Performance Evaluation and Exhaust Emission Reduction from A DI Diesel Engine Employing Dual Injection with (Bio-Diesel) Palm Kernel Methyl Ester and Water at the Suction End

Dr. M. Govinda Raju[1]
[1]Principal & Professor of Mechanical Engineering
Sri Venkateswara College of Engineering and Technology
Srikakulam, Andhra Pradesh, INDIA

Dr. B. Sateesh
Professor of Mechanical Engineering
Vignan's Institute of Information Technology
Visakhapatnam, Andhra Pradesh, INDIA

Dr. B.V.A Rao2
Professor in Marine Engineering Department
Andhra University, Visakhapatnam, INDIA

R. Rudrabhi Ramu
Associate Professor
Vignan's Institute of Information Technology
Visakhapatnam, Andhra Pradesh, INDIA

***Abstract*-- The present work aims at evaluating the performance and NO_x reduction of Direct Injection Diesel Engine. The engine was fed with Diesel, neat Palm Kernel Methyl Ester (PKME), and PKME with different percentages of Water Injection. The effects of water injection in the intake pipe are investigated. An attempt is made with water injection at the suction end at an appropriate time after inlet valve fully opens (Fig: 2.2) while Biodiesel is injected through the conventional nozzle. The injection pressure of the water is 3 kg/cm^2 and is injected with a separate nozzle operated electronically through a microprocessor. The quantity of water injection can also be changed by tuning the electronic device. The injector is arranged in such close proximity upstream in the suction manifold that it injects directly into the combustion chamber with semi spherical bowl configuration. The incoming velocity of suction air also atomizes the water injected at pressure and thus supports thorough mixing.**

In this experiment, 15% water injected created saturated vapor for the air drawn in almost at all loads for the existing compression ratio. More than this quantity of water there is a risk of crank case dilution. Exhaust emissions measurements confirm the tremendous effectiveness of water injection in reducing the engine environmental impact. Results have shown that water injection really represents a new way to control NO formation. better NO reduction along with reduction in other components of exhaust (because of Biodiesel usage) with water injection at the suction end is observed. Knocking frequencies have been eliminated because of low temperature combustion but engine suffers from marginal thermal efficiency reduction and SFC increase.

Keywords—PKME- Palm Kernel Methyl Ester, DI- Direct Injection, NO_x – Oxides of Nitrogen

I. INTRODUCTION

Biodiesel is identified as the alternative to the Petro-Diesel. Experiments are being conducted to employ neat Biodiesel in the existing diesel engines without any engine design modification. Biodiesel oil, being a vegetable oil, is known for its capacity to reduce CO_2 emission which is responsible for global warming and is efficient to regulate other emissions. It is also known for its **higher NO_x emission**. Due to more emphasis on environmental issues, efforts are being focused mainly in particular on finding ways of reducing diesel engine. The most successful approach to lower NO_x emission is to reduce the peak temperature during combustion. *Low temperature combustion will reduce the NO_x emission* ***[1].*** But it should not induce trade off with other components of exhaust emission or contaminate the crank case oil of the engine. This low temperature combustion can be achieved by **injecting water** into the combustion chamber through the inlet manifold.

Trans-esterification of non- edible oil (Palm Kernel oil) is taken up ***(fig 1.1)*** *in this work* to experiment on a laboratory-based engine with the esterified vegetable oil. The non edible oil under consideration is Palm kernel. After making the required quantities of methyl ester, necessary properties of these esters are established as per the IS test methods (IS: 1448). The results are tabulated in **Table 1.1.** The ester samples were tested on the laboratory based D.I. Compression Ignition Engine for performance evaluation and exhaust emission analysis.

