of oxygen in KME enhances combustion, the engine's BTE for B5O improves as the nozzle holes in number rises. In addition, it is predicted that the shortened combustion time would increase combustion efficiency; the B50 blend's reduced combustion time combined with an increase in the number of nozzle holes indicates an increase in performance and combustion efficiency [3].

Manjunath Channappagoudra et al (2018) did experiment in diesel engine using 5-hole nozzle that for Diesel and other DSOME mixes, there is a differential between BTE and braking power. Based on his research, because of its lesser calorific value, higher specific gravity, and larger viscosity, biodiesel has a lower BTE for all loads than petroleum diesel. Furthermore, increasing the biodiesel content in diesel reduces the BTE due to the lower calorific value. His research with several blends of biodiesel revealed that the DSOME-B20 blend outperforms the DSOME-B30 blend and DSOME-B100 blend. This is due to enhanced calorific value, reduced viscosity, and
reduced density, which result in higher performance and a BTE that is extremely close to that of HS diesel. According to the data, diesel has the 31.32 percent BTE, after that DSOME-B10 with 30.42 percent BTE, which is slightly higher than DSOME-B20 with 29.93 percent BTE. However, even if it has more BTE, a 10 percent reduction in petroleum diesel is not a satisfactory result. When compared to the DSOME-B30 and DSOME-B100, the DSOME-B20 BTE is identical to the DSOME-B10. As a result, DSOME-B20 is determined to be the best mix among others [4].

Narayanan, S., et al. (2019) used a four, five, and six-hole nozzle to test various kapok methyl ester mixtures in a diesel engine. According to his research, As the IHN and mix ratio increase, the brake thermal efficiency improves. Higher brake thermal efficiency might be due to increased cylinder wall temperature as a function of load. Increase in IHN boosts brake thermal efficiency. When the injection angle changes, the engine's thermal efficiency improves because more air and fuel are mixed together. BTE was found to be 15.2 percent, 17.6 percent, and 18.5 percent for B20, B30, and B40 correspondingly, at minimal load, while it was 20.3 percent, 23.4 percent, and 24.2 percent at maximum load (Jindal et.al, 2010; Syed alamet.al, 2016). Let's look at the reading for B30 with the smallest load using IHN. 15.2 percent, 17.2 percent, and 20.4 percent were recorded for three distinct IHNs[5].

Ranganatha Swamy L. et al. (2014) found that, the nozzle shape with 5 holes and an orifice diameter of 0.3 mm had the maximum braking thermal efficiency at fixed injection opening pressure (IOP). This might be because the atomization, spray properties, and air mixing were all enhanced, this results in better combustion. At 80 percent load, the BTE was found to be 28.5 percent, with the maximum value achieved with a 5HN and a 205 bar injection pressure. The BTE of 3HN and 4HN was 24.80 percent and 27.56 percent, respectively at 205 bar. The number of holes had no effect on ignition delay, but it did enhance the rate of fuel-air mixing, hence the 5HN was chosen as the superior. The holes in the 5HN were reduced in size from 0.3 to 0.2 mm, As a result, the combustion chamber's air and fuel mixture is enhanced and therefore increased BTE. When the thickness is smaller than 0.2 mm, the BTE is decreased because fuel droplets travel quicker than air, results poor in mixing and engine efficiency [6].

Khandal S. V. et al. (2015) found that, When the Hole count is raised from three to four for the same compression ratio and injection pressure, the BTE rises, but when the injection pressure is raised (240 bar), BTE decreases. Because Honge oil methyl ester (HOME) is nearly twice as viscous as diesel for the same injection pressure and compression ratio, the injected biodiesel droplets will be larger, resulting in a higher number of holes to enable appropriate mixing of the fuel injected (HOME) with the surrounding air. As a result, using a four-hole injector improves the process of fuel combustion. It also makes the charge more homogenous, which explains why the heat release rate (HRR) after premixed combustion is at an all-time high. The BTE increased as the number of holes was increased from three to four under similar injection time (IT) and compression ratio circumstances. This might be due to the fine biodiesel jets released by the 4hole injector, which provide ideal liquid fuel/air mixture, causing in better combustion. There is improved BTE as the number of holes was amplified from three to four for the similar injection time and injection pressure. As previously said, because HOME has a higher viscosity than diesel, a higher number of holes will allow the injected fuel to mix properly with the air, resulting in a more efficient fuel combustion process [7].

