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The Effect of Injection Timing on Combustion, Performance and Emission Parameters with AOME Blends as a Fuel for Compression Ignition Engine

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Abstract: An experimental investigation has been carried out to analyze the effect of injection timing on performance, combustion and emission parameters of a single cylinder compression ignition engine when algal oil methyl ester and its blends are used as a fuel in the ratio of 5, 10 and 20% without any modification in the existing experimental setup. The algal oil methyl ester is derived from *Spirulina* sp. and its properties are validated against ASTM standards and found within limits. The present study is focused on experimentally investigating the influence of injection timing with advancement, rated and retarded crank angle and load on combustion pressure, Rate of Heat Release (ROHR), Brake Specific Fuel Consumption (BSFC), Brake Thermal Efficiency (BTE), Unburned Hydrocarbon (UBHC), Carbon monoxide (CO), Oxides of Nitrogen (NO_x) and smoke. It has been observed that BSFC, UBHC, CO and smoke is reduced with advancement of injection timing of 5° from the original setting and combustion pressure, ROHR, BMEP and NO_x are increased. The retardment of injecting timing by 5° created a negative improvement of the above parameter. The best injection timing was found to be 340 crank angle degree with optimum performance, better combustion characteristics and minimal emission.

Key words: Algal oil, combustion pressure, biodiesel, heat release, injection timing

INTRODUCTION

Over few decades, the feasibility of using alternative fuels has gained more attention due to energy crisis in the year 1973 and 1978, fast depletion of fossil fuel and stringent environmental norms for emission. More researchers have reported the use of biodiesel in compression ignition engine as straight vegetable oil and blended with diesel. Among many alternative fuels, vegetable biodiesel has been identified as one of the most promising substitute for diesel fuel. The use of biodiesel also reduces the emission of carbon-di-oxide contributing in the reduction of effect. Biodiesel is a biodegradable, non toxic, oxygenated and renewable fuel which can be used in a CI engine with minor or no modifications (Hariram and Kumar, 2011; Azam *et al*., 2005). The biodiesel from vegetable also has certain drawbacks like, growth duration, oil separation and extraction which resulted in algal biodiesel. The lipid formation in the algal biomass is photosynthetic in nature. Significant contribution on algal biodiesel was give by more number of researchers because algae are fast growing they have potential to multiply their biomass within a short period of time and yield nearly more than ten times higher oil per heacter than conventional crops. Algae have greater capability in fixing atmospheric CO_2 and can be grown even in small area of land (Chaumont, 2005). Generally most algal oil constitutes of 15-22% of FFA content which can be removed by using acidic transesterification with 2% concentrated sulphuric acid. The literature survey has shown that using biodiesel reduces the emission of CO, UBHC, smoke and particulates with a marginal increase in NOx and brake specific fuel consumption (Agarwal, 2007). The physical and chemical property of algal oil methyl ester was found satisfactory against ASTM standards. The main aim of the present study is to analyze the feasibility of using AOME in compression ignition engine and examine the performance, combustion and emission parameters with respect to injection timing of the fuel with various loading conditions and blend ratios. A research engine Kirloskar DM10 equipped with performance and combustion pressure measurement. Various researchers have contributed by studying several parameters affecting the performance, combustion and emission

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Table 1: Properties of AOME in comparision with ASTM D6751 (Biodiesel) and ASTM D975 (Petro-deisel)

Property	Unit	AOME[a]	ASTM D975 Petro-diesel	ASTM D6751 biodiesel
Density at 40°C	g cm^{-3}	0.8712	0.834	0.86-0.90
Specific gravity at 40°C	g cm^{-3}	0.894	0.851	0.88
Flash point	°C	145	60-80	100-170
Kinematic viscosity	40°C, mm^2 sec^{-1}	5.76	1.91-4.1	1.9-6.0
Water content	%	0.04	0.02	<0.03
Ash content	%	0.02	0.01	<0.02
Carbon residue	%	0.03	0.17	-
Acid value	mg KOH g^{-1}	0.34	0.35	0.5
Sulphur content	%	0.042	0.5	0.05

[a]Algal oil methyl ester

parameters in which injection timing seems to be very significant (Crookes, 2006; Qi *et al*., 2011). The properties of AOME in comparison with straight diesel and ASTM standards are shown in Table 1.

This experimental investigation is focused on analyzing the influence of injection timing on engine performance, combustion characteristics and emission parameters on comparison between blends of AOME with straight diesel and the final result is arrived at optimum injection timing during which minimum emissions, maximum performance and better combustion is achieved.

MATERIALS AND METHODS

AOME production and its characterization: The algal culture stain of *Spirulina* sp. is obtained from NCIM, Pune. BG11 medium is used as a nutrient media for the algal growth which constitutes magnesium sulphate ($MgSO_4.7H_2O$, 0.2 g), dipotassium phosphate (K_2HPO_4, 0.2 g), calcium chloride ($CaCl_2.H_2O$, 0.1 g), boric acid (H_3BO_3, 286 mg), manganese chloride ($MnCl_2$. $4H_2O$, 181 mg), zinc sulphate ($ZnSO_4.7H_2O$, 22 mg), sodium molybdate ($Na_2MoO_4.2H_2O$, 39 mg) and copper sulphate ($CuSO_4.5H_2O$, 8 mg). It is mixed in 1000 mL of distilled water and boiled to 100 mL. The ethylenediamine tetra acetic acid solution is prepared by adding 745 mg of sodium EDTA and 557 mg of ferrous sulphate in 1 L of distilled water and boiled it 100 mL. Both the solutions are mixed thoroughly and are maintained at pH level of 7.5. The culture stain is allowed to grow till the cell count reaches 10^6 and transferred to an open pond system till 10^9 cell count. Later the algal biomass is harvested and dried. Hexane and ether solvents are added for oil separation followed by centrifugation process. Solvent expeller method is used for oil extraction (Demirbas, 2011). Transesterification process is carried out with 1% of sodium hydroxide and 20% of methanol by weight at 70°C. The mixture is kept in a rotating agitator for 8 h followed by separation of glycerol, washing and removal of excess water and impurities. The properties of AOME are determined at ITA lab, Chennai as given in Table 1 and 2.

