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Combustion evaluation of Diesel - Soyabean methyl ester blends using variable piston geometry in direct injection compression ignition engine

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Abstract: *The present paper is focussed on analysing experimentally the combustion and heat release characteristics of Soyabean biodiesel in compression ignition engine. Biodiesel is formed by transesterification of Soyabean crude oil using sodium hydroxide and methanol which resulted in 95% of Soyabean biodiesel. The piston geometry of the engine was varied by erosion and electrochemical deposition of metals to form Deep Torodial and Shallow Torodial combustion chamber. The results showed that SOME biodiesel exhibits better combustion characteristics with Shallow Torodial piston geometry than Deep Torodial piston geometry. The combustion peak temperature was increased by 4% to 6% in Shallow Torodial piston where as Deep Torodial piston showed 3% to 5% negative improvement in cylinder pressure. The rate of heat release also showed positive improvements with Shallow Torodial piston geometry.*
Keywords*: Soyabean biodiesel, Combustion, Rate of heat release, Piston geometry, Transesterification*

I. INTRODUCTION

In recent years, Fossil recourses are declining day by day and the price of petroleum crude oil has been raised rapidly, hence researches are looking for alternative fuel sources. Currently biodiesel is one of the most promising source of renewable energy with high potential and has an ability to replaces the petroleum derived fuel. Vegetable oil are obtained from different plant species and oil extraction can be achieved be physical or chemical processes. Non edible vegetable oil sources can be grown in agronomic geographical places and it can be blended with diesel to create esterified forms. The level of viscosity of vegetables oils is extremely higher than diesel fuel which changes the flow properties of the fuel and also leads to variation in spray characteristics, fuel vaporization and air fuel mining in the combustion chamber.

Researchers have analyzed the performance, emission and heat release analysis of direct injection diesel engine using diesel and Soyabean biodiesel and found that the performance characteristics of Soyabean biodiesel were similar to conventional diesel with a slight variation in torque and power output. He also noticed that the emission like HC, CO, NO_x and CO_2 lies close to diesel fuel at all loads. He suggested Soyabean biodiesel to be suitable replacement for the fossil fuel [2]. Experimentally investigation on neem oil methyl ester blends in a single cylinder diesel engine has been carried out and the combustion, performance and emission characteristics has been analyzed. They found that at full load, peak combustion pressure was higher for NOME blends where as peak heat release rate at premixed combustion phase was lower for NOME blends. The ignition delay was also noticed to be lower for neem oil methyl ester blends at full loading condition. NO_x emission was seen reducing with a marginal increase in HC and CO when NOME was used [17].

Combustion, performance and emission characteristics of a slow speed diesel engine fuelled with Soyabean biodiesel has been studied which resulted in 2.6% and 8.8% increase in brake thermal and mechanical efficiencies respectively [14]. Combustion and heat release characteristics of Hazelnut biodiesel has been reported by several researchers in which they have used potassium hydroxide as a catalyst along with methanol during Transesterification. He has comprehensively analysed the combustion and heat release parameters and observed that modification in injection timing, compression ratio and injection pressure significantly affected the combustion and heat release [7]. Comparison in combustion of Jatropha, Karanja and Polanga biodiesel in a single cylinder diesel engine has been presented and the test revealed that the neat Polanga biodiesel showed maximum peak cylinder pressure. The ignition delay was consistently reduced with increase in Jatropha biodiesel [15].

The present work was aimed at studying the combustion parameter when Soyabean biodiesel blend was used as a fuel in various combustion chambers with variable piston geometry. Hence it is important to carry out a detailed analysis of combustion pressure and rate of heat release for various pistons used in diesel engines fuelled with biodiesel. Soyabean biodiesel was blended with diesel in 5%, 10% and 15% ratios respectively and combustion study was carried out at 20%, 40%, 60% and 80% loading condition with the Torodial piston, Shallow Torodial and Deep Torodial pistons.