Thirunavukkarasu .R et al. (2018) found that, increasing the nozzle hole from single to 4 hole and 5 hole results in greater atomization of fuel, reduction in physical delay period of combustion which improves the BTE on a ceramic coated piston. The BTE of single and five hole nozzle gradually decreases by increasing the load but four hole nozzle BTE increases with increase of load. It’s found that spray penetration, droplet size has greater influence on nozzle performance [11]. The power output was increased by increasing the peak pressure of cylinder by employing double and triple injection pulses. [13].
3.1.2. Brake Specific Fuel Consumption (BSFC)

Sangeetha krishnamoorthi et al. (2021) conducted experiments by using Spirulina methyl ester using a 1 hole & 3 hole nozzle for blend B20, as well as a 1HN and 3HN for B20 preheating up to 60°C for blend B20. The value of BSFC for diesel is low when compared to unheated Spirulina among the several nozzles investigated due to the high calorific value of diesel. The BSFC of preheated spirulina with a 1HN was greater, but the BSFC of preheated spirulina with a 3HN was comparable to diesel. The BSFC of preheated spirulina with a 3HN was greater, but the BSFC of preheated spirulina with a 3HN was comparable to diesel. Preheated Spirulina at 60°C with a 3HN yielded the lowest value. BSFC for neat diesel was 0.29 kg/kw-hr with a 1HN, 0.34 kg/kw-hr for B20 Spirulina Preheated at 60°C with a 1HN, and 0.30 kg/kw-hr for B20 Spirulina Preheated at 60°C with a 3HN. At maximum load levels, the BSFC showed that the preheated Spirulina outperformed the unheated biodiesel. The Brake Specific Energy Consumption (BSEC) is a measure that is used to compare the calorific content of different fuels. The BSEC denotes the effectiveness with which a certain fuel may be used to generate electricity. In addition, the BSEC values rise when the Blend value rises and the calorific value falls [1].

A. J. Deokar et al. (2019) did experiments with 3, 4 and 5 hole nozzle. Because of the increased calorific content of the B0 blend, it had the lowest brake specific fuel consumption of all the blends evaluated. The area of the nozzle holes reduces as the diameter of the nozzle holes decreases, the 5HN has the lowest BSFC of the various nozzles examined. As a consequence, fuel consumption is reduced and thermal efficiency is improved. The BSFC increases for 4 hole nozzle because the spray pattern was uneven, allowing maximum amount of fuel that may be sprayed onto the cylinder wall, resulting in better BSFC. [2].

The engine's BSFC for B50 blend has been presented by C. Nandakumar et al. (2020). For B50 with 5HN type, BSFC decreases as the number of nozzle holes increases, and eventually approaches diesel. The engine's BSFC drops for B50 with 3HN and 5HN from 250 g/kWh to 200 g/kWh respectively. The lower calorific value of KME required more fuel injection to reach the essential power yield, which cost the B50 with 3HN a higher BSFC. The BSFC, however, decreased as the count of nozzle holes increased because finely atomized fuel droplets favour evaporation of fuel and so expedite the combustion process. Previous study associating an increase in nozzle holes in diesel fuel to a drop in BSFC contradicts the results. [3].

As per Narayanan. S, et al (2019) findings the relationship between BSFC and primary factor load, as well as secondary variables for 1HN and blend ratio BSFC falls as 1HN rises, showing that the conversion of fuel's chemical energy into braking power is becoming more efficient. This might be attributable to greater air-fuel mixing in certain conditions [5].

