Nat. Volatiles & Essent. Oils, 2021; 8(5): 3886 - 3906

Influence of injection timing on performance, emission, and combustion characteristics of CI engine working with ternary blended biodiesel

H S Anantha Padmanabha[1] **Dillip kumar mohanty**[2]

[1]*School of Mechanical Engineering, VIT-AP University, Amaravati, India-522237*
[2]*School of Mechanical Engineering, VIT-AP University, Amaravati, India-522237*
E-mail: ananth.7016@gmail.com

Abstract

The performance, emission, and combustion characteristics of JKC biodiesel in CI engines at different injection timing are investigated in this study. The tests were carried out with four dissimilar biodiesel compositions containing 5, 6.66, 8.33, and 10% JKC biodiesel, respectively. The JKC biodiesel with 6.66% Jatropha-Karanja-Cottonseed (JKC6.66D80) has been determined to be the optimum composition depending on the efficiency of brake thermal and underneath emissions. At 25° before top dead center (BTDC) injection timing, maximum brake thermal efficiency (BTE) of 28.2 percent and the lowest BSFC (brake specific fuel consumption) of 0.3 kg/KWhr were attained, corresponding to the blended JKC6.66D80 fuel. The emissions of hydrocarbon and carbon monoxide are inferior for JKC6.66D80 fuel with 28 ppm and 0.18% at 25° BTDC injection timing. The cylinder pressure reached 76.99 bar for injection 25° BTDC, with a rate of pressure rise 9.05 bar/crank angle.The cumulative heat release rate and heat release rate are extreme for JKC6.66D80 blended fuel at 25° BTDC. At 25° BTDC injection for JKC6.66D80 blended fuel, the performance, emission, and combustion characteristics are improved than 23° BTDC standard diesel injection timing. As a result, JKC6.66D80 fuel can replace diesel substitutes in CI engines with a minor advance in injection timing.

Keywords: Karanja oil; Jatropha oil; Cottonseed oil; Ternary blended Biodiesel; Transesterification; Emission.

Introduction

Fast urbanization, industrialization, and growth in the transportation sector, as well as domestic applications, have been the primary reasons for to increase in demand for power-producing fuels. The world is facing problems in huge energy demand with petroleum, coal, and Natural gas which are coming from fossil fuels. The energy sources are expected to be exhausted in the future which has an unfavorable effect on the environment; it means the air purity is derogatory. Due to these problems, there is a need to find an alternative source for renewable energy which relegates the emissions. The alternate fuels should be economically viable, renewable, and less polluting so that they can be successfully adopted for satisfying the energy demand, having the potential to resolve the issues like price hikes, sustainability, air pollution, and global warming. Using edible oils is not possible for the production of biodiesel due to the scarcity of food. The biodiesel which is prepared from animal fats and plant oil is one of the alternatives among the vegetable oil in a diesel engine [1]. The oils like algae, Karanja, Jatropha, Cottonseed, soya, Mahua, Sunflower seeds, rice bran, etc. which are coming from plant species are the main sources for biodiesel production [2]. Non-toxic, Fewer air pollutants, and biodegradable are the benefits of biodiesel and 40 to 90 percent energy yield presence in biodiesel [3]. Besides, the biodiesels exhibit reduced emissions of greenhouse gases, minimal influence on global climate, and high sustainability [4].

The performance and emissions of blends of jatropha biodiesel on CI engine were studied by Jayaraj et.al. By adding the additives like CNTs, TiO_2, and AL_2O_3 with biodiesel, it was reported that the blend B20 (10% jatropha, 90% diesel) showed reduced emissions and increased brake thermal efficiency with the comparison of diesel [4]. Rajesh et.al Patil evaluated the effect of operating parameters on the performance of the engine with Jatropha biodiesel. It was reported that Jatropha methyl ester shows reduced smoke emissions and increased NOx at 12°CA btdc in comparison with diesel [5]. Bhaskar et.al conducted tests on the CI engine with the blends of Jatropha Methyl Esters (JME). Author reveals that the blend 20% JOME (20% biodiesel, 80% diesel) gave well performance and emissions which is similar to pure diesel [6]. Aparna et al.compared the Jatropha oil and diesel fuel in a diesel engine with heterogeneous catalyst. They accomplished that the blend B20 (20% biodiesel, 80% diesel) shows better performance and higher emissions of HC among jatropha oil compare topure diesel. In case of emissions of NOx there is a slight increased in comparison with pure diesel [7]. Oduro et.al performed test on diesel engine with dissimilar proportions of jatropha biodiesel. Author concluded that the blend 97.4% biodiesel and 2.6% diesel gave better performance and emission similar to diesel [8].

Dewi et.al have done investigation on CI engine with the blends of Karanja biodiesel. They reported that the blend B40 (40% biodiesel, 60%diesel) gave better BSFC and BTE which is similar to pure diesel [9]. Lee et.al estimated the performance as well as emissions on diesel engine with the proportions of Karanja biodiesel. Author conclude that 40% karanja biodiesel shows decreased emissions and increased NOx compare to diesel [10]. Varatharaju et.al conducted tests on CI engine with the blends of pongamia pinnata biodiesel. The author reveals that the blend B20(20% biodiesel, 10%diesel) shows reduced CO, as well as HC emissions, also more smoke level, has been observed [11]. Puneeth et.al.reveal that the 20% of karanja biodiesel blend gave better thermal efficiency and BSFC compared to diesel[12]. Avinash et.al exhibit the consequence of Karanja biodiesel and its proportions on engine combustion characteristics in a direct injection CI engine [13]. The test results show that B20 (20% karanja, 80% diesel) blend gave better performance, emissions, and combustion characteristics. Muralidharan et.al concludedTransesterification was used to make biodiesel which is coming from non-edible pongamiapinnata raw oil, which would be applied as a fuel in a diesel engine. At full load, blend B5 (5% karanja and 95% diesel) emits less unburned hydrocarbon, carbon dioxide, carbon monoxide, and oxides of nitrogen according to the authors [14].

Subhash et.al experimented on a CI engine with proportions of biodiesel from cottonseed. It was concluded that the blend B20(20% cottonseed, 80%diesel) reduces the ignition delay and rate of pressure rise due to high cetane number and also reduced NOx emissions has been observed [15]. Shelke et.al has done an investigation on the effect of EGR in a diesel engine with blends of cottonseed oil. It was reported that decreased ignition delay from11°CA from standard diesel to6.5°CA for 20% blend which contains 20% biodiesel in 80% pure diesel has been notified [16]. Mustafa et.al researched performance characteristics on cottonseed biodiesel, concluded that 20% cottonseed oil shows a reduction in emissions compared to diesel fuel [17]. Duple et al. carried out the experiment using cottonseed oil blends with diesel in compression ignition engines. The author reveals that the engine performance with blend WCCO10 (10% cottonseed, 90% diesel) differs slightly compare with diesel, and emissions of hydrocarbon and carbon monoxide are lower than pure diesel and conclude that 20% biodiesel blend exhibit better performance and exhaust emission compare with other blends of biodiesel [18].

Paul et.al conducted tests on CI engine with palm and jatropha blended biodiesel. It was concluded that blend D90PB5JB5 (i.e. 90% diesel & 10% biodiesel) shows slight reduction seen in BSFC in comparison to standard diesel [19]. Satyajeeth et.al shows the test results on the CI engine with the mixed blends of Rapseed and mahua biodiesel. Tentative results show that the blend BL20 (10% of rapseed and mahua, 80% diesel), was found to be 2.79% lower brake thermal efficiency than neat diesel and reduced emission characteristics at full load conditions [20]. The reduced emissions and higher NOx with lower exhaust temperature, when compared with gasoline for PM20 (10%Pongamiapinnata and 10%mustard blend and 80% diesel) blend, has been observed by srithar et.al [21]. Teoh et.al investigated engine performance as well as emission with blends of Millettia pinnata and Croton megalocarpus biodiesel. The author concluded that the blend MP5CM15 (5% MP and 15% CM 80% diesel) gave a better heat release rate, smaller ignition delay, higher in-cylinder peak pressure, and duration of combustion [22].Singh et.al done an investigation on dual blend biodiesel produced by mixing argemonemexicana with mahua, which exhibits significantly better characteristics in comparison to biodiesel blend of only mahua oil. The dual blended biofuel can achieve higher brake power than that of diesel with low HC as well as CO emissions [23]. Pugazhendhi et.al reported dual biodiesel based on oil extracted from Roselle and Karanja and the results were tested for CI engine at different load conditions. The experimental results revealed that the blend having 10% each of Roselle and karanja oil with 80% of diesel can operate as an alternative for pure diesel [24]. Dabhi et. al. prepared an emulsified fuel extracted from the dual biodiesel blend of castor and Jatropha oil which achieved an approximately 14% hike in BTE with around 60% reduced NOx emission [25]. Senthur et. al. prepared a 1:1 biodiesel blend of oils extracted from papaya seeds and watermelon seeds and reported that the biodiesel containing 10% of each blend offered engine efficiency and combustion characteristics very similar to diesel[26]. Karthick et.al carried out the test on CI engine with the blends of lineseed and rubber biodiesel. The author reveals that (5% biodiesel, 5% biodiesel rubber, and 90% diesel) and (10% biodiesel linseed, 10% biodiesel rubber, and 80% diesel) blends reduce the emissions of CO, HC when compare to diesel [27].