Fig 1.1: Trans-esterification of palm kernel non edible vegetable oil –

II. EXPERIMENTAL SETUP

The test engine is a single cylinder with L/D 110 mm/ 80 mm, 5hp @1500 rpm & compression ratio 16:1.Pressure crank angle history is obtained from the engine data logger for the load defined. After obtaining the data for combustion cycle, the net heat release rate is calculated based on Gatowski heat release rate model.The fuel consumption for the Palm Kernel Methyl Ester and water at various proportions with reference to 1kg/hr diesel fuel consumption at full load running of the engine as well as for the diesel is measured at all defined loads both with U-tube manometer and fuel Rota meter. This is an attempt to evaluate engine performance for comparison. The threshold mass flow rate after which the crank case dilution starts was identified. The exhaust gas and smoke analysis is taken up to classify the merits and demerits. The results are elaborately discussed.

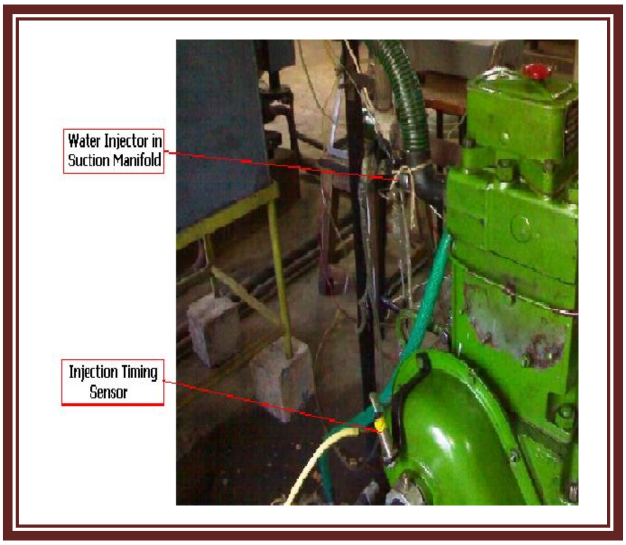

Fig :2.1 Diesel Engine Test Rig with Water Injector in the suction manifold

A. EXPERIMENTAL PROCEDURE

The experimentation is conducted on the test engine **(fig:2.1)** operated at normal room temperatures of 28^0C to 33^0C in the Department of Marine Engineering, Andhra University using ester of Palm Kernel oil (PKME) and diesel oil at five discrete part load conditions. The data collection is done independently for Diesel, neat PKME and PKME+ Different percentages of water Injection. Combustion pressure and fuel consumption is measured for every load on the engine. From the P-θ signatures obtained, the net heat release rates have been derived for the above said combinations with the software designed based on the Gatowski heat release rate model. Exhaust gas and smoke measurements are also made at different loads. The same procedure is repeated for the dual operation with the water and PKME injection to compare the performance of the engine for comparative analysis.

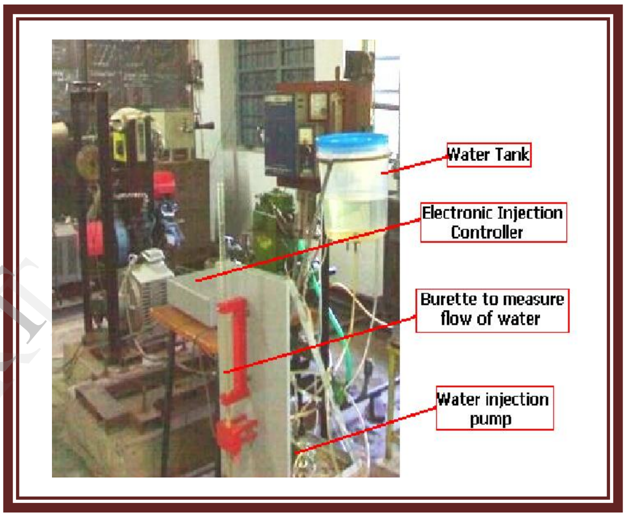

Fig 2.2: Diesel Engine Test rig with Water Injection System setup

B. Fuel Consumption Measurement

Time taken for 10 ml consumption of fuel is recorded at all the above mentioned loads with neat PKME operation with all percentages of water. Same procedure is repeated for both diesel and only PKME without water injection at the same loading conditions for comparison. Finally the fuel consumption is expressed in kg/hr.

