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Optimisation of Diesel Spray, Combustion and Emission Characteristics of Biofuel by Varying Injection Pressure and Timing in a DICI Engine

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ABSTRACT

The combustion process in Internal Combustion engines is greatly influenced by the fuel injected into the chamber and its interaction with the air. Investigation of which involves analyzing injection process from the structure point of view of the fuel spray. In addition, optimizing the spray conditions is highly important in reducing the exhaust emissions and improving the performance and combustion characteristics. The main objective is to optimize various parameters of spray for different blends of biodiesel and injection pressure mainly with respect to Sauter Mean Diameter (SMD), spray tip penetration and spray cone angle using concept of Taguchi and also identifying its contribution using analysis of variance commonly known as ANOVA with the help of “Minitab 14.0” software where the optimum levels of parameters were found using higher Signal - Noise ratio. Based on the number of trials of experiments, spray images of biodiesel for the different combination of control factors were captured and analyzed. Furthermore performance, emission and combustion characteristics are compared by advancing as well as retarding the injection timing in existing Compression Ignition engine for the optimum condition obtained from the experiments conducted in spray chamber. The higher brake thermal efficiency is attained when it is retarded may be due to lower fuel consumption. Unburned hydro carbon is lower for KB20 due to unstable nature and simple molecular structure. Further, among all the blends KB20 can be considered to the best blend on the basis of spray characteristics.

1. Introduction

Most of the energy is obtained from burning the traditional fossils which are non-renewable in nature. Apart from that, current utilization rate of resources could not meet the requirement in the near future and therefore sustainable use of these fuels is highly essential. In addition, combustion of such conventional fuels result in high pollutant emissions ultimately prompts environmental issues and global warming. Therefore, finding economically viable and sustainable substitute fuels has become an important issue. Among the different alternative fuels, biodiesel is the most popular where both the transport and industrial worlds have compensated great attention. Biodiesel fuels produced starting animal fats, vegetable oils and useless biological oil (drainage oil) is a fresh and renewable fuel with reduced exhaust emissions and soot as a result of desirable quality of its high oxygen content. However, in contrast to conventional diesel, biodiesel is hardly atomized because of its fundamental higher surface tension and viscosity. To improve these properties, biodiesel is currently blended with diesel. Moreover, biodiesel fuel blends offer drastically higher lubricity and can be used without modification of the engine.

Many technical factors directly affect quantity and composition of emissions, such as load atmospheric conditions and fuel quality. Also fuel development is necessary in order to meet the stronger Euro emissions limits.

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Shanmughasundaram et al. [1] optimized the levels of the parameters such as rubber seed biodiesel blend, injection pressure and applied load of the single cylinder diesel engine with respect to smoke density and exhaust gas temperature through the Taguchi and ANOVA techniques. The optimum levels of the parameters were found using Signal - Noise ratio. He also investigated the contribution of parameters on the response using Analysis of variance (ANOVA). Multiple linear regression models were generated to predict the responses. It was found that the applied load was the most dominant factor influencing the exhaust gas temperature and smoke density followed by injection pressure and biodiesel blend.

Karthikeyan et al. [2] has investigated using Eucalyptus oil used as alternate for diesel. Eucalyptus having lower cetane number it is not easy to burn aloneso it is blend with diesel. Eucalyptus oil and diesel fuel to study its change ability, combustion and emission behavior. His observation involves three parameters such as injection pressure, injection timing and blend proportions a simultaneous optimisation method Taguchi requires fewer numbers of trials for fixing optimum levels. This is the primary advantage of this method, nine trials were experimented and its results were used for optimisation. ANOVA was also performed for the parameters to evaluate its percentage contribution over the desired output. The results of the Taguchi experiment showed that the 40Eu blend (60% diesel and 40% Eucalyptus oil) performed better at 29°bTDC injection timing and at 180 bar injection pressure than other blends and had a capacity to cold start the engine. Using the optimum levels, a full range experiment was also conducted using 40Eu blend to compare its performance and emission behavior with standard diesel. The experiment showed that the 40Eu blend offered approximately 2.5% higher brake thermal efficiency than diesel operation without much deterioration the exhaust emission.

Hemanandh et al. [3] analysed on generate a statistical modelling for the input parameter of the engine such as injection pressure, timing, blend proportion and the output factor brake thermal efficiency and brake specific fuel consumption. The four stroke direct injection, diesel engine was used to conduct the experiments. The refined corn oil was Trans esterifies with Methanol and Sodium Hydroxide to obtain corn methyl esters. The corn methyl esters were blend with diesel in various proportions and use as fuel. The response was predicted using Analysis of Variance (ANOVA). The developed models were analysed using the R – Squared value.