Abbreviations and Nomenclature	
BG 11	Blue green medium
NaOH	Sodium hydroxide
GC-MS	Gas Chromatography Mass spectrometry
RT	Retention time
SOME	Soyabean oil Methyl Ester
HC	Hydrocarbons
CO	Carbon mono-oxide
NOx	Oxides of Nitrogen
BTDC	Before top dead center
ROHR	Rate of heat release
CAD	Crank angle degree
DI	Direct injection

II. Materials And Methods

Soyabean oil was obtained from Ahamed, Gujarat, India. The chemical solvents like Methanol and Sodium hydroxide were purchased from nearby markets in Chennai. The biodiesel samples were tested in SAIF lab for Gas Chromatography Mass spectrometry and ITA lab for chemical properties of the biodiesel blends.

a. Transesterification process

Transesterification is the process of obtaining Soyabean biodiesel from crude Soyabean oil in the presence of Sodium hydroxide as a catalyst and Methanol. The Transesterification process was carried out in the round bottomed flask. Soyabean oil was heated up to 60^{o}C for 1hr 10 min. Sodium hydroxide was mixed thoroughly with methanol to form Sodium methoxide. This sodium methoxide solution was mixed with Soyabean oil and stirred thoroughly to initiate the reaction. The mixture was kept in a rotating agitator at 200 rpm for 18 hrs and allowed to cool thereafter. A stagnant reaction period of 12hrs was allowed for the formation of Soyabean Methyl ester and Glycerol as a by-product. The entire mixture was placed in a inverted separating funnel which removes the glycerol and segregates the SOME. SOME was washed with 5% distilled water to remove traces of impurities [4,5,16]. The properties of esterified SOME blends are given in table (2).

b. Gas chromatography / Mass spectrometry

GC/MS analysis was carried out using JEOL GC MATE 2 GC MS data system which is equipped with double focussing high resolution electron impact helium gas carried with a time range of 60 to 600 ionizations. JEOL GC MATE identified four major fatty acid esters namely Myristic acid, Niacin acid, Palmitic acid and Stearic acid present in the Soyabean biodiesel as given in table (1). The base peak of the chromatogram was found at RT 9.2 was with reference to McFaffarty rearrangement. Several minor and major peaks were also seen at RT 8.09, RT 8.50 and RT 10.23 as shown in fig (1). At m/z 213.00 a minor peak was seen which may be due to repositioning of hydrogen and carbon atom and at m/z 256.00 may be due to decay of methoxy protons and α ions expulsion [10,11].

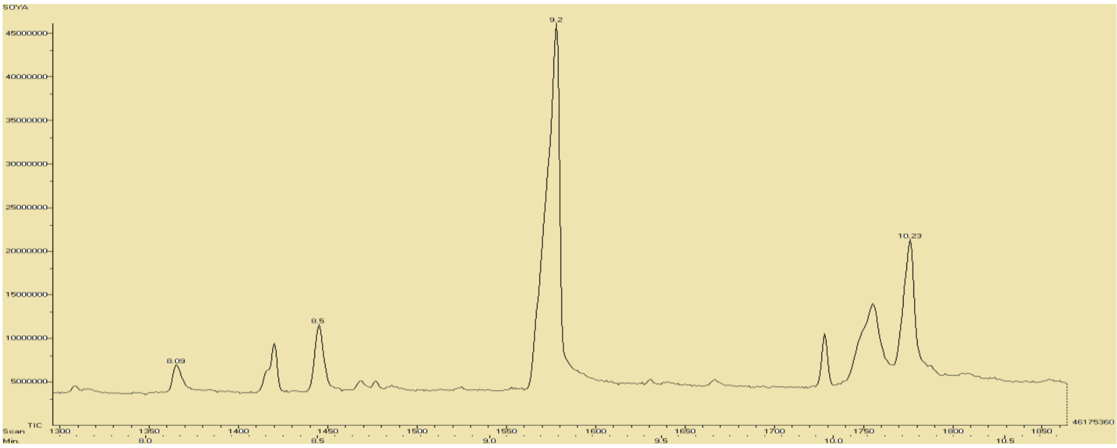

Figure 1: GC/MS Mass spectrum for Soyabean oil Methyl ester

Table 1
Fatty acid methyl ester in SOME

S. No	Retention time	Name of ester	Name of fatty acid	No of Ions
1	8.09	Tetradecanoic methyl ester	Myristic acid	1631
2	8.5	Tryptophan N-[N-{1-Oxodecyl-a-alanyl}-methyl ester	Niacin acid	1597
3	9.2	n-hexadecanonic methyl ester	Palmitic acid	733
4	10.23	Octadecanic methyl ester	Stearic acid	1219

