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Experimental and Analytical studies on Combustion parameters in DI CI engine fuelled with emulsified blends of Canola biodiesel

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ABSTRACT

Biodiesel is found to be one of the major alternative sources for conventional petro-diesel in today's world. The possibilities of using emulsified straight diesel-biodiesel-ethanol blended fuel is experimentally analysed in this article. Ternary analysis has been conducted with 66 samples of emulsified fuels at different ratios which aimed at increasing the oxygen content and as fuel extender, in the absence of co-surfactant which affect the combustion performance and stability index indicate D30-CBD30-E40 and D40-CBD40-E20 to be stable and found to have enhanced properties for using in Compression Ignition Engine. Combustion analysis which includes in-cylinder pressure, net heat release rate and rate of pressure rise were analysed experimentally and validated theoretically using zero-dimensional thermodynamic model simulated using MATLAB which supports the experimental results with the deviation of 8-9% and 1º crank angle shift.D30-CBD30-E40 emulsified blend exhibited better combustible properties on comparison with D40-CBD40-E20due to enhanced micro explosion of ethanol and comparable calorific value.

KEY WORDS: Biodiesel, Combustion, Net heat release, Zero dimensional model, Ternary analysis.

1. INTRODUCTION

Based on survey conducted by International Energy Agency in 2013, the average global energy consumption was around 18TW. The amount is large so that conventional fossil fuels are not sufficient to fulfil the energy demands in current scenario of world starving for energy. From then two major resources oil and natural gas are considered as a key to fulfil future energy demands as the fossil fuels have started to deplete. On the other side the worst environmental scenario has forced the scientists and engineers to find an alternative source that can bridge the gap between energy production and energy consumption without disturbing the current ecosystem and environment. In such cases, vegetable oils have given a promising hope to satisfy the needs without affecting the surroundings. Biofuels can be extracted from Transesterification of vegetable oils that can be directly used in compression ignition engines that are considered as best choice in the energy industry, automobiles and agriculture industries.

Simulation means replica of real world process or a system to study the characteristics of the system without its physical intervention. It all requires a model that comprises set of mathematical equation that are capable of defining the entire system. Development in the field of computers have proved the possibility and ease of solving more complex equations within a matter of seconds. In case of Compression Ignition engines considering it as a closed system during the reign of combustion few models are developed based on thermodynamics that are self-sufficient to predict the combustion characteristics of engine.

In the current study investigation on highly stable and better emulsified blends D30-CBD30-E40 and D40-CBD40-E20 were taken for experimentation. Optimization of physio-chemical properties of blends were carried out separately to obtain the better combustion results. Experimental analysis were carried out to determine combustion parameters such as In-cylinder pressure, Net Heat Release rate and Rate of Pressure Rise and compared between straight diesel, D30-CBD30-E40 and D40-CBD40-E20. The results obtained were compared with simulated results of zero dimensional thermodynamic model of multizone.

2. MATERIAL AND METHODS

Canola Biodiesel Production: Canola seeds collected from local farming agency in Chennai and was cleaned thoroughly in running water to remove traces of dust and sand muds. Sanitization of seed was followed by dehumidification under direct sunlight for 60 – 90 hours to make it viable for crushing into fine grain particle. Fine grained Seeds were subjected to oil extraction through soxhlet extraction procedure in the presence of n-hexane as reaction medium, process was optimised to reach 98.2% oil extraction efficiency at 68ºC Reaction temperature and 150 minutes reaction time period. Oil extraction was followed by settling process in which oil was kept undisturbed for about 7 -14 hours to separate suspended particles, which has significant effect on biodiesel conversion efficiency. Post biodiesel production was carried out, based on single stage base catalysed Trans-esterification process. Here canola oil was heated in separate heating mantle up to 78ºC for 20 minutes to carryout efficient Trans-esterification. Process results with 92% biodiesel conversion efficiency in the presence of methanol and KoH at 65ºC to 75ºC operation temperature and 120 minutes operation duration with molar ratio of 1:6 and catalyst concentration of 2.8%. Gas Chromatography coupled with Mass Spectroscopy analysis was experimented on biodiesel obtained, in which presence of 7 major Fatty Acid Methyl Esters as primitive composition for any biodiesel was found here such as, Lauric acid, Myristic acid, Palmitoleic acid, Pentadecylic acid, Linoleic acid, Oleic acid, Arachidic acid and Behenic acid (Hariram, 2015).

