

ASSESSMENT OF EMISSION AND PERFORMANCE OF COMPRESSION IGNITION ENGINE FUELED WITH RUBBER SEED OIL AT DIFFERENT INJECTION TIMING

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ABSTRACT

Energy is an indispensable factor for human to preserve economic growth and maintain standard of living. As the fossil fuels are depleting day by day, there is a need to find out an alternative fuel to fulfill the energy demand of the world. Biodiesel is one of the best available resources that have come to the forefront recently. Engine performance improvement and exhaust emissions reduction are the two most important issues to develop a more efficient engine with fewer environmental impacts. For a diesel engine, injection timing is one of the major parameters that affect the engine performance and emissions. In this paper, studies are focused on characterizing the influence of injection timing on engine performance and exhaust emissions. Experiments were conducted on a 4-stroke, water cooled, direct injection, compression engine with 20% blend of rubber seed oil methyl ester (RSMOME) and Diesel. Performance and emission parameters were studied at different injection timings (i.e. 23°bTDC, 27°bTDC, 30°bTDC and 33°bTDC).

KEY WORDS: Rubber seed oil, Transesterification, Injection timing.

INTRODUCTION

As the fossil fuels are getting depleted day by day, the urge for an alternative fuel to fulfill the energy demands of the world is also increasing. Bio-diesel is one of the best available sources to fulfill the energy demands of the world. Though the petroleum fuels play a very important role in the development of industrial growth, transportation, agricultural sector and to meet many other basic human needs, these fuels are limited and depleting day by day as the consumption is increasing rapidly. Moreover, its usage is alarming and it causes a lot of environmental problems

to the society i.e. burning of the fossil fuel which releases smog and greenhouse gases that contribute to global warming [1].

Bio-diesel is gaining more importance as an alternative fuel to meet out the energy demands of the society [1]. Biodiesel fuels seem to be providing a promising alternative and solution to all the present problems. Biodiesel can be produced using renewable resources such as vegetable oils (e.g. Soy bean, Canoga, Sunflower, rubber seed oil and Palm oil etc.), animal fats (Tallow, Tard, Poultry fat, Fish oils, etc.), or waste cooking oils from the food industry, restaurants or domestic kitchens. Whilst the edible vegetable oils are used for human consumption, but non edible oils like rubber seed oil, mahua oil, found to be attractive feedstock for biodiesel production. The primary problem associated with straight vegetable oil as a fuel in a diesel engines is high viscosity and low volatility, which causes improper atomization of fuel during injection leading to incomplete combustion and results in formation of deposits on the injectors and cylinder heads, leading to poor performance, higher emissions and reduced engine life. The high viscosity of vegetable oils can be reduced by using transesterification process. The main advantage of this biodiesel is that many of its properties are quite close to that of diesel. There are numerous other advantages of biodiesel compared to diesel, including its biodegradability, higher flash point, i.e. less flammability, and it is a clean burning fuel, allowing for 78 % reduction in CO₂ lifecycle emissions compared to petroleum diesel [2,3]. Hence, the potential use of biodiesel fuel using rubber seed oil methyl ester is presented in this paper and Table 1 enlists the various properties of crude, refined and methyl ester of rubber seed oil.

TRANSESTERIFICATION OF RUBBER SEED OIL

Transesterification (alcoholysis) is the chemical reaction between triglycerides and alcohol in the presence of catalyst to produce mono-esters. The long and branched chain triglyceride molecules are transformed to monoesters and glycerin. Transesterification process consists of a sequence of three consecutive reversible reactions. That is, conversion of triglycerides to diglycerides, followed by the conversion of diglycerides to monoglycerides. The glycerides are converted into glycerol and yielding one ester molecule in each step. The properties of these esters are comparable to that of diesel. The overall transesterification reaction can be represented by the following reaction scheme [3].

