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Assessment of Compression Ignition Engine's Performance and Emissive Attributes Powered with Hybrid Biofuels

Turki Alamro

Department of Mechanical Engineering, Umm Al-Qura University, Makkah, Saudi Arabia.

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ABSTRACT

The exigence and utilization of fossil fuels (FF) are increasing globally with each passing second. Soon, the fossil fuel reserves will come to end, hence the need for an alternate source which decreases the dependence of FF to power internal combustion engines (ICE) has got great capability. Use of non-edible oil-based biofuels are preferred over edible oil-based biofuels as they will not influence nature's food cycle. Current research is for enhancing the functional capacity of compression ignition (CI) engine fueled employing biofuels of trans esterified castor and rice bran oil (CASOME and RBOME) as per the ASTM standards. The CI engine functional and emissive attributes are evaluated when fueled by diesel and different biofuel blends for variable load. Experiment scheme involves optimization injection timing (IT) from manufacturer arrangement of 23° ahead of top dead center (ATDC) in the increments of 4°. For both CASOME and RBOME biofuels at the optimized operating parameters like IT 23° ATDC, six-hole nozzle having 0.1 mm orifice diameter at 80% load resulted in lower smoke, carbon monoxide (CO) and Hydrocarbons (HC) emission. By using lower orifice diameter of nozzle, enhancement in performance and decrease in emissions are noted. Brake thermal efficiency (BTE) with toroidal re-entering type (TRE) combustion chamber has been improved for 20% biodiesel (B20) blend by reducing CO and HC emissions compared to diesel. Nitrous oxides (NOx) emissions were higher due to rise in peak cylinder temperature and decreased the dependence of FF in promoting the national energy security.

1. Introduction:

The progress of any nation predominantly supported by the energy reservoirs available. Beside gradual rise in energy consumption, stringent pollution controlling regulations and exhaustion of FF gave rise to a huge expenditure in energy section to satisfy the demand and look for environmental-friendly fuel resources. The limited resources of FF are alarming the globe energy demand. The combustion of FF become a major cause for CO_2 discharges. The primary motivation of the scientists and engine inventors is to enhance the engine performance with less emissions [1]. However, vegetable oils were considered as good replacement for FF, its synthesis remains time consuming and expensive process. This causing a barrier/hindrance in the further suitability of vegetable oils as alternative fuels. Although biofuels are high-priced, the recommenced interest in fuels research from green matter has become the need of an hour for ICE. The alternate fuel source comprises of edible and nonedible vegetable oil fuel properties in comparison with FF [2] and are counted in their main list because of its overriding. Jatropha, sunflower, cottonseed, soyabean, castor oil and many more are reported to be suitable substitutes for petroleum-based fuels using commonly available vegetable oils [2-4].

Ethanol is considered as a first-generation biofuel obtained by fermentation of sugar obtained from sugarcane, sugar beets and so on by use of creatures which yields ethanol and butanol [5]. Biochemical or thermochemical are used in production of second-generation biofuels from green matter. In spite of commercial success of fuels produced by thermochemical processes, the method did not attain much acknowledgment. Non-edible oil sources such as jatropha, karanja (Pongamia pinnata), castor bean seed (Ricinus communis), neem seeds, rubber seed, tobacco seed (Nicotiana tabacum), rice bran and so on have great potential to reflect themselves in the field of energy source for ICE [3]. The engine functional conditions assessment of a diesel CI fueled with CASOME from trans esterified using Potassium hydroxide are found in close agreement with diesel in spite of its low calorific value (CV). The blend B10 brought about a better power output result is superior than a diesel fuel [5]. Transesterification of castor oil biodiesel using Sodium hydroxide is found best suited for cold climate conditions. Employing ASTM D6751 standards for biofuel, the thermal properties (TP) were determined and found in close agreement with the diesel fuel, but B100 demonstrated highest viscosity. Biodiesel viscosity increases with increasing 20% blends had the lowest impact on fuel atomization attributes [6]. The deterioration in cloud and pour point were reported with an increase of blend amount in biodiesel suitable for severe climate circumstances without any type of additives to preserve its fluidity. Castor oil biodiesel results showed that it has abundant capability to use as a solvent such that it prevents the residues formation which cause obstacles in fuel flow line and filters [7].