Ternary analysis: Fuel modification was carried out in biodiesel obtained by blending with anhydrous ethanol and straight biodiesel. Characterization of fuel blending was carried out in order to obtain optimized performance and combustion without any complex engine modification.

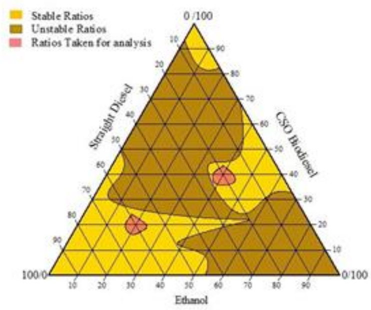

Figure.1.Ternary analysis of Straight diesel – Canola Biodiesel - Ethanol

Here ternary analysis (i.e. fuel blending) was carried out between straight diesel-canola seed oil biodiesel-anhydrous ethanol with varying ratios between 0 to 100% (Cumulative composition of all the three fuel taken for blending).Characteristic ternary blends were obtained in the absence of any co-surfactants in-order to achieve wide susceptibility and miscibility of fuels, on the other hand absence co-surfactant efficiently results in optimised combustion of blend and lower suspended particles content. Homogeneous mixture of ternary blend was obtained on volumetric basis of fuels employed. Mixing of fuels was carried out using magnetic stirrer for 130-150 seconds, followed by 72 – 96 hours observation period at varying temperature between 26ºC to 34ºC. Resulting homogenous ternary blend seems to highly stable for following ratios such as D30-CBD30-E40 and D40-CBD40-E20 as shown in figure no 1. Above ratios were selected based on their characteristics of single/homogeneous behaviour, physical appearance and blend stability. Finally, blends obtained were subjected to repeatability to standardize the ternary blend obtained (Leahey, 2007).

Table 1. Comparison of test fuel properties

Properties	Straight Diesel	Canola Biodiesel	D30-CBD 30-E40	D40-CBD 40-E20
Density(Kg/m^3)	860	868	832	845
Viscosity(Cst)	3.1	4.12	2.6	2.9
Calorific Value(MJ/kg)	45.5	34.3	33.04	36.47
Cetane Number	52	61	37	46
Flash point(^{0}C)	49	98	42	61
Pour point(^{0}C)	-2	-9	-15	-10
Cloud point(^{0}C)	0	-3	-11	-6
Acid value (mg/ KOH/g)	0.1	0.016	-	-
Saponification value	-	165	50	66
Iodine value	-	89	27	36

Table (1) shows the Physio-chemical property comparison of straight diesel, canola biodiesel with emulsified test fuels D30-CBD30-E40 and D40-CBD40-E20. It shows that calorific value of diesel as 45.5 MJ/Kg whereas canola biodiesel has 34.3 MJ/Kg and emulsified fuels D30-CBD30-E40 and D40-CBD40-E20 as 33.04 MJ/Kg, 36.47 MJ/Kg respectively. The Cetane number of canola biodiesel is found as 61 slightly higher than diesel as 52 on comparing with test fuels D30-CBD30-E40 as 37, which is lesser due to higher ethanol concentration when compared withD40-CBD40-E20 as 46. It can be found that D30-CBD30-E40 has density lower than any as 832 Kg/m^3 whereas D40-CBD40-E20, canola biodiesel and diesel as 845 Kg/m^{3,} 868 Kg/m^3 and 860 Kg/m^3 respectively. On seeing the flash point canola biodiesel has very high of 98 since it is straight biodiesel whereas D30-CBD30-E40 is found to be lowest, straight diesel and D40-CBD40-E20 lies between other two as 52 and 46 respectively. From the above discussion it is concluded that canola biodiesel possess higher values when compared with straight diesel, on the other hand emulsification of canola biodiesel to D30-CBD30-E40 and D40-CBD40-E20 optimizes the Physio-chemical property and seems to have comparably equivalent.

