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Experimental Investigation of Combustion Characteristics of VCR Diesel Engine using Biodiesel Derived from Waste Cooking Oil

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Abstract - *The objective of this study is to investigate the combustion characteristics of a Kirloskar diesel engine fuelled with diesel and its different blends with WCME biodiesel (10 and 20% by volume). The experiment was performed on a single cylinder, four stroke VCR diesel engine at different loads and a constant speed of 1500 rpm. The compression ratio was kept 18:1. The combustion parameters studied were cylinder pressure, heat release rate and mass fraction burned. The results were compared with pure diesel and also among different biodiesel blends. The experimental results showed that diesel has the highest peak pressure and with the addition of WCME in the fuel blends, the peak pressure and ignition delay decreases with the increasing percentage of biodiesel, also there is a sudden decrease in the heat release rate with the addition of WCME biodiesel in the fuel blend.*

***Key Words*: Combustion, Performance, Diesel Engine, Biodiesel, Alternative Fuels.**

1. INTRODUCTION

The world economy is mainly dependent on energy economy. Currently fossil fuels like coal, petroleum and natural gas, dominate the world energy market occupying 26–27% each of total energy consumption. In particular, petroleum products holds the major share since they are mainly used in transportation and industrialization sectors. With the growth of both these sectors, the energy consumption has also increased. It is estimated that by 2030, the per-capita energy consumption growth will be at a rate of 0.7% per year. At present, fossil fuels namely coal, petroleum and natural gas dominates the energy scenario with a share of about 26–27% each as predicted by International Energy outlook, 2030 [4].

In India, liquid fuels consumption is forecast to grow by 0.2 million b/d in 2017 and by almost 0.3 million b/d in 2018. The growth is expected to result from increased use of transportation fuels, of naphtha and ethane feedstock for new petrochemical projects, and of propane for residential purposes. The Indian government's currency demonetization program in late 2016 contributed to declines in India's oil consumption in the first quarter of 2017. However, as India's oil consumers adjusted to the currency changes, liquid fuels consumption began growing again in the second quarter of 2017 [5].

As a well-established fact that fossil fuels are non-renewable. The growing demand and the rising cost as a result of depleting fossil reserves as well as problems relating to greenhouse gas emissions have been the most important driving factors for seeking out new sources of energy [6]. The emissions standards becoming stringent day by day indicate that fuels that burn cleaner and have lower sulphur content will be favoured [7]. A variety of alternative sources of energy, ranging from wind, solar, nuclear, etc., already exist but several challenges such as capital cost, portability, inefficiency, storage, and further environmental degradation make these sources of energy inadequate and in some cases non-viable.

For internal combustion (IC) engines, liquid biofuels have emerged as viable alternatives to fossil fuels. Biofuels are fuels typically made from renewable sources such as animal feedstock, plants, and biomass. Biofuel production and consumption has increased in recent years partly as a result of government support, mostly because they have been found to effectively supplement current fossil fuels [8].

Biodiesel is a form of diesel fuel manufactured from vegetable oils, animal fats, or recycled restaurant greases. Biodiesel proves to be a boon to auto industries by providing renewable, non-toxic, biodegradable and cleaner energy source [9]. It also solves environmental problems by reducing greenhouse effect. Biodiesel is going to play an extremely important role in meeting the world's energy needs since it provides energy security by reducing imports [10]. The raw material that is used to produce biodiesel plays an important role in the fuel industry. The scale between low production costs and large production scale should be balanced. Biodiesel can be produced using renewable resources such as vegetable oils (e.g., soybean, canola, sunflower, rapeseed, peanut and palm oil), animal fats (tallow, lard, poultry fat, fish oils, etc.) and waste cooking oils [11].

Biodiesel is a type of biofuel made from the trans-esterification process and involves reaction of a feed stock, usually oil or fatty acids from oil, with an alcohol in the presence of a catalyst [12]. The end product of the trans-esterification process is a fatty acid methyl ester (FAME), also called biodiesel. Biodiesel has several benefits over conventional fossil diesel; it is renewable, non-toxic, has greater lubricity, generally lower emissions and most of all has similar properties to conventional fossil diesel [13].