The effect of compression ratio (CR) on the functional characteristics and emission of Direct Ignition diesel CI engine running on ROME and ethanol blends revealed that Ideal CR was produced higher BTE. The B40 blend was optimum yielded maximum BTE with decreased emissions like CO, HC and increased NOx [8]. Highest Cetane number for CASOME synthesized using methanol and NaOH catalysts shown the TP using ASTM standards were in great approximation with diesel, nontoxic with high flash point and therefore, storage and shipping is safe. The jatropha biodiesel (B100) suits its operation in diesel engine and by decreasing the free fatty acids the biodiesel yield can be enhanced [9]. Experimental and computational analysis on a CI engine having a single cylinder powered with CASOME biodiesel and ethanol shown optimum performance is noticed with reduced NOx and HC emissions. The

[*] **Corresponding Author**
Department of Mechanical Engineering, Umm Al-Qura University, Makkah, Saudi Arabia.
E-mail address: tsamro@uqu.edu.sa (Turki Alamro).

output parameters of a CI engine using different combustion chamber shapes fueled with blends of castor oil biodiesel shown TRE combustion chamber was effective [10]. The potential of RBOME as a blend for diesel CI engine obtained from various catalysts of crude RBOME oil on esterification rate is discussed. The thermo-physical properties of ROME are on par with diesel especially, blend B50 with a peak BTE. [11]. The fuels produced from green matter have got great potential to fuel IC engines. Even though many researchers have synthesized castor oil biodiesel, the techniques that reduce the viscosity by transesterification is one such method. Extensive research has been done on ethanol blending but the engine performance and exhaust gas analysis can be done by direct injection [10]. Many biofuels are tested on the engines to achieve best results in terms of performance. But less work is carried towards using biofuels in engines with modification in design and operating conditions. A research has been found related to impact of IT, injection output pressure (IOP) on engine output parameters [12]. Nozzle geometry (Number of holes), combustion chamber shape and EGR have great impact on the output of the engine, hence investigation associated to that has got immense importance [13].

The current research deals with synthesis of CAOME and ROME by transesterification process from their respective raw oil and to evaluate the thermo-physical properties. The study comprises estimation of functional, emissive and combustion attributes of CI engine fueled with selected fuels. The FF combustion emits large amounts of greenhouse gases, employment of biofuels for engine applications to reduce these emissions, and this justifies the current research.

2. MATERIALS, METHODS AND EXPERIMENTAL SETUP

High quality castor (CAS) beans without fungal infection, moisture was carried using dehulling and winnowing to detach the shell from the nibs. Moisture content test is conducted by using a hot air oven by drying selected quantities of seeds at 50°C for 60 minutes. Density of methanol selected for synthesizing biodiesel must be less than 790 Kg/m^3 and free from water, and sediments. Water used for washing of biodiesel must maintain a pH7, demineralized and free from suspended dust particles. The oil can be extracted from seeds by two conventional methods such as Rotary crushing and Expeller type machine. In spite of having a higher yield rate, the expeller method is not suitable for small scale production hence CAS oil is obtained from dried castor beans by conventional rotary crushing method. Oil purification is carried by mixing 750 ml of water for every 10 kg of raw oil in a container made of Indolium at a temperature of 400°C for one and half hour, mean time stirring is carried till water completely evaporates. Sediments settle at the bottom and purified oil is collected at the top surface of the container.

The technique adopted for synthesis of biodiesel from raw castor oil and raw rice bran oil based on the percentage of free fatty acid (FFA) in the single stage process (base catalyst) if FFA is less than 4%. Otherwise, two stage process (acid-base catalyst) if FFA is more than 4%. The solution used in the burette is 0.1N NaOH, which is obtained by mixing 4 grams of NaOH with 1 liter of distilled water in a measuring flask by continuous stirring. In a flask, raw oil is mixed with isopropyl alcohol, stirred well till the mixture becomes transparent and the same is heated at 60°C to dissolve remaining residues of raw oil in the conical flask. Few drops of phenolphthalein indicator are added to the above mixture and is used as a solution for conical flask. The FFA content in castor seed oil is less than 4% hence single stage transesterification process is adopted and FFA content in rice bran oil is more than 4%, hence two stage transesterification process is adopted for the biodiesel production.

Methanol is recovered by heating the biodiesel mixture in a 3-neck flask at a steady temperature of 70°C with continuous stirring at 100 rpm speed. Methanol evaporates which is condensed using a condenser. After methanol recovery, the biodiesel is transferred to the washing funnel. Warm water is (40°C-45°C) mixed and retained for a duration of 20-25 minutes and the process is repeated three to five times to remove soap content until the pH of water reduces to seven. The synthesized biodiesel is heated at a static temperature of 105°C, using a heater to eliminate the moisture.

2.1. Preparation of biodiesel blends

The engines fueled with diesel exhibit higher efficiency compared to biodiesel operation as biodiesel are highly viscous and display poor combustion characteristics. According to energy plan bill, the maximum % biodiesel added to diesel is 20 or for preparing 1 liter of biofuel consists of around 200 ml biodiesel, 800 ml of diesel (20% biodiesel, and 80% of diesel) in B20 blended fuel. When the biofuel percentage in blend is less their properties are similar to diesel, as percentage of blend increases results in variation in fuel properties that affect brake power and exhibit reduction in thermal efficiency. Therefore, hybrid biofuel blends can be prepared on mass or volume basis. In the present work, volume base method is adopted for preparation of biodiesel blends (refer Figure 1.). Blends of rice bran oil and castor oil with diesel considered for present work are provided in Table 1.