Experimental methods: The experimental investigation of combustion analysis on canola biodiesel blends was carried out with the aid of single cylinder, four stroke compression ignition engine. Table 2 shows the engine specification. It is measured to have 110mm stroke, 87.5 mm bore with cubic capacity of 661cc. It delivers the power of 3.5 KW at 1500 rpm with-in 12-18 CR range in diesel fuel mode. Load tests on engine was carried out using water cooled, eddy current dynamometer, which was powered by load sensor and RPM sensor having a capacity to apply the load range of 0-12 Kg. Various features powered with engine to quantify the metadata's are piezoelectric sensors PZ1 and PZ2 to analyse airflow into the chamber and swirl flow of the A/F mixture inside the chamber, these PZ sensors can measure up to 350 bar. Crank angle adjustments and Injection timing adjustments were installed conjointly to vary the CR and IT for varying load condition. Also, air and fuel flow to the combustion chamber was measured with accuracy up to 500mm WC, 250mm WC respectively. Temperature measurements were carried out at six different catastrophic regions with RTD type sensor such as T_1 and T_3 at Rotameter, T_6 at gas analyser, T_4 and T_5 at calorimeter, T_2 at engine compartment. Here data acquisition system is computerized with the help of NI USB-6210, 16 bit system with capacity up to 250Ks/s data transfer speed. It helps to collect the various signals interpreted by various sensors with the whole system such as Flow signal (A&F mixture flow), Pressure Signal (Pressure variation inside the combustion chamber), Temperature Signals (from all 6 temperature sensors), Load signals (From dynamometer load sensor) and rpm signal (from dynamometer rpm sensor). Engine soft – engine performance analysis software is used to analyse and interpret the data's collected to graphically visualize the P-Ө curve, Net heat release rate and rate of pressure rise of the combustion process. Figure 2 depicts the layout of complete engine setup and process flow.

Table.2. Specification of test engine

Engine Specification	
Make & Model	Kirloskar 240 PE
Number of Cylinder	1
Number of stroke	4
Cooling system	Water cooled
Stroke (mm)	110
Bore (mm)	87.5
Capacity(cc)	661
Power (KW)	3.5
Speed(rpm)	1500
CR Range	12-18
Injection Variation	0-25˚ BTDC

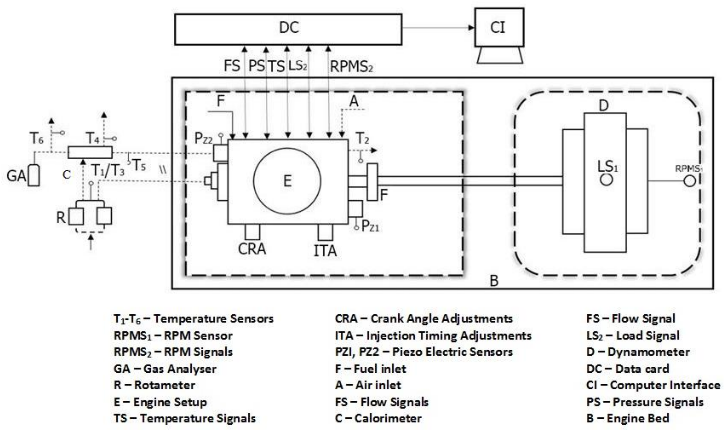

Figure.2. Experimental setup

Empirical modelling: Mathematical modelling of direct injection compression ignition engine has been carried out with the aid of zero dimensional thermodynamic model which can predict the In-cylinder Pressure, Net Heat Release and Rate of Pressure Rise for every 1º crank angle intervals. The thermodynamic model is also coupled with engine kinematic model for calculating the volume at every crank angle considering the piston cylinder arrangement as slide-crank mechanism. Additionally models that can predict heat release rate, ignition delay and gas dynamic model to simulate intake and exhaust flows are considered in order to get better accuracy in the results. The mathematical models are then coded using MATLAB/C Software and result validation are carried out using experimental data obtained (Rakopoulos, 2004; Ferguson, 1986).