Many studies have investigated the influence of biodiesel on engine performance, combustion and emissions [14–24]. From these studies, fuel physical and chemical properties play a significant role in the results obtained. Biodiesel has a higher cetane number when compared to diesel and as such it has a shorter ignition delay [25, 26]. Other properties such as fuel penetration, atomization and droplet size are also important for the combustion of the fuel and ultimately its emissions [27]. The general consensus is that biodiesel results in a slight increase in brake specific fuel consumption and higher brake thermal efficiency than diesel [14, 15]. Biodiesel generally produces lower hydrocarbon and carbon monoxide emissions; however, NOx emissions are typically higher than diesel [14, 15, 20, 21]. Biodiesel has some disadvantages such as higher production cost, restriction on feedstock use, lower energy density (due to oxygen content), higher viscosity, stability, and higher freezing point amongst others [12,13].

The objective of this study is to determine how these newly developed renewable fuels like in our case WCME biodiesel perform compared to fossil fuels like diesel which is our basis for comparison in a diesel engine. The experimental study is focussed on engine combustion characteristics.

1.1 Properties of WCME Biodiesel

There is a lot of research going on in the use of vegetable oils for making renewable diesel, due to its less polluting nature than conventional diesel fuel. Renewable fuels such as biodiesel, hydrogen fuels and ethanol are important because they have a tendency to replace petroleum fuels. They also offer many advantages like rural development, sustainability and the security in fuel supply [2, 3].

Some of the properties of WCME are as follows:

Table -2: Comparative Fuel Properties

Properties	Diesel	WCME Biodiesel
Cetane number	40-55	55-65
Energy density(MJ/kg)	43	38
Density (kg/m3)	838	872
Viscosity@40°C (mm2/s)	3.5	4.5
Lubricity	Baseline	Good
Oxygen content wt%	0	10

2. EXPERIMENTAL SETUP

Experimental study on a VCR diesel engine (computerized), fuelled with diesel and different percentages of WCME biodiesel blended with diesel were investigated with respect to the combustion characteristics.

The setup consists of single cylinder, four stroke, Diesel engine connected to eddy current type dynamometer for loading purpose. Provision is also made for interfacing airflow, fuel flow, temperatures and load measurement. The setup has stand-alone panel box consisting of air box, fuel tank, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and engine indicator. Rotameters are provided for cooling water and calorimeter water flow measurement. The cylinder pressure was measured with a water cooled piezoelectric transducer. The charge output of the transducer was amplified into an equivalent voltage signal using a suitable charge amplifier. The crank angle and the position of the top dead center (TDC) were measured using an angle encoder, mounted rigidly on the camshaft of the engine.

The setup enables study of engine combustion, performance and emission parameters but the study is focused on engine combustion characteristics.

A brief specification of the test engine, used for the study is given in the Table 3 and schematic arrangement of the experimental setup is shown in Figure 1.

Table -3: Test Engine Specifications

Make	Kirloskar
Engine Model	TV 1
Engine Type	Vertical, 4-stroke, water cooled, VCR diesel engine
No. of Cylinder	One
Maximum power	5.2 kW@1500RPM
Bore	87.5 mm
Stroke	110.0 mm
Compression Ratio	18:1
Capacity	661.45cc