C. Combustion Pressure Measurement and Heat release Rate Calculations

The Piezo electric transducer is fixed (flush in type) to the cylinder body (with water cooling adaptor) to record the pressure variations in the combustion chamber for each and every degree of Crank angle. Crank angle is measured using crank angle encoder. Exact TDC position is identified by the valve timing diagram and fixed with a sleek mark on the fly wheel and the same is used as a reference point for the encoder with respect to which the signals of crank angle will be transmitted to the data logger. The data logger synthesizes the two signals and finally the data is presented in the form of a graph on the computer using C7112 software.

The net heat release rates and the cumulative heat release rates are derived from this recorded Pressure-Crank angle data with the help of C7112 software designed and developed based on Gatowski model for heat release rates. The derived output is also presented for every crank angle in the graphic format by the above said software.

The heat transfer from the gases to the cylinder is computed and deducted from the net heat release rate to arrive at the gross heat release rate which is presented in the form of graphs. The recorded pressure data, Computed net HRR and cumulative HRR profiles are shown in **fig 2.3.1, Fig 2.3.2 and fig 2.3.3.**

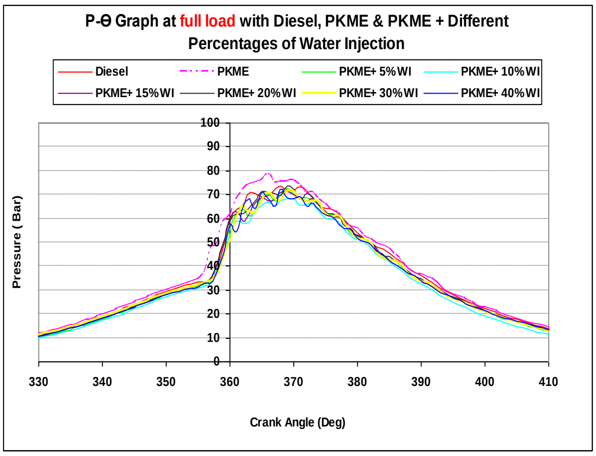

Fig: 2.3.1 Input: Combustion pressure trend at full load operation with PKME & water injection.

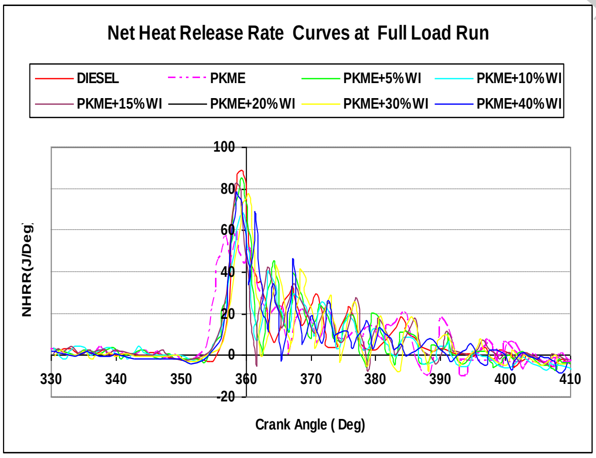

Fig: 2.3.2 Output: Net heat release rate of combustion for all combinations at full load

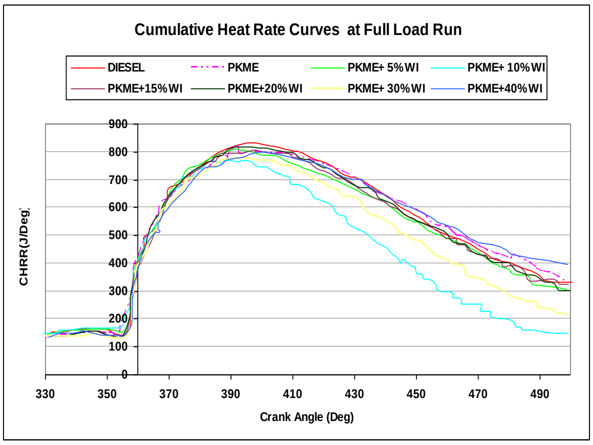

Fig: 2.3.3: Output: Cumulative heat release rate of combustion for all combinations at full load