Geometric modelling: Considering the piston cylinder arrangement as slide crank mechanism as shown in fig. the volume at particular crank angle can be obtained by,

$$V(\theta) = \frac{\pi}{4} B^2 S \left[\frac{r}{r-1} \cdot \frac{1-\cos 2\theta}{2} + \sqrt[\frac{1}{2}]{\left(2 \cdot \frac{l}{s}\right)^2 - \sin\theta} \right] \quad (1)$$

Where,

B=Bore diameter in mm
s=Stroke Length in mm
r =Compression ratio
l=Length of connecting rod

Combustion modelling: During period of combustion the engine is considered as closed system since there is no mass transferred between systems and surrounding, since the energy transfer out of the system in the form of pdV work which forces the piston from Top dead centre to Bottom dead centre. From First law of thermodynamics. The energy equation for non-flow closed system is given by (Rakopoulos, 2007),

$$\frac{dQ_g}{d\theta} - \frac{dQ_l}{d\theta} = \frac{dv}{d\theta} + P\frac{dv}{d\theta} \quad (2)$$

$$\frac{dQ_n}{d\theta} = \frac{dv}{d\theta} + p\frac{dv}{d\theta} \quad (3)$$

$$\frac{dQ_n}{d\theta} = mC_v\frac{dT}{d\theta} + p\frac{dV}{d\theta} \quad (4)$$

Where,

Q_n- Net Heat in J/KgK
Q_g – Heat generated by fuel in J/Kg
Q_l – Heat loss to the surrounding in J
m- Mass of Fuel in Kg
C_v- Specific heat at constant volume
P- Pressure in bar
$\frac{dv}{d\theta}$- Change in volume mm^3

Heat release at particular crank angle is obtained by,

$$\frac{dQ_n}{d\theta} = 6.908 \times (m+1)\left(\frac{Q_{av}}{d\theta}\right)\left(\frac{\theta-\theta_0}{\theta}\right)^m exp\left[-6.908\left(\frac{\theta-\theta_0}{D\theta}\right)^{m+1}\right] \quad (5)$$

Where,

Q_{av}-Average heat release rate.
m is factor depending upon the combustion assumed between 3-10 for CI engine.

3. RESULTS AND DISCUSSIONS

The results for in-cylinder pressure increase and net heat release rate and rate of pressure rise are discussed with straight diesel, D30-CBD30-E40 and D40-CBD40-E20. As fuels at low load, part load and full load conditions. The blend ratios of diesel, canola biodiesel and ethanol were investigated using ternary analysis in which the emulsification process showed better results. In the above blend ratios with 72-96 observation period.

Variation in In-cylinder pressure: The Figure (3A) shows the comparison of experimental and simulation results of in-cylinder pressure rise for straight diesel and emulsified fuelsD30-CBD30-E40, D40-CBD40-E20 at low load condition. Emulsified blend ratios which are validated with simulated results. It shows that the in-cylinder pressure for straight diesel was found to be 48 bar and 52.8 bar for experiment and simulation values respectively. D30-CBD30-E40 blend ratio showed a decrease of 2 bar in-cylinder pressure and D40-CBD40-E20 also showed a decreased in-cylinder pressure of 3 bar with respect to straight diesel which may be due to higher latent heat of vaporization with the addition of ethanol and increase in density of biodiesel. At part load condition as shown in figure (3D),in-cylinder pressure for straight diesel,D30-CBD30-E40 and D40-CBD40-E20 was found to be 59 bar, 56 bar and 54 bar respectively. The simulated results also supported the part load condition 65 bar, 61 bar and 60 bar, for straight diesel, D30-CBD30-E40 and D40-CBD40-E20 respectively. During this condition the fuel blends exhibited a gradual reduction in cetane number which lead to increased ignition delay, which provides a narrow region for pre-mixed phase to occur. Hence the peak pressure for emulsified fuel was lower than straight diesel. At full load condition (12kg to deliver 3.5 Kw of power) the in-cylinder pressure of straight biodiesel was found to be 68 bar and 75 bar for experimental and simulation results respectively as shown in figure (4A). The emulsified blends (i.e) D30-CBD30-E40 and D40-CBD40-E20 showed lower peak pressure than straight diesel, which may be due to reduction in cetane number which resulted in reduced premixed combustion phase. The theoretical simulation for full load condition for thermodynamic model also reflected the reduction in peak pressure for emulsified fuel blends than straight diesel (Balaji Mohan, 2015; Huang, 2003).

