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Effect of Injection Timing on the Performance and Exhaust Emissions of a Diesel Engine using Diesel– Pupae biodiesel blends

Pradeep N.R*, Dr. S. Kumarappa**, Dr. B. M. Kulkarni***
**(Assistant Professor, Mechanical Department, BIET, Davanagere*
*** (Professor & Head, Mechanical Department, BIET, Davanagere*
**** (Professor, Chemical Department, BIET, Davanagere*

ABSTRACT : This paper deals with the experimental work which has been carried out to investigate the effect of fuel injection angle (18°, 23° and 28°CA BTDC) on the performance and emission characteristics of single cylinder variable compression ratio (VCR), direct injection compression ignition (DICI) engine fuelled with the blends of pupae biodiesel and diesel. The compression ratio of the engine is set to 16.5 to estimate brake thermal efficiency (BTE), brake specific fuel consumption (BSFC), exhaust gas temperature and the exhaust emissions measured were carbon monoxide (CO),Unburnt hydrocarbon (UHC), oxides of nitrogen ($NO_{X)}$ and smoke opacity. The test was conducted at different injection timings of 18°, 23° and 28° CA BTDC, keeping constant injection pressure at 200 bar and rated speed of 1500 rev/min at constant 80% load. For each trail, fuel flow rate, air flow rate, exhaust gas temperature, CO, HC, NO_X and smoke emissions were recorded. Based on the readings with the specified condition, optimum injection timing (IT) was recorded for each of the fuel tested.
Keywords – Pupae oil, transesterification, POME, Pupae Biodiesel Blends.

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I. INTRODUCTION

The twin crisis of fuel depletion and environmental degradations has led to the explore for another fuel which should be sustainable and also environment friendly without sacrificing the performance. Biofuels are renewable and reduce gasses emissions. Biodiesel are of two types: one derived from edible oil and other derived from non-edible oil source. Because of demand of edible oil for domestic purpose, non-edible oil is preferred for Biodiesel production. One of the prominent sources of non-edible oil is the oil derived from silkworm pupae, which is commonly known as pupae oil in India. The viscosity of the pupae oil is more compared to Diesel fuel. The viscosity is reduced by removing the glycerol in the pupae oil by the process of transesterification. The transesterification is the process of chemically reacting triglycerides with methanol in presence of potassium hydroxide as a catalyst. The Biodiesel obtained by transesterification of pupae oil is called pupae oil Methyl ester (POME). A study has been conducted on oil extraction and bio-diesel production process from silkworm pupae. Looking into its physico-chemical properties, it was concluded that the silkworm pupae may works as a sustainable feedstock for biodiesel production that is equivalent to fossil fuel as per ASTM 6751. As per the literature review [1], it was reported that POME suitability for CI engine and the subsequent effect of different Injection timings (ITs) on this biodiesel fueled engine was scarcely reported. Hence the present work aims to study the combustion, performance and emission characteristics of diesel engine powered with POME with different IT combinations.

II. EXPERIMENTAL APPARATUS AND PROCEDURE

The experiments were conducted on a VCR single cylinder, four stroke, direct injection, naturally aspirated engine. Details of the engine specification are shown in Table 1. The engine was coupled to an Eddy current dynamometer to control engine speed and load. Engine oil temperature, coolant temperature, exhaust temperature, and inlet air temperature were measured using K type thermocouples. The exhaust emissions (CO, unburned HC, NOx, and CO_2) were measured using DiGas AVL gas analyzers and smoke opacity by AVL smoke meter. To prepare Biodiesel blended fuel mixture, two fuels (diesel and Pupae Biodiesel) were used Diesel was obtained from near gasoline station. Pupae biodiesel is produced from silkworm pupae by Transesterification method. The diesel was blended with Pupae biodiesel to get different fuel blends like B0, B10, B15, B17, B20, B23, B25, B30, B40, B50, B60, B70, B80, B90 and B100 (neat biodiesel) i.e. B23 means 23% biodiesel and 77% neat diesel by volume. The fuel blends were prepared just before starting the experiment to ensure that the fuel mixture is homogenous. The original injection timing (ORG) of the test engine is 23°CA BTDC. Thickness of the shim, located in the connection place between the engine and fuel pump, is 0.15 mm and adding one shim advances the injection timing 5°CA. Experiments were carried out in three different injection timings (18°, 23° and 28°CA). All test runs were conducted on the test bench. In each run, engine speed and load were recorded. The combination of all tests included engine setting at constant load 4.29 bar, BMEP (80%) and constant engine speed at 1500 rpm intervals for each injection timing. The values of engine oil temperature, mass flow rate of air, engine speed, exhaust temperature, and pollutants such as CO, unburned HC, NOx and smoke opacity were recorded during the experiments. Each test was repeated three times. The values given in this study are the average of these three results. Before each experiment, the engine was regulated according to the catalogue values. All data were collected after the engine stabilized.