Hosmath et.al [28] investigated Honge methyl esters as well as Jatropha (JOME) and Sesame (SOME) in a direct injection diesel engine with 1-cylinder based on four strokes. These blends show low NOx emission comparison with diesel. The mixed blends JNM 25 and JNM 30 performed similarly to diesel while emitting less pollution with reduced hydrocarbon and carbon monoxide emissions while NOx (nitrogen oxide) emissions increased by a small extent. Anafi et.al reported triple blended biodiesel of Jatropha, cottonseed, and neem oil for the evaluation of a stationary multicylinder CI engine. The results concluded to show the lowest exhaust temperature, highest combustion efficiency, and reduced CO_2, NOx emissions [29]. Olsen et.al. Prepared blends of camelina, carinata, and pennycress biodiesel and test carried out in direct injection CI engine with no adjustment [30]. Patil et.al approved an investigation on Variable Compression Ratio engine (VCR) using Diesel with biodiesel proportions based on Jatropha, Mahua, and Neem. These biodiesel shows low NOx and high CO, HC, and smoke emissions when compared with pure diesel [31].

The blending of diesel with methyl ester extracted from particular feedstock influences the properties of the biofuels to exhibit certain improvements in performance or emission. The dual blended biofuels offer some betterment in this regard. Keeping in view achieving enhancement in the engine characteristics, ternary blend biodiesel has been investigated in the present work. This study aims to look into the performance, combustion characteristics, and exhaust gas emissions of biodiesels derived from Jatropha, Karanja, and Cottonseed mixed proportions with pure diesel at different injection timing in a Variable Compression Ratio (VCR) diesel engine. The reason for selecting these biodiesels is that they have properties similar to diesel and are available easily.

Materials and Methodology

Biodiesel preparation

In the presence of a catalyst, Karanja oil is chemically reacted with an alcohol (methyl) to create the methyl ester. For the transesterification of oil from Karanja, a two-stage process is used. The acid-catalyzed process is the first stage, used to reduce the free fatty acids (FFA) content in Karanja oil by esterification process with methanol (99% pure) and sulfuric acid (98% pure) in a closed reactor vessel for one hour at 57°C. The Karanja crude oil is heated up to 50°C, then 0.5% sulfuric acid (by weight) and 13% methyl alcohol (by weight) are added to the heated oil. To speed up the reaction, an excess amount of methyl alcohol is added. This reaction was carried out with 700 rpm stirring and a temperature of 55-57°C for 90 minutes, with continued analysis for FFA every few minutes. The reaction has stopped when the FFA content falls to 1%.The water formation is the main drawback to the acid-catalyzed esterification process for FFA. The conversion of FFA to esters can be slowed down by the presence of water. The esterified oil was fed into the transesterification process after it had been dewatered.

In the trans-esterification process, Sodium hydroxide (NaOH) is commonly used as a catalyst at 1% of the total amount of oil mass. It is distilled with the normal agitator for 20 minutes at 700 rpm in the 13 percent of distilled methanol (CH3OH). The alcohol-catalyst solution was made fresh to preserve catalytic activity and avoid moisture absorption. It is gradually charged into preheated esterified oil after completion. To avoid the moisture and loss of alcohol, the system gets closed when the methoxide was added to esterified oil. To speed up the reaction, the temperature of the reaction mix was held between 60 and 65 degrees Celsius (near the boiling point of methyl alcohol) till 70min with the stirring speed of 560-700rpm. Every 20min the reaction mixture was taken for FFA analysis. Once the methyl ester formation was complete, the heating was turned off, and the products were chilled and carried to a separating funnel. It is permitted to settle for 8 to 10 hrs in a separating funnel after the reaction is complete. At this point, two main products have been obtained; one is glycerin and the second is biodiesel. The glycerin part has settled down due to heavy than the biodiesel one which has floated up. The excess alcohol in every step was extracted by the process of distillation after the glycerin and biodiesel stages were separated. After removing the glycerin and alcohol, the obtained biodiesel was refined by gently washing it with warm water to eliminate any remaining catalyst or soaps. Similarly, the same processes have been followed for Jatropha and Cottonseed oil which is considered for present analysis in the present work.

The quality of the fuel and consequently the engine characteristics are determined based on fuel properties like calorific value, cetane number, fire and flash point, viscosity, and density. The individual properties of Cottonseed, Jatropha, and Karanja oil are illustrated in Table 1. The cottonseed oil has distinct fuel properties that make it an alternative to natural diesel. The density of the cottonseed oil is 881 kg/m^3 which on one hand is similar to diesel and on the other hand much lower compared to Jatropha and Karanja oil. Similarly, the calorific value of 40.7 MJ/kg also observed in cottonseed oil is the highest among the three variants. The cetane number 54 and flash point 192 ^{0}C is observed in Karanja oil is higher in comparison to jatropha and cottonseed. But higher fire point of 209 ^{0}C is observed for Karanja oil which is much higher than other biodiesel and natural diesel. Viscosity is one of the main properties of the fuel which is the measure of the resistance of the fuel to flow. For Jatropha biodiesel, the viscosity of 5.70 CST has been observed which is nearly equal to that of standard diesel. Reducing the viscosity and simultaneously having moderate density and cetane number can be achieved in jatropha biodiesel even though it is having a lower calorific value compared to other biodiesel. By considering these three oil variants, it is possible to get optimum value for density, viscosity, calorific value, Cetane number, flash, and fire point. The purpose of the present work is to provide the alternate fuel which can perform comparably to diesel by adding the Jatropha, Karanja, and Cottonseed oils in suitable proportion with pure diesel. As each oil possesses certain advantages, a suitable combination of all these oils can give a new blend that will be having properties almost similar to pure diesel as a result of which the performance can be achieved similar to pure diesel.

The produced biodiesel from Jatropha-Karanja-Cottonseed has been indicated as JKC followed by the numeral which illustrates the percentage. The test was carried out in four different types of the mixed blend of jatropha-Karanja-Cottonseed biodiesel, each containing 15, 20, 25, and 30% JKC methyl ester. It means JKC5D85 contains 5% Jatropha Methyl ester (JME), 5% Karanja methyl ester(KME), 5% Cottonseed methyl ester (CME) and 85% Diesel while JKC6.66D80 contains 6.66% JME, 6.66% KME 6.66% CME and 80% of Diesel. For example, a measurable scale of 5% JME- 5% KME- 5% CME and 85% diesel was collected in a beaker to prepare the JKC5D85 blend for the test. Initially, a mechanical stirrer was used to continuously mix the well-proportioned liquid fuel for 15–20 minutes while controlling the stirrer's rpm. After 3–5 minutes of mixing on the mechanical stirrer, the blended liquid was placed on a magnetic stirrer. For a 30-minute operation, the speed of the magnetic stirrer was maintained to 600 to 700 rpm. A magnetic pellet was used to combine the ingredients in a magnetic stirrer. To prevent the loss of valuable material from the mixture, the beaker was sealed with aluminum foil. With the aid of the ultrasound, 90 percent of mixing was done with the magnetic stirrer, and nano-sized particles were well blended. With the aid of a stand, the perfectly mixed liquid was put in the ultrasonicator, and the ultrasonicator's bath was filled with distilled water. The vibrations created by sound waves within the sonicator help to mix the liquid at the nano level. The temperature of the setup was held between 45 and 50 degrees Celsius, and the process was run for 30 minutes with intervals of 10 minutes. The fuel was then permitted to lose the heat over the next 3-5 minutes and it had gained due to the vibrations. To prepare the JKC6.66D80, JKC8.33D75, and JKC10D70 blends, a similar procedure has been followed.

Properties of Fuel

Table 1: Pure diesel- Biodiesel properties

Properties	Diesel	Jatropha (J)	Karanja (K)	Cottonseed (C)	ASTM Standard
Density(Kg/m^3)	830	901	910	881	ASTMD287
Flashpoint(^{0}C)	53	67	192	156	ASTMD93-58T
Viscosity@40^{0}C (CST)	2.09	5.70	11.15	6.43	ASTMD445
Cetane number	49	46	54	41	ASTMD613
Firepoint(^{0}C)	56	89	209	164	ASTMD93-58T
Calorific Value(KJ/Kg)	42991	36460	37682	40731	ASTMD4809

Table 2: Blended Properties of diesel-Biodiesel

Properties	Diesel	JKC5D85	JKC6.66D80	JKC8.33D75	JKC10D70	ASTM Standard
Density(Kg/m^3)	830	840	842	847	850	ASTM D287
Flashpoint(^{0}C)	53	66	69	74	78	ASTM D93-58T
Viscosity@40^{0}C(CST)	2.09	2.94	3.21	3.51	3.79	ASTM D445
Cetane number	49	54	53	51	50	ASTM D613
Firepoint(^{0}C)	56	70	75	80	85	ASTM D93-58T
Calorific Value(KJ/Kg)	42991	42285	41974	41811	41580	ASTM D4809

The properties like Calorific value, density, flash point, Cetane number, fire point, and viscosity of Jatropha-Karanja-Cottonseed (JKC) blends of biodiesel were all determined according to standards of ASTM-6751. A hydrometer was used to assess density as reported to ASTMD4052 specifications at a 15 °C standard temperature. Using a Redwood viscometer at 40 °C the viscosity of the blends was deliberate by ASTMD445. Under controlled test conditions, the temperature of the flashpoint is one to measure the test specimen's proclivity to form a combustible mixture of air. The flashpoints and fire points were calculated using a closed-cup Pensky-Martens system within the temperature of 40–260 °C, according to the ASTMD93 and ASTMD92. The calorific value was calculated using an ASTMD5865-compliant bomb calorimeter. In CI engines, characteristics of combustion are evaluated by Cetane number for pure diesel. The Cetane number was evaluated by the ASTMD613 standard protocol, and the testing was performed on a scale of 30 to 65. The thermophysical properties of the different proportions of biodiesel are presented in (Table 2).