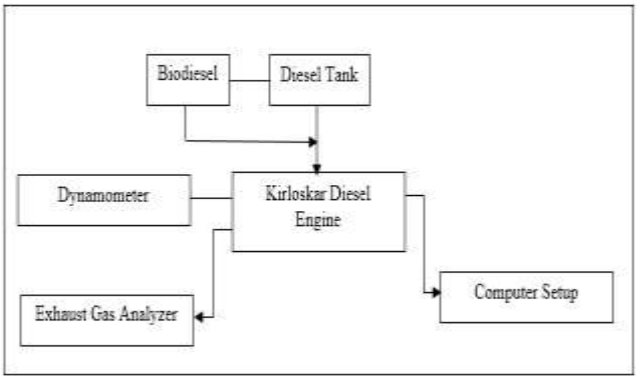

Fig -1: Schematic Diagram of Experimental Setup

3. TESTING PROCEDURE

1. Start the cooling water supply to ensure proper circulation for eddy current dynamometer, engine and calorimeter.

2. Start the experimental set up and run the engine at no load about 15 minutes.

3. Switch the computer on and run "EnginesoftLV" software. Confirm the configuration data of EnginesoftLV.

4. Gradually increase load on the engine.

5. Wait for steady state to be achieved (for about 15 minutes) and log the data in the "EnginesoftLV" software.

6. Gradually decrease the load on the engine.

7. View the results and combustion plots in "EnginesoftLV".

Experiments were conducted with diesel and WCME blends having 10% and 20% of WCME biodiesel on volume basis at different load levels. Engine combustion tests were also conducted on pure diesel as a basis for comparison. The experiments were repeated thrice and the average values were taken for combustion measurements [2].

4. RESULTS AND DISCUSSIONS

4.1 Engine Combustion Parameters

4.1.1 Cylinder Pressure

Chart 1 shows variation of cylinder pressure (in bar) with crank angle (C.A.) (in degree). The result shows that diesel has the highest peak pressure and with the addition of 10% WCME biodiesel, the peak pressure decreases, this is due to lower calorific value of the WCME blended fuel and reduced ignition delay period and retarded injection [29,30]. With the addition of 20% WCME a similar kind of reduced peak pressure was obtained. This may be due to reduction in the premixed combustion and the lower heat release of the WCME blends; as peak pressure mainly depends upon the combustion rate in the initial stages, which is influenced by the fuel taking part in uncontrolled heat release phase. A similar kind of results were obtained in [29, 31]. There is a sharp decrease in the peak cylinder pressure for 20% blended WCME than 10% blend of WCME.

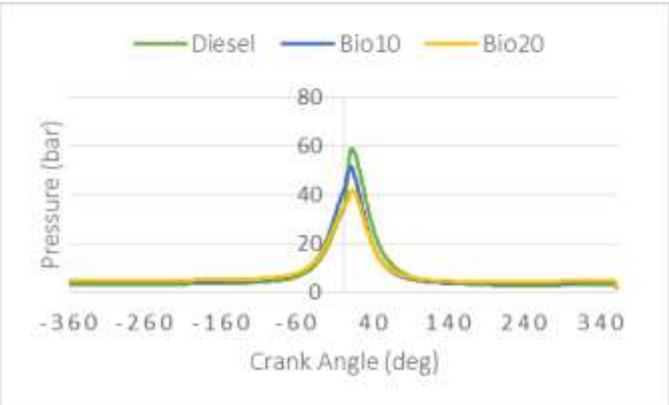

Chart -1: Variation of Cylinder Pressure with Crank Angle

4.1.2 Net Heat Release Rate (NHRR)

Chart 2 shows variation of net heat release (in Joules/degree) with crank angle (in degree). The result shows that there is a sharp decline in the heat release rate (HRR) with the addition of WCME biodiesel. Heat release diagram is a quantitative description of timely burning of fuel in the engine. Because of the vaporization of the fuel during ignition delay, a negative heat release is observed at the beginning and, after the combustion is initiated, it becomes positive. In general, during the ignition delay, the fuel droplets spread over a wide area around fresh air to form the fuel–air mixture. Once the ignition delay is over, the premixed fuel–air mixture burns, releasing heat at a very rapid rate, after which diffusion combustion takes place [28]. Diesel exhibits higher heat release rate. The main reason for this is increased accumulation of fuel during the relatively longer delay period resulted in higher rate of heat release at the time of the premixed combustion [32, 33]. It is observed that the value of maximum HRR decreases with the increase of biodiesel in the fuel. This is due to the lower ignition delay of the biodiesel owing to its higher cetane number and high latent heat of vapourization.