Table 2
Properties of Diesel and SOME blends

S.No	Propeties	Diesel	SOME 5%	SOME 10%	SOME 15%
1	Density @ 15^0C in gm/cc	0.830	0.8089	0.8140	0.8273
2	Kinematic viscosity @ 40^0C in CST		2.05	2.20	2.24
3	Flash point (Abel) ^{0}C	50	69	71	73
5	Calculated cetane Index	49	54	55	57
6	Gross calorific value in kcals/kg	45800	43250	40255	39760
7	Sulphur content		0.20%	0.24%	0.23%

III. Experimental Setup

The experimental investigation was carried out on a single cylinder naturally aspirated four stroke vertical air cooled engine as given in table (3). The engine was coupled to a DC dynamometer as a loading device. An electronic fuel flow meter was installed to measure the fuel consumption. The engine speed was measured using incremental encoder and an orifice coupled manometer was employed for the measurement of intake air. In cylinder pressure was measured using Kistler 701A model transducer equipped with cooling adapter and high temperature cables. A multipurpose charge amplifier and AVL crank angle calculator was also used for acquisition of data and transferred to a personal computer. Crypton five gas analyzer and Bosch smoke meter was user to measure HC, CO, NO_x, Particulates and Smoke as shown in fig (2). SOME was blended with straight diesel in 5%, 10% and 15% blend ratio and combustion analysis were conducted in all the above blends with straight diesel as the base with three different type of piston namely Torodial (existing) Shallow Torodial piston and Deep Torodial piston. The variation in the piston was achieved by erosion and electrochemical deposition process on the combustion surface of the piston so the compression ratio was varied. The compression ratio was assessed based on melting wax method and found to have significant variation (i.e) Torodial piston showed 18:1, Shallow Torodial piston showed 19.5:1 and Deep Torodial piston exhibited 16:1 as shown in fig(4) and fig(3) respectively.

Table 3
Specification of test engine

Engine make	Greaves
Model no	5520
Engine type	Single cylinder four stroke vertical air cooled
Bore	78mm
Stroke	68mm
No of cylinders	1
BHP	5hp
Compression ratio	18:1
Speed	3000-3600 rpm
Injection timing	26^0 BTDC