3.2. Emission Parameters

3.2.1. CO Emissions

Sangeetha krishnamoorthi et al. (2021) investigated the relationship between carbon monoxide emissions and brake power for clean diesel with 1HN and 3HN, unheated Spirulina with 1HN and 3HN, and preheated B20 Spirulina with 1HN and 3HN. CO emissions were found to be reduced at the start load and even up to 75% load circumstances, but were shown to be higher at maximum load circumstances. When comparing unheated Spirulina to diesel and preheated Spirulina with 3HN, the CO emissions for unheated Spirulina were found to be higher. The reason for increased CO emissions at greater loads is that there is less oxygen supply when more fuel is injected. Co emission was 0.06 percent Vol for diesel with 3HN and 0.07 percent Vol for unheated Spirulina with 3HN. Even at maximum load, preheated B20 Spirulina with 3HN had a value of 0.04 percent. Vol, which is less than the value of diesel [1].

A. J. Deokar et al. (2019) discovered that the B0 blend emits the least carbon monoxide of all the blends examined due to its higher calorific value. Because the diameter of the nozzle holes reduces, the area of the nozzle holes likewise lowers, the 5-hole nozzle emits the least carbon...
monoxide of the various nozzles examined. As a result, fuel consumption is lower, thermal efficiency is improved, and carbon monoxide emissions are reduced. Carbon monoxide emissions rise with the 4-hole nozzle because the spray pattern was uneven, allowing the maximum quantity of fuel to impact on the cylinder wall, resulting in higher carbon monoxide emissions [2].

C. Nandakumar et al. (2020) discovered that increasing the number of nozzle holes, the fuel jet's finer dispersion lowers the fuel core inside the spray, allowing for lean mixing and burning of the well-mixed fuel/air mixture. As the nozzle holes in numbers increases for B50, the air-fuel equivalency ratio decreases, lowering CO emissions. Furthermore, the oxygen concentration in the fuel and greater highest heat output during combustion improve CO oxidation, lowering CO by 47.3 percent for B50 with 5-hole nozzle compared to 3HN. CO emissions for B50 with standard 3-hole nozzle geometry were determined to be higher than for diesel because of the dense mixture created by KME's greater viscosity and lower calorific content. CO emissions are reduced as the fuel mixing procedure improves, and the number of nozzle holes increases, bringing it closer to diesel [3].

Narayanan, S, et al (2019) found that the combustion quality in an internal combustion engine is measured by carbon monoxide emissions. CO is a result of incomplete combustion, hence the lower the CO emission, the better the combustion quality. Because the calorific value only lowers slightly with the fuel mix, the data does not suggest any major variance in CO emission with regard to blend ratio. The increase in the number of nozzles from four to six enables increased air and fuel miscibility, improving the odds of full combustion and thereby lowering CO emissions [5].

Ranganatha Swamy L. et al. (2014) discovered that emissions of CO followed the same pattern as HC emissions, with lesser CO emissions from 5HN than 3 and 4 HN. Incomplete combustion was the cause of the higher CO levels in the exhaust for 5 hole injectors with orifice sizes ranging from 0.3 to 0.2 mm. CO emissions were shown to be lower as injector hole sizes were reduced, owing to less wall impingement with diesel related to bigger hole sizes. Higher hole size injectors, on the other hand, result in fuel deposition on the combustion chamber walls. As a result, CO emissions from 0.3 mm hole injectors were discovered to be higher [6].

According to Khandal S. V. et al. (2015), For any given injection pressure, carbon monoxide decreases with compression ratio. CO, on the other hand, diminishes as the injection pressure is increased. At a higher compression ratio (17.5) and injection pressure of 230 bar, the quantity of CO was determined to be low. CO reduces as the compression ratio increases for a fixed value of injection time(IT), nevertheless as the IT grows, the quantity of CO rises. CO behaved similarly to HC in terms of process parameters (injection pressure and injection time). By increasing the number of holes in the injector from three to four, CO was decreased. The increased HRR accumulated for a four-hole injector may help to cut CO emissions. However, because higher non-homogeneity decreases combustion efficiency, a larger CO area was found close the piston wall with a 3HN [7].