Experimental Setup:

The 1-cylinder 4 stroke Variable Compression Ratio (VCR) diesel engine was used to achieve tests for various parameters of efficiency and emissions. It is a 1500rpm rating and a 3.5KW (AV1) Kirloskar oil engine. The representation of the full engine set-up which is used to do research and also experimentation is illustrated in Figure 1. The detailed specifications of the engine are shown in (Table 3). A burette, stopwatch, and also three-way valve were provided additionally to the test setup. It comprises Functioning with a system of gravity, having a differential u-tube manometer with a 15 mm orifice meter. It also consists of a proximity sensor with utmost 4000 rpm speed and length of 0.135m spring wing torque bracelet and five-point temperature scanner with digitally connected with Type K thermocouple. To measure the crack angle and combustion pressure, sensors of piezo and Crank are placed on the engine head and flywheel. A 5HP 1500 rpm capacity is coupled with a VCR engine. For digital load control, an eddy current dynamometer and also sensor was mounted inside the cylinder. For the measurement of pressure. To measure the room temperature, Water cooling inlet, and outlet temperatures, and air inlet and outlet, a temperature sensor was placed on the cylinder. To avoid overheating, a continuous supply of water to the eddy current dynamometer housing was provided.

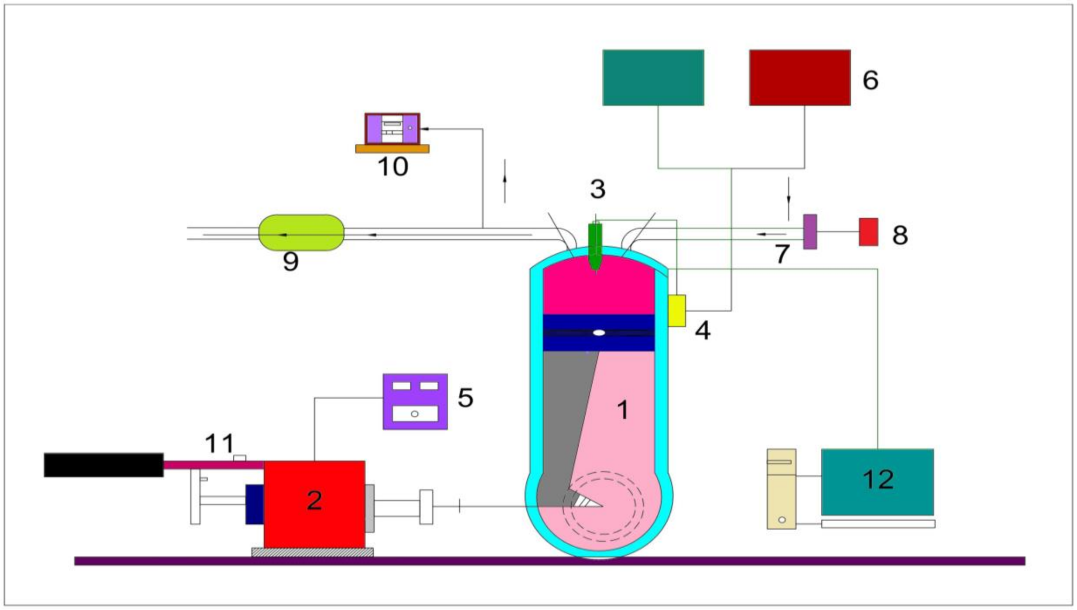

Figure. 1 Schematic representation of Engine test setup

1. Kirloskar oil engine, 2. Dynamometer, 3.Injector, 4.Pump, 5.Control Panel, 6.Fuel tank, 7. Air-stabilizing Tank, 8.Air filter, 9. Exhaust gas silencer, 10.Exhaust gas analyzer, 11.Crank encoder, 12.Data acquisition system

The AVL Vehicle Gas Analyzer is used to determine emissions of carbon monoxide (CO), Nitrogen oxides (NOx), and hydrocarbons (HC) which are coming from the exhaust. The spare parts of the AVL are the O ring, 400 mm gas exhaust probe, AC adaptor, condensation hose, RPM pickup, and outlet gas hose. For leak findings rubber seal, two gas exhaust hoses, and DiGas 444 with RS232 cable.The front view of the gas analyzer consists of an LC monitor, an automated water separator with a fine filter for the test gas, four feature keys, and an inlet for the test gas. The rearview consists ventilator, test gas exit, and link point for the calibration of gas. The rearview persist the additional two filters which are provided to shield the water pump and sample cells from the condensation medium. Approximately 10 minutes of heat-up time was given to the gas analyzer before starting the experiment.

Table 3: Specifications of Engine

Engine Name	4-stroke single-cylinder computerized Diesel engine with variable compression ratio with Dynamometer of Eddy current.
Manufacturer name	Kirloskar engine

Model	AV 1
Type of Engine	Single acting, fully locked, high speed vertical four-stroke loop CI engine
By starting	Hand Cranking
Number of Cylinder	Single
At 1500 rpm rating	3.7 (5.0) KW (bhp) max rated 5HP
At 1800 rpm rating	4.4 (6.0) KW (bhp)
Rotational Direction	When looking at the flywheel end, clockwise/anticlockwise
Diameter of Bore	80mm
Stroke value	110mm
CC	0.553L
Compression Nominal ratio	16.5:1 VCR range 10:1 to 20:1
Normal Engine Timing of Fuel Via spill (BTDC)	23^0
The inlet valve open (BTDC)	4.5^0
The inlet valve Closes (ABDC)	35.5^0
The exhaust valve open (BBDC)	35.5^0
The exhaust valve Close (ATDC)	4.5^0
Dynamometer	Eddy Current
Dynamometer power	5HP on 1500 RPM

Results and Discussions

Determination of Optimal Biodiesel Configuration

The experiments focused on the preliminary stage, determining the most efficient blend from the perspective of efficiency and emission. In addition, research was carried out on different types of experiments in a VCR engine at a fixed compression ratio and constant speed for Diesel and blends of Jatropha-Karanja-Cottonseed (JKC) biodiesel between 10 and 40% by volume. The experiments were conducted at a constant load. Various biodiesel blends such as JKC5D85, JKC6.66D80, JKC8.33D75, and JKC10D70 have been prepared and also investigated the efficiency and emissions for an optimized ratio of blend. The performance of brake thermal efficiency (BTE) and also brake specific fuel consumption (BFSC) are evaluated for each blend composition. For the emissions study parameters like oxides of nitrogen (NOx), carbon monoxide (CO), and Hydro Carbon (HC) were taken to account. Obtained parameters of JKC were compared with diesel to obtain optimum biodiesel.

Brake Thermal Efficiency (BTE)

The sequence of BTE in respect of load for Pure Diesel and mixed biodiesel blends of Jatropha-Karanja-Cottonseed (JKC) is shown in figure 2. The mixed biodiesel blends show low brake thermal efficiency under all load conditions ascribed to inferior calorific value and superior viscosity compare with diesel. The process of combustion suffers adverse impact ascribed to the higher viscosity of biodiesel proportions and lower calorific value offers lower output power.

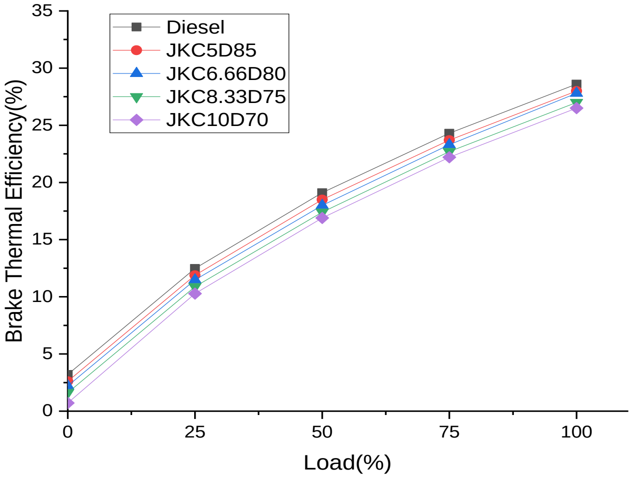

Fig. 2 Variation of BTE with Load

At maximum load, the BTE for Pure Diesel is 28.6%, however, when the engine is fueled with proportions of JKC with diesel such as JKC5D85, JKC6.66D80, JKC8.33D75, and JKC10D70, the BTE values are 28, 27.8, 27, and 26.5 % respectively. From the test outcome, it has been observed that BTE for the JKC5D85 blend is greater among the other blends and it is closer to the diesel value. It can also be observed that reducing the diesel content from 85 to 80% in the biodiesel leads to a negligible drop in BTE by 0.2% while further decreasing diesel content from 80 to 75% results in the decrease of BTE by 0.8%.

Brake Specific Fuel Consumption (BSFC)

Figure 3 shows the decreased BSFC with the load for all fuels. All blends of biodiesel have a higher BSFC than diesel fuel. For blends JKC5D85, JKC6.66D80, JKC8.33D75, and JKC10D70, BSFC was found to be 0.33, 0.38, 0.44, and 0.48Kg/KWhr at full load condition, while for Pure Diesel is 0.29 Kg/KWhr. From the test results, it can be accomplished that BSFC is growing by the proportion of JKC biodiesel in diesel.