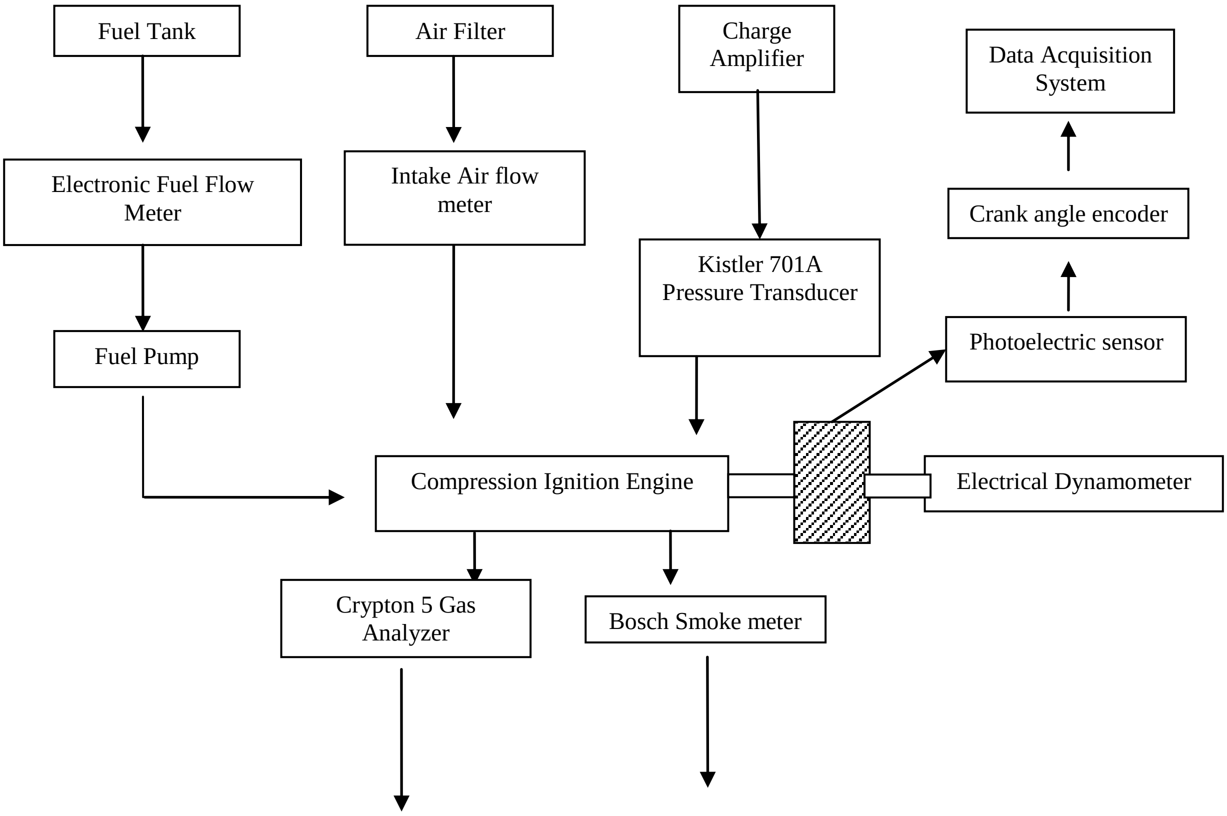

Figure 2. Block diagram of experimental setup

Figure 3. Deep Torodial piston

Figure 4. Shallow Torodial piston

IV. Results And Discussion

a. Comparison of In-cylinder pressure

The variation of In cylinder pressure with crank angle at part load and full load for Torodial, Shallow Torodial and Deep Torodial pistons are compared in Fig (5) to Fig (10) with Diesel and SOME blends as fuel. It is clearly observed for the Fig (5) and Fig (6) that Torodial piston shows variations in combustion pressure at about 56 bar to 58 bar for diesel and SOME blends. SOME 15% blend showed higher in cylinder pressure at 58.5 bars. It can be also seen that with the addition of SOME blends, combustion starts much earlier than diesel combustion which helps in complete oxidation of the fuel molecules. During the start of combustion, the premixed combustion phase shows very rapid increase in pressure because of increased ignition delay period which may be due to increase in viscosity of the fuel as the SOME blends are increased [6-9].

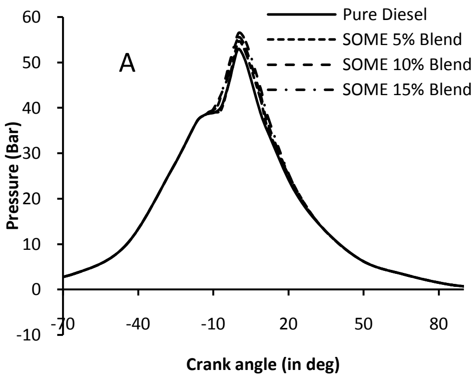

Figure 5. Comparison of In cylinder pressure for Torodial piston with Diesel, SOME 5%, 10% and 15% Blend at 40% load

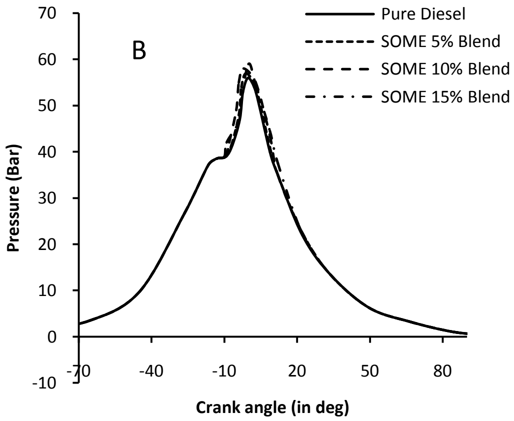

Figure 6. Comparison of In cylinder pressure for Torodial piston with Diesel, SOME 5%, 10% and 15% Blend at 80% load