Table 1. Engine details

Model and Make	Kirloskar
No. of cylinder	Single
Cycle	Four stroke
Combustion Chamber	Direct Injection
Bore and stroke	80 mm and 110 mm
Rated Power	3.72 kW at 1500 rpm
Compression ratio	16.5
Dynamometer	Eddy current with loading unit

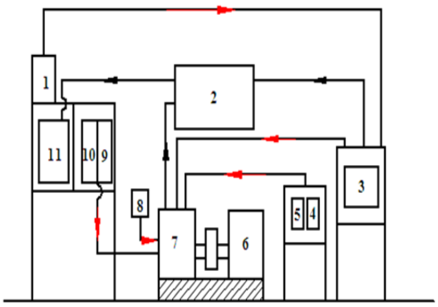

Figure 1. Schematic diagram of Single Cylinder Multi Fuel VCR engine with exhaust gas analyzer and smoke meter,

*1.Fuel tank, 2.Controller box, 3.High pressure variable fuel injection system, 4. Smoke meter, 5. Exhaust gas analyzer, 6. Eddy current dynamometer, 7. VCR Engine, 8.Air flow measuring unit, 9.Fuel flow meter, 10. Dynamometer control (load cell), 11.Computer system.

III. RESULTS AND DISCUSSION

Pupae biodiesel blended diesel fuel can reduce the pollutant emissions. However, to reach the emission reduction, it may require some modification on the engine. The injection timing has a significant effect on the performance and exhaust emissions in a DICI engines. Therefore, the effects of injection timing for Pupae biodiesel blended diesel fuel on the performance and exhaust emissions were experimentally investigated on a single VCR engine. From the readings obtained at each specified conditions, optimum IT was found out.

Performance Characteristics

➢ **Brake Thermal Efficiency**

The variation of brake thermal efficiency (BTE) for various Injection timing order and for various blends is given in Fig. 2. The maximum BTE was recorded with B0 for 80% engine load. BTE indicates the ability of the combustion system to accept the experimental fuel, and provides comparable means of assessing how efficient the energy in the fuel was converted to mechanical output. BTE results are presented in Figure 2 for different injection timings. The B0 fuel at 4.29 bar, BMEP for 23°CA injection timing produced the highest BTE as 26.2%. The higher BTE of B0 operation can be attributed to its LHV. Figure 2 shows the variations of the BTE with different Pupae biodiesel-diesel blended fuels for different injection timings at 4.29 bar, BMEP constant load. The best results in terms of BTE were obtained at 23°CA injection timing. Retarded or advanced injection timing diminished BTE values. For example, when the injection timing was retarded and advanced 5 °CA compared to injection timing at 23°CA, BTE decreased by 4.9 % and 5.4 % for B15and B17 at 4.29 bar, BMEP load, respectively.

➢ **Brake specific Fuel Consumption**

The amount of fuel introduced into the engine cylinder for a desired fuel energy input has to be greater with the Pupae biodiesel. Minimum BSFC was acquired as 0.308 kg/kWh with the B0; 0.313 kg/kWh with the B10; 0.316 kg/kWh with the B15; 0.317 kg/kWh with the B17 for ORG injection timing at 80 % (2.97 kW) load. Figure 3 indicates the variations of BSFC for different Pupae biodiesel blended diesel fuels under different injection timing at 80 % (2.97 kW) constant load. When the injection timing was retarded 5 °CA BTDC compared to ORG injection timing, BSFC increased by 10.23% for B15. With advancing injection timing at 28°CA, the ignition delay will be longer and speed of the flame will be shorter. This cause reduction of maximum pressure and engine output power. Thus, fuel consumption per output power will increase [2],[3]. On the other hand, retarding injection timing at 18°CA means later combustion, and therefore pressure rises only when the cylinder volume is expanding rapidly and results reduced effective pressure to do work. As a result, minimum BSFC was obtained at 23°CA injection timing for all the fuel blends.

- **Exhaust Gas Temperature**

Figure 4 shows the effect on combustion temperature with injection timing. The advanced injection timing at 28°CA produced a higher cylinder temperature which caused an increase in the chemical reaction speed of combustion region. Also, the advanced injection timing increased the oxidation process between carbon and oxygen molecules [4], among all blends B100 releases lower EGT because of lower heating of B100 fuel compared to other. The increase in EGT around 12°C for B0 as the Injection timing is increases from 23° to 28°.