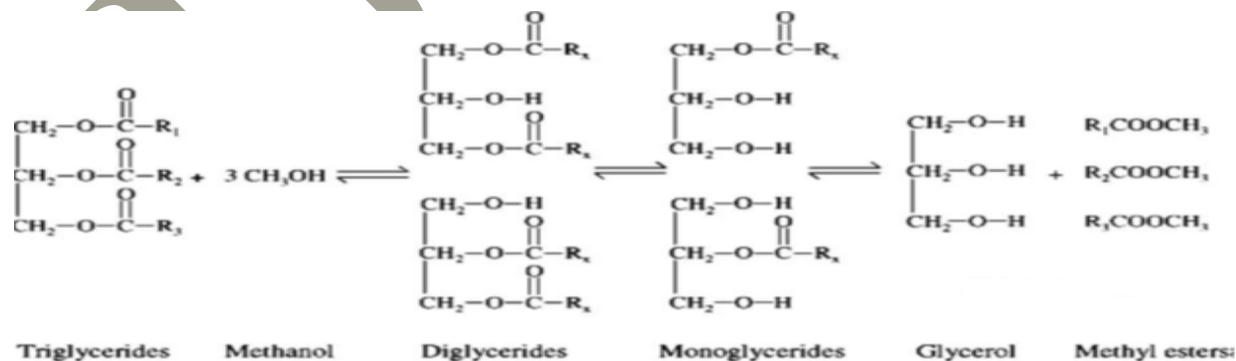


Figure1: Transesterification of Triglyceride Reactions.

ACID ETHERIFICATION OF RUBBER SEED OIL TO REDUCE FREE FATTY ACID

In order to reduce the FFA content (i.e. reducing the acid value), the crude rubber seed oil is initially esterified by using acid (H_2SO_4) as a catalyst. Hundred milliliter of raw rubber seed oil is taken for each acid esterification process. The oil is taken in round bottom flask and heated to the designed temperature. Proper proportion of methanol and sulphuric acid were added with the heated oil and stirred at atmospheric pressure using magnetic stirrer for 30–60 mins. After the stipulated time the process is stopped and the excess alcohol separates at the top surface along with the impurities in the separating funnel. The process parameter for acid esterification and the variation levels were finalized by pilot experiments over wider range. The oil separates at the bottom and collected for characterization. The optimized acid esterification process was identified where the acid values of the raw rubber seed oil was below 3.8 mg KoH/g. The average yield for this process is above 95% by weight and hence this was not considered as the major criterion for the optimization of first stage [4].

ALKALINE ESTERIFICATION OF RUBBER SEED OIL TO PRODUCE BIO DIESEL

The objective of the first stage, i.e. acid esterification process, is to reduce the acid value of the raw rubber seed oil from 35 mg KoH/g to less than 4 mg KoH/g. Accordingly, sufficient quantity of oil having FFA less than 2% (3.8 mg KoH/g) were extracted through the established optimum process parameters. However, the percentage of yield during the alkaline-esterification process in which the triglycerides are converted to monoester (biodiesel) is considered as the major objective in the second stage. Alkaline catalyzed esterification process uses the similar experimental setup used for acid esterification. By conducting pilot experiments the experimental parameters were carefully selected and the range for conducting experiments was finalized. For every experimental run in the second stage, 20 ml of the oil extracted from the first stage is taken in a flask and heated to designed temperature. The required amount of methanol and KoH are then added into the flask and stirred using magnetic stirrer for definite period as per the design. After the stipulated time, the reaction is stopped and the products are allowed to settle. Because of its low specific gravity, methyl ester (yellow in colour, known as biodiesel) settled on the glycerol surface, whereas glycerol settles down at the bottom. The biodiesel is collected and quantified for calculating the percentage yield of bio diesel in the transesterification process. The process parameters were then optimized [4].

Table 1. Physicochemical Properties of Crude, Refined and Methyl Ester of Rubber Seed Oil

Analysis	Crude RSO	Refined RSO	RSOME
Specific gravity at 30°C	0.922	0.918	0.885
Viscosity (cSt) 30°C	41.24	37.85	6.29
Cloud point (°C)	0	-1.0	0.4
Flash point (°C)	294	290	235
Fire point (°C)	345	345	276
Heat of combustion (KJ:g)	39.25	38.76	38.65
Ash content (%)	0.2	0.02	0.01
Calculated cetane index	34.00	34.00	44.81
Iodine value	142.6	142.6	144.0
Peroxide value (meq:kg)	2.5	1.0	0.8
Acid value	4.0	1.0	0.9

EXPERIMENTAL SETUP

The experiments were performed on a TV1, Kirloskar, single cylinder, 4-Stroke, water cooled diesel engine having a rated output of 7.5 kW at 1500 rpm and a compression ratio of 17.5:1 under variable injection timing at 200 bar injection pressure. The engine tests were carried out using 20% blend of rubber seed oil methyl ester and diesel. The engine was coupled with an eddy current dynamometer to apply different engine loads. The block diagram of experimental set up of engine is as shown in Figure 2.