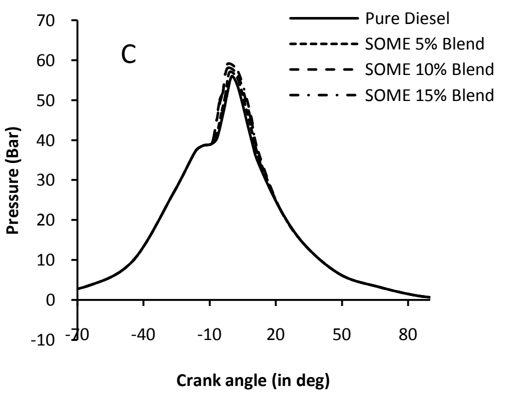

Figure 7. Comparison of In cylinder pressure for Shallow Torodial piston with Diesel, SOME 5%, 10% and 15% Blend at 40% load

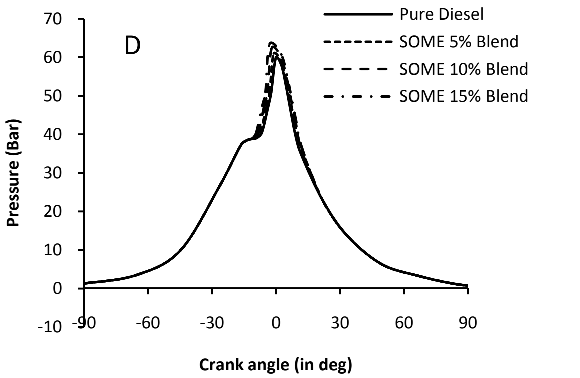

Figure 8. Comparison of In cylinder pressure for Shallow Torodial piston with Diesel, SOME 5%, 10% and 15% Blend at 80% load

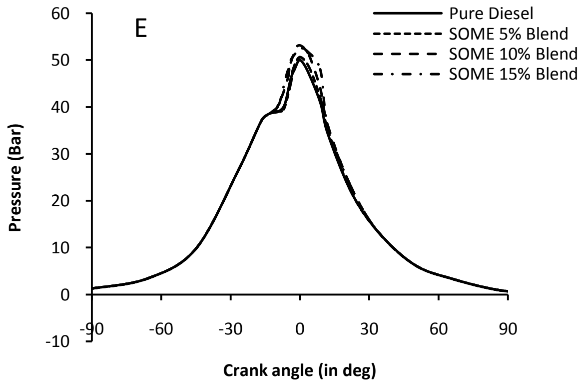

Figure 9. Comparison of In cylinder pressure for Deep Torodial piston with Diesel, SOME 5%, 10% and 15% Blend at 40% load

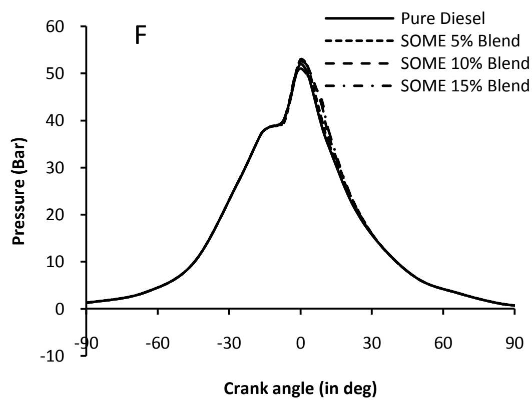

Figure 10. Comparison of In cylinder pressure for Deep Torodial piston with Diesel, SOME 5%, 10% and 15% Blend at 80% load

After the premixed combustion phase, the combustion is smooth and slows down gradually till all the fuel particles are completely combusted and continuous till the end of expansion stroke. The maximum rise in combustion pressure for diesel lies below SOME blends with SOME 15% blend at 58.6 bar at full load condition. Fig (7) and Fig (8) shows variation in combustion pressure for Shallow Torodial piston with diesel and SOME blends with positive improvement than Torodial piston with 4% to 6% increase in combustion pressure at part load and full load condition. As the compression ratio is varied by 0.5% to 1% in shallow, the ignition delay is extended to a greater period for SOME blends and results in more quantity of fuel accumulated in the combustion chamber. This accumulated fuel eventually leads to higher peak combustion pressure at the time premixed combustion phase [13]. The combustion chamber also shows variation in start of combustion which may be due to increased ignition delay. Fig (9) and Fig (10) showed variation of in cylinder pressure for Deep Torodial piston with SOME blends and diesel as fuel. It showed negative improvement towards combustion pressure by 6% to 8% when compared with Torodial and shallow Torodial piston across all blends of SOME. This may be due to decrease in compression ratio to great extent. Fig (6) showed a peak pressure of 52 bar at full load which is 4% lower than shallow Torodial piston which may be due to longer combustion duration at all blends of SOME due to diffusive combustion period [1,3,12].