- **Carbon Monoxide Emission**

The effect of fuel injection timing on the CO emissions is shown in Figure 5. CO emissions increased with retarded fuel injection timing at 18°CA. Retarding the fuel injection timing decreases the amount of fuel burned in the premixed combustion phase and increases the amount of fuel burned in the subsequent diffusive combustion phase. The latter phase always takes place in a rich mixture environment and easily produces the incomplete burning product CO [5],[6]. Retarding the injection timing by 5° (from 23°to 18°CA BTDC) caused the CO emission, which increased by 10.87 % for B23 at 4.29 bar, BMEP load. However, the CO emission decreased with the advanced injection timing at 28°CA.

- **Hydrocarbon Emission**

Figure 6 shows the effect of fuel injection timing on HC emissions. When combustion was retarded, which happens with the retarded start of injection, the maximum gas temperatures were lower, as shown in Figure 4. While the volume increases during the expansion stroke, HC emissions increased drastically [7]. Retarding the injection timing by 5°(from 23°to 18°CA BTDC) caused the emission to augment by 4.67 % for B23 at 4.29 bar, BMEP load. On the other hand, the advanced injection timing at 28°CA caused an earlier start of combustion relative to the TDC. Because of this, the cylinder charge, being compressed as the piston moved to the TDC, had relatively higher temperatures and thus lowered the HC emissions.

- **Nitrogen Oxides Emission**

Figure 7 illustrates the effect of fuel injection timing on NOx emissions. Retarding the fuel injection timing at 18°CA caused a decrease in the ignition delay and cylinder gas temperature. Consequently, the NOx concentration tended to be less [8],[9]. The exhaust gas temperatures obtained in the experiments are shown in Figure 4, which confirmed this statement. Retarding the injection timing by 5° (from 23°to 18°CA BTDC) caused the NOx emission to reduce by 7.03 % for B23 at 4.29 bar, BMEP load.

- **Smoke Opacity**

The effect of injection timing on smoke opacity can be seen in Figure 8. Retarding the fuel injection timing at 18°CA increased the smoke opacity. This is due to increasing the fraction of diffusive combustion while retarding the fuel injection timing [10],[11]. Retarding the injection timing by 5° (from 23°to 18°CA BTDC) caused the smoke emission to increase by 8.15 % for B23 at 4.29 bar, BMEP load.