Sandeep kumar duran et al. [4] has done investigational analysis and is made to estimate the ignition and performance individuality of direct injection diesel engine using different blend of karanja methyl ester with diesel. The Karanja biodiesel is mixed with diesel in extent of 20%, 50% and 100% by volume and studied under various loading condition i.e. at No load, 25%, 50%, 75% and full load in diesel engine. The combustion parameters were found close to that of diesel. The blend of karanja biodiesel performed absolute and smoother combustion process than diesel. The various parameters values like brake thermal efficiency, and heat corresponding to useful work were recorded adjoining to diesel. The fuel air ratio also record higher than diesel. Whereas the mean gas temperature for pure karanja biodiesel was higher than diesel which is on account of complete combustion on account of 10-12% fuel bound oxygen. On the basis of brake thermal efficiency, KB20 blend was establish to be the best blend.

Hongzhan et al. [5] considered the spray characteristics of inedible oil using trial and simulation methods. Spray penetration, spray cone angle and spray tip penetration were measured at different biodiesel blends in a constant volume chamber with wide visualization and elevated back pressure, using a high-speed camera. The uniqueness of biodiesel spray was replicated under the same conditions using Star-CD software. The experimental outcome showed that, as the ratio of biodiesel in the blends improved, spray penetration and spray speed increased, but the spray cone angle decreased. All the way through the spray injection period, the region at 0.05-0.475S (spray tip penetration) was a key area affecting spray cone angle. From 0.8 ms after injection, the spray penetration deviation ratio started to augment with increasing biodiesel blend. Simulation outcome show similar macroscopic spray character to the investigational consequences for Jatropha. The outcome also show that the Sauter mean diameter of blend fuels was greater than that of diesel, and spray was more concentrated, appropriate to the elevated viscosity and surface tension of the biodiesel, compare with diesel. The macroscopic and microscopic spray property of blend fuels containing 5%, 10% and 20% biodiesel were comparable to diesel.

Wang et al. [6] analyze Biodiesel as a renewable power is suitable gradually more striking due to the increasing insufficiency of conventional fossil fuels. Meanwhile, the improvement of after-treatment technologies for the diesel engine brings new approaching regarding emissions particularly the particulatematter pollutants. In order to study the coupling effects of biodiesel blend and CCRT (Catalysed Continuously Regeneration Trap) the particulate matter emissions from an urban bus with and without CCRT burning BD0 and BD10 respectively was tested and analyzed with electrical low pressure impactor (ELPI). The operation environment included steady state and transient conditions. Outcome showed that the particulate number-size giving out of BD10 and BD0 both had two peaks in nuclei form and increase mode at the conditions of idle, low and medium speed while at high speed condition the particulate number-size distribution only had one peak.

Raghu et al. [7] spray penetration length improved with increasing injection pressure for all tested fuels, apart from of the temperament of the fuel. Elevated values of density and viscosity of the biodiesel lead to longer spray penetration in the non evaporating chamber.

Literature review observation the operating parameters of bio fuel and diesel blends has influence the combustion and emissions. However the effect of spray characteristics on operating conditions as injection timing, injection pressure on the engine combustion and exhaust emissions. Center of attention of research is about modification on engine parameters for the best output using optimization techniques.

2 Experimental methods

2.1 Optimization technique

The most common optimization techniques used for analysis are grey relational analysis, response surface method, genetic algorithm, non-linear regression and Taguchi method. Design of experiments for Taguchi technique has been popular for optimization. DOE has the loss function concept which combines cost, target and variations and the signal to noise ratio (S/N). Signal to noise ratio is defined as the ratio of the amount of energy for intended function to the amount of energy exhausted. Orthogonal arrays are considerable parts of Taguchi. As a replacement for of one factor at a time variation all factors are varied simultaneously, design array and the response values are observed. It has the capability to evaluate several factors in a minimum number of tests.

The design and operating parameters are the main factors responsible for the fuel economy and engine emissions. The fuel injection parameters resembling injection pressure and the injection timing also have influence on fuel economy and emissions.

DOE approach is to find the effect of operating parameters on spray characteristics. Penetrations, Sauter Mean Diameter and Cone angle varied widely with different injection pressure and blend.