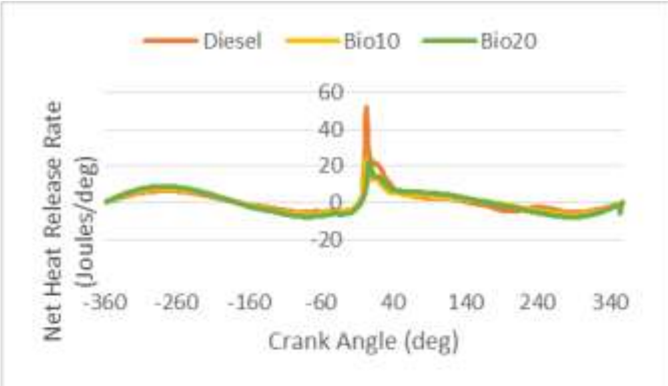

Chart -2: Variation of Net Heat Release Rate with Crank Angle

4.1.3 Mass Fraction Burned

Chart 3 shows variation of mass fraction burned (in %) with crank angle (in degree). The result shows that with the increase of WCME percentage in the fuel blend there is a reduction in the ignition delay and a shift of combustion to an earlier stage of crank angle. According to the chart below, premixed combustion burn rate is higher for WCME blended fuel due to the contribution and the amount of oxygen atoms, enhancing the exothermic reactions. The lower calorific value of WCME biodiesel results in increased fuel consumption [34].

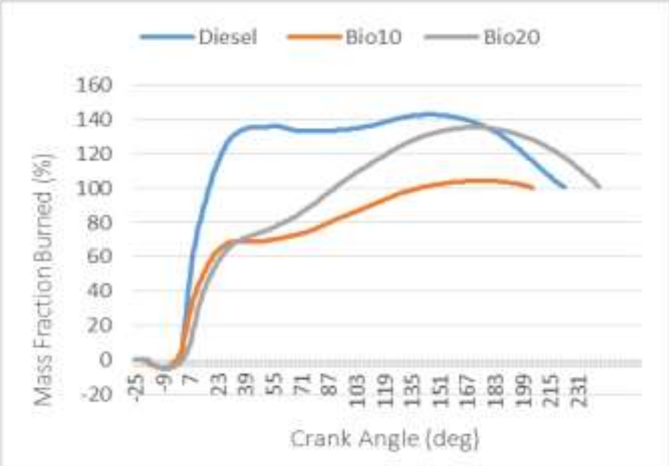

Chart -3: Variation of Hydrocarbon with Load

5. CONCLUSIONS

WCME biodiesel, produced from renewable and often domestic sources, represents a more sustainable source of energy and will therefore play an increasingly significant role in providing the energy requirements for stationary and transportation purposes. Therefore, more studies need to done on WCME engine combustion characteristics. Although there are data available on WCME combustion parameters, there have been inconsistent trends for WCME engine combustion characteristics due to the different tested engines, the different operating conditions, the different measurement techniques or instruments, etc. Therefore, in the present study, efforts have been made to perform the engine combustion tests under controlled conditions [1,2].

The following conclusions have been made from this study:

1 Diesel has the highest peak pressure and with the addition of WCME biodiesel in the fuel blends, the peak pressure decreases with the increasing percentage of biodiesel.
2 There is a sharp decline in the heat release rate with the addition of WCME biodiesel.
3 There is a reduction in the ignition delay with the increase of WCME percentage in the fuel blend.
4 The fuel consumption increases with the increased percentage biodiesel in the blend.

NOMENCLATURES

WCME	Waste cooking oil methyl ester
VCR	Variable compression ratio
RPM	Revolutions per minute
b/d	barrels per day
FAME	Fatty acid methyl ester
NOx	Nitrogen oxides
CI	Compression Ignition
CA	Crank Angle
HRR	Heat Release Rate
NHRR	Net Heat Release Rate
IC	Internal Combustion
AFR	Air-Fuel ratio
deg	Degree
TDC	Top Dead Centre

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