D. EMISSION MEASUREMENT

The DELTA 1600- L measures the exhaust emissions such as Carbon Monoxide (CO), Carbon Dioxide (CO_2), Hydro Carbon (HC), Oxygen (O_2) and Nitric Oxide (NO) by means of infrared measurement. These five gases of analysis is processed by integrated micro processor quantitatively and shown in the display panel. At the end of a measurement, the measured values, the date and time can be documented by an integrated printer.

III. RESULTS AND DISCUSSION

The main objective of employing Biodiesel and water injection is to reduce engine emissions by low temperature combustion. Our basic attempt here is to reduce NO_x emission, vis-a vis other emissions. There is certain amount of sacrificing the performance quality in this attempt. The aspects like SFC and thermal efficiency suffer marginally with the injection of water since the combustion is delayed leading to poorer torque conversion at the retreating stage of the piston.

Crank case dilution is observed after 15% water injection and that is why serious consideration of the results after 15% has been forfeited. But observations have also been made with higher percentages water injection to explore the extent of engine degeneration in performance. The engine was tested with 15% water injection for days together (with limited six hours per day operation) and it was observed no crank case dilution with this percentage of water injection. Incidentally, *15% water injection is adjudged as the compatible one which yielded good results in the most of the engine aspects.*

A. Engine Performance And Comparison

It is observed from **fig 3.1** that there is a decrease in peak pressure with the increase in water injection. But for 15% of water injection, there is rise in peak pressure and for other higher water percentages the peak pressures plummet down. This is true with respect to all the loads tested on the engine. It can be observed steep rate of pressure rise when 15% water injection has been executed and hence 15% water injection has been the best and it can also be concluded with the verification of other parameters. Better premixed and diffused combustion is observed in case of 15% water injection.

.

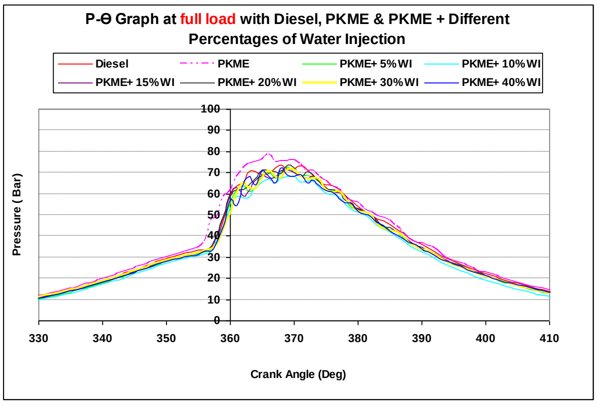

Fig: 3.1 Combustion pressure trend at full load operation PKME & water injection

The net maximum heat release rate has decreased with the increase of water dilution as can be observed from **fig 3.2**. This is true with respect to all loads. **Fig 3.3** shows the net heat release rate graphs with different water dilution in which 15% water injection is represented with dotted connotation. It is clearly indicating that 15% water injection ensures efficient combustion.