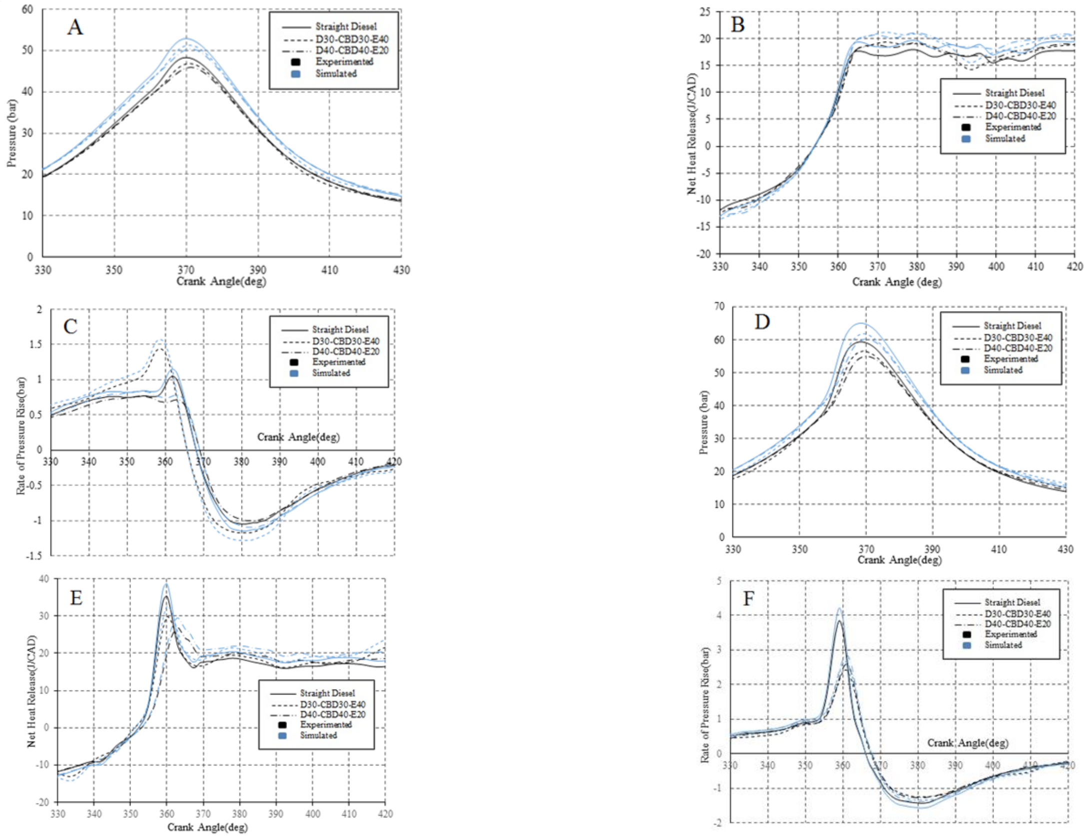

Figure.3. Variation in In-Cylinder pressure, Rate of Heat release and Rate of pressure rise at Low load (A, B, C) and Part load (D, E, F) conditions