Figure 1. Different blends of biodiesel

Table 1 Blends of CASOME, RBOME and diesel

Blends	Percentage of different oils (%)		
	RBOME	CASOME	Diesel
100 Diesel	00	00	100
100 CASOME	00	100	00
100 RBOME	100	00	00
10 RBOME + 90 Diesel	10	00	90
20 RBOME + 80 Diesel	20	00	80
30 RBOME + 70 Diesel	30	00	70
10 CASOME + 90 Diesel	00	10	90
20 CASOME + 80 Diesel	00	20	80
B30 CASOME + 70 Diesel	00	30	70

2.2. Determination of Properties of Fuels

The physico-chemical properties namely, density, CV, kinematic viscosity, flash and fire point of biodiesel and its blends are evaluated as per ASTM standards [14]. The biofuels are denser compared to diesel fuel found from hydrometer and CV of fuel is calculated by using a bomb calorimeter. The flash and fire point of the diesel, biodiesel and their blends are determined employing the device Pensky martin equipment and Pensky Martin Cannon calibration viscometer is exercised for finding the viscosity of biodiesel and their blends. The properties of raw oil and biofuel are presented below (Refer Tables 2 and 3).

Table 2. Raw Oil Properties

Properties	Raw Castor oil	Raw Rice bran oil
Flash point (°C)	320	316°C
Fire point(°C)	345	342
Kinematic viscosity (cSt)	52	43.52
Density (kg/m^3)	956	920

Table 3. Properties of CASOME and RBOME [15]

Properties	Diesel	CAOME	ROME
Density (kg/m^3)	834	927	872
Kinematic viscosity (cSt)	2.38	5.57	4.81
CV in (kJ/kg)	42250	37730	41382
Specific gravity	0.834	0.927	0.872
Flash point (°C)	60	189	157
Cetane number	45-55	41	55-56.

Fuel injectors/ nozzle used in current work with 3, and 6 holes. The engine functional and emissive attributes are evaluated when fueled with diesel and different biofuel blends for variable load. Experiment scheme involves optimization IT from manufacturer specification of 24° before top dead center (BTDC) in the increments of 4°. For the optimum IT, IOP and for best nozzle geometry experiments are conducted on different combustion chamber shapes. For the optimum IT, IOP and for best nozzle geometry and best combustion chamber shape experiments are performed on biofuel blends (10-30%) of CASOME and RBOME to obtain the optimal blends that result in best performance and minimum emissions.

2.3. Experimentational Work

To measure the performance parameters of the engine, certain basic measurements need to be recorded from the calibrated engine setup such as gas pressure in the cylinder, engine speed, airflow, torque produced, temperature attained, fuel intake, and exhaust flow of the engine. Pressure of gases present in the engine cylinder and TDC signals are recorded by a high-speed computer based Digital Data Acquisition System. The test rig is provided with a non-contact type proximity sensor which is attached to the engine to measure the engine speed, which develops the pulse output and speed in RPM displayed on the digital meter. By using a knob in the control panel of the setup the desired speed can be attained. The performance test of an engine is carried by varying the load from zero to full load. Eddy current dynamometer and load cell with strain gauges are required. The load cell converts force into electrical signal and display in output of the system. Airflow consumption is also important for an engine because the basic food of an engine consists of flammable mixture that is fuel and air. The quantity of fuel supplied to the engine is measured by using burette on volume basis. The time taken for 10 cc fuel consumption is recorded by using a stopwatch. Thermocouples are fixed at different places of assessing spots, the temperature can be measured, the chromium-aluminium (k-type) thermocouples have been fixed in the engine and all these are directly connected to the digital meter that gives the temperature reading in the system of computer screen (refer Figure 2). Various parameters like brake power, total fuel consumption (BSFC or ISFC) and different emissions of the engine like hydrocarbon, oxides of nitrogen and CO_x are measured.