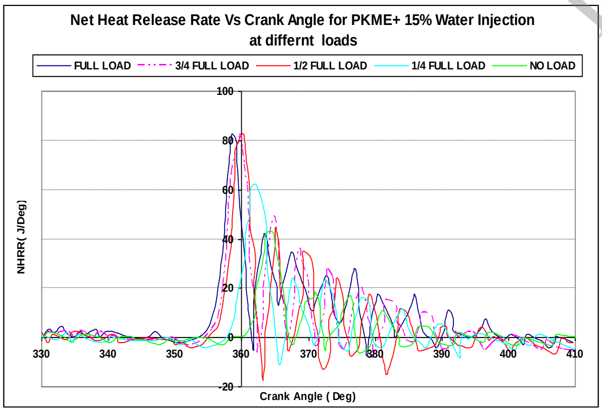

Fig:3.2: Net heat release rate of combustion with 15% water injection

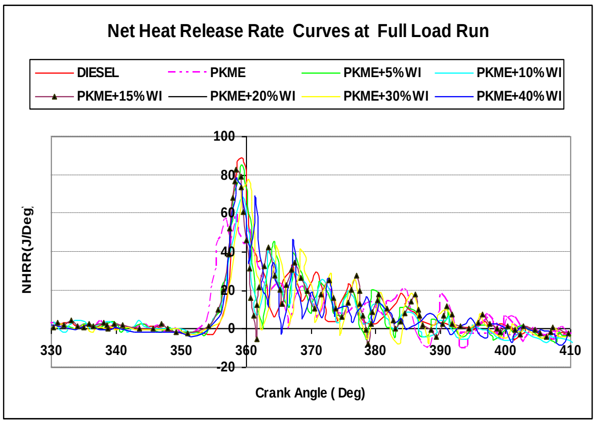

Fig: 3.3: Net heat release rate of combustion for all combinations at full load

Better performance of 15% water injection can also be observed in the cumulative heat release rate curves from **fig 3.4** with higher cumulative heat release at all the loads comparatively. The cumulative heat release rates for various water dilution percentages at full load are depicted in **fig 3.5**. In these figures, one can observe deteriorated diffused combustion for the percentages of water dilution of 10 and 30. The 10% injection performed worse than that of 30%.

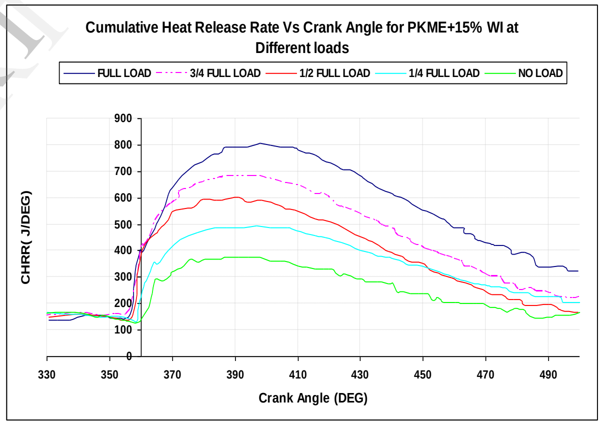

Fig:3.4 Cumulative heat release rate of combustion with 15% water injection

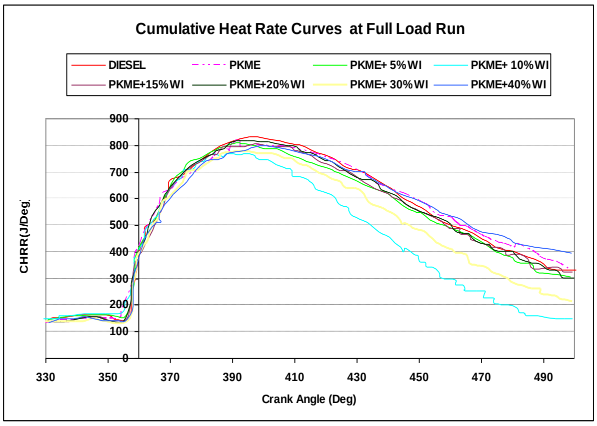

Fig: 3.5 Cumulative heat release rate of combustion for all combinations at full load

At 15% water dilution, the diffusion of water spray might be systematic controlling effectively the combustion with least quantity of water condensation which if at all there, obviously goes with the exhaust gasses without diluting the crank case oil.