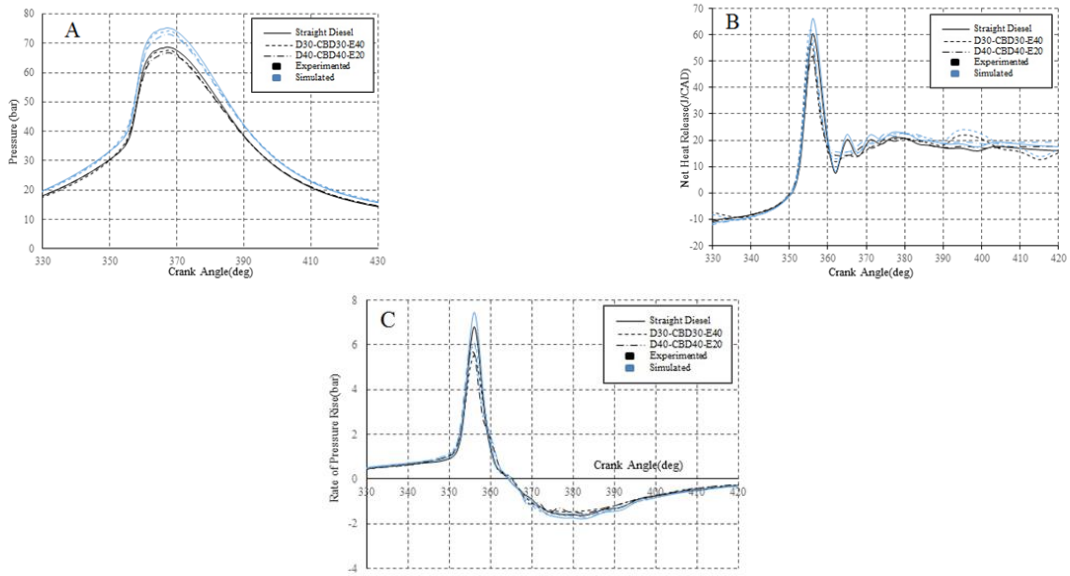

Figure.4. Variation in In-Cylinder pressure (A), Rate of Heat release (B) and Rate of pressure rise (C) at Full load condition

Variation in Rate of heat release: The Figures (3B), (3E), (4B) shows the net heat release rate for straight diesel,D30-CBD30-E40 and D40-CBD40-E20 at low load condition, part load condition and full load condition for experimental and simulation studies. It can be noted that for straight diesel the net heat release rate was found to be 22.29 J/CAD whereas D30-CBD30-E40 and D40-CBD40-E20 exhibited 19.9 J/CAD and 19.54 J/CAD. Theoretical studies also revealed the net heat release rate as 24.29 J/CAD, 21.69 J/CAD and 21 J/CAD for straight diesel, D30-CBD30-E40 and D40-CBD40-E20 respectively. With close relevance which may be due to reduction in viscosity with rise in ethanol blends. The concentration of ethanol mainly effects the premixed combustion which influences the dissociation of fuel blends and causes un-uniform diffusive combustion phase (Lewander, 2009).

At the part load conditions the maximum heat release rate for straight diesel was found to be 35.3 J/CAD and 38.6 J/CAD for experimental and simulated studies respectively. With the addition of ethanol and biodiesel blends (D30-CBD30-E40 and D40-CBD40-E20.) with straight diesel resulted in reduction of net heat release rate up to 29.82 J/CAD & 26.85 J/CAD for experimental and 32.65 J/CAD & 29.40 J/CAD for theoretical studies respectively, which may be due to reduction in calorific value of emulsified fuels. The full load condition exhibited experimental net heat release rate of 60.32 J/CAD, 56.40 J/CAD & 51.20 J/CAD and theoretical heat release rate of 66 J/CAD, 61J/CAD & 57 J/CAD for straight diesel, D30-CBD30-E40 and D40-CBD40-E20 respectively. The net heat release rate straight diesel was found to be higher in both experimental and simulated studies with D30-CBD30-E40 emulsified blend the net heat release rate was found to be slightly lower than straight diesel but higher than D40-CBD40-E20 which may be due to accumulation losses and increase ethanol concentration up to 40% enhances the net heat release effectively, which is also reflected in theoretical studies. Another reason for higher net heat release rate with D30-CBD30-E40 may be the micro explosion of ethanol at higher temperature which reduces the non-dissociation effect of biodiesel (John, 1988; Graboski, 1998).