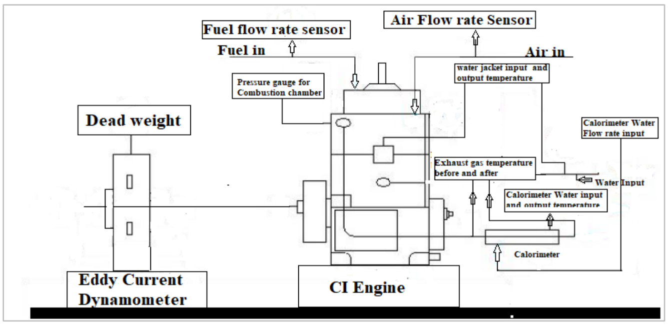

Figure 2. Schematic view of Experimental Test rig

3. Results and Discussion

3.1. Influence of IT, IPO, Nozzle hole diameter (NHD) and combustion chamber shape (CCS) on the Performance of CASOME and RBOME Fueled Diesel Ci Engines

The initial set of experimental procedure includes optimization of IT, IPO, NHD and CCS. The outcomes of trials made on a customized CI engine run with diesel, CASOME and RBOME fuels to assess the effects of IT, IPO, NHD and CCS are reported on the functional, emissive attributes of a single cylinder CI engine running on diesel, CASOME and RBOME. It is operated at a 1500 rpm speed, CR is 17.5, for variable load at IT values of 20°, 24°, 28° and 32° ATDC by maintaining IPO at 210 bar. At all specified loads the parameters such as BTE, HC, CO, smoke, NO_x emissions, etc. are noted. Average from five readings at all detailed conditions, the results were collected to determine optimum IT for engine fueled with CASOME and RBOME are as follows:

3.1.1. Impact of IT on BTE varying with Brake power (BP)

The impact of IT on BTE for CASOME and RBOME at various ITs is shown in Figure 3. The maximum BTE is achieved for diesel at a static IT of 24° BTDC. BTE is lower for CASOME and RBOME in comparison with diesel for all four IT's considered. The energy content of CASOME and RBOME is less than diesel fuel which contribute to lower values of BTE due to high fuel intake for the same power output and also the high viscosity of CASOME and RBOME adversely affects mixture formation and subsequent combustion. The maximum BTE for CASOME and RBOME are at 24° BTDC is 25.5% and 26.5% as compared to 32.5 % for diesel. Conversely, by advancing the IT at 4º crank angle, an improvement in BTE (about 26.7 % and 27.42% at an IT of 28°ATDC) is noted for both CASOME and RBOME. Based on intensity of BTE, the optimum value of IT for diesel at 24°ATDC and both biofuels at 28°ATDC are preferred. However, 24°ATDC is the optimum IT value prescribed by the manufacturer while operating with diesel fuel as the experimental results validate the same.

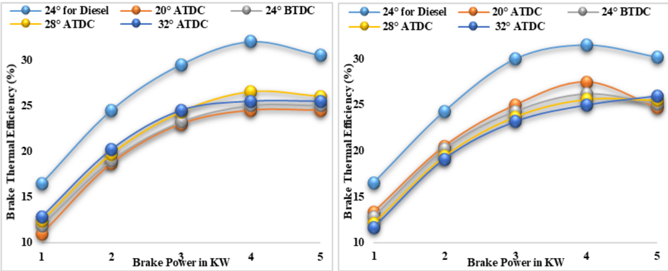

Figure 3. Impact of IT on BTE varying with BP for (a) CASOME (b) RBOME

3.1.2. Impact of IT on Peak Pressure varying with BP

Figure 4 characterizes the impact of IT on peak pressure varying with respect to BP for diesel, CASOME and RBOME operated engine. Self-ignition temperature of the fuel influencing the plot distribution in the pressure angle graph of the CI engine. For CASOME and RBOME used engine shows lower peak pressures at all ITs in contrast to diesel due to its lower CV, ignition delay, lower adiabatic flame temperature and slow burning nature of green fuel. However, for varying IT values, the peak pressure growth is reported as a result of increased delay period for CASOME and RBOME operation.

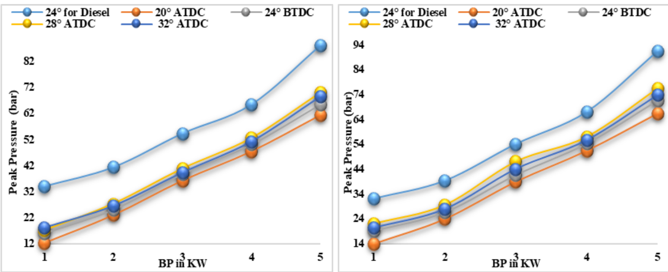

Figure 4. Impact of IT on Peak Pressure varying with BP for (a) CASOME (b) RBOME

3.1.3. Effect of IT on Ignition Delay varying with BP

Figure 5 represents the impact of IT on ignition delay against varying BP showed Steady IT is utilized to compute ignition delay as the time interval from the injection starting point to the point at which pressure-angle curve separates from the motoring curve in a gauge. This is reduced with increase of load and under same conditions ignition delay increased for both CASOME and RBOME fuels. CASOME and RBOME exhibited increased and prolonged ignition delay in comparison to diesel. Conversely, when the IT is advanced the ignition delay lowered as the better BTE offers enhanced combustion for CASOME and RBOME operation.