Table 2. Specification of engine.

Make	Kirloskar
Capacity	10 HP
Compression ratio	17.5:1
Cylinder bore	80 mm
Stroke	110 mm
Cylinder capacity	553 cc
Cooling	Water cooled
Loading	Eddy current dynamometer
Speed	1500 RPM
Maximum loading	40 N-m
Injection pressure	180 bar
No. of cylinders	1

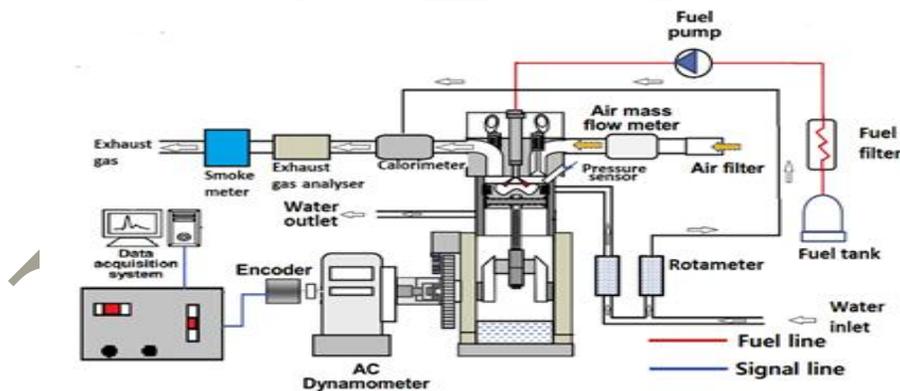


Figure 2. Schematic Diagram of the Experimental Set Up

RESULTS AND DISCUSSIONS

BRAKE SPECIFIC FUEL CONSUMPTION

The variation of Brake Specific fuel consumption (BSFC) with load at different injection timings for ROME are depicted in Figure 3. It can be observed from the Figure that the BSFC is marginally higher in ROME compared to Diesel fuel. This may be due to lower calorific value

of biodiesel. It is evident from the Figure 3 that by retarding the injection timing (24° bTDC) the BSFC has increased to that of rated injection timing (27° bTDC). Retarding injection timing causes delayed combustion and therefore pressure rise is only when the cylinder volume is expanded rapidly. Again by advancing the injection timing (30° bTDC), the BSFC has reduced. Further advancing the injection timing to 33° bTDC the BSFC has increased. Since with more advanced injection timing, the ignition delay will be longer and speed of the flame will be shorter, this cause reduction of maximum pressure and engine output power. Therefore, fuel consumption per output power will be increased [5].

BRAKE THERMAL EFFICIENCY

It can be seen from the Figure 4 that, the Brake Thermal Efficiency (BTE) has increased with increase in load at all injection timings. This is due to reduction in heat loss and increase in power with increase in load. It is evident from the Figure 4 that during retarded injection timing (24° bTDC) the BTE of R SOME has reduced compared to that of rated injection timing (27° bTDC) because of smaller ignition delay and poor atomization of fuel. During advanced injection timing (30° bTDC), the BTE is higher than the baseline Diesel fuel which may be due to longer ignition delay and proper atomization of fuel as time duration is higher and also due to increase in cetane number of the fuel. Further advancing the injection timing (33° bTDC) has decreased the BTE due to incomplete combustion [5].

EMISSION CHARACTERISTICS

UNBURNT HYDROCARBONS

The variation of Unburnt Hydrocarbons (UBHC) emission with load at different injection timings for R SOME is depicted in Figure 5. The UBHC level has increased with increase in load at all injection timings this is due to incomplete combustion of fuel. It is evident from the Figure that during retarded injection timing (24° bTDC) the UBHC emission of R SOME has increased compared to that of rated injection timing (27° bTDC) which may be due to shorter ignition delay, lesser availability of oxygen for combustion, poor combustion and poor atomization of fuel. At advanced injection timing (30° bTDC) the UBHC emissions for R SOME shows a significant reduction because of longer ignition delay during which more oxygen is available for complete combustion and better ignition quality. Furthermore, at 33° bTDC injection timing the UBHC shows an increasing trend. The increase in UBHC emissions at this injection timing may be due to higher fuel consumption.