B. SFC & Thermal Efficiency Evaluation:

With diesel fuel, the specific fuel consumption (SFC) at full load run of the engine is 0.309 kg/ kW hr and for Biodiesel 0.384kg/kW hr because of its lower heat value. Water dilution aspect reduced SFC at full load when compared to the Biodiesel except at 10% dilution. At this percentage, atomized water entraining the air tries for a phase change into dry vapor absorbing the latent heat from the combustion and hence reduction in cumulative heat with a time lag. Values of thermal efficiency also increased with water dilution **(Fig3.7)** and the increase at 15% water dilution is by 2.2% at full load operation of the engine.

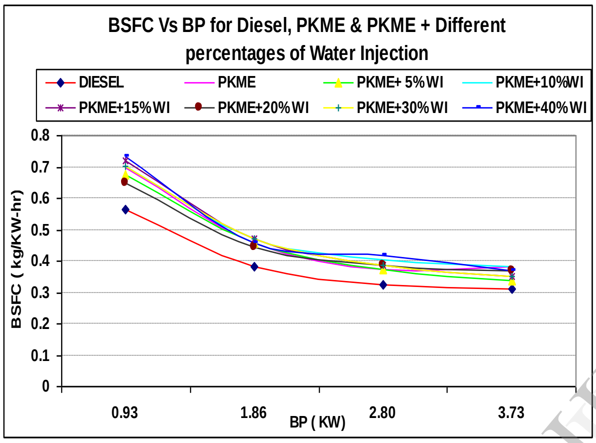

Fig: 3.6. BSFC Plots for combinations of PKME and water injection

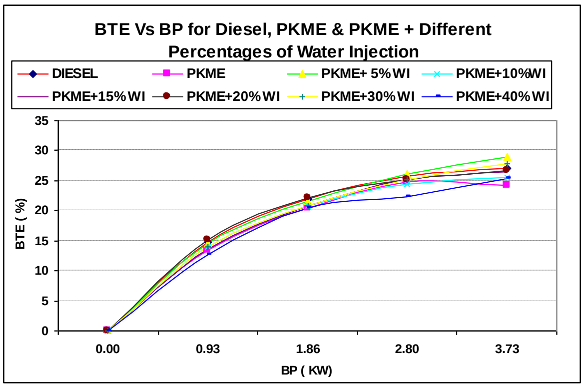

Fig: 3.7 BTE Plots for combinations of PKME and water injection

IV. EXHAUST EMISSIONS:

In this work, an attempt is made to reduce the combustion temperatures by injecting water at different proportions as a fraction of the fuel injected. This is assumed to ensure lower combustion temperatures. NO_x form at a temperature more than 1200^0C and water injection ensures the combustion temperatures not to rise more than this temperature and thus reducing the formation of NO_x. NO emissions decreased continuously with the increase of water injection percentage. NO emission has decreased by 35% at 15% water injection **(fig: 4.1)** along with Biodiesel at full load running of the engine taking diesel fuel run as the reference.

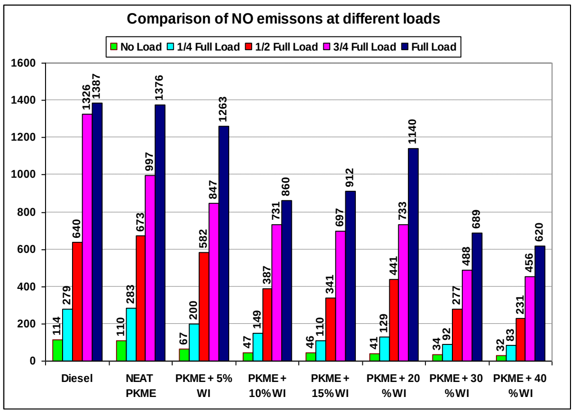

Fig: 4.1: NO Emission for different water injection percentages and load)

Referring to the **fig 4.2**, the HC in exhaust first decreased with the water injection increase up to 15% and then increases with the percentage increase of water. More water in the combustion makes some portion of fuel unburned and that is why more HC component emission. 15% water injection ensures the best of all the proportions tested. There is nearly 8ppm decrease in the HC level at 15% water injection when compared to the neat Biodiesel operation. It is observed 65ppm reduction with 15% water injection which is observed appropriate with respect the neat diesel fuel operation.