The density and specific gravity of AOME and diesel used in study is found at 40°C which lied close to each other against the ASTM standards. The flash point of AOME is found to be 145°C which lies within the ASTM biodiesel standards. The kinematic viscosity at 40°C for AOME was found to be 5.67 mm^2 sec^{-1}. AOME was found to have slight higher water content than ASTM biodiesel standards. The cetane was found to be increasing with an increase in AOME in diesel while the calorific value of AOME was found to be decreasing with the addition of AOME (Heat of combustion for straight diesel is 42000 kJ kg^{-1} while AOME 20% has 40920 kJ kg^{-1} which is lesser. The flash point and boiling point also exhibits a decreasing trend with an increase in AOME blends. AOME is blended with straight diesel in the ratio of AOME 5%, AOME 10% and AOME 20% for this study.

Experimentation: The experiments was conducted using single cylinder, four stroke, air cooled Kirloskar DM10 diesel engine with a compression ratio 17.5:1 as shown in Table 3. The engine is loaded with AVLm 20 eddy current dynamometer. The measurement of air intake is carried out with an orifice meter. The specific fuel consumption is determined using AVL fuel meter and the fuel injection pump PE10A model is used. The cylinder pressure is measured using Kistler 5645A Model pressure sensor and the engine speed is measured using inductive speed pickup. Measurement of cylinder pressure and crank angle is stored in the data acquisition system. The cylinder combustion pressure and crank angle calculator was employed for amplifying the signals and connected to the data acquisition system. Crypton 2000 five gas analyzer is used to measure HC, CO and NOx. Bosch smoke meter is used to determine the smoke opacity. The data were transferred through the ethernet cable and stored in personal computer for further analysis.

The injection timing is varied using spill method in which an adaptive needle is used to determine the spill. A protractor with a resolution of 0.5° is placed on the front side of the engine and the recommended injection timing (25° BTDC) is marked. The fuel injection pump is fitted with a number of leaves for advancing and retarding the injection timing. A leaf with 0.321 mm thickness is added to retard the injection timing by 5°C and a leaf of 0.295 mm thickness is removed from the original setting for

Table 2: Properties of algal oil methyl ester blend with straight diesel

Fuel/Property	Cetane No.	Density ($g\ cm^{-3}$)	Boiling point (°C)	Flash point (°C)	Heat of combustion ($k\ J\ kg^{-1}$)
Straight diesel	45.00	0.8340	317.00	60-80	42000
AOME 5% (Diesel blend)	46.78	0.8214	268.75	62.25	41200
AOME 10% (Diesel blend)	47.10	0.8197	261.14	61.73	41005
AOME 20% (Diesel blend)	47.59	0.8168	254.32	60.49	40920

Table 3: Technical features of study engine setup

Parameters	Specification
Engine make and model	Kirloskar DM10
Number of cylinders	Single
Bore (mm)	102
Stroke (mm)	118
Capacity (cc)	984
Compression ratio	17.5:1
Maximum power (bhp)	10
Rated speed (RPM)	1500
Fuel pump	PE10A
Injector opening pressure (bar)	190-200
Injection timing	25°BTDC

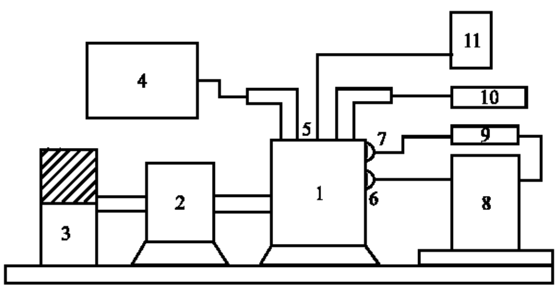

Fig. 1: Experimental setup; 1: Kirloskar test engine; 2: Eddy current dynamometer; 3: Dynamometer controller 4: Air filter for intake manifold; 5: Fuel injector; 6: Crank angle sensor; 7: Pressure transducer; 8: Cathode ray oscilloscope; 9: Charge amplifier; 10: Exhaust gas analyzer; 11: Fuel tank

advancing the injection timing by 5°C. The injection timing was checked manually after retarding and advancing of leafs in the FIP (Fig. 1).

Calculation of heat release: In this study, several assumptions are made to calculate Rate of Heat Release (ROHR) such as cylinder contains homogeneous mixture, uniform temperature and uniform pressure throughout the combustion process. At each crank angle ROHR is determined using Eq. 1:

$$Q = \frac{\gamma}{\gamma-1}(PdV) + \frac{1}{\gamma-1}(VdP) + Q_w \quad (1)$$

Where:

- Q = The rate of heat release (J)
- γ = Specific heats
- P = Cylinder pressure (bar)
- V = The instantaneous volume of the cylinder (m^3)
- Q_w = Heat transfer rate (J)

Table 4: Details of uncertainty of measured parameters

Measurements	Percentage of uncertainty
Speed	±0.11
Load	±0.45
Mass flow rate of air	±0.60
Mass flow rate of fuel	±0.71
Brake power	±0.23
Brake thermal efficiency	±0.21
NOx	±0.90
HC	±0.12
CO	±0.82
Smoke	±1.90

Table 5: Uncertainty and accuracy range of instruments

Instruments	Range	Accuracy	Percentage of uncertainty
Speed measurement	0-10000 rpm	+10 to -10 rpm	±0.09
Exhaust gas measurement	0-900°C	+1°C to -1°C	±0.15
Smoke measurement	BSU 0-10	+0.1 to -0.1	±0.85
Stop watch	-	+0.4 sec to -0.4 sec	±0.15
Pressure transducer	0-110 bar	+0.1 kg to -0.1 kg	±0.11

The cylinder wall temperature is assumed to be 723 K. For calculating the rate of heat release, the cylinder pressure data was acquired for every 0.364°CA upto 150 cycles. The averaged pressure value of 150 cycles is used in this study (Brunt *et al.*, 1998; Gumus, 2010).