b. Comparison of Rate of Heat release

Theoretically, heat release analysis was considered with the equation (1) as given below

$$\frac{dQ_n}{dt} = \frac{\gamma}{\gamma - 1} P \frac{dV}{Dt} + \frac{1}{\gamma - 1} V \frac{dp}{dt} \quad (1)$$

Where γ is the net heat release rate, P is instantaneous cylinder pressure and V is instantaneous cylinder volume.

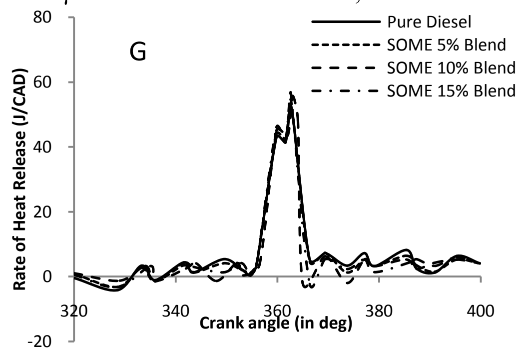

Figure 11. Comparison of Rate of Heat release for Torodial piston with Diesel, SOME 5%, 10% and 15% Blend at 40% load

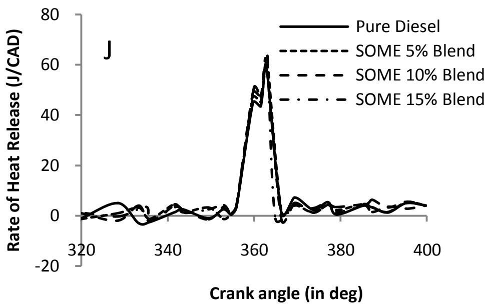

Figure 14. Comparison of Rate of Heat release for Shallow Torodial piston with Diesel, SOME 5%, 10% and 15% Blend at 80% load

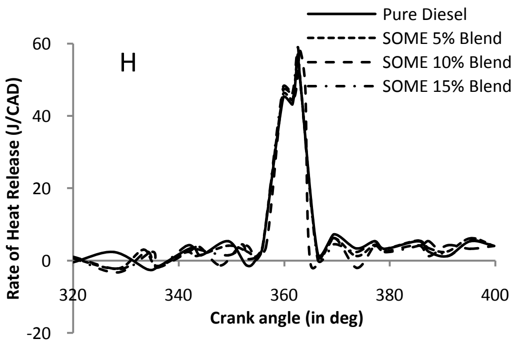

Figure 12. Comparison of Rate of Heat release for Torodial piston with Diesel, SOME 5%, 10% and 15% Blend at 80% load

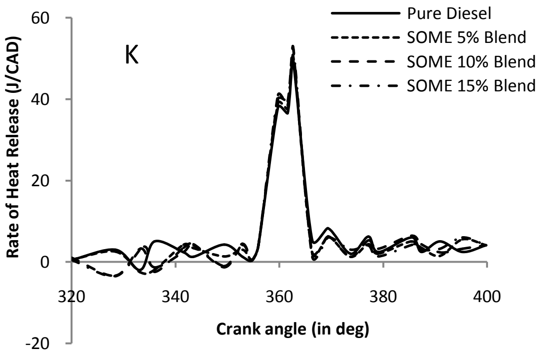

Figure 15. Comparison of Rate of Heat release for Deep Torodial piston with Diesel, SOME 5%, 10% and 15% Blend at 40% load