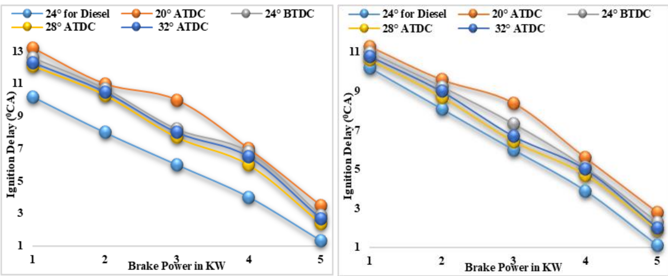

Figure 5. Influence of IT on Ignition Delay varied with BP for (a) CASOME (b) RBOME

3.1.4. Role of IT on Combustion Time (CT) against varying BP

The influence of IT on combustion time is shown in Figure 6 is measured based on the period from initiation of combustion to 90% aggregate heat release. The CT is directly related to BP for both diesel, CASOME and RBOME fuels under all ITs, and this is for the reason that increased quantity of fuel injected to obtain higher power output. The biofuels are highly viscous, requires more time for mixture formation, all these result in rise in combustion duration. At advanced IT of 28° ATDC less combustion duration is observed in comparison with others for CASOME and RBOME operation. This is because of the rise in amount of fuel that burnt inside the cylinder.

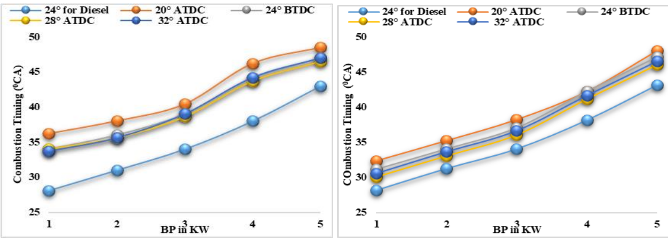

Figure 6. Influence of IT on Combustion time varied with BP for (a) CASOME (b) RBOME

3.1.5. IT influence on Smoke Opacity for BP Variation

The influence of IT on smoke discharge (SD) for diesel, RBOME and CASOME is presented in Figure 7 showed SD increased with increasing BP. The transformation method of hydrocarbon fuel molecules into soot particles is called as smoke. The heavyweight molecule structures, high viscosity, and density of RBOME and CASOME attributes to emit heavier hydrocarbon molecule emission in comparison with diesel fuel. The lower CV and volatility of both biofuels compared to result into unfinished combustion due to varying air to fuel ratio and hence high SD [13]. The decreasing IT from 24° to 20° ATDC results in increased SD for CASOME and RBOME fuels and minimum emissions were reported at progressing IT of 28° ATDC, where the fuel injection occurs into the cylinder at low pressure and temperature and this results in ID which leads to fuel's major share burning in already mixed form [16]. Further rise in IT to 32° ATDC shows higher levels of smoke emissions.

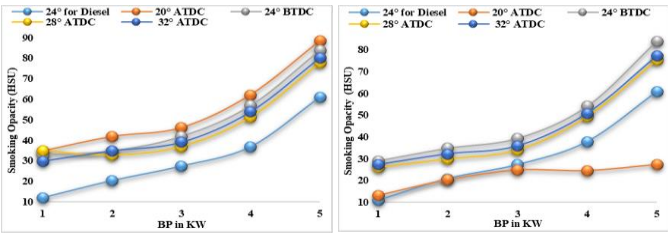

Figure 7. Effect of IT on Smoke opacity varying with BP for (a) CASOME (b) RBOME

3.1.6. Role of IT on HC for varying BP

For CI engines running on diesel, CASOME and RBOME, the influence of IT on HC emissions is depicted in Figure 8 revealed that unfinished combustion ends up with HC emissions emanating from them. During ID, the presence of lean and irregular mixture formation ends in condensed velocity at the injector orifice which produces HC emissions [17].

At all chosen ITs for CASOME and RBOME fuel operated HC and CO emissions are found greater in comparison with diesel fuel as it shows poor spray characteristics, irregular mixture formation, low combustion efficiency and injected biodiesel resulting in wall wetting [18].