Estimation of uncertainty: The uncertainty analysis is essential to prove the accuracy of the experiment. The uncertainty can arise from selection of instruments, test conditions, calibration and observations (Ramadhas *et al.*, 2005). In this study, gaussion distribution method is used to estimate uncertainty with a confidence limit of +2σ 97% of the measured data lie within limits as in Eq. 2. The uncertainty of instruments used and measured parameters are shown in Table 4 and 5. The overall uncertainty of the experiment is estimated to be ±1.12% from the Table 3-5:

$$\Delta R = \sqrt{\left[\left(\frac{\partial R}{\partial X_1}\Delta X_1\right)^2 + \left(\frac{\partial R}{\partial X_2}\Delta X_2\right) + \ldots\left(\frac{\partial R}{\partial X_n}\Delta X_n\right)^2\right]} \quad (2)$$

RESULTS AND DISCUSSION

Variation of combustion pressure and rate of heat release: From the Fig. 2, it can be noticed that the static injection timing plays a vital role in affecting the in

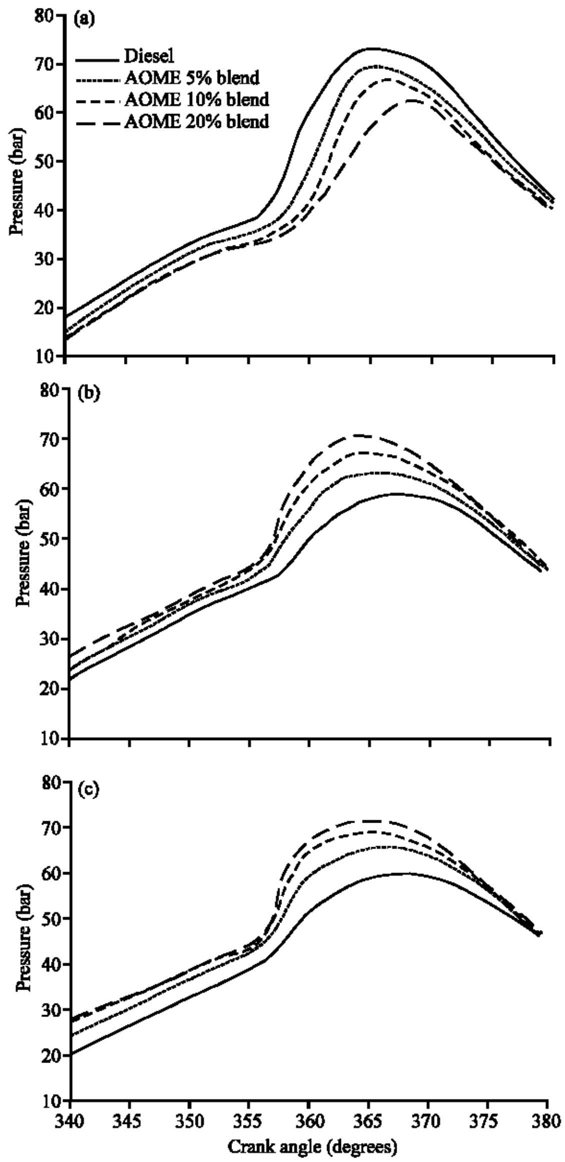

Fig. 2: Comparison of In cylinder pressure for diesel, AOME 5, 10 and 20% at 340; a) 345 b) 350 and c) CAD injection timing

cylinder pressure at all loads for all blends of AOME under different operating condition. In case of diesel fuel at standard injection timing, the start of combustion occurs at a predetermined stage but for AOME 20% blend, at the same injection timing, the start of combustion occurs slightly earlier when compared with diesel fuel Fig. 2b. This is due to the increase in cetane number at increased AOME blends which causes ignition delay to shorten. On advancing the injection timing, the start of combustion occurs very earlier than the rated crank angle and the pressure curve takes the near vertical path towards the peak than the rated pressure Fig. 2a. This is due to the premixed combustion phase advancement and start of combustion takes place mush before. At this stage, the ignition delay is long. When the injection timing is retarded, it makes the premixed combustion phase much longer than the predetermined crank angle and results in shorter ignition delay (Heywood, 1989). In this case the pressure curve shows gradual increase in pressure. At retardment of injection timing, the fuel is injected mush close to start of ignition which leads to excess quantity of fuel injected during the delay period. This results in poor atomization, low temperature development and more heat loss due to latent heat of vaporization Fig. 2c.

Figure 3 shows the comparison of heat release rate at advanced, rated and retarded injection timing. It is seen that at factory set injection timing (345 CAD), the heat release of AOME blends are higher than diesel. It is also seen that at all loading conditions, HRR of AOME is higher than that of diesel at 345 CAD injection timing Fig. 3b. During advanced injection timing (340 CAD), it is noticed that rate of heat release for diesel is higher than all blends of AOME but still higher than rated injection timing Fig. 3a. This may be due to reduction in the calorific value of the fuel as the blend of AOME with diesel is increased. At 8 Nm, the HRR of diesel is 92 kJ/CAD where as for AOME 5%, AOME 10% and AOME 20% is 90, 89 and 87 kJ/CAD, respectively.

