Experimental studies on a DI-CI engine using blends of diesel fuel with Plasti diesel derived from Plastic Waste at 275 bar injection pressure

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Abstract- *Increasing fuel prices and depleting fossil fuel resources in recent years drawn attention towards the use of alternative fuels for diesel engines. The use of vegetable oil is popular, economic and implementable source among the various fuel alternatives. The compression ignition engines are widely used due to its reliable operation and economy. As the petroleum reserves are depleting at a faster rate due to the growth of population and the subsequent energy utilization, an urgent need for search for a renewable alternative fuel arise.*

"In the present day scenario emissions associated with the exhaust of automobiles resulting in global warming is a major menace to the entire world and also detrimental to health. An experimental investigation is conducted to evaluate the use of Plasti diesel derived from plastic waste in a direct injection (D.I), C.I engine. The tests are conducted using each of the petro diesel and Plasti diesel at 275 bar fuel injection pressure, with the engine working at Constant speed. Fuel consumption, and exhaust regulated gas emissions such as nitrogen oxides, carbon monoxide and total unburned hydrocarbons are measured. The differences in the measured performance, combustion and exhaust emissions from the baseline operation of the engine, i.e., when working with petro diesel fuel and the plasti diesel are determined and compared. The experimental results show that blends of plasti diesel, with diesel lowers the viscosity and leads to good improvement in brake thermal efficiency"[11,12].

Keywords- CI engine, Emissions, Combustion, Plasti diesel and Petro diesel

I. INTRODUCTION

"Automobile emissions are increasing day by day and there is catastrophic future in respect of human health degradation. The emission regulatory boards are imposing stringent rules in controlling emissions world wide. The population of fossil fuel run vehicles is increasing in multifold every year leading to peak pollution levels. Research round the globe is focused on the ways to reduce regulated and unregulated tail pipe emissions. Regulated emissions like NOx, HC and CO emissions are important ones to be contained. Therefore, the need for reducing/minimizing emission levels of NO¬x, HC, CO etc drawing attention of many a researcher. This can be achieved either by switching over to renewable fuels or by any other method which do not invite major changes in the design aspect of the engine in use which entails additional expenditure.

Rudolph Diesel stipulated as a condition of his rational heat motor that fuel must be introduced gradually so as to maintain an isothermal combustion process [1].

Hence, from the early days of diesel engine development, it appeared that diffusion burn combustion would dominate. Nevertheless, this developmental road progressively changed direction as awareness of vehicle emissions and their impact on the atmosphere surfaced [2]. As researchers learned more about diesel engine combustion, it became increasingly clear that the diffusion burn portion was largely responsible for its soot emission [3]. Therefore, the desire to overturn Diesel's condition of isothermal combustion developed, and attention shifted to premixed combustion modes [4]. Today, the development of combustion strategies resembling homogenous charge compression ignition (HCCI) strategies is vigorously pursued. The promise of simultaneously reduced NOx and Particulate Matter (PM) offers attractive incentives, especially considering the associated minor penalties in fuel economy. The popular press has become excited at the prospects of HCCI-type combustion systems, which are viewed as the internal combustion engine's best response to future competition from fuel cells and hybrids [5]. Much of the developmental strategies and targets are dictated by ever stringent emissions standards on passenger vehicles.

The second alteration is a redesign of the piston bowl to reduce cylinder compression ratio from 19:1 (production compression ratio) to 16:1