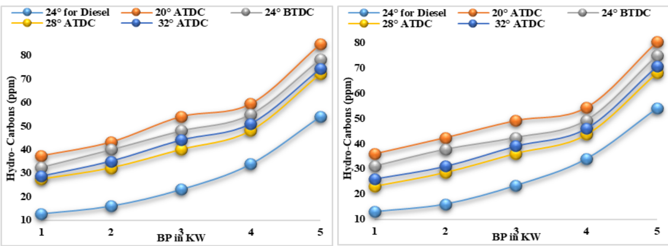

Figure 8. Influence of IT on HC Emissions varying with BP for (a) CASOME (b) RBOME

3.1.7. CO Emissions vs BP

CO is a toxic byproduct releases when a partial burning of the premixed mixture remaining in the engine cylinder. The CO emissions are low at part and amplified at higher loads under all the ITs for both biofuels and diesel is as shown in Figure 9. CASOME and RBOME exhibited relatively higher CO emissions, the credible reasons may be poor spray characteristics and incomplete combustion.

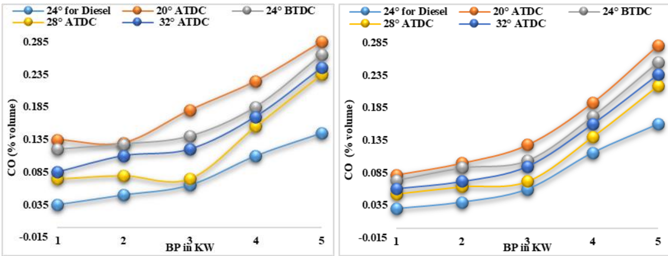

Figure 9. Influence of IT on CO Emissions varying with BP for (a) CASOME (b) RBOME

The CO emissions for CASOME fuel run at 80% load for four IT's are 0.25%. 0.22%, 0.18% and 0.203% for 20°, 24°, 28°and 32° ATDC respectively. The CO emissions for RBOME fuel run at 80% load under all ITs are 0.22%. 0.198%, 0.168% and 0.187% for 20°,24°,28°and 32° ATDC respectively. For both biofuels (CASOME and RBOME) operated fuel engine produces the HC and CO emissions in which minimum of these emissions occurred at 28° ATDC compared to other ITs.

3.1.8. Influence of IT on NOx Emissions vs BP

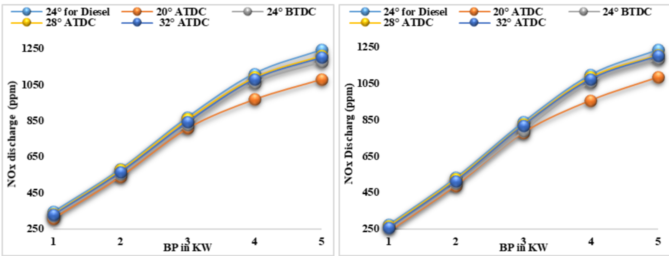

Figure 10. Influence of IT on NO_x Emissions varying with BP for (a) CASOME (b) RBOME

ITs effect on NOx emissions with BP for diesel, CASOME and RBOME are displayed in Figure 10 revealed that its quantity in fewer ppm in biofuels compared to diesel fuel under at all the Its values. cylinder temperature, availability of oxygen and residual time are the key factors influencing NOx production or in general, the deferred injection ends up in abundant reduction in NOx emissions. The lower concentration of NOx emission at reducing IT because of decreased ignition efficiency and low cylinder temperature.

NOx levels are greater with CASOME and RBOME operation at advanced ITs of 24°, 28° and 32° ATDC as more rate of heat releases due to ID [19]. The above results conclude that the optimum IT of 28° ATDC for CASOME and RBOME operation as the BTE is higher while emissions are lower except NOx.

3.2. EFFECT OF BLENDS OF CASOME AND RBOME with Diesel

In this section, a tailored diesel CI engine was run with blends of CASOME and RBOME with diesel fuel respectively is varied from 10-30% in steps for the augmented settings of IOP: 240 bar, IT: 28° ATDC, 6-hole nozzle with 0.1 mm opening diameter and TRE combustion chamber. The engine performance and emissive results are discussed in the subsequent sections.

3.2.1. Impact of IT on BTE varying with BP

For both biofuels (CASOME and RBOME), blend B20 showed better outcomes in terms of higher BTE in comparison to other blends and is slightly lower when compared with diesel (Figure 11). Increasing the biofuel percentage beyond 20% results in weak mixture formation because of higher viscous natured blend and lowered blend CV as well [20]. Highest BTE is discovered to be 30.72 % and 31.2 % for B20 blend of CASOME and RBOME respectively.