It was also observed that the blend plays a major role in both SMD and cone angle using factorial design of experiments.

Taguchi method is applying on operating parameters can be optimized and to increased engine efficiency. Based on the analysis of those images in image J software, these properties were tabulated and are ultimately given as response parameter for optimisation in MINITAB software.

A Taguchi L9 orthogonal array was selected for this study as it can control two factors, each at three levels. In the present investigation, 9 tests will be carried out according to the L9 array as shown in Table 2.

In this study, “smaller is better” S/N ratio is used to predict the optimum parameters because lower Sauter Mean Diameter is desirable. On the other hand “Larger is better” S/N ratio is used to predict the optimum parameters because higher spray tip penetration and cone angle is desirable. In addition, the experimental results were analysed using analysis of variance (ANOVA) to study the influence of the factors on the performance.

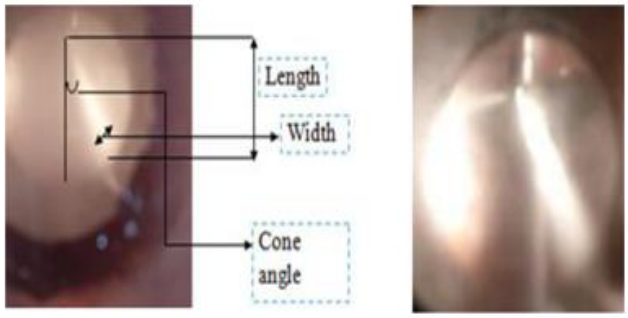

Fig 1. Spray Images.

Table 1 Property of KOME, KB20 and Diesel

PROPERTY	KOME	KB20	DIESEL
Specific gravity	0.883	0.842	0.827
Viscosity at 40^0C	5.43	3.1	2.87
Flash point (^{0}C)	204	80	76

Table 2 Orthogonal array

Blend	Fuel pressure	Spray Length (mm)	Coneangle (Degrees)	SMD(μm)
1	1	58.41	12.85	12.82
1	2	60.56	13.85	12.16
1	3	63.7	14.85	11.59
2	4	54.83	15.85	14.22
2	5	57.15	16.85	13.49
2	6	59.95	17.85	12.86
3	7	55.41	18.85	12.86
3	8	59.28	19.85	12.19
3	9	60.38	20.85	11.62

2.2 Analysis of variance

2.2.1 S/N ratio

Signal to Noise ratio that are expressed in a dB scale, evaluated from the quadratic (quality) loss function. The S/N ratio is found for each experiment. Measured values and S/N ratio indicates the mean value and the term noise indicates the variance value (undesirable) for the output response of the process. This technique is used to identify the controllable factors that reduce the effect of the uncontrollable (noise) factors on the response. The chosen factors with the highest S/N ratio would give the optimum quality with the least variance. Ranking of parameters using signal to noise ratio was obtained and the load was the dominant parameter followed by injection pressure and fuel blend. From the S/N ratio found that the optimum parameters are KB20 and injection pressure (220 bar) for response parameters.

2.2.2 ANOVA

ANOVA which is a statistical technique can be employed to identify the significant parameters and to find the percentage contribution of parameters on the performance characteristic. ANOVA was performed by employing MINITAB 14 software for a level of significance of 5% to study the contribution of the parameters. If P-value is less than 0.05, the parameter can be considered as statistically highly significant. Since P-value for all three parameters have less than 0.05, they are highly significant at 95% confidence level for the blend proportion and injection pressure of the fuel.

It can be observed that the percentage contribution (Pc %) of each variable in the total variation indicating their degree of influence on the specific fuel consumption of the engine. Blend (85%) was the major contributing factor followed by injection pressure (66.82%) influencing the spray characteristics of the fuel.

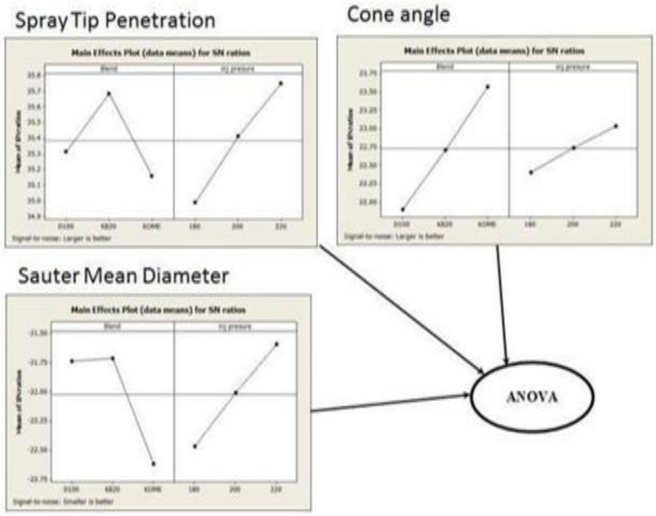

Fig 2. Anova results for Spray parameters.