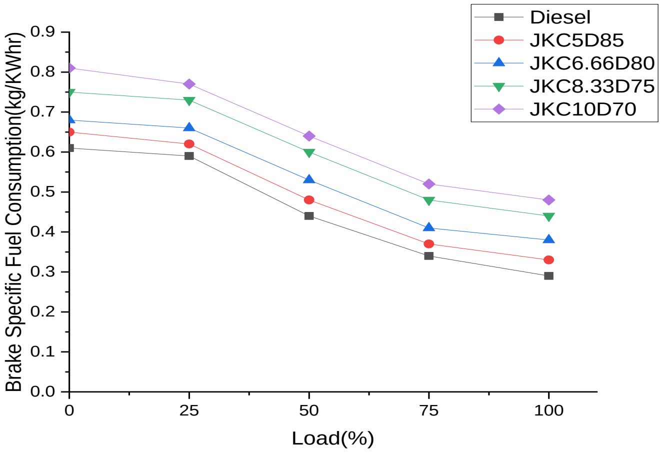

Fig. 3 Variation of BSC with Load

Because of the lower calorific value, higher density, viscosity, and increased JKC methyl ester, proper mixing of Air-Fuel are impossible, resulting in improper combustion. In addition, the JKC5D85 biodiesel blend BSFC is 0.33 Kg/KW-h which is higher (0.29 kg/KW-h) than pure diesel. Moreover, as opposed to the other biodiesel blends, the JKC5D85 has BSFC values similar to diesel. It's because JKC5D85 has a calorific value that's comparable to that of diesel.

Exhaust gas temperature (EGT)

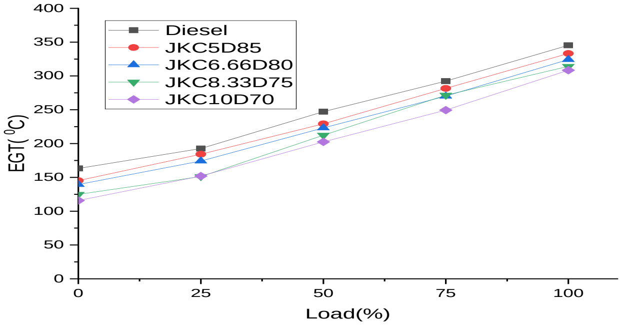

Fig. 4 Variation of EGT with Load

EGT characteristics under different load conditions as represented in figure 4. The exhaust gas temperature increased with the load and falls with the blended mixture, as shown in figure 4. The variation in EGT for Pure Diesel is 345.28^{0}C and its blends JKC5D85, JKC6.66D80, JKC8.33D75, and JKC10D70 are 333.26, 324.25, 314.25, and 304.51^{0}C correspondingly at full condition. The higher exhaust gas temperature can be seen in the figure. 4 than pure diesel because diesel has a higher heating value than biodiesel blends. As a result, at the end of compression, more heat energy is produced within the engine [20]. From the test outcomes, it can be noticed that the EGT for the JKC10D70 blend is a lower value of EGT than the other biodiesel blend.

Hydrocarbon Emissions (HC)

Figure 5 illustrates the HC emissions variation in respect to load for blends of JKC biodiesel and gasoline. The formation of HC is caused by incomplete combustion and unburned charge remaining in the crevice volume. The amount of hydrocarbons from the engine exhaust is measured in HC concentrations [32]. The exhaust gas contains a wide range of hydrocarbon species. The fuel combination has an important effect on the composition of HC emissions [33]. Higher HC emissions are produced by fuels with a higher percentage of olefins and aromatics. Raw emissions from HC are lower at inferior loads, but it increases as the load raises.

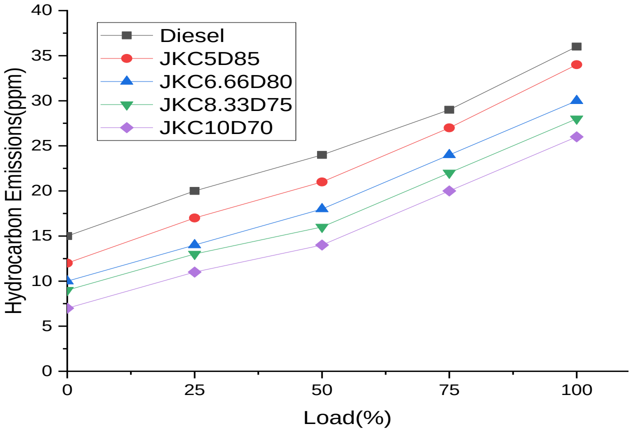

Fig. 5 Variation of HC with Load

The HC emissions for JKC5D85, JKC6.66D80, JKC8.33D75, and JKC10D70 were 34, 30, 28, and 26ppm at maximum load condition, while the emissions for standard diesel were registered as 36 ppm. The emissions of HC are decreased ascribed to higher content of oxygen as well as Cetane number. It can be observed from the reported values that the emission for the blend JKC6.66D80 was lower than JKC5D85 which is less than pure diesel. For the JKC6.66D80 blend, the reduction in HC emissions is owing to the efficient combustion process within the combustion chamber compared to Pure Diesel. Biodiesels have a higher accumulation of fatty acids with long-chain saturated as well as unsaturated and a relatively low aggregation of short-chain carbon structures, but they also have higher oxygen content in fuel, resulting in inferior HC emissions. [34]

Carbon monoxide Emissions (CO)

CO emissions play an important task in the pollution rise and pose a significant environmental hazard. The incomplete or partial combustion in a compression ignition engine due to unavailability of sufficient oxygen or abnormal entrainment of the fuel-air mixture inside the combustion chamber leads to improper oxidation reaction consequences in carbon monoxide emissions.

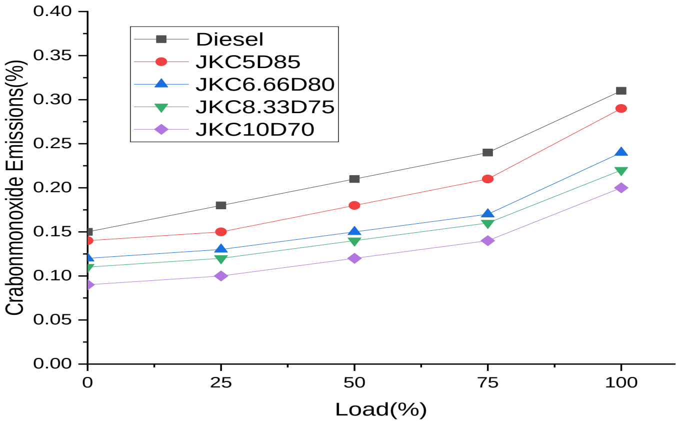

Fig. 6 Variation of CO with Load

Primarily the blending of air fuel and their thermo-physical properties of the fuel significantly affect the CO emission of a CI engine along with other various parameters. For diesel, JKC5D85, JKC6.66D80, JKC8.33D75, and JKC10D70 in full load condition, as noticed from the experiments, the emissions of CO were observed to be 0.31, 0.29, 0.24, 0.22, and 0.2% respectively, as can be seen from Figure 6. Since they produce more oxygen content, the CO emissions of Jatropha-Karanja-Cottonseed biodiesel (JKC) and their equivalent blends were originate to be much inferior to diesel. In comparison to pure diesel, the CO emissions were obtained at lesser values for all tested biodiesels due to the complete process of oxidation that has not occurred in the case of diesel. The conversion rate of CO_2 is high due to the being extra oxygen contents, while the complete combustion of biodiesel contributes to the minimization of emissions of carbon monoxide.

Oxides of nitrogen (NOx)

The NOx emissions of a CI engine primarily contain constituents of nitric oxide and nitrogen dioxide. The major causes of NOx formation in compression ignition engines are the higher oxygen content of the fuel, enhanced combustion temperature, and ignition delay. The NOx emission from the exhaust of a CI engine becomes high corresponding to higher output power because of an increased amount of fuel injection.

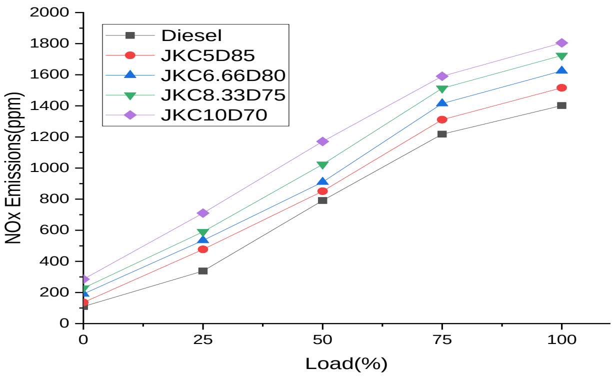

Fig. 7 Variation of NOx with Load

Comparisons between NOx emissions and Load for Pure Diesel and Jatropha-Karanja-Cottonseed (JKC) biodiesel blends are shown in figure 7.Emissions of NOx were found to be 1402, 1516, 1625, 1724, and 1805ppmrespectively for diesel, JKC5D85, JKC6.66D80, JKC8.33D75, and JKC10D70, observed from the test operations. Cetane numbers are higher for proportions with lesser biodiesel content, which contributes to a shorter delay in ignition. Complete combustion occurs when the oxygen content is higher in biodiesel than neat diesel, which eventually contributes to higher temperature and heat release rates. It is the cause of higher emissions of NOx during the premixed combustion process of biodiesel.