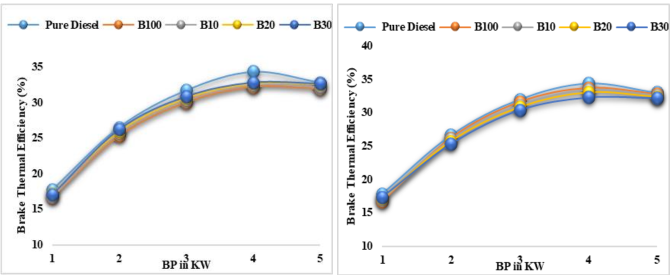

Figure 11. BTE vs BP for (a) CASOME and (b) RBOME blended Biodiesel

3.2.2. Impact of IT on Peak Pressure varying with BP

Figure 12 specifies peak pressure change for different blends of CASOME+ Diesel and RBOME+ Diesel with brake power showing that enhanced ignition efficiency for B20 blends by means of improved fuel atomization and oxygen in biofuels. This is the indication of higher peak pressure in comparison with other blends and is slightly lower than the peak pressure achieved for diesel [19].

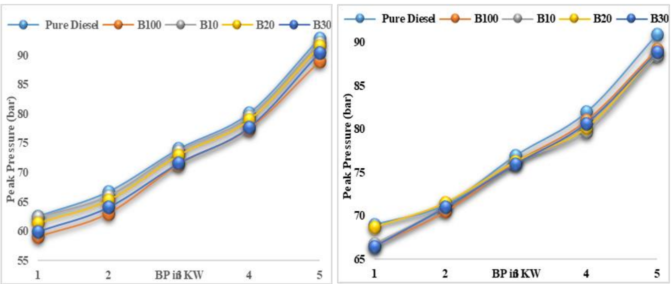

Figure 12. Peak pressure vs BP for (a) CASOME and (b) RBOME blended Biodiesel

3.2.3. Impact of IT on Ignition delay varying with BP

Figure 13 flashes ID for different blends of CASOME + Diesel and RBOME + Diesel with BP showing that it is lower for B20 blend in comparison with other blends of both fuels and the results were slightly higher compared to diesel [19, 21].

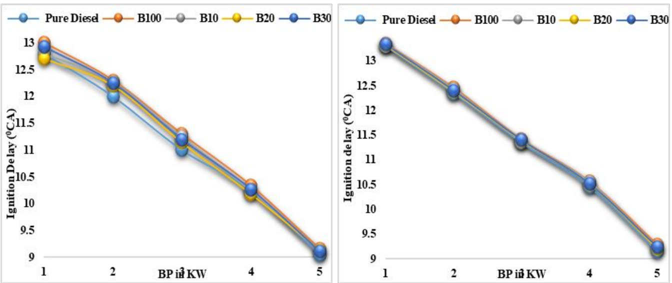

Figure 13. Ignition delay vs BP for (a) CASOME and (b) RBOME blended Biodiesel

3.2.4. Impact of IT on Combustion duration Varying with BP

Figure 14 indicates combustion duration for different blends of CASOME + Diesel and RBOME + Diesel with BP. Generally, biofuels need more combustion time due to their low energy content and higher viscous nature. The combustion time for B20 blend is found lesser in comparison with other blends and higher than the diesel [21].

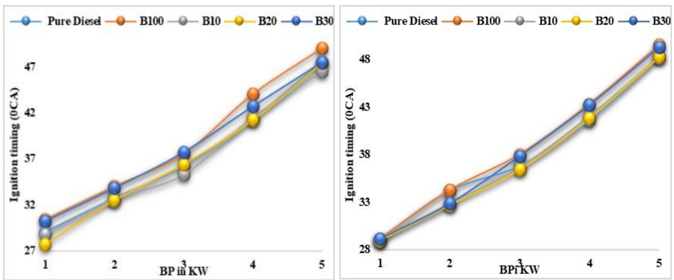

Figure 14. Combustion duration vs BP for (a) CASOME and (b) RBOME blended Biodiesel

3.2.5. Impact of IT on Smoke opacity varying with Brake power (BP)

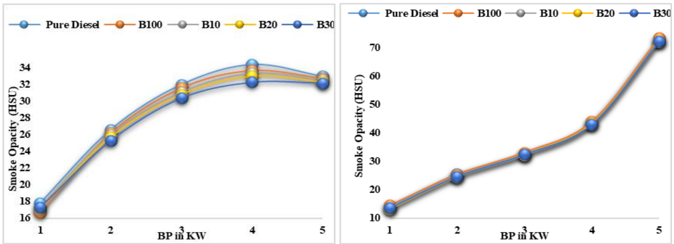

Figure 15. Smoke opacity vs BP for (a) CASOME and (b) RBOME blended Biodiesel

Figure 15 indicates the change of smoke opacity for different blends of CASOME and RBOME with brake power. B20 Blend shows lesser smoke emissions in comparison with other blends for both CASOME and RBOME respectively. The oxygen in biofuel promotes combustion [20, 22] and there by smoke emissions decreases. For blends higher than 20 percent of biofuel results in increased smoke emission for both CASOME and RBOME biofuels due to inferior atomization.