The increase in heat release rate than the rated injection timing may be also due to reduction in ignition delay period which in turn reduces the effect of premixed combustion phase of AOME blends. During this period, the HRR of diesel is higher than AOME blends because ignition delay period is longer due to more accumulation of fuel before combustion. At 8 Nm load, maximum heat release occurs much earlier for AOME blends because of shorter ignition delay. The ROHR for diesel and AOME blends at retarded injection timing (350 CAD) is shown in Fig. 3c. The heat release rates of AOME blends are higher than diesel at any loading condition at retarded injection timing. The ROHR for diesel (50 kJ/CAD) is less that all blends of AOME which may be due to reduced ignition delay. All the AOME blends show a similar trend of lower ROHR when compared with rated and advanced injection timing at rated speed and all loading condition. This also may be due to reduced ignition delay and less premixed combustion phase (Sahoo and Das, 2009; Laforgia and Ardito, 1995).

Variation of brake specific fuel consumption and brake thermal efficiency: Comparison of BSFC and BMEP for diesel and different blends of AOME at rated injection

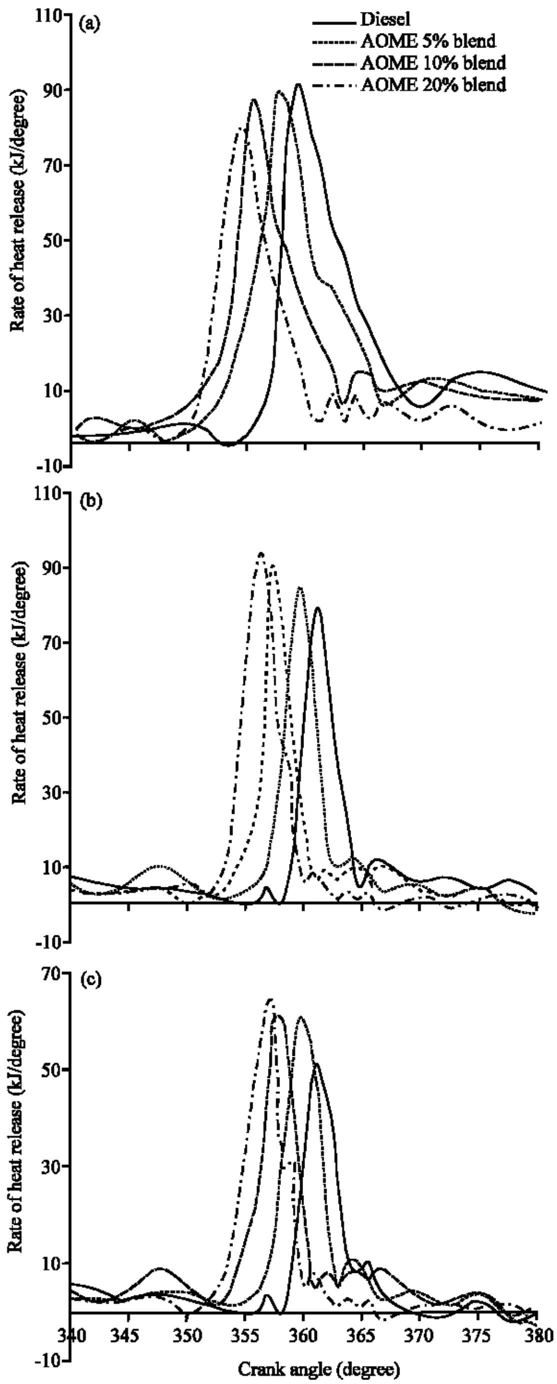

Fig. 3: Comparison of heat release rate for diesel, AOME 5,10 and 20% at; a) 340 b) 345 and c) 350 CAD injection timing

timing (345 CAD) is shown in Fig. 4b. It can be seen that there is a gradual decrease in BSFC on rated injection timing. The trend of AOME blend also follows a similar pattern as the load increases. At advanced injection

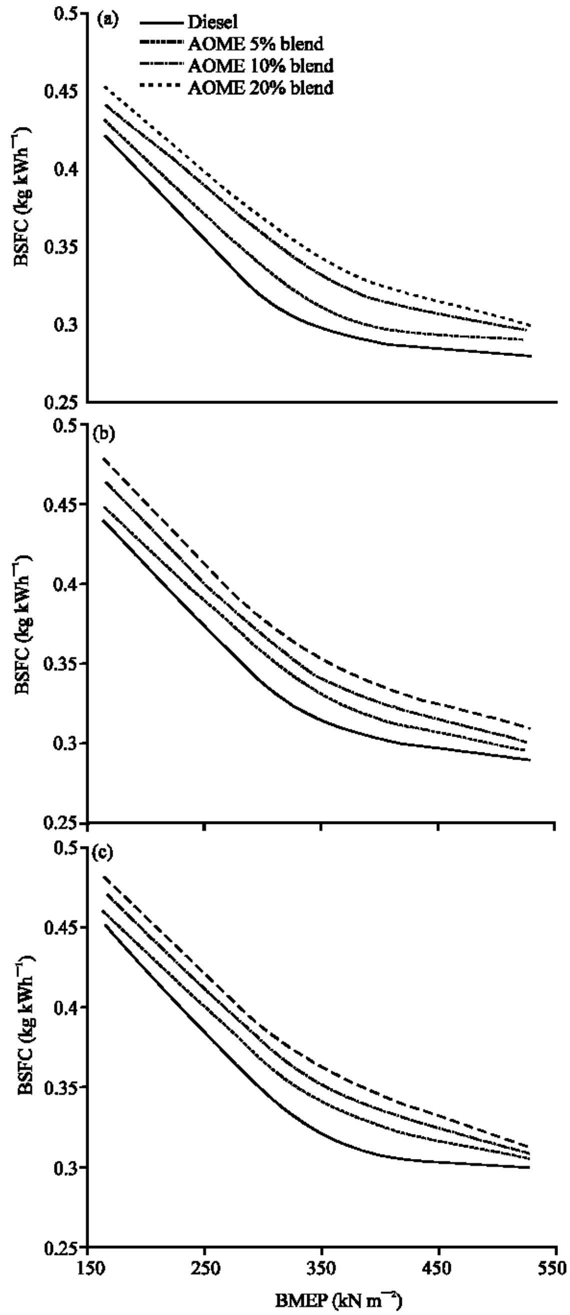

Fig. 4: Comparison of BSFC for diesel, AOME 5, 10 and 20% at; a) 340 b) 345 and c) 350 CAD injection timing

timing, the BSFC of AOME blends are higher than diesel as shown in Fig. 4a with a slight lower value than the rated injection timing. During retarded injection timing (350 CAD), the BSFC for diesel and all blends of AOME shows a higher value when compared with rated and advanced injection timing and reaches a minimum of

0.3 g kW h^{-1} at high loads Fig. 4c. Generally, all injection timing (340-350 CAD), the BSFC for diesel is lower than all blends of AOME at all loading conditions. From this study, the optimum injection timing for diesel and blends of AOME is observed at advanced injection timing (340 CAD) with better efficiency and operating condition which is also reported in the previous studies (Lin *et al.*, 2009).