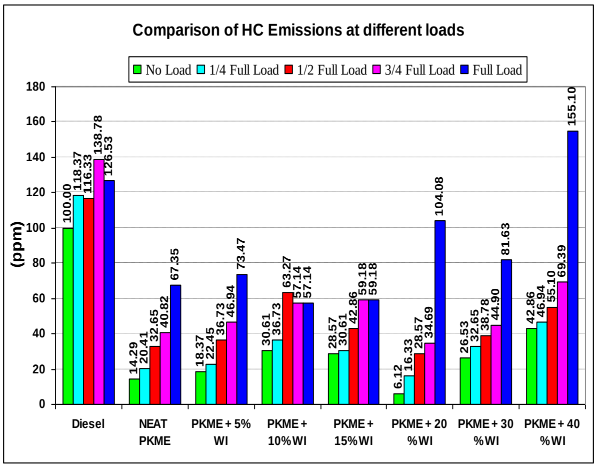

Fig: 4.2: HC Emission for different water injection percentages and load fractions

Lower combustion temperatures normally increase CO emission and the same can be observed from the **fig 4.3** the 15% water injection with Biodiesel fuel is closer to the neat Biodiesel operation with an increase of 0.01% at full load running of the engine. All other higher percentages of water injection proved inefficient in reducing the CO emission.

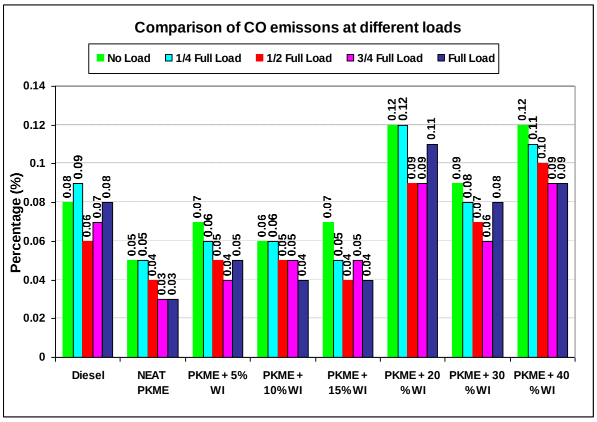

Fig: 4.3: CO Emission for different water injection percentages and load fractions

Smoke emission **(fig 4.4)** has shown some relief at 15% water injection because of saturated gas combustion which can be attributed to the status of combustion mix.

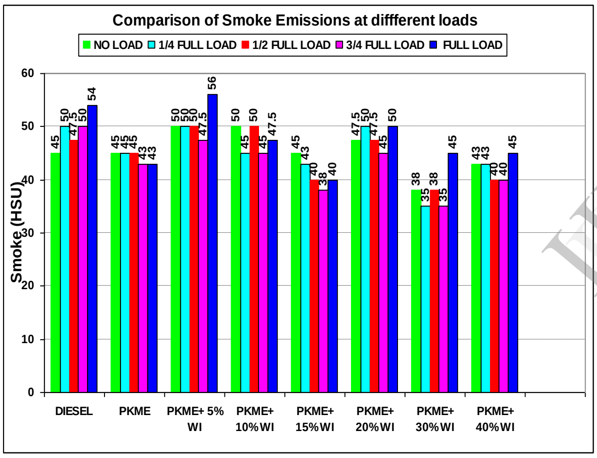

Fig: 4.4 Smoke Emission for different water injection percentages and load fractions