3.2.2. HC Emissions
Sangeetha krishnamoorthi et al. (2021) investigated the HC emissions of plain diesel with 1HN and 3HN, unheated Spirulina with 1HN and 3HN, and preheated Spirulina B20 at 600 C with 1HN and 3HN. The value of HC emission for unheated Spirulina and diesel was found to be higher than for warmed Spirulina due to the large quantity of fuel stored in the combustion chamber because of the extended ignition delay. Diesel had an HC value of roughly 29ppm with a 3HN, whereas unheated Spirulina had an HC value of roughly 27ppm with a 3 HN. The HC emission amount of preheated spirulina B20 is 24ppm. This is due to the warmed Spirulina B20 blend's reduced igniting latency at extreme power output. Poor combustion is among the causes
for the existence of unburned HC, and the HC value in biodiesel is low owing to full combustion due to the molecular oxygen present[1].

A. J. Deokar et al. (2019) discovered that of all the blends examined, the B0 blend emits the least amount of hydrocarbons due to its greater calorific value. Because the diameter of the nozzle holes reduces, the area of the nozzle holes also lowers, the 5 hole nozzle emits the least amount of hydrocarbons of all the nozzles examined. As a result, fuel consumption is lower, thermal efficiency is better, and hydrocarbon emissions are reduced. The hydrocarbon emission from the 4 hole nozzle rises because the spray pattern of the 4 hole nozzle is uneven, allowing the maximum quantity of fuel to impact on the cylinder wall, resulting in greater hydrocarbon emission [2].

For different nozzle hole geometries, C. Nandakumar et al. (2020) discovered HC emission of B50 mix. It indicates that when the engine load increases, the HC emission rises due to an increase in the equivalency ratio. The B50 mix emits more HC than a single diesel with a traditional 3HN. This is due to the B50 blend's increased viscosity and density when compared to diesel. These features have a negative impact on the fuel atomization process, resulting in bigger fuel droplets for B50 than pure diesel. The evaporation rate decreased as a result of this activity, the quantity of gasoline absorbed by the wall and via holes began to grow. The quantity of HC released is reduced as the nozzle geometry's hole count increased. The B50 emits HC emissions that are equivalent to diesel at lower loads when equipped with a 5-hole nozzle. The HC emission is greatly decreased with greater loads. At 80 percent and 100 percent load, the HC emissions of a B50 with 5HN are lowered by 11.66% and 8.86%, respectively, when compared to a diesel with a 3HN. As the count of nozzle holes rises, the atomization of the fuel stream gets thinner, resulting in a quicker vaporization rate and improved fuel-air mixing. Furthermore, the inclusion of extra oxygen molecules in the kapok biodiesel molecular structure reduces HC emission [3].

Narayanan. S, et al (2019) discovered that the unburnt hydrocarbons are commonly referred to as hydrocarbon emissions, meaning that they are a product created when fuel particles are not entirely burned. The graph shows a modest drop in unburned hydrocarbons as IHN increases, indicating that combustion improves. In relation to the biofuel blend, there is no substantial change in HC emissions[5].

Ranganatha Swamy L. et al. (2014) discovered that, the 5 hole nozzle shape resulted in a considerable reduction in HC emission due to improved combustion. A decreased ignition delay will result from improved atomization. The physical delay will be reduced as the spray quality improves. The 5 hole nozzle geometry was found to emit less HC than the 3 and 4 hole nozzle geometry. Because of enhanced atomization and correct combustion of diesel, there were less unburned hydrocarbons with the 5 hole nozzle [6]. Apart from injection strategy nozzle geometry like orifice diameter nozzle hole size, spray angle affects fuel distribution which have direct impact of HC emissions [20, 21].