Figure 5 shows the effect of injection timing on brake thermal efficiency at all loading condition for compression engine running on diesel and AOME blends. At rated injection timing (345 CAD), the BTE of diesel was found to be maximum of 31% at all loads while AOME blends was seen at 30.2-29% al all loading conditions. In general, at any injection timing and loading condition, the BTE of diesel lies higher than all blends of AOME. This may be due to higher viscosity and gradual reduction in calorific value of AOME blends which results in improper combustion and poor atomization characteristics. During advanced injection timing (340 CAD), the AOME blends show higher BTE (33.5%) 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. During retarded injection timing (350 CAD), the BTE is reduced by 3-4% because of smaller ignition delay and poor atomization of fuel. In general, the BTE is determined by duration of start of combustion. During advanced injection timing, the combustion is started earlier than the predetermined timing and result in higher BTE and during retarded injection timing, the combustion is started after the predetermined timing resulting in lower BTE. The optimum efficiency is observed at rated timing (345 CAD) and maximum BTE is seen at 340 CAD for diesel and all blends of AOME.

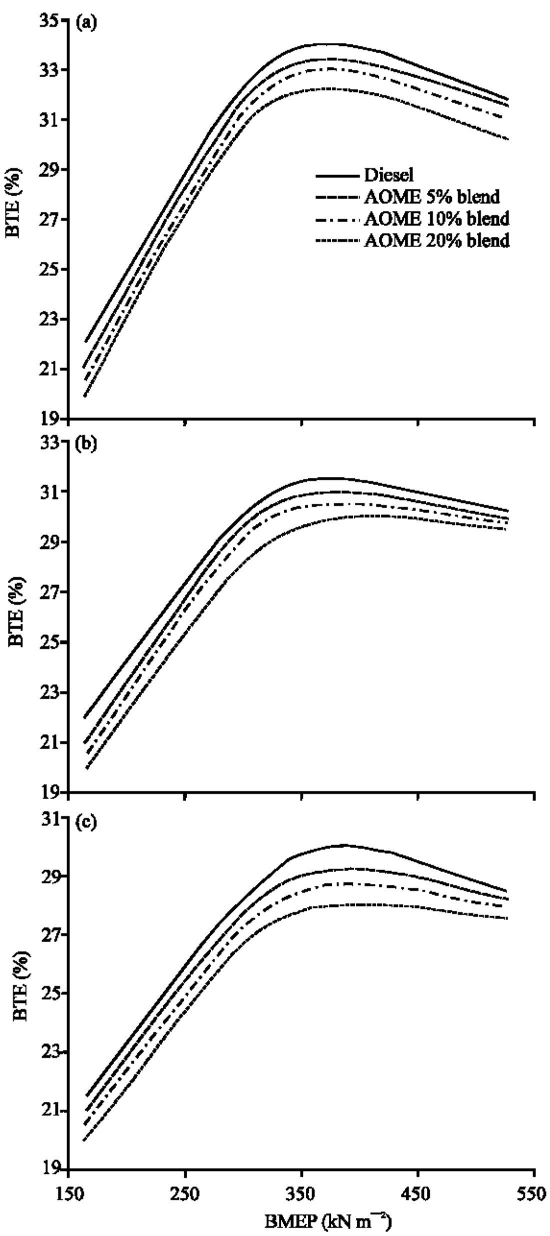

Fig. 5: Comparison of BTE for diesel, AOME 5, 10 and 20% at; a) 340 b) 345 and c) 350 CAD injection timing

Vaiation of unburned hydrocarbon: Figure 6 shows the variation of UBHC for diesel and AOME blends at all loads during various injection timing (340, 345 and 350 CAD). The UBHC emission for diesel is higher than all blends of AOME all loads at various injection timing. During rated injection timing (345 CAD) at 1500 rpm. HC emission for diesel shows a significant reduction which may be due to longer ignition delay during which more oxygen is available for complete combustion than the rated injection timing and better ignition quality. However, the HC emission for diesel is higher than AOME blends at all loads. At 345 CAD, HC emission for diesel at full load is noted as 0.29 g kW h^{-1} which are higher than advanced injection timing. This may be due to relatively short combustion duration than advanced injection. Figure 6c shows HC emission during retarded injection timing in which HC emission is extremely higher which may be due to shorter ignition delay, lesser availability of oxygen for combustion, poor combustion and poor atomization of fuel (Sybist *et al.*, 2007). In general, diesel shows higher HC emission than all blends of AOME at all loads and sminimum HC emission is observed during part load at all injection timing. Advanced injection timing (340 CAD) was observed as the optimum condition for HC emission at all loads.