Variation in Rate of pressure rise: Figure (3C), (3F) and (4C) depicts the experimental and simulated values for straight diesel D30-CBD30-E40 and D40-CBD40-E20 operated at low load, part load and full load condition respectively. Here at low load condition of engine operation straight diesel showed higher rate of pressure rise than emulsified blends which was around 1.43 bar for straight diesel and 0.77 & 1.05 bar for D30-CBD30-E40 and D40-CBD40-E20 respectively. Here, we can find that the peak pressure rise rate forD30-CBD30-E40 is lower than that of D40-CBD40-E20 since increase of ethanol composition in blends reduces the in cylinder temperature due to its higher latent heat of vaporisation which in turn responsible for slower rise in pressure for as much as pressure and temperature are directly proportional to each other. Obviously which reduces the gradient at which the pressure builds up and as a result it shows reduced values. This is also confirmed by simulation values of 1.56 bar, 0.84bar and 1.1.4 bar for straight diesel, D30-CBD30-E40 and D40-CBD40-E20 respectively. While the engine is operated in part load the peak value of rate of pressure rise can was noted to be as 3.85 bar for straight diesel whereas the value for D30-CBD30-E40 and D40-CBD40-E20 are found to be 2.42 bar and 2.6 bar respectively, which is similar to the previous trend. Here due to better premixed combustion phase the pressure rises evenly in diesel where as in blends (D30-CBD30-E40 and D40-CBD40-E20) density plays a major role in atomization and so reduces the gradient in which the pressure rises.

At full load operation, the experimental peak value of rate of pressure rise was noticed at 6.81 bar for straight diesel, 5.54 and 5.69 for D30-CBD30-E40 and D40-CBD40-E20 respectively. This was again replicated in simulation results as 7.4 bar, 6.03 bar & 6.23 bar for diesel, D30-CBD30-E40 and D40-CBD40-E20 respectively. The reason for increasing in rate of pressure rise for high loads is due to increase in brake mean effective pressure of the engine and rise in peak pressure of the engine. In all the loads diesel showed higher rate of pressure rise than emulsified fuel.

4. CONCLUSION

Straight diesel-Canola biodiesel-Ethanol emulsified blends were experimentally investigated and a zero dimensional multi zone thermodynamic model also developed to validate the experimental results and following conclusion were drawn.

1. Single stage base catalysed Trans-esterification was used to extract canola biodiesel with methanol (molar ratio 1:6) and KoH (2.8% Conc.), which resulted at 92%of biodiesel production.
2. Ternary analysis of straight diesel-canola biodiesel-ethanol with 66 samples revealed stability and homogeneity with D30-CBD30-E40 and D40-CBD40-E20 samples. The Physio-chemical properties of the emulsified blends were also found to be with in ASTM Limits.
3. At low load, in-cylinder pressure for straight diesel, D30-CBD30-E40 and D40-CBD40-E20 exhibited 48 bar, 47 bar and 45 bar respectively. At part load the pressure was 59 bar, 56 bar, 54 bar for straight diesel and emulsified blends respectively, which may be due to increased ignition delay and higher latent heat of vaporisation. The theoretical study also revealed similar in-cylinder pressure with variation in about 8 – 9%. The heat release rate for straight diesel, D30-CBD30-E40 and D40-CBD40-E20 was found to be 22.29 J/CAD, 19.9 J/CAD, 19.54 J/CAD for low load condition and 35.3 J/CAD, 29.82 J/CAD, 26.85 J/CAD for part load respectively, which was also supported by numerical data's. Rate of pressure rise for straight diesel and emulsified blends also showed similar results in experimented and theoretical studies.

- At full load condition, due to decrease in density of the emulsified blends the dissociation is enhanced simultaneously reducing physical delay period. In other hand reduction in cetane number increases the chemical delay across the emulsified blends, resulting in pressure lesser than that of straight diesel by 1.5% for D30-CBD30-E40 and 3% for D40-CBD40-E20.

It can be concluded that D30-CBD30-E40 emulsified blend exhibited combustion characteristics better than D40-CBD40-E20 blend which was nearer to straight diesel which may be due to optimum concentration of ethanol and biodiesel.

REFERENCES

Balaji Mohan, Wenming Yang, Wenbin Yu, Kun Lin Tay, Siaw Kiang Chou, Numerical investigation on the effects of injection rate shaping on combustion and emission characteristics of Biodiesel fuelledCl engine. Applied Energy, I60, 2015, 737-745.