CARBON MONOXIDE

The variation of Carbon Monoxide (CO) emission with load at different injection timings for R SOME are shown in Figure 6. It is seen from Figure that volume of CO emission initially decrease but increase at full load indicating better burning conditions at higher temperature assisted by improved qualities with uniform charge preparations of biodiesel. From the Figure it is observed that CO emissions at retarded injection timing (24° bTDC) is more because of ignition delay is very short i.e., the time duration for conversion of CO into CO_2 is very small and ultimately results in incomplete combustion. It can also be seen from the Figure that advance injection timing (30° bTDC) shows a decrease in CO emissions, this may be due to that the advanced injection timing produces higher cylinder temperature and increasing oxidation process

between carbon and oxygen molecules. Further increase in injection timing (33^0 bTDC) results in an increased CO emissions than the rated injection timing. CO emission is generally higher in Diesel engine when compared RSOME fuels at all loads [5].

OXIDES OF NITROGEN (NO_x)

The variation of Oxides of Nitrogen(NO_x) emission with load at different injection timings is shown in Figure 7. The NO_x emissions are slightly higher than the Diesel fuel at full load. This is attributed to the presence of more oxygen, better mixing of air and fuel in the premixed combustion phase and high combustion chamber temperature caused by improved combustion. It is evident from the Figure that the NO_x emissions are lower at rated injection timing (27^0 bTDC). When the injection timing was retarded, a decrease in NO_x emissions was observed. Retarding the injection timing decreases the peak cylinder pressure because more fuel burns after TDC. Lower peak cylinder pressures results in lower peak temperatures. As a consequence, the NO_x concentration starts to diminish. At advanced injection timing there is a higher NO_x emissions, this is due to rise in cylinder peak pressure caused by increased amount of premixed mass burning. It can be seen that at advanced injection timing (30^0 bTDC), the NO_x emissions of RSOME fuels is 1.63% higher than the Diesel fuel [6, 7].

SMOKE OPACITY

The variation of smoke opacity with load at different injection timings for RSOME is shown in Figure 8. Smoke opacity emissions shows an increasing trend with load at all injection timings. During low load and part load, smoke opacity is lower because of longer ignition delay and presence of more oxygen which oxidizes the soot into CO_2 . But when the load increases, more rich mixture is supplied into the combustion chamber which affects oxidation reaction and smoke opacity is comparatively increased as seen from Figure. It is evident from the Figure that the smoke opacity is lower at rated injection timing (27^0 bTDC). When the injection timing was retarded (24^0 bTDC), the smoke opacity has increased. This may be due to shorter ignition delay, prolonged diffusive combustion phase, poor atomization, improper mixing of air and fuel. Also during further advanced injection timing (33^0 bTDC) the smoke opacity has increased for RSOME.