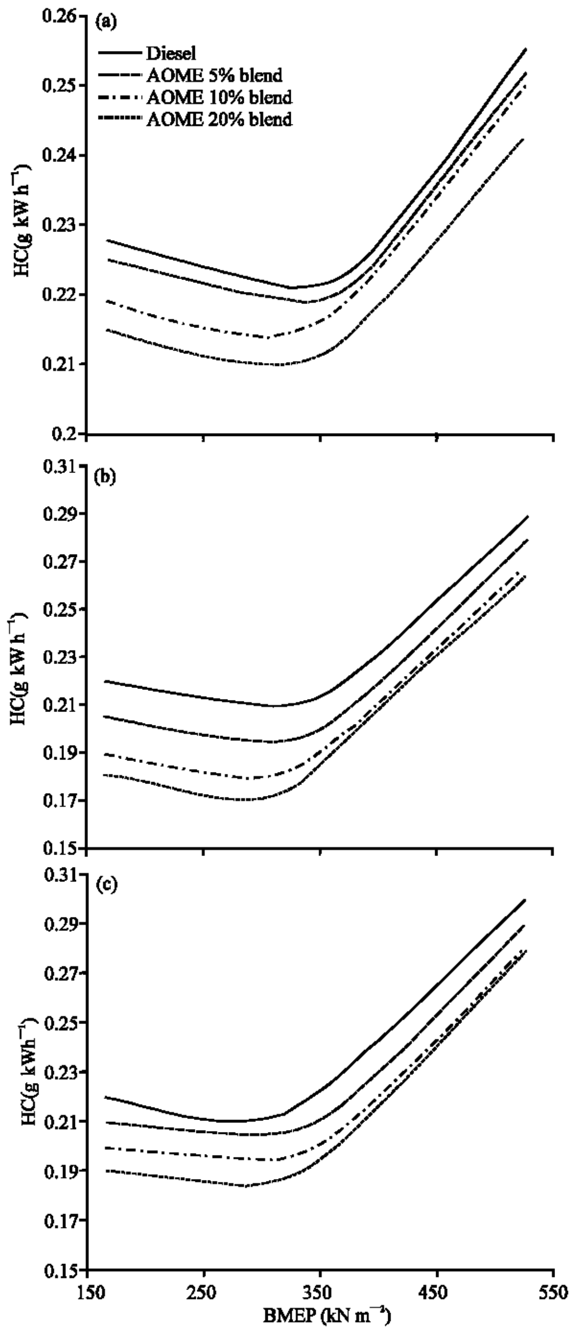

Fig. 6: Comparison of HC emission for diesel, AOME 5, 10 and 20% at; a) 340 b) 345 and c) 350) CAD injection timing

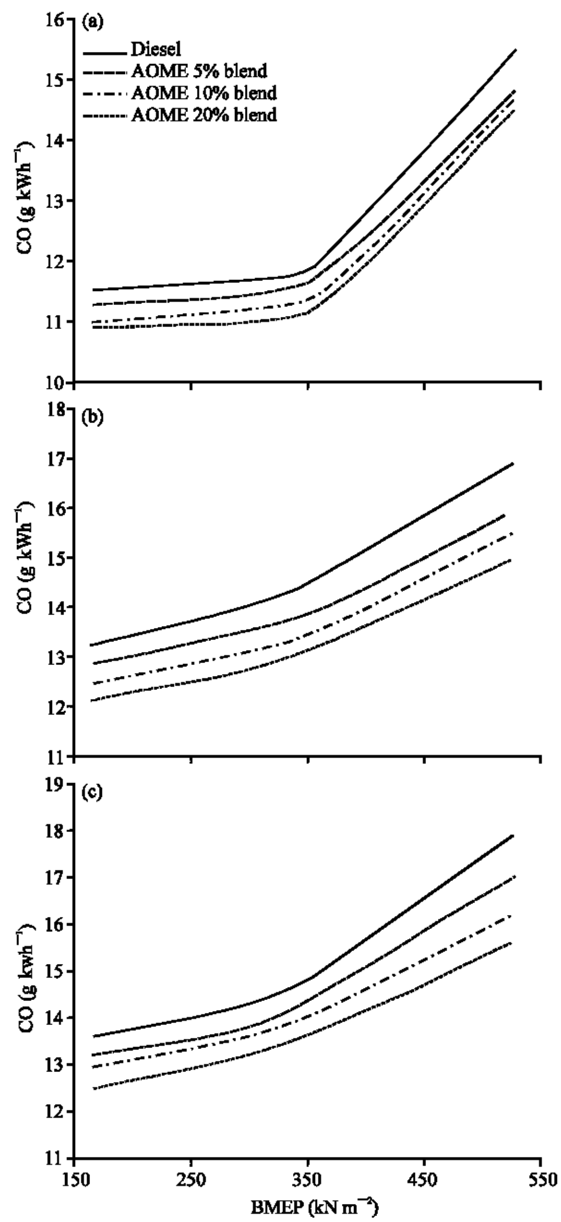

Fig. 7: Comparison of CO emission for diesel, AOME 5, 10 and 20% at; a) 340 b) 345 and c) 350) CAD injection timing

Variation of carbon monoxide: The influence of injection timing on CO emission at all loads for diesel and all blends of AOME is shown in Fig. 7. CO emission is generally higher in diesel when compared with AOME blends at all that CO emission is less at 340 CAD which may be due to loads. Ignition timing have marginal effect on CO emission during rated timing (345 CAD) and retarded timing (350 CAD) but significantly affects at advanced injection timing (340 CAD). From the Fig. 7a, it can be observed prolonged ignition delay during which more oxygen is available for the conversion of monatomic oxygen into carbon dioxide. At higher loads, CO emission is gradually reduced because better combustion is initiated due to increase in engine working temperature. During the rated injection timing (345 CAD) CO emission shows marginal increase upto 2.5% than advanced injection timing at all