3 Performance Characteristics

3.1 Brake thermal efficiency

The variation of brake thermal efficiency with brake power for different injection timing is presented fig. 3. All the loads, brake thermal efficiency increased with increased the brake power. This may be attributed to reductions in heat losses and increase in power with increase in load. Karanja biodiesel has 10-11% more oxygen content than diesel which helps in better combustion in engine. Karanja biodiesel recorded less value when it is advanced this is because of lower IMEP and calorific value of Karanja biodiesel than diesel. The higher brake thermal efficiency is attained when it is retarded may be due to lower fuel consumption and additional lubricity provided by blends. Further, among all the blends KB20 can be considered to the best blend on the basis of spray characteristics and higher brake thermal efficiency. Brake thermal efficiency of KB20 is generally higher. Brake thermal efficiency was highest at 220 bar, 190 bTDC for all load. Karanja biodiesel blends, which suggests that higher injection pressure is more effective in improving the spray characteristics of fuels with lower viscosity, which compared to diesel. However, from literature survey decrease in brake thermal efficiency of diesel with increase in fuel injection pressures from 180 to 240 bar while for biodiesel, found increased with increasing fuel injection pressure at full load. It is also reported that retarding injection timing by few degree crank angle resulted in minor improvement in thermal efficiency at part loads.

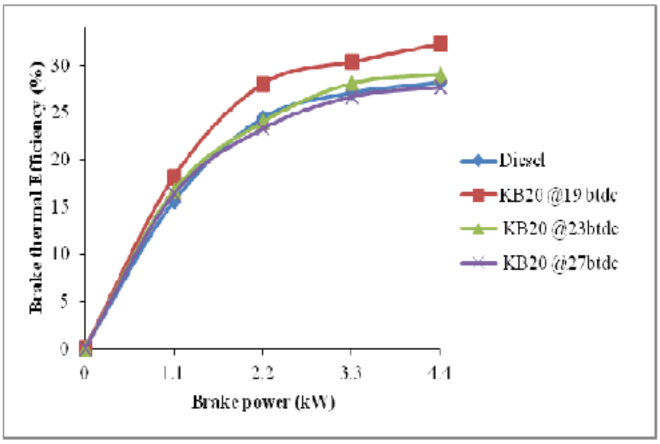

Fig 3. Variations of brake thermal efficiency with brake Power.

3.2 Brake specific fuel consumption.

Fig.4 shows the variations of brake specific fuel consumption with brake power for different injection timing. Brake specific fuel consumption for advanced injection timing is higher than diesel. Observed that KB20 almost similar to diesel due to significant difference in physical properties of the fuels. Reduction of calorific value of fuel with increasing concentration of KOME was responsible for increase in brake specific fuel consumption for KB20.These results are in conformity with our literature reviews which are primarily due to approximately 10-13% lower calorific value of bio diesel compared to diesel. At 220 bar brake specific fuel consumption lowest at 19° bTDC for all load. At high injection pressure, brake specific fuel consumption will be lower. brake specific fuel consumption was lower at 27° aTDC for all loads. At higher injection pressure, advanced of injection timings are restricted very high rate of pressure rise.

Increasing fuel injection pressure reduces the injection duration, leading to finer spray droplets, which improve the air-fuel mixing, thus increasing the premixed heat release, which results in significant portion of heat being released during the compression stroke, especially for advanced inject on timing. Higher heat release during the compression stroke is counter-productive beyond a certain limit because it works against the piston, which is trying to reach TDC in the compression stroke, hence mini mum brake thermal efficiency is observed for retarded injection timings with increasing fuel injection pressure.