Bhaskor J, Bora, Ujjwal K, Saha, Soumya Chatterjee, Vijay Veer, Effect of compression ratio on performance, combustion and emission characteristics of a dual fuel diesel engine run on raw biogas. Energy Conversion and Management, 87, 2014, 1000–1009.

Binbin Yang, Mingfa Yao, Wai K, Cheng, Yu Li, ZunqingZheng, Shanju Li, Experimental and numerical study on different dual-fuel combustion modes fuelled with gasoline and diesel, Applied Energy, 113, 2014, 722–733.

Bo Yang, Chengxun Xi, Xing Wei, Ke Zeng, Ming-Chia Lai. Parametric investigation of natural gas port injection and diesel pilot injection on the combustion and emissions of a turbocharged common rail dual-fuel engine at low load. Applied Energy, 143, 2015, 130–137.

DattatrayBapuHulwan, Satishchandra, Joshi V, Performance, emission and combustion characteristic of a multicylinder DI diesel engine running on diesel–ethanol–biodiesel blends of high ethanol content. Applied Energy, 88, 2011, 5042–5055.

Dhandapani Kannan, Senthil kumar Pachamuthu, Md. NurunNabi, Johan EinarHustad, TereseLovas. Theoretical and experimental investigation of diesel engine performance, combustion and emissions analysis fuelled with the blends of ethanol, diesel and Jatropha methyl ester. Energy Conversion and Management, 53, 2012, 322–331.

Ferguson C.R, Internal Combustion engines, New York,Wiley press, 1986

Graboski MS, McCormick RL. Combustion of fat and vegetable oil derived fuels in diesel engines. Prog Energy Combust Sci, 24, 1998, 125–164.

GvidonasLabeckas, StasysSlavinskas, Marius Mazeika, The effect of ethanol–diesel–biodiesel blends on combustion, Performance and emissions of a direct injection diesel engine. Energy Conversion and Management, 79, 2014, 698–720.

Hariram V and Vasanthaseelan S, Optimization of Base catalysed transesterification and characterization of *Brassica napus* (Canola seed) for production of biodiesel. International Journal of Chemtech Research, 8(9), 2015, 418-23.

Huang ZH, Jiang DM, Zeng K, Liu B, Yang ZL, Combustion characteristics and heat release analysis of a direct injection compression ignition engine fuelled with diesel–dimethyl carbonate blends. ProcInstMechEngrs Part D, J AutomobEng, 2003, 217.

John B Heywood, Internal Combustion Engines Fundamentals, Mc-Graw Hill publications, 1988, 491-667.

Leahey DM, Cowart JS, Jones BC, Gilligan JW, Brown LP, Hamilton LJ. Combustion of biodiesel– and ethanol–diesel mixtures with intake injection. Powertrain and fluid systems conference and exhibition and commercial vehicle engineering congress and exhibition. SAE paper no, 2007-01-4011.

Lei Zhu CS, Cheung WG, Zhang Zhen Huang A, Effect of charge dilution on gaseous and particulate emissions from a diesel engine fuelled with biodiesel and biodiesel blended with methanol and ethanol, Applied Thermal Engineering, 31, 2011, 2271-2278.

Lewander M, Ekholm K, Johansson B, Tunestal P. Investigation of the combustion characteristics with focus on partially premixed combustion in a heavy duty engine. SAE Int J Fuels Lubricants, 1(1), 2009, 1063–1074.

Rakopoulos CD, Rakopoulos DC, Giakoumis EG, Kyritsis DC, Validation and sensitivity analysis of a two zone Diesel engine model for combustion and emissions prediction, Energy Conservation and management, 45, 2004, 1471-1495.

Rakopoulos CD, Antonopoulos KA, Hountalas DT, Multi-zone modelling of combustion and emissions formation in DI diesel engine operating on ethanol diesel fuel blends. Energy Convers Manage, 48(4), 2007, 389–99.

Shuaiying Ma, ZunqingZheng, Haifeng Liu, Quanchang Zhang, Mingfa Yao, Experimental investigation of the effects of diesel injection strategy on gasoline/diesel dual-fuel combustion, Applied Energy, 109, 2013, 202–212.