3.2.6. Hydrocarbon and CO emissions

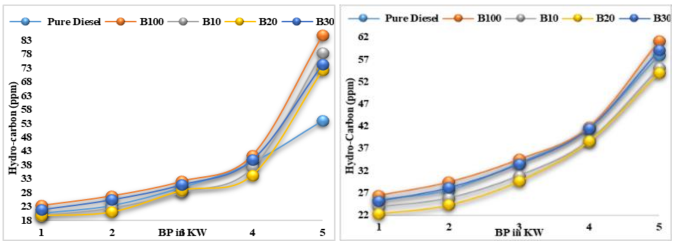

Figure 16. Hydrocarbon emissions vs BP for (a) CASOME and (b) RBOME blended Biodiesel

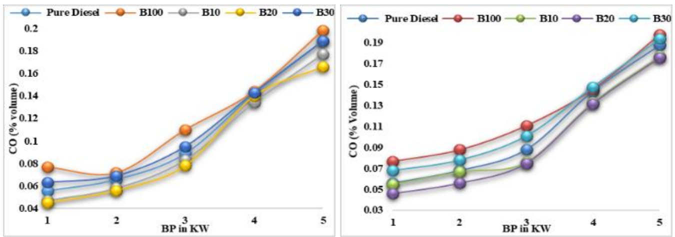

Figure 17. CO vs BP for (a) CASOME and (b) RBOME blended Biodiesel

Figure 16 and Figure 17 indicates the variation of HC and CO emission for various blends of CAOME-Diesel and ROME-Diesel with brake power respectively. HC and CO emissions from the engine signify incomplete or poor combustion. HC and CO emissions are lesser for B20 blend in comparison with other blends of both biodiesels with diesel and it is lesser compared to diesel. Oxygen in biofuel increases combustion efficiency and thereby results in lower HC and CO emissions [21, 23].

3.2.7. Nitric oxide emissions

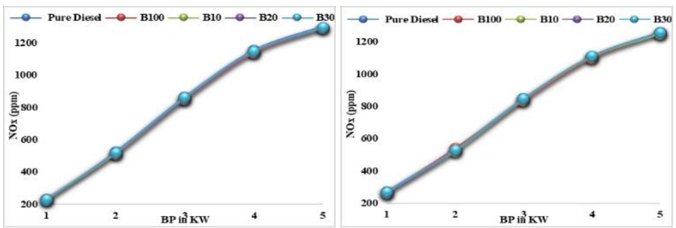

Figure 18. NOx vs BP for (a) CASOME and (b) RBOME blended Biodiesel

Figure 18 signifies NOx emissions for respective blends of CAOME + Diesel and ROME + Diesel with brake power. The key factors that account for formation of NOx is amplified in-cylinder temperature, availability of oxygen and residual time prevailing inside the engine cylinder. B20 Blends of CASOME and RBOME biodiesels show higher NOx emission in comparison with B10 and B30 blends respectively [24]. As BTE is higher for B20 blend due to improved combustion it results in higher NOx emission, but further rise in biofuel percentage negates the rise in combustion efficiency due to higher viscous nature of biofuels [20, 25].

4. Conclusion

Various inferences derived from the above studies are presented as follow:

- For a hemispherical combustion chamber the maximum BTE at 24° ATDC is 25.5 % in comparison with 32.5 % for diesel. But, by advancing the IT by 4° Crank angle, an enhancement in BTE was obtained. It is about 27.5 % at an IT of 28°ATDC. Based on the magnitudes of BTE the optimum IT for diesel, CASOME and RBOME are selected accordingly as 24^0, 28^0 and 28^0 ATDC respectively. Manufacturer stated the optimum IT of 24°BTDC for diesel operation and experimental results confirmed the same.
- For a TRE combustion chamber at an IOP of 240 bar for a six-hole nozzle has resulted in optimum output with BTE of 28.3% as a result of improved atomization, improved spray characteristics and better mixing of fuel with air and which enhanced combustion efficiency with minimum emission of smoke, CO and Unburnt Hydrocarbons.
- Six-hole nozzle with 0.1 mm orifice diameter at 240 bar IOP and IT of 28° ATDC for TRE Combustion chamber for B20 blend for both CASOME and RBOME has resulted in higher BTE of 31.25% and 30.5% at 80% of full load and the results are in close agreement with the output of engine operated with pure diesel. CO and HC emissions for blend B20 are less than diesel but NOx emissions are higher due rise in peak cylinder temperature.

Studies can be executed to estimate the impact of nano-particle addition on the performance of the engine for optimized conditions. Study can also be undertaken to enhance the performance using the method of preheating of fuel using EGR. The results of research undertaken can be validated using mathematical modelling and Computational simulation tools.

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