4 Combustion characteristics

4.1 Variation of pressure rise with crank angle

The pressure rise plays very important role in engine combustion characteristics because it affect the smooth progress of combustion process. The variation of rate of pressure rise is shown in fig 4. Observe that the pressure rise increased with increasing load for all fuels. However, from literature survey we inferred rate of pressure rise was lower for the blends at higher load in comparison to that of diesel, probably due to lower calorific value of the blends. With increasing the load, the more amount of fuel is injected in engine cylinder and more amount of fuel is burned so that the cylinder peak pressure increased. Apart from that, consider injection timing of KB20 minimizing the engine noise level compared to diesel is to increasing the engine life and smoothness of combustion process. Fig 4 we can observe that even at higher loads KB20 pressure rise is lower than normal and advanced injection timing, which indicate that combustion of blends is smooth and it does not cause knockin g which helps to improve engine life.

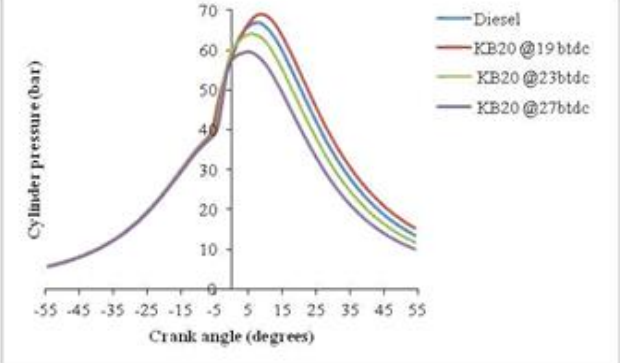

Fig 4.Variation of pressure rise with crank angle for full.

4.2 Variation of heat release rate with crank angle

The heat release rate indicates how much heat is to be added in the cylinder in order to produce the observed pressure. The variation of heat release rate with crank angle from different injection timing at full load as shown in fig 5.The heat release rate increases with increased load, generally the diesel has higher heat release rate than KB20 this is due the reason that blends have lower calorific value. With the increase in the load, there were two peaks of energy release found where second peak of lower magnitude, which indicates that at lower load, premixed combustion phase is more predominant whereas at higher load the diffusion phase of combustion is more dominant. Fig 5.shows the comparison of net heat release rate curves of KB20 at maximum load and different injection timings. It is observed that retarding injection timing confer lower heat release rate at higher loads.

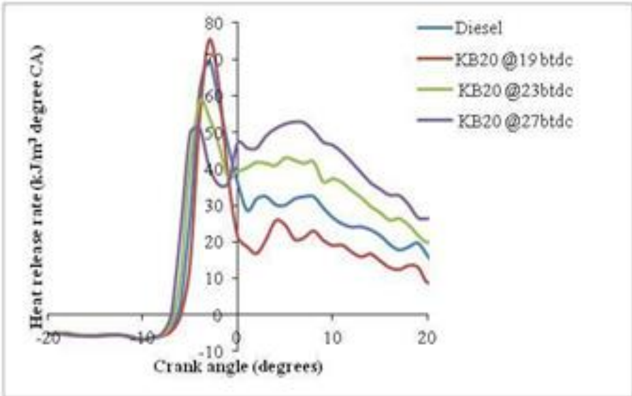

Fig 5. Variation of heat release rate with crank angle for full load.

5. Emission characteristics

5.1 Nitrogen of oxides

Nitrogen of oxides of KB20 is higher than diesel at all loads as shown fig 6 reason that the cetane number suppresses property of KOME. Generally, low cetane fuels resolve comprise longer ignition interruption and liberate more heat at the premixed period of combustion. This cause elevated combustion temperature and quickly enhances the reaction between oxygen and nitrogen and accordingly yields more Nitrogen of oxides. The greatest Nitrogen of oxides obtains with KB20 at full load at 220 bar advanced injection timing.

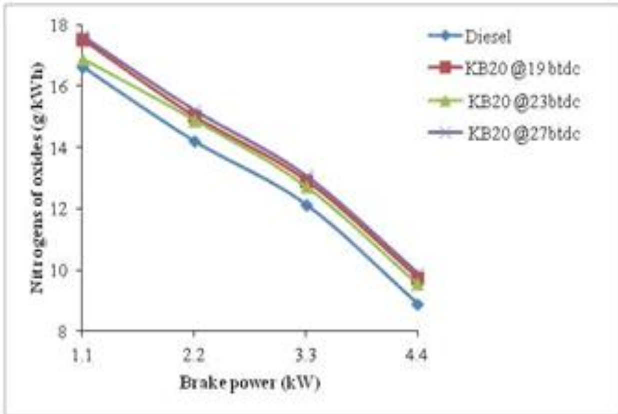

Fig 6.Variation of nitrogen of oxides with brake power.