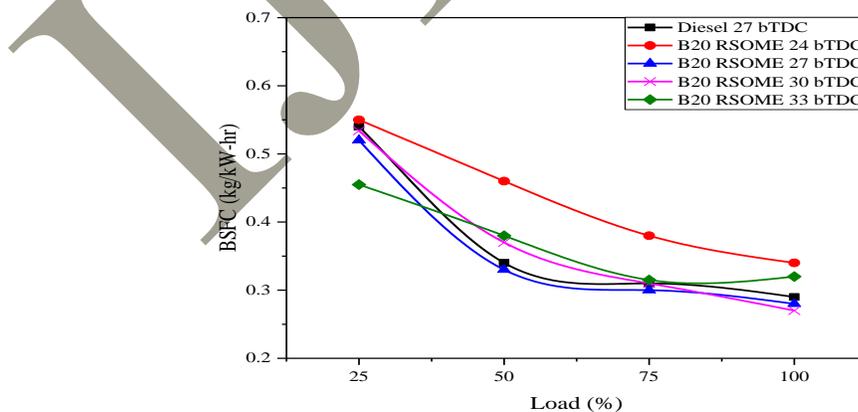


Figure 3. Variation of BSFC with Load for RSOME at Different Injection Timings

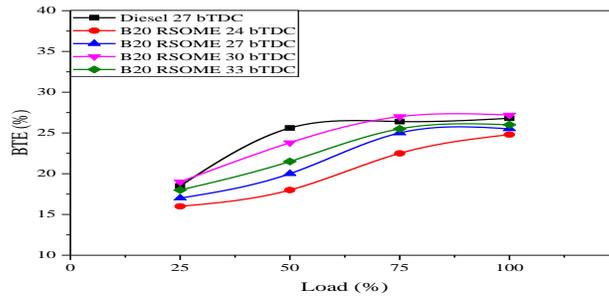


Figure 4. Variation of BTE with Load for RSOME at Different Injection Timing

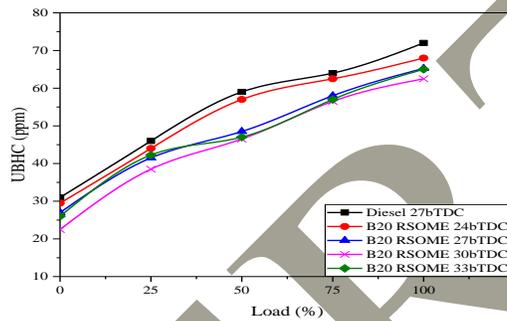


Figure 5. Variation of UBHC Emissions with Load for RSOME at Different Injection Timing

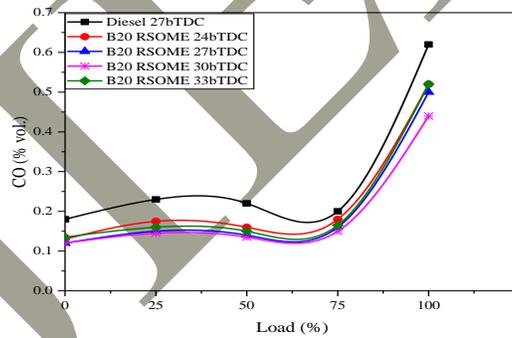


Figure 6. Variation of CO Emissions with Load for RSOME at Different Injection Timing

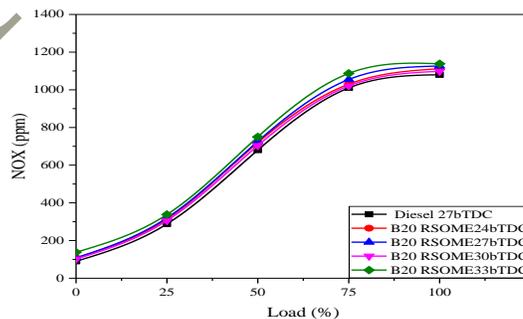


Figure 7. Variation of NO_x Emissions with Load for RSOME at Different Injection Timing

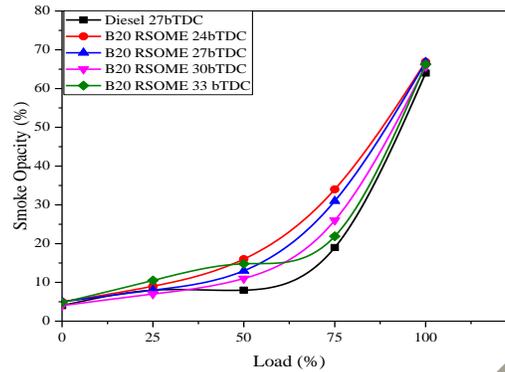


Figure 8. Variation of Smoke Opacity Emissions with Load for RSOME at Different Injection Timings

CONCLUSION

The influence of effect of fuel injection timing on performance and emission characteristics of Rubber seed biodiesel has been investigated experimentally. Advancing the injection timing (24⁰bTDC) causes reduction in BSFC, CO and smoke and increase in BTE, HC and NO_x emissions. Retard injection timing causes increase in BSFC, CO, HC and and reduction in BTE, smoke and NO_x. At any given injection timing, load torque and speed, BSFC and NO_x are higher with rubber seed biodiesel than that of diesel. However, BTE, CO, HC and smoke for rubber seed biodiesel are lower than that of diesel. The best injection timing for rubber seed biodiesel operation with minimum BSFC, CO, HC and smoke and with maximum BTE is found to be 30⁰bTDC. Therefore a proper injection timing tuning process can lead to significant benefits in terms of performance and emissions, when the diesel engine is operated with rubber seed biodiesel.

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