V. CONCLUSIONS

- The Peak combustion pressures are decreased with the water dilution when compared with neat Biodiesel operation. There is increase in delay period with the increase of water injection. Phase change of water at 10% water injection especially became vulnerable because some of the heat generated is expended to evaporate the water and hence poorer cumulative heat release rate. After observing the other water injection rates, it is concluded that 15% water injection is the most economical one which, possibly, might have formed saturated mixture of gas in the combustion chamber promoting better combustion.
- The brake specific fuel consumption (BSFC) for neat Biodiesel is higher because of its lesser lower calorific value. With the increase in percentage of water injection (5% - 40%) there is an increase in BSFC. This is due to the presence of water in the combustible mixture and excess consumed fuel is going in the way of either HC emission or CO emission and a part goes with condensed water in to crank case at higher injections of water. 15% of water injection is adjudged as the most feasible combination with the Biodiesel leading to emission control despite some sacrifice with the BSFC.
- The brake thermal efficiency (BTE) decreased as the percentage of water dilution increased at all loads. Maximum 4% percent decrease in BTE is observed with higher water dilutions when compared with the diesel fuel run.
- The emission components like HC and CO are decreased with the increase in the percentage of water dilutions up to 15% at all loads. However, for higher percentages of water injection there is a moderate increase in HC emissions at full load and high increase in CO emissions at all loads. Therefore, it is clear that the engine operating with 15% water injection along with Biodiesel gives a lower CO& HC emissions at all loads.
- Water injection reduced combustion temperatures and helps in reducing the NO emissions. Nearly 34% NO emissions are reduced with engine operating with 15% water injection along with methyl ester when compared with the neat Biodiesel run. Further reduction in NO emissions is achieved by increasing the water dilution. For PKME + 40% water injection NO emissions are reduced by 55% and this is happening at the cost of increase in other emissions. Hence it can be concluded that, the 15% water injection along with the methyl ester is the optimum percentage of water dilution for this type and capacity of the engine.
- The smoke levels for the 15% water dilution are lower than that of all combinations at all loads. A moderate increase in the CO_2 emission is observed with higher percentages of water injection at all loads. Combustion in the presence of water becomes good especially at part loads because of good entrainment of fuel with the air inducted. The evaporation of the fuel coated on the water droplet because of lower fuel gravity is more and entrains easily with the air around the droplet leading to controlled combustion.

REFERENCES

[1] NIcholls, J. E., EL-Messir., I. A., And Newhall, H. K.: Inlet Manifold Water Injection for Control of Nitrogen Oxides--Theory and Experiment, Paper 690018 presented at SAE International Automotive Engineering Congress and Exposition, Detroit, Mich., January 1969.
[2] Ferguson CR, Kirkpatrick. "Internal Combustion Engines". 2nd ed. Singapore: Wiley; 2001. p. 7–8.
[3] Ishida, M. et al., "Studies on Combustion and Exhaust Emissions in a High Speed DI Diesel Engine," SAE Paper, No. 901614 (1990).
[4] Kazunori Hamasaki et.al 'Combustion Characteristics of Diesel Engines with Waste Vegetable Oil Methyl Ester' (3-09), The fifth international symposium on diagnostics and modeling of combustion in internal combustion engines (COMBODIA2001) July 1-4, 2001 Nagoya.
[5] Wartsila Corporation, April 2004. Marine Technologies for Reduced Emissions [Online] Available from:

http://www.wartsila.com/Wartsila/docs/en/ship_power/media_publications/technical_papers/sulzer/marine_technologies_for_reduced_emissions.pdf [Accessed 29th August 2006]

[6]. Melton JR., R. B., Lestz, S. J., and Quilian JR., R. D.: Direct Water Injection Cooling for Military Engines, U.S. Army Contract DAAD05-72-C-0053, USAFLRL Report No. 32, DDC No. AD 780175, March 1974.

[7] * Dr.B.V.A.Rao, M. Govinda Raju ‘Study of Performance and Exhaust Emissions Using Biodiesel (Mahua Methyl Ester) with Water Fumigation at the Suction End of DI Diesel Engine’ 6th Asia-Pacific Conference on Combustion, Nagoya Congress Center, Nagoya, Japan 20-23 May 2007

[8] Krieger R B , and Bormann G L., “The computation of Apparent Heat release for Internal combustion engines” ASME paper 66-WA/DGP-4, 1956.