Khandal S. V. et al (2015) found that, for any given injection pressure value, HC falls with compression ratio. For decreased HC, a grouping of 230 bar injection pressure and a elevated compression ratio (17.5) was shown to be effective. Increasing the number of holes in the injector from three to four resulted in lower HC when the injection pressure and compression ratio are the same. This might be attributable to a 4hole injector's improved mixing of air and fuel in the combustion chamber, resulting in full combustion. Furthermore, in these situations, increased BTE might be to blame for the tendency for a given injection time, HC reduces uniformly as the compression ratio increases, while HC tends to rise as the IT increases. For decreased HC emission, a lower IT with a greater compression ratio was critical. When compared to greater compression ratios, HC was more susceptible to lower compression ratios, especially with a 4-hole nozzle. Even Increasing the count of holes in the nozzle from three to four reduces the HC for the same injection pressure and injection timing [7].
3.2.3. NOx Emissions

Sangeetha krishnamoorthi et al. (2021) show how NOx emissions change with BP for diesel with 1HN and 3HN, unheated Spirulina with 1HN and 3HN, and Preheated Spirulina B20 with 1HN and 3HN. The amount of NOx in unheated Spirulina is determined to be closer to that of diesel, and this is why because the insufficient vaporization in biodiesel, which resulted in lesser combustion, which resulted in lesser NOx emissions. The NOx amount for preheated B20 Spirulina with 1HN and 3HN are greater than the other two findings, owing to the premixed phase of combustion has the greatest temperature, resulting in higher NOx emissions. Diesel and unheated Spirulina had NOx levels of 1086 ppm and 1147 ppm, respectively. The Preheated Spirulina B20 with 1HN and 3HN was determined to be 1150 ppm and 1228 ppm at maximum load circumstances. [1].

A. J. Deokar and colleagues (2019) found among all blends, because the B0 blend has a larger calorific value than the other blends examined, it emits more nitrogen oxide. Because the width of the nozzle holes reduces as the area of the nozzle holes’ decreases, the 5-hole nozzle emits the most nitrogen oxide of all the nozzles examined. This leads to increased fuel consumption and thermal efficiency, as well as increased nitrogen oxide emissions. Due to the pattern of the spray of the 4HN was uneven, the greatest quantity of fuel was impacted on the wall of the cylinder, resulting in lower NOx emissions [2].

C. Nandakumar et al. (2020) discovered smoke and NOx emissions for B50 with varied number of nozzle holes. Regardless of the presence of oxygen, NOx emissions for B50 were observed to be decreased than for diesel, owing to high viscosity, as a result, fuel atomization and combustion have been hampered, decreasing in-cylinder temperature and, as a result, NOx emissions. To offset the aforementioned problem, increase the number of nozzle holes, as finer atomization leads to more combustion, which boosts the in-cylinder temperature. As a consequence, NOx emissions increase steadily as increasing the number of holes in the nozzle and with a 5HN form, NOx emissions are determined to be equivalent to diesel. Furthermore, because the droplet size is projected to be lower, there will be insufficient momentum to drive the spray forward, resulting in a shorter fuel penetration length in order for it to evaporate and mix properly with the air. The heat loss would have decreased the in-cylinder temperature if the spray had penetrated farther to reach the wall. However, it is considered that such a phenomena did not occur, and that the homogenous mixing of air/fuel mixtures at the combustion chamber's limits increased the temperature within the cylinder, resulting in greater NOx emissions. However, when the number of holes in the nozzle rises, smoke production decreases because soot oxidation is favoured in the spray's flame regions. The fuel core will be short and lean as a result of the better air/fuel mixing, oxygen molecules will have an easier time identifying and oxidising the soot precursors formed during the premixed combustion phase, lowering smoke emissions. When compared to the typical 3-hole nozzle geometry, the smoke emission for B50 with 5HN geometry was reduced by 14.8% [3].