An investigation has been made of engine efficiency and emission features of a VCR diesel engine with Jatropha-Karanja-Cottonseed combination, including JKC5D85, JKC6.66D80, JKC8.33D75, and JKC10D70. The engine BTE decreases with the increase in BSFC by the proportion of the blend. At the same time decreases HC and CO emissions and raises NOx emissions as; blend levels grow. In comparison, it has been noticed that the JKC6.66D80 blend shows improved performance for BTE and BSFC parameters more than JKC8.33D75 and JKC10D70. Though the JKC6.66D80 blend appears to be better than other blend concentrations but JKC5D85 blend efficiency is slightly more than JKC6.66D80. From experimental results, it has also been noticed that the BTE decreases when the NOx emission increased with the concentration of the blend increases beyond 25 percent. It is recommended that not to increase the blend content by more than 20% since the substantial change in efficiency or emission parameter cannot be noticed. From the investigation, it can be seen that increase in the JKC blend from 20 to 25% tends to degrade the performance of BTE, BSFC, and NOx emission, whereas the HC and CO emissions performance is improved while comparing with neat Diesel. Therefore, because of optimum and better performance, the JKC6.66D80 blend has been chosen for the comparison of parameters.

Effect of Injection timing

The initiate of fuel injection into the combustion chamber is known as injection timing. The different injection variables control the efficiency as well as emissions of biodiesel in CI engines, which plays a crucial role in the timing of injection. The advanced timing of the injection would result in a longer combustion delay and a lower flame speed it leading to a decrease in the optimum output of power and optimum pressure of the diesel engine. As a consequence, the power output increases fuel consumption. Advancement in injection timing results in increased mixture instability, faster combustion, lower temperature and pressure, and a longer ignition delay within the combustion chamber [35–37]. Retardation in injection timing results in peak temperature and pressure, a slower burning rate, delayed combustion, a shorter ignition delay inside the combustion chamber [35, 38, 39]. In comparison with the normal injection timing, superior in-cylinder and peak cylinder pressure are noticed for advanced timing of injection. The 23° BTDC is the regular injection timing for the measured engine. To evaluate the effects of advanced and retarded injection, a range of 21° to 27° injection timing was used.

Brake Thermal Efficiency (BTE)

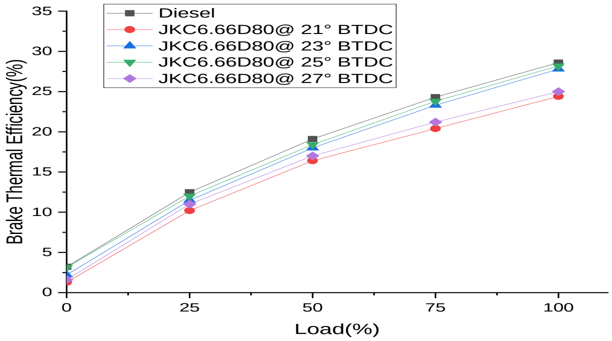

Fig .8 Effect of IT for BTE with Load at full load condition

The variance of brake thermal efficiency (BTE) in respect to load at different injection timings is depicted in Fig. 8. The BTE increases with increasing the load has been observed in figure 8. The 23^0-bed injection timing was the finest one for standard diesel, which resulted in a greater BTE. However, when compared to pure diesel, BTE for JKC6.66D80 blended fuel was decreasing at 23^0 BTC ascribed to inferior energy content, higher fuel viscosity, and increased consumption of fuel [40]. For the blend JKC6.66D80, the higher fuel viscosity produces an extravagant mixture of spray and air, accompanying deliberate combustion. BTE rises with advanced injection timing leading to a longer duration of ignition delay. In increasing the ignition delay stage, more period is provided for blending of air fuel inside the chamber, which aids in the process of combustion by supplying a stronger combination of air and fuel. It results in increased BTE due to superior cylinder temperature, pressure, and also heat release. Reduced ignition delay caused by lowering the injection timing (IT) to 21^0 BTC from 23^0 btdc induces excessive mixing of fuel-air, resulting in inferior heat release rate and BTE. The results shows , values of BTE for Diesel-23^0 btdc, JKC6.66D80-21^0 btdc, JKC6.66D80-23^0 btdc, JKC6.66D80-25^0 btdc and JKC6.66D80-27^0 btdc at full load conditions are 28.6, 24.4, 27.8, 28.2 and 25 % respectively. As a result, the best injection timing for JKC6.66D80 is 25^0 btdc, as it has a 28.2 percent BTE value, which is nearer to the standard value of diesel.

3.2.2 Brake Specific Fuel Consumption (BSFC)

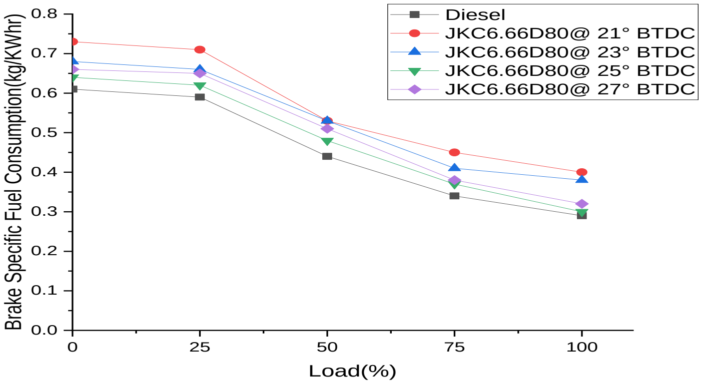

Fig .9 Effect of IT for BSFC with Load at full load condition

The deviation of BSFC for load at various injection timings is illustrated in fig 9. The figure shows that pure diesel has a lower BSFC compared to various JKC6.66D80 injection times. This is because the calorific value is low for JKC6.66D80 fuel than pure diesel, so more biodiesel must be applied to the combustion chamber to generate the same output power as standard diesel. [41, 42]. From the test results, BTE values for Diesel-23^0 btdc, JKC6.66D80-21^0 btdc, JKC6.66D80-23^0 btdc, JKC6.66D80-25^0 btdc and JKC6.66D80-27^0 btdc at full load conditions are 0.29, 0.4, 0.38, 0.3 and 0.32 kg/KWhr correspondingly at maximum load condition. According to the mentioned results, the

BSFC for JKC6.66D80 at 25^0 btdc is 0.3kg/ kw.hr, which is lower than the BSFC for JKC6.66D80 at 23^0 btdc. As the injection timing is advanced from 23^0 btdc to 25^0 btdc for JKC6.66D80, more time has required for the preparation of the air-fuel mixture, ensuing in enhanced premixed combustion. For that reason advanced injection timing of 25^0 btdc shows a moderately scale-down BSFC 0.3 kg/kwhr for JKC6.66D80 fuel.

3.2.3 Exhaust gas temperature (EGT)

The difference in Exhaust gas temperature (EGT) in respect to loading at various injection timings is presented in fig 10. The figure shows that pure diesel has a higher EGT when compare to various JKC6.66D80 injection times. This is because, for JKC6.66D80 fuel, pre-ignition happens before the start of combustion due to this engine catches rapid-fire and leads to a rise in the exhaust gas temperature.

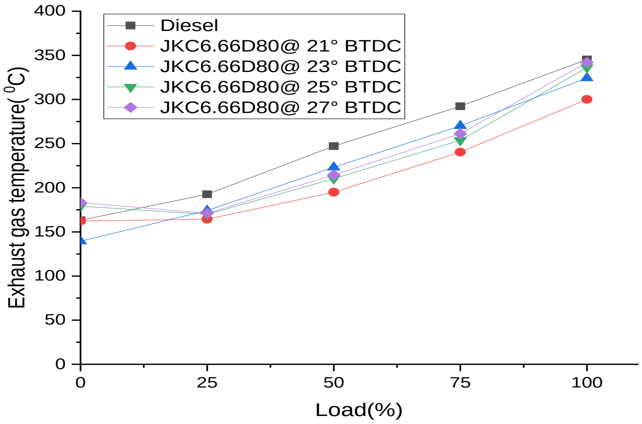

Fig .10 Effect of IT for EGT with Load at full load condition

From the test results, values of EGT for Diesel-23^0 BTC, JKC6.66D80-21^0 btdc, JKC6.66D80-23^0 btdc, JKC6.66D80-25^0 btdc and JKC6.66D80-27^0 btdc are 345.82, 300.22, 324.25, 336.2 and 342.1^0C respectively at maximum load condition. According to the mentioned results, the EGT for JKC6.66D80 at 25^0 btdc is 336.2 ^{0}C which is higher than the EGT for JKC6.66D80 at 23^0 btdc. With the advancement in Injection timing, most of the heat gets released before the completion of compression stroke causes higher heat losses and thus increasing Exhaust gas temperature, as higher EGT is the indication of higher Heat loss. For that reason, advanced injection timing of 25^0 btdc shows a moderately higher EGT for JKC6.66D80 blended fuel.