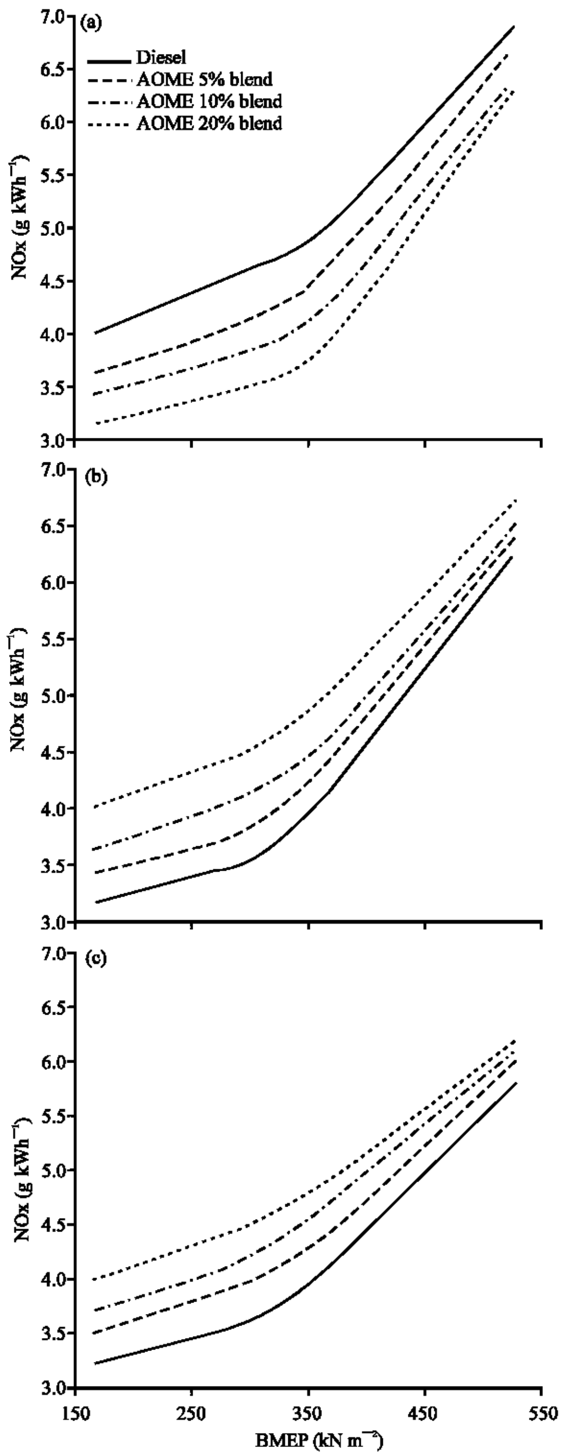

Fig. 8: Comparison of NOx emission for diesel, AOME 5, 10 and 20% at; a) 340 b) 345 and c) 350 CAD injection timing

loads and AOME blends. Retarded injection timing (350 CAD) emits more CO because ignition delay is very short the time duration for conversion of CO into CO_2 is very small and ultimately results in incomplete combustion. However, CO emission is observed as an increasing trend because of increase in load for diesel and all AOME blends.

Variation of oxides of nitrogen: Generally, when the injection timing is advanced, NO emission is increased and when injection timing is retarded, NO emission is reduced. Figure 8a shows an increasing trend of NO for diesel and AOME blends at advanced injection timing (340 CAD) which may be due to enhanced combustion in the premixed combustion phase during prolonged ignition delay and overall increase in combustion temperature. At 340 CAD injection timing, diesel shows higher NO emission than AOME blends and reduces as the AOME blend increases. During rated injection timing (345 CAD) NO emission was higher in AOME blends than in diesel as shown in Fig. 8b because of the presence of more oxygen, better mixing ofair and fuel in the premixed combustion phase and high combustion chamber temperature caused by improved combustion. It is observed that AOME 20% blend emits 6.5 g kW h^{-1} of NO mainly at full load conditions. Figure 8c shows retarded injection timing (350 CAD) which also exhibits similar trend of NO emission as the rated injection timing but 2.5-3.4% less than the rated timing. This may be due to shorter ignition delay, less warm up time and less calorific value as the AOME blends are increases. It is also reported in the literature that NO emission is increased with advanced injection timing and diesel emits more NO than AOME blends with increasing loads (Stergar and Chastain, 2009; Haik *et al.*, 2011).

Variation of smoke emission: Generally, smoke emission shows an increasing trend with all injection timing all loads and all blends of AOME. Figure 9 shows the effect of smoke density due to advanced injection timing at all loads for diesel and AOME blends. During advanced injection timing (340 CAD) the smoke density for diesel and AOME blends gradually increases as the load increases. During low load and part load, smoke density is lower because of longer ignition delay and more oxygen presence 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 density is comparatively increased which is also reported in literature. During retarded injection timing, the ignition delay is shorter results in increase of smoke density which may be also due to late injection, prolonged diffusive combustion phase, poor atomization, improper mixing of air and fuel. Especially during high load