5.2 Carbon monoxide

Fig.7 shows the variations in carbon monoxide with brake power. Conclude that 19° bTDC injection timing carbon monoxide is nearer to diesel for all loads. In contrast, they will tend to increase the injection timing. Advanced timings resulted in greater formation of fuel rich zones due to increased ignition delay and relatively inferior atomization of fuel injected during early phase of fuel injection, when in-cylinder pressure and temperature were comparatively lower. This leads to higher combustion hotness and elevated exhaust gas temperature and accordingly yields low volumetric efficiency. Consequently, the injected KB20 somewhat lower oxygen and emit additional carbon monoxide. This may possibly be one of the main reasons for high carbon monoxide at all loads.

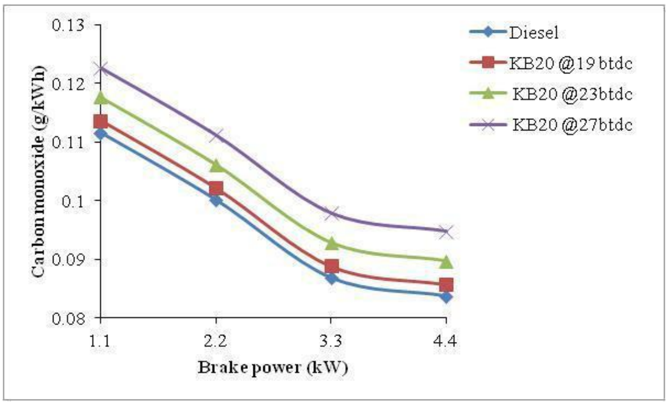

Fig 7. Variation of carbon monoxide with brake power

5.3 Unburned hydrocarbon

Fig.8 compares the unburned hydro carbon of KB20 at varying injection timing with diesel. It shows lower HC emission for KB20 than that of diesel at all loads. This may be appropriate to the creation of higher ignition temperature, plain molecular formation and uneven character of KB20. The higher explosive nature and enhanced air entrainment are considered as the possible reasons for lesser unburned hydro carbon.

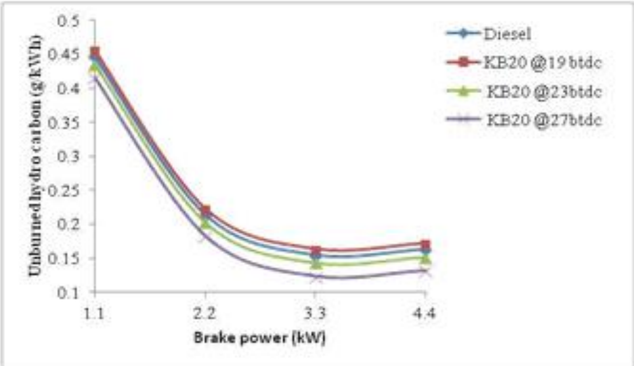

Fig 8. Variation of unburned hydro carbon with brake power

6. Conclusion

In this study we present optimized condition of KB20 compared with diesel to change injection timing in two conditions along with standard injection timing in a DICI engine. Brake thermal efficiency of KB20 is generally higher at 220 bar, 19^0 bTDC for all load. The higher brake thermal efficiency is attained when it is retarded may be due to lower fuel consumption and additional lubricity provided by blends. KB20 almost similar to diesel due to significant difference in physical properties of the fuels, specific fuel consumption for advanced injection timing is higher than diesel. Rate of pressure rise has been lower for the KB20 at higher load in comparison to that of diesel, probably due to lower calorific value of the blends. With increasing the load, the more amount of fuel is injected in engine cylinder and more amount of fuel is burned so that the cylinder peak pressure increased.

It is observed that retarding injection timing confer lower heat release rate at higher loads. Nitrogen of oxides higher because of that ignition temperature and rapidly enhance the effect between oxygen and nitrogen. High burning temperature and elevated exhaust gas temperature and low volumetric effectiveness. Hence, the injected KB20 having lesser oxygen and emits additional carbon monoxide. Unburned hydro carbon is lower for KB20 due to unstable nature and simple molecular structure. Further, among all the blends KB20 can be considered to the best blend on the basis of spray characteristics.

The spray images of biodiesel for the different combination of control factors specified in the orthogonal array formulated in the Minitab software were captured and the spray images obtained are analysed. Further, KB20 at 220 bar injection is found to be the best condition.

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