Hydrocarbon Emissions (HC)

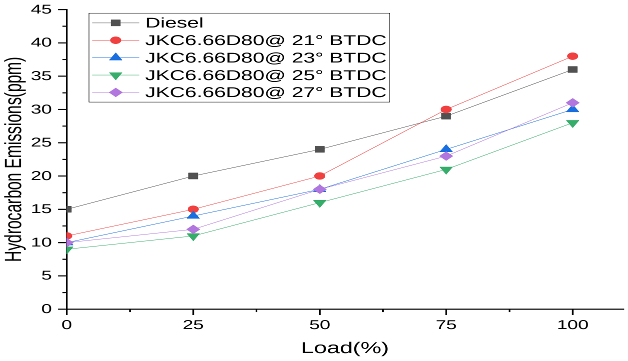

Fig .11 Effect of IT for HC with Load at full load condition

The consequence of injection timing on HC with load for blended fuel JKC6.66D80 is shown in fig 11. The two major causes of HC pollution in engines are a lean mixture during the delay time process and poorly mixed fuel coming from the nozzle injector with low speed. The obtained results for JKC6.66D80 showed lower HC emissions in comparison to standard diesel. It is due to improved combustion efficiency for JKC6.66D80 fuel as the better mixture of air-fuel grounding rate, results improved premixed process of combustion [40,43]. From the test outcomes, obtained HC emissions were 36, 38, 30, 28 and 31 ppm for Diesel-23^0 btdc, JKC6.66D80-21^0 btdc, JKC6.66D80-23^0 btdc, JKC6.66D80-25^0 btdc and JKC6.66D80-27^0 btdc at maximum load. The emissions of HC are reduced at advanced injection timing of 25^0 btdc with JKC6.66D80 blend as a fuel because of better air-fuel mixing and thus increased oxidation, which leads to full combustion. According to the test results, emissions of HC for advanced injection timing of 25^0 btdc are lower than 23^0 btdc which has the injection timing of diesel**.**

Carbon monoxide Emissions (CO)

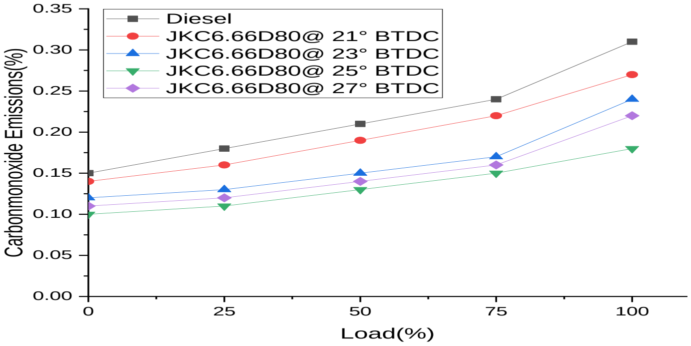

Fig .12 Effect of IT for CO with Load at full load condition

The emissions of CO for load at different injection timings are illustrated in fig 12. The lower CO emissions with full load conditions for JKC6.66D80 fuels have been demonstrated at injection timing 25^0 btdc among all advanced injection times. It may be ascribed to a rise in pressure and temperature in the cylinder, usage of a lean mixture of air-fuel, and improved conversion rate to CO2 from CO owing to the occurrence of the huge amount of oxygen molecules in blended JKC6.66D80 fuel [40]. As of the test outcomes, the values of CO at maximum load were obtained for standard Diesel-23^0 btdc, JKC6.66D80-21^0 btdc, JKC6.66D80-23^0 btdc, JKC6.66D80-25^0 btdc and JKC6.66D80-27^0 btdc were 0.31, 0.27, 0.24, 0.18 and 0.22% respectively at maximum load condition. In comparison to diesel emission (0.31%), the JKC6.66D80 blended fuel emission (0.18) is lower with injection timing of 25^0 btdc because of improved efficiency of combustion, resulting in a quicker heat release rate for the period of the premixed cycle. By growing the injection timing from 23^0 btdc to 25^0 btdc, emissions of CO have been reduced to 0.18 of 0.24%

Oxides of nitrogen (NOx)

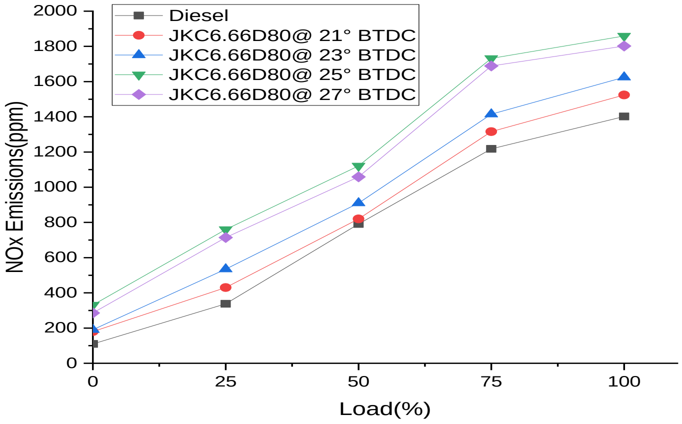

Fig .13 Effect of IT for NOx with Load at full load condition

The consequence of injection timing on NOx emissions with load for blended fuel JKC6.66D80 is demonstrated in fig 13. With increasing fuel consumption, more heat is released as the combustion chamber's temperature rises, which leads to increased NOx emissions. With advanced injection times the amount of NOX emissions increases owing to the consequence of the premixed process of combustion time, which outcome at high pressure and cylinder temperature [44, 45]. From the test results, emissions of NOx for Diesel-23^0 btdc, JKC6.66D80-21^0 btdc, JKC6.66D80-23^0 btdc, JKC6.66D80-25^0 btdc, and JKC6.66D80-27^0 btdc were found to be 1402, 1524, 1625, 1859, and 1802 ppm at maximum load conditions. The emissions of NOx for injection timing at 23^0 btdc of 1625 increased to 1859ppm for the superior injection timing of 25^0 btdc with JKC6.66D80 blended fuel. It may ascribed to the time obtained for blending of fuel-air appropriately which results in improved oxidation and combustion.

Combustion Characteristics

Cylinder Pressure

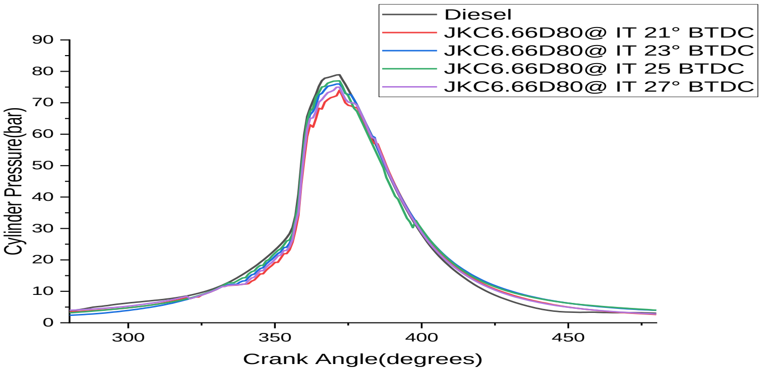

Fig. 14. Cylinder pressure variation with the crank angle at full load conditions with different IT.

The difference of cylinder pressure (CP) in opposition to crank angle with pure diesel and blended JKC6.66D80 fuel at different injection timings (IT) is illustrated in fig.14 at maximum load conditions. The fixed 210bar injection pressure has been maintained at the time of the injection process. The JKC6.66D80 had a comparatively low cylinder pressure level in comparison to diesel and the variability of gas pressure in maximum load condition is also soft as the injection timing is advanced, as the engine noise is normal. The maximum cylinder pressure was obtained at 78.92 bar for diesel injected at 23^0 btdc, and 76.99 bar for JKC6.66D80 fuel injected at 25^0 btdc. The ignition delay phase was improved and the engine ran smoothly as the injection timing was advanced to 25^0 btdc from 23⁰ btdc. The graph shows that the impact of superior injection timing at 25⁰ btdc on engine output with blended JKC6.66D80 fuel is very significant. From the test outcomes, the values of CP for Diesel-23⁰ btdc, JKC6.66D80-21⁰ btdc, JKC6.66D80-23⁰ btdc, JKC6.66D80-25⁰ btdc and JKC6.66D80-27⁰ btdc were obtained 78.2, 74, 75.99, 76.99 and 75bar respectively for maximum load conditions. In comparison with other injection timings, the IT at 25⁰ btdc with JKC6.66D80 fuel have the highest cylinder pressure of 76.99 bar. The proper mixing of fuel and air can lead to better combustion and oxidation, as a result releasing high heat and chemical energy leading to high cylinder pressure. The outcomes are comparable to the tendency which is stated by Annamali et. al.[37] and Murugan et. al. [39].

Heat release rate

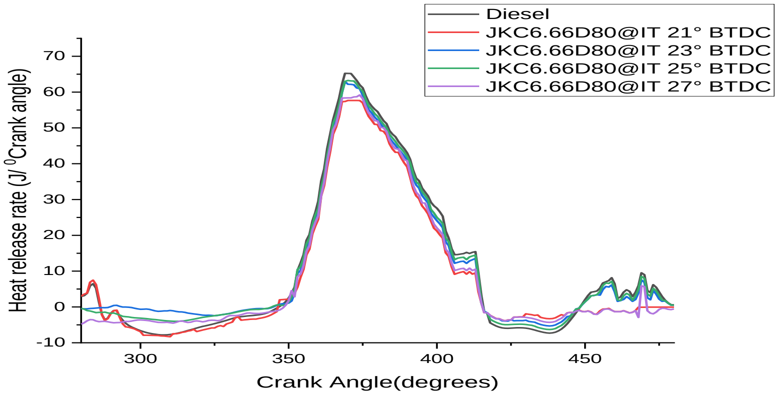

Fig. 15. HRR variation with crank angle at full load conditions with different IT.