Narayanan, S, et al (2019) found at very high temperatures, the nitrogen molecule in the fuel reacts with oxygen to form nitrogen oxides (NOx). Fuel droplets impinging on the wall are thought to be a major source of NOx emissions. The graph below shows that increasing the nozzle hole number from 4 to 6 reduces NOx emissions. This means that as the nozzle hole gets bigger, the wall impingement gets smaller. Because kapok oil contains more oxygen than regular diesel fuel, increasing the fuel mixture improves combustion quality. The higher combustion quality raises the temperature within the cylinder, which raises NOx levels. Increased injector hole number resulted in a modest reduction in NOx, as seen by the statistics. NOx emissions appear to grow with increasing load in all configurations. NOx emissions grow as the proportion of biofuel increases across all fuel mixes [5].

According to Ranganatha Swamy L. et al. (2014), Because of the cycle's quicker combustion and greater temperatures, NOx emissions grow as the number of injector holes increases NOx levels vary in response to changes in adiabatic flame temperature. It's conceivable that increased NOx
with larger holes is due to more heat created during premixed combustion and improved combustion inside the engine cylinder. These things change with the spray pattern of fossil fuels, implying that fuel composition has an impact on reaction zone stoichiometry and post-combustion mixing. With a 5 hole injector, reducing the injector orifice size cuts NOx emissions even further. Diesel had the greatest NOx emission of 963 ppm with a 0.3 mm opening, which might be related to the higher adiabatic flame temperature related with its combustion [6].

According to Khandal S. V. et al. (2015), NOx levels progressively rise as the compression ratio rises, regardless of injection pressure and NOx also rises with increasing injection pressure for a 3HN. The behaviour of NOx was shown to be non-linear, despite the fact that the results were the similar for 4HN. At delayed values of ITs, NOx grows linearly with the compression ratio for a 3HN (19-23 degree). However, at 25 degrees IT, NOx remains relatively constant, but for greater values of IT, NOx drops. For a specified value of injection time, NOx rises with an rise in the compression ratio, and NOx grows with more advanced injection time in the case of a 4-hole injector. The compression ratio had little effect on NOx. Advanced IT increases NOx for both 3 and 4 hole nozzles. Increased NOx was seen when the number of holes in the nozzle was increased from 3 to 4. The greater peak temperature in the combustion chamber may be the cause of increased NOx in the case of 4-hole injectors [7].

According to Shijun Dong et al. (2018), NOx emissions are considerably decreased by using reduced nozzle hole size on a dual fuel engine due to the lower combustion temperature. Soot emissions are increased slightly but maintained within the approved limits. [12]. Diesel engines fuelled with biodiesel emits NOx emissions in greater level than the fossil diesel fuels due to increased cylinder temperature [15]. By using waste tire oil the HC and CO emissions are considerably decreased but NOx emission increased than conventional fuel . [23 ] From the literature it is evident that by adding butanol in the diesel fuel can reduce Nitrogen oxide emissions. [24,25 ]

4. Conclusion

We can conclude from this study that by decreasing the number of holes and size in the engine's nozzle, greater mixing of air and fuel in the combustion chamber is achieved, resulting in improved combustion and, as a result, higher BTE. Fuel particle sizes will grow as the hole’s number in injector decreases, and the ignition delay period during combustion will lengthen. The BSFC rises as a result of this condition. Increased injector hole number, as a result the ignition delay time is reduced. As a consequence, the chances of homogenous mixing diminish while BSFC increases. CO emissions decreased as injector hole sizes were lowered, leading to less wall impingement with diesel as especially for larger hole sizes. Higher hole size injectors, on the other hand, result in fuel deposition on the combustion chamber walls. As a result, bigger hole injectors were found to produce greater CO emissions. If the number of nozzle holes was increased, which results in a drop in HC. This might be ascribed to a bigger hole injector allowing for better air fuel mixture to the combustion chamber, resulting in full combustion. Because of quicker combustion and greater temperatures achieved during the course of the cycle, NOx emissions increase as the number of injector holes rises. Greater NOx with bigger holes might be the result of enhanced combustion inside the combustion chamber and much more heat generated for the duration of premixed combustion.

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