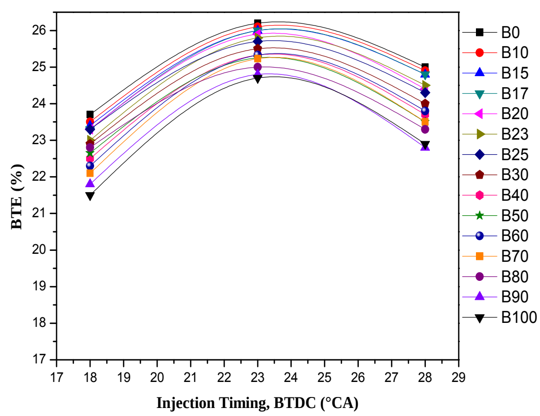

Figure 2. BTE results at different injection timings

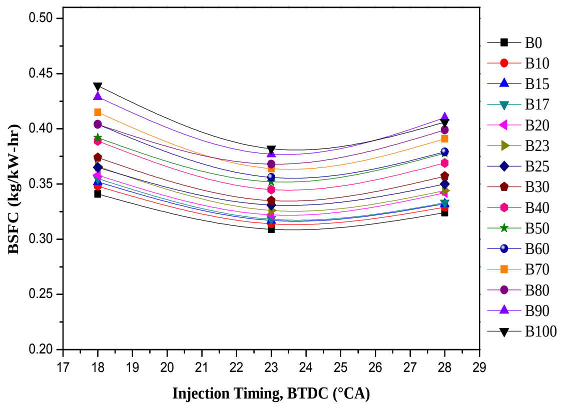

Figure 3. BSFC results at different injection timings

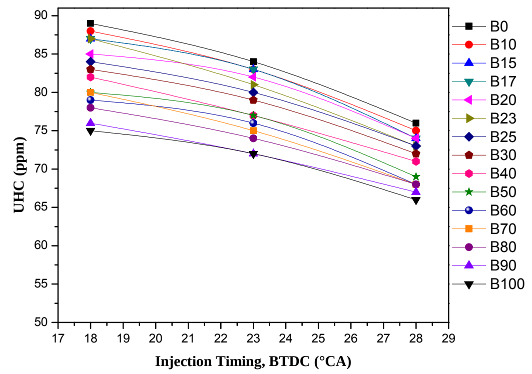

Figure 6. UHC results at different injection timings

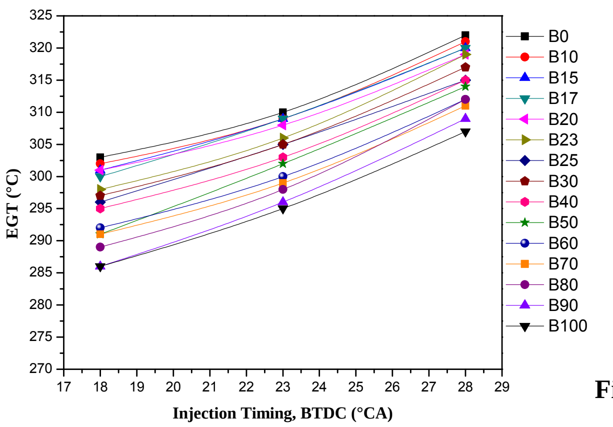

Figure 4. EGT results at different injection timings

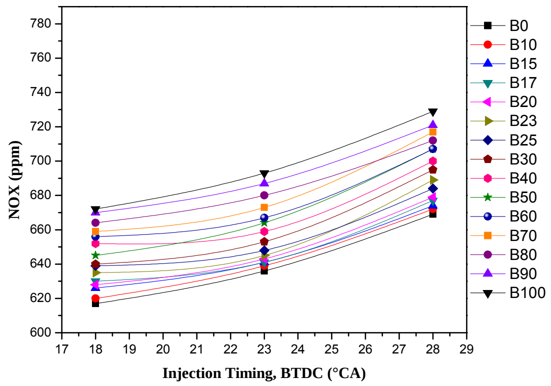

Figure 7. NOx results at different injection timings

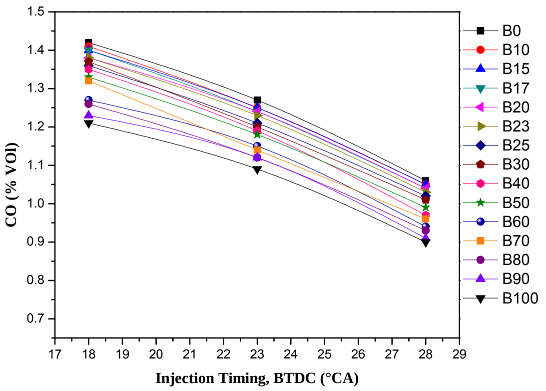

Figure 5. CO results at different injection timings

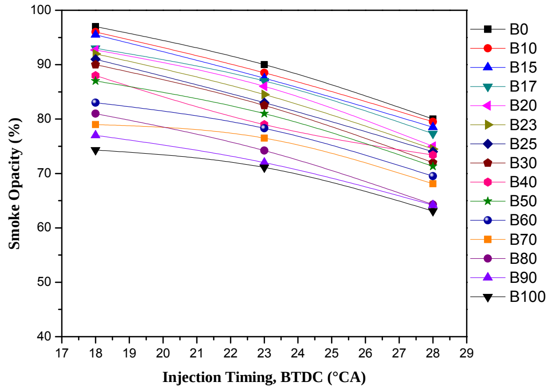

Figure 8. Smoke Opacity results at different injection timings

IV. CONCLUSION

Engine was made to run with all different blends at different injection angles successfully and the following conclusions are drawn from experimental investigation

- POME and its blends can be used as substitute fuel for Compression Ignition engine with a small compromise in BTE.
- Fuel Injection Timing of 23ºCA yielded good performance in terms of high BTE and less emissions.
- For POME and its blends with diesel fuel, BSFC increased by retarding the fuel injection timing at 18°CA compared with standard injection timing at 23°CA and results in increased CO, unburnt HC, and Smoke emissions with lower in NO_X emission.
- On the other hand, advancing the fuel injection timing at 28°CA reduces CO, unburnt HC, and Smoke emissions but with increased in BSFC and NO_X emission
- The exhaust gas temperature increased for all fuel blend ratios by advancing the engine fuel injection timing, indicating complete combustion. The exhaust gas temperature was found to be higher results in higher NO_X emissions than the usual fuel injection timing setting with retarding the fuel injection timing to 18ºCA, indicating incomplete combustion.

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