The effect of injection timing in heat release rates (HRR) with load for JKC6.66D80 fuel at full load conditions is represented in Fig. 15. For the duration of the ignition delay, the HRR initially showed some small negative values. It is due to loss of heat through the walls of cylinder as well as the cooling effect of the vaporization of blended JKC6.66D80 fuel. When the combustion process begins, conversely, the HRR becomes optimistic. At 25⁰ btdc the heat release rate for blended JKC6.66D80 fuel injection timing is inferior to Diesel-23⁰ btdc. It may be ascribed to JKC6.66D80's lower calorific value and insufficient atomization, resulting in a weak fuel-air mixture. The combustion performance improves as the injection timing is improved from 23⁰ btdc to 25⁰ btdc. As a result, increasing the ignition delay by early injecting fuel allows additional time for mixing of air fuel, facilitating reactions of pre-combustion for vaporization [35, 39]. Reducing the injection timing to 21⁰ btdc from 23⁰ btdc results in a decrease in heat release rate and temperature, which is attributed to a reduction in combustion delay, which causes excessive fuel and air mixing. The HRR values for Diesel-23⁰ btdc, JKC6.66D80-21⁰ btdc, JKC6.66D80-23⁰ btdc, JKC6.66D80-25⁰ btdc and JKC6.66D80-27⁰ btdc were found to be 65.23, 57.36, 62.92, 63 and 58.36 J/⁰crank angle at full load. The highest HRR for JKC6.66D80 blended fuel injection timing at 25⁰ btdc is 63 J/⁰ crank angle in comparison with other IT related to the same fuel.

Cummulative heat release rate

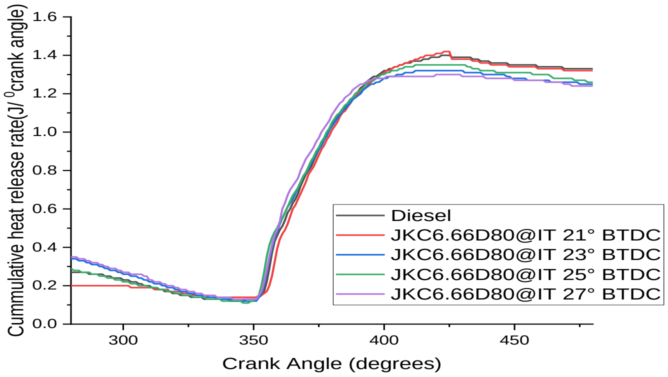

Fig. 16. CHRR variation with crank angle at full load conditions with different IT.

The difference in cumulative heat release rate (CHRR) in respect to crank angle at different injection timings is represented in fig 16 at maximum load condition. The increased CHRR at 25^0 btdc is improved as the combustion progresses has been observed from the graph due to ascribed to a large amount of heat release due to the presence of a large amount of fuel in the process. The CHRR values for Diesel-23^0 btdc, JKC6.66D80-21^0 btdc, JKC6.66D80-23^0 btdc, JKC6.66D80-25^0 btdc, and JKC6.66D80-27^0 btdc were found to be 1.4, 1.42, 1.32, 1.35, and 1.3 J/^{0}crank angle correspondingly at full load condition. The CHRR increases with injection timings at first, reaches a high, and then decreases for JKC6.66D80, according to the experimental data. The blended fuel JKC6.66D80 achieves the maximum CHRR at injection 25^0 btdc, which is almost equivalent to diesel injected at standard injection timing, owing to the faster combustion in the combustion chamber. As the time of injection progresses, the ignition time becomes longer, resulting in further fuel accumulation. As a result, during the premixed combustion process, the volume of fuel burned within the combustion chamber increases, ensuing in a higher heat release rate [39]. In addition, a longer ignition delay lengthens the flammability region, increasing the rate of heat release. [37].

Rate of Pressure rise

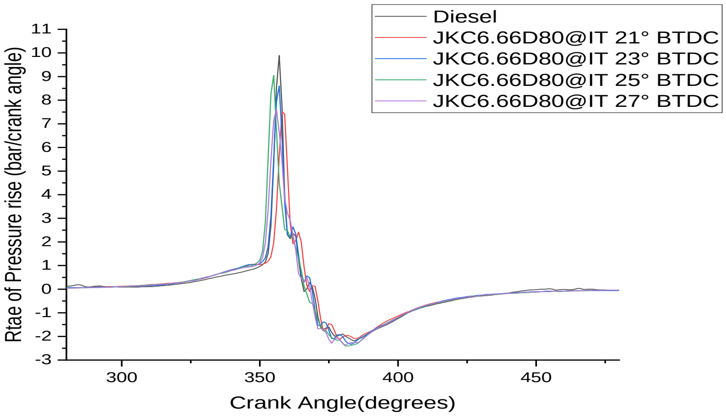

Fig. 17. Rate of pressure rise variation with the crank angle at full load conditions with different IT.

The effect of injection timing(IT) in the rate of pressure rise (RPR) with the crank angle for JKC6.66D80 fuel at maximum load conditions is represented in Fig. 17. The advanced IT at 25^0 btdc for JKC6.66D80 blended fuel resulted in higher RPR when compare with standard 23^0 btdc. Diesel has the highest CHRR as compared to blended fuel JKC6.66D80, which is ascribed to the JKC6.66D80's lower calorific value, volatility, and high viscosity. More time is required for blending air fuel properly when the IT is superior to 25^0 btdc, resulting in improved combustion efficiency and a faster rate of pressure rise. The curve falls to lower levels after the peak pressure is reached. The cylinder pressures indicate an increased phase, similar to other biodiesels, which corresponds to the advanced injection time [35,46]. The rate of pressure rise test outcomes for Diesel-23^0 btdc, JKC6.66D80-21^0 btdc, JKC6.66D80-23^0 btdc, JKC6.66D80-25^0 btdc, and JKC6.66D80-27^0 btdc were found to be 9.89, 7.52, 8.6, 9.05, and 7.6 bar/crank angle respectively at full load conditions. The RPR for JKC6.66D80 blended fuel with leading injection timing of 25^0 btdc is 9.05 bar/crank angle, in comparison to diesel with normal injection timing of 23^0 btdc. The modern timing of injection simplifies enhanced flame front and fast combustion process of the accurate mixing of fuel-air which attains higher cylinder pressure.

Conclusion

The efficiency, emission, and characteristics of combustion for biodiesel made from Jatropha-Karanja-Cottonseed have been studied. The blended JKC6.66D80 fuel was originating to be the finest biodiesel composition in comparison to other blends like JKC5D85, JKC8.33D75, and JKC10D70 based on performance and emission point of observation. In addition, injection timing has been investigated to accomplish improved efficiency and inferior emissions. The tests were carried out to compare the efficiency, emissions, and combustion characteristics of pure diesel at 23° before top dead center (BTDC) versus optimum biodiesel JKC6.66D80 with injection timings of 21°, 23°, 25°, and 27° BTDC. The test results illustrate that the brake thermal efficiency and brake-specific fuel consumption for JKC6.66D80 blended fuel at 25° BTDC are almost identical to the diesel at injection 23 ° BTDC. The emissions of HC and CO are 28% and 0.18% for JKC6.66D80 fuel which is lower than diesel and also slender increase in emission of NOx than pure diesel. For the JKC6.66D80 blend, the cylinder pressure reaches its optimum value which allows for full combustion ascribed to sufficient mixing of air fuel. The rate of pressure rise, heat release rate, and cumulative heat release rate are extreme for JKC6.66D80 fuel at 25° BTDC compared to other timing of injection. By considering the performance, emission, and combustion characteristics, it can be inferred that JKC66.66D80 blended fuel can be a suited alternative fuel for diesel in automobiles with a minor advance in injection timing.

References

1. Shah AP, Patil SD. Performance, emission and combustion analysis of biodiesel from acidic oil: A by-product of soybean oil refining process. Modeling, Measurement and Control C .2018; 78(3):337-350.

2. Pawar R, Jagadale K, Gujar P, Barade V, Solankure B. A comprehensive review on the influence of biodiesel and additives on performance and emission of diesel engines. Chemical Engineering Transactions 2018; 65:451-456.

3. Kumar S, Chaube A, Jain SK, Bhopal RGPV. Experimental evaluation of CI engine performance using diesel blended with jatropha biodiesel. International Journal of Energy and Environment 2012; 3(3): 471-484.

4. Gada M S, Jayaraj S.A comparative study on the effect of nano-additives on the performance and emissions of a diesel engine running on Jatropha biodiesel.Fuel 2020; 267: 117168. doi.org/10.1016/j.fuel.2020.117168

5. Vineet Kumar, Rajesh Kumar Saluja. The effect of operating parameters on performance and emissions of DI diesel engine fuelled with Jatropha biodiesel. Fuel 2020; 278: 118256. doi.org/10.1016/j.fuel.2020.118256

6. Bhaskar K, Subramanian S, Nagarajan G, Sampath S. Emission characteristics of biodiesel obtained from jatropha seeds and fish wastes in a diesel engine. Sustainable Environment Research 2017; 27: 283-290.

7. Aparna Singh, Shailendra Sinha.Optimization of performance and emission characteristics of CI enginefueled with Jatropha biodiesel produced using a heterogeneous catalyst(CaO). Fuel 2020; 280: 118611. doi.org/10.1016/j.fuel.2020.118611

8. Forson F K, Oduro E K, Hammond-Donkoh E . Performance of jatropha oil blends in a diesel engine. Renewable Energy 2004; 29: 1135–1145. http:// doi:10.1016/j.renene.2003.11.002

9. Dewi H, Saleh A A, Reddy ANR, Hamdan S. An Experimental Investigation of Karanja Biodiesel Production. Journal of Engineering 2018: 4174205. https://doi.org/10.1155/2018/4174205

10. Sanghoon Lee a, Chang Sik Lee. Spray characteristics, engine performance and emissions analysis for Karanja biodiesel and its blends. Energy 2017; 119: 138-151. doi:10.1016/j.energy.2016.12.043

11. Varatharaju P, Ilangkumaran M.Experimental analysis of engine performance, combustion andemission using pongamia biodiesel as fuel in CI engine.Energy 2017; 129: 228-236. doi.org/10.1016/j.energy.2017.04.120.