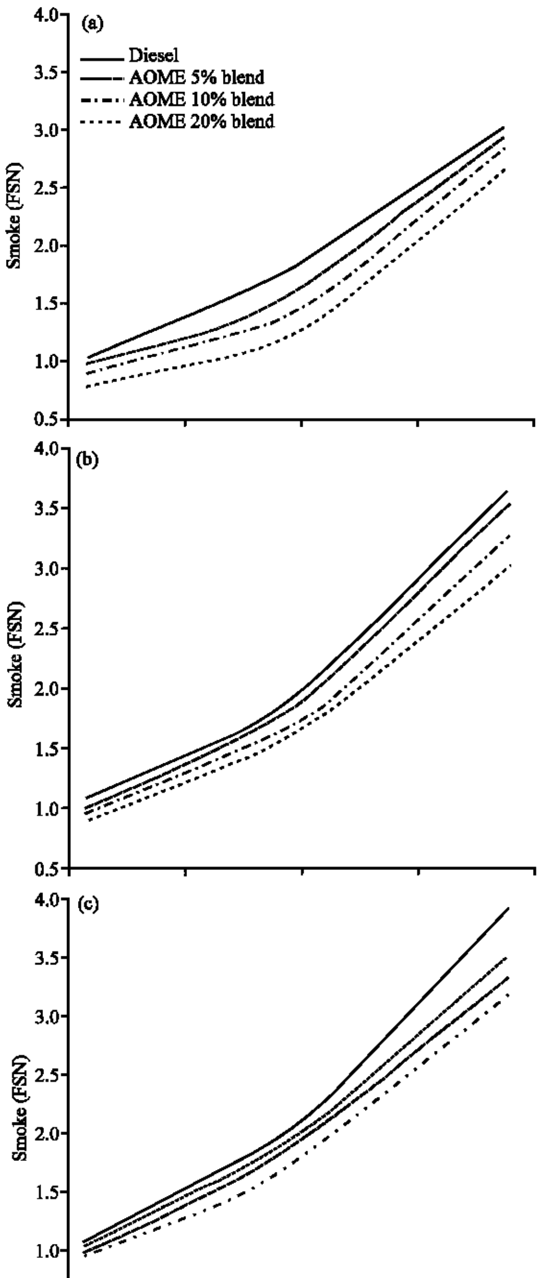

Fig. 9: Comparison of smoke emission for diesel, AOME 5, 10 and 20% at; a) 340 b) 345 and c) 350 CAD injection timing

condition, smoke density is very high for diesel and AOME blends because of higher fuel injection, more rich mixture, shorter ignition delay and poor mixing (Purushothaman and Nagarajan, 2009; Sayin *et al.*, 2009). Generally, it is observed that AOME blends emit less smoke than diesel at all loads and at all injection timing.

CONCLUSION

The effect of injection timing on engine performance, combustion and emission has been investigated carefully with advanced (340 CAD), rated (345 CAD) and retarded (350 CAD) injection timing on diesel and AOME blends and found to have very significant effect on all the parameters. Advanced injection timing (340 CAD) exhibits significant reduction in brake specific fuel consumption, unburned hydrocarbon, carbon monoxide and smoke and increases combustion pressure, rate of heat release, brake mean effective pressure and oxides of nitrogen. Retarding injection timing shows and increase in BSFC, HC, CO and smoke with marginal improvement in combustion pressure, ROHR, BMEP and NOx emission. It is also noted that advancement of injection timing improves diesel fuel combustion and emits more NOx than AOME blends. The optimum injection timing for AOME blends is found to be 340 CAD which evident better combustion and performance with minimal emission. The investigation finally proves that performance, combustion and emission parameters can be optimized by advancing the fuel injection timing with AOME blends as fuel.

REFERENCES

Agarwal, A.K., 2007. Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines. Prog. Energy Combust. Sci., 33: 233-271.

Azam, M.M., A. Waris and N.M. Nahar, 2005. Propects and potentials of fatty acid methyl ester of some non-traditional seed oil for use as biodiesel in India. Biomass Bioenergy, 29: 293-302.

Brunt, M.F.J., H. Rai and A.L. Emtage, 1998. The calculation of heat release energy from engine cylinder pressure data. SAE Technical Paper No. 981052, University of Central England.

Chaumont, D., 2005. Biotechnology of algal biomass production: A review of systems for outdoor mass culture. J. Applied Phycol., 5: 593-604.

Crookes, R.J., 2006. Comparative bio-fuel performance in internal combustion engines. Biomass Bioenergy, 30: 461-468.

Demirbas, M.F., 2011. Biofuels from algae for sustainable development. Applied Energy, 88: 3473-3480.

Gumus, M., 2010. A comprehensive experimental investigation of combustion and heat release characteristics of a biodiesel (hazelnut kernel oil methyl ester) fueled direct injection compression ignition engine. Fuel, 89: 2802-2814.

Haik, Y., M.Y.E. Selim and T. Abdulrehman, 2011. Combustion of algae oil methyl ester in an indirect injection diesel engine. Energy, 36: 1827-1835.

Hariram, V. and G.M. Kumar, 2011. Experimental investigation of algal oil diesel blends on combustion process and emission parameters in a single cylinder diesel engine. Ciit Int. J. Automat. Autonomous Syst., 3: 43-47.

Heywood, J.B., 1989. Internal Combustion Engine Fundamental. 2nd Edn., McGraw Hill, New York, USA.

Laforgia, D. and V. Ardito, 1995. Biodiesel fueled IDI engines: Performances, emissions and heat release investigation. Bioresour. Technol., 51: 53-59.

Lin, B.F., J.H. Huang and D.Y. Huang, 2009. Experimental study of the effects of vegetable oil methyl ester on DI diesel engine performance characteristics and pollutant emissions. Fuel, 88: 1779-1785.

Purushothaman, K. and G. Nagarajan, 2009. Effect of injection pressure on heat release rate and emissions in CI engine using orange skin powder diesel solution. Energy Conversion Manage., 50: 962-969.

Qi, D., M. Leick, Y. Liu and C.F.F. Lee, 2011. Effect of EGR and injection timing on combustion and emission characteristics of split injection strategy DI-diesel engine fueled with biodiesel. Fuel, 90: 1884-1891.

Ramadhas, A.S., C. Muraleedharan and S. Jayaraj, 2005. Performance and emission evaluation of a diesel engine fueled with methyl esters of rubber seed oil. Renewable Energy, 30: 1789-1800.

Sahoo, P.K. and L.M. Das, 2009. Combustion analysis of Jatropha, Karanja and Polanga based biodiesel as fuel in a diesel engine. Fuel, 88: 994-999.

Sayin, C., M. Ilhan, M. Canakci and M. Gumus, 2009. Effect of injection timing on the exhaust emissions of a diesel engine using diesel-methanol blends. Renewable Energy, 34: 1261-1269.

Stergar, J.P. and J.P. Chastain, 2009. Engine performance and emission characteristics when using biodiesel in diesel engine. Am. Soc. Agric. Biol. Eng., 3: 349-358.

Sybist, J.P., J. Song, M. Alam and A.L. Boehaman, 2007. Biodiesel combustion, emission and emission control. Fuel Process. Technol., 88: 679-691.