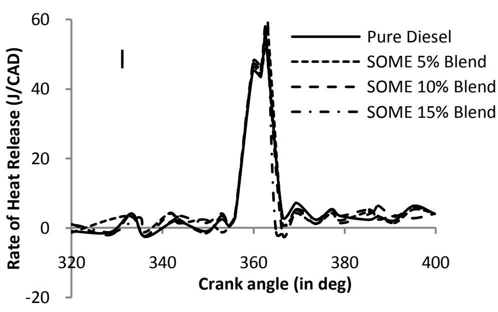

Figure 13. Comparison of Rate of Heat release for Shallow Torodial piston with Diesel, SOME 5%, 10% and 15% Blend at 40% load

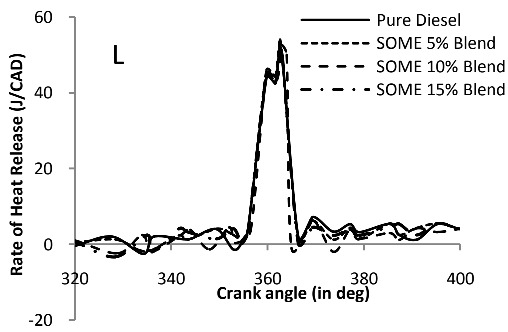

Figure 16. Comparison of Rate of Heat release for Deep Torodial piston with Diesel, SOME 5%, 10% and 15% Blend at 80% load

The variation in the rate of heat release with crank angle at part load and full load for diesel and SOME blends with Torodial, Shallow Torodial and Deep Torodial pistons are shown from fig (11) to fig (16). Irrespective of the combustion chambers, diesel and SOME blends shows positive improvement in the rate of heat release with addition of loads [18-19]. Fig (11) and Fig (12) showed ROHR for Torodial piston with SOME blends and Diesel at part load and full load in which SOME 15% blend represented 3% to 4% increase in ROHR. The rate of heat release for SOME 5% blends was found to be 51 J/CAD where as SOME 15% blend showed 54 J/CAD which may be due to rapid premixed combustion phase and fuel combustion due to ignition delay period. As the SOME blends are increased, the ROHR also shows increase due to better mixing of fuel with air and more oxygen release at high loads. Similarly, Shallow Torodial piston showed 6% to 8% increase in ROHR than Torodial piston because of longer ignition delay and more fuel accumulated during this period which is completely burned. The premixed combustion phase also showed a very rapid increase which may be due to higher volatility with increase in SOME blends. SOME 15% blends showed 61.4 J/CAD at part load and 62.8 J/CAD at full load which is 2% to 3% lower when compared with Torodial piston. On the other hand, combustion in Deep Torodial piston showed negative ROHR which is 8% to 12% lower than Torodial and Shallow Torodial piston (i.e) 50.5% J/CAD at part load and 51.57 J/CAD at full load as shown in fig (13) and fig (14) respectively. This may be due to lower ignition delay as the SOME blend are increased, poor and complex preflame reactions at all loads and thermal cracking of SOME compounds which may undergo early ignition. It can also be seen that with increase in SOME blends, ROHR reduces gradually with increase in loads which may be resulted due to lower volatility and higher viscosity [20].

V. Conclusion

The main aim of this study was to analyse the suitability of Soyabean methyl ester blends in compression ignition engine under variable piston geometry. Combustion analysis includes study of rise in maximum combustion pressure and rate of heat release was carried out at part load and full loading condition. Based on the experimental results, the following conclusion can be made,

Transesterification process with sodium hydroxide and methanol resulted in 95% of Soyabean oil methyl ester formation.

- The viscosity of Soyabean oil methyl ester was higher than diesel at low temperatures.
- Because of properties variation, the combustion characteristics also varied with various blends of SOME at all loading conditions.
- At part load condition, peak in-cylinder pressure was higher as compared with SOME blends in Torodial and Deep Torodial piston geometry.
- Ignition delay period was longer for all blends of SOME in Shallow Torodial piston at all loading condition.
- At full loading condition, SOME 15% blend showed 4% to 6% increase in In-cylinder pressure rise for diesel in Torodial piston and 5% to 8% increase in Shallow Torodial piston geometry. Deep Torodial piston showed 2% to 3% negative improvement in combustion pressure for all blends of SOME at all loads.
- The rate of heat release also exhibited 4% to 8% increase in Shallow Torodial piston across all blends of SOME and diesel as compared with Torodial and Deep Torodial piston geometry.

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