12. Puneet Verma, Gaurav Dwivedi. Experimental investigation of diesel engine fuelled with different alkyl esters of Karanja oil. Fuel 2020; 275:117920.doi.org/10.1016/j.fuel.2020.117920

13. Atul D, Avinash Kumar A. Performance, emissions and combustion Characteristics of Karanja biodiesel in a transportation engine.Fuel 2014; 119:70-80. doi.org/10.1016/j.fuel.2013.11.002.

14. Muralidharan, K., Govindarajan, P.The effect of bio-fuel blends and fuel injection pressure on diesel engine emission for sustainable environment. Am. J. Environ. Sci.2017; 7:377–382.

15. Pankaj Shelke S, Nitin Sakhare M, Subhash L. Investigation of Combustion Characteristics of a Cottonseed Biodiesel Fuelled Diesel Engine. Procedia Technology 2016; 25:1049-1055. http://doi.org/10.1016/j.protcy.2016.08.205.

16. Nitin M, SakharePankaj S, ShelkeSubhash L. Experimental Investigation of Effect of Exhaust Gas Recirculation and Cottonseed B20 Biodiesel Fuel on Diesel Engine.ProcediaTechnology 2016; 25:869-876. doi.org/10.1016/j.protcy.2016.08.195

17. Murat Kadir Yesilyurt, Mustafa Aydin. Experimental investigation on the performance,combustion and exhaust emission characteristics of a compression-ignition engine fueled with cottonseed oil biodiesel/diethyl ether/diesel fuel blend. Energy Conversion and Management 2020; 205: 112355. doi.org/10.1016/j.enconman.2019.112355.

18. Sunil S, Duple S, Murugavelh S. Biodiesel production from waste cotton seed oil: engine performance and emission characteristics.Biofuels 2016; 7(6): 689-698. http://doi.org/10.1080/17597269.2016.1192442

19. Nalgundwar A, Paul B, Sharma SK. Comparison of performance and emissions characteristics of DI CI enginefueled with dual biodiesel blends of palm and jatropha. Fuel 2016; 173:172–179. http://doi.org/10.1016/j.fuel.2016.01.022

20. Saravanan A, Murugan M, Sreenivasa Reddy M, Satyajeet P. Performance and emission characteristics of variable compression ratio CI engine fueled with dual biodiesel blends of Rapeseed and Mahua. Fuel2020; 263: 116751.http://doi.org/10.1016/j.fuel.2019.116751.

21. Srithar K. Experimental investigations on mixing of two biodiesels blended with diesel as alternative fuel for diesel engines. J King Saud Univ Eng Sci 2017; 29: 50– 56. http:// doi.org/10.1016/j.jksues.2014.04.008

22. Ruhul A M, Kalam M A, Masjuki H H, Shahir S A, Abdullah A, Teoh Y H, How H G, Reham S S. Evaluating combustion, performance and emission characteristics of Millettia pinnata and Croton megalocarpus biodiesel blends in a diesel engine.Energy2017; 141: 2362-2376.http://doi.org/10.1016/j.energy.2017.11.096.

23. Kumar R, Singh M. Experimental investigation of performance and emission Characteristics of DI CI engine with dual biodiesel blends of Mexicana argemone and mahua. Materials Today Proc 2019; 16(2) : 321 – 328. doi.org/10.1016/j.matpr.2019.05.097

24. Shrivastava P, Verma TN, Pugazhendhi A. An experimental evaluation of engine performanc and emisssion characteristics of CI engine operated with Roselle and Karanja biodiesel. Fuel 2019; 254 :115652. http://doi.org/10.1016/j.fuel.2019.115652.

25. Roy A, Dabhi Y, Brahmbhatt H, Chourasia SK. Effect of emulsified fuel based on dual blend of Castor-Jatropha biodiesel on CI engine performance and emissions. Alexandria Eng Journal 2021; 60(1):1981 – 1990. https://doi.org/10.1016/j.aej.2020.12.003.

26. Asokan MA, Senthur prabu S, Kamesh S, Khan W. Performance, combustion and emission characteristics of diesel engine fuelled with papaya and watermelon seed oil bio-diesel/diesel blends. Energy 2018;145:238–245.http://doi.org/10.1016/j.energy.2017.12.140.

27. Sudalaiyandi K , Karthick Alagar. Performance and emission characteristics of diesel engine fueled with ternary blends of linseed and rubber seed oil biodiesel. Fuel 2021; 285: 119255. doi.org/10.1016/j.fuel.2020.119255.

28. Banapurmath NR, Tewari PG, Hosmath RS.Performance and emission characteristics of a DI compression ignition engine operated on Honge, Jatropha and sesame oil methyl esters. Renew Energy 2008; 33:1982– 1988. http://doi.org/10.1016/j.renene.2007.11.012.

29. Kaisan MU, Anafi FU. Exhaust emissions of biodiesel binary and multi-blends from Cotton, Jatropha and Neem oil from stationary multi cylinder CI engine. TransportRes Part D.2017; 53: 403–414.http://doi.org/10.1016/j.trd.2017.04.040.

30. Drenth AC, Olsen DB. Compression ignition engine performance and emission evaluationof industrial oilseed biofuel feedstocks camelina, carinata, and pennycress across three fuel pathways. Fuel 2014; 136 :143–155.http://doi.org/10.1016/j.fuel.2014.07.048.

31. Sharad D, Patil R V. Experimental Analysis of Effect of Mixed Biodiesel Blends On Performance, Combustion, and Emission of Variable Compression Ratio Engine. Model Measure Control. 2019; 80(1): 29-36.http://doi.org/10.18280/mmc_c.800

32. Lin BF, Huang JH, Huang DY. Experimental study of the effects of vegetable oil Methylester on DI diesel engine performance characteristics and pollutant emissions. Fuel 2009; 88(9):1779– 1785. http://doi.org/10.1016/j.fuel.2009.04.006.

33. Attia AM, Hassaneen AE. Influence of diesel fuel blended with biodiesel produced from Waste cooking oil on diesel engine performance. Fuel 2016; 167:316– 328.https://doi.org/10.1016/j.fuel.2015.11.064

34. Ruhul MA, Abedin MJ, Rahman SA, Masjuki BH, Alabdulkarem A, Kalam MA. Impact of fatty acid composition and physicochemical properties of Jatropha and Alexandrian laurel biodiesel blends: an analysis of performance and emission Characteristics. J Cleaner Prod 2016; 133 :1181–1189.https://doi.org/10.1016/j.jclepro.2016.06.017

35. Shameer PM, Ramesh K. Assessment on the consequences of injection timing andinjection pressure on combustion characteristics of sustainable biodiesel fuelledengine. Renew Sustain Energy Rev 2018; 81:45–61.

36. Kannan GR, Anand R. Experimental evaluation of DI diesel engine operating withdiestrol at varying injection pressure and injection timing. Fuel Process Technol2011; 92:2252–63.

37. Jaichandar S, Senthil Kumar P, Annamalai K. Combined effect of injection timingand combustion chamber geometry on the performance of a biodiesel fueled diesel engine. Energy 2012; 47:388–94.

38. Ganapathy T, Gakkhar RP, Murugesan K. Influence of injection timing on performance,combustion and emission characteristics of Jatropha biodiesel engine. ApplEnergy 2011; 88:4376–86.

39. Sharma A, Murugan S. Combustion, performance and emission characteristics of aDI diesel engine fuelled with non-petroleum fuel: a study on the role of fuel injecti timing. J Energy Inst 2015; 88:364–75.

40. Channappagoudra M, Ramesh K, Manavendra G. Effect of injection timing onmodified direct injection diesel engine performance operated withiry scumbiodiesel and Bio-CNG. Renew Energy 2020; 147:1019–32.

41. Karthic SV, Senthil Kumar M, Nataraj G, Pradeep P. An assessment on injectionpressure and timing to reduce emissions on diesel engine powered by renewablefuel. J Clean Prod 2020; 255:120186.

42. Zheng M, Mulenga MC, Reader GT, Wang M, Ting DSK, Tjong J. Biodiesel engineperformance and emissions in low temperature combustion. Fuel 2008; 87:714–22.

43. Jaichandar S, Senthil Kumar P, Annamalai K. Combined effect of injection timingand combustion chamber geometryon the performance of a biodiesel fueled dieselengine. Energy 2012; 47:388–94.

44. Wang S, Karthickeyan V, Sivakumar E, Lakshmikandan M. Experimental investigationon pumpkin seed oil methyl ester blend in diesel engine with various injection pressure, injection timing and compression ratio. Fuel 2020; 264:116868

45. Ramalingam S, Rajendran S, Ganesan P, Govindasamy M. Effect of operatingparameters and antioxidant additives with biodiesels to improve the performance and reducing the emissions in a compression ignition engine–a review. RenewSustain Energy Rev 2018; 81:775–88.

46. Labecki L, Ganippa LC. Effects of injection parameters and EGR on combustion andemission characteristics of rapeseed oil and its blends in diesel engines. Fuel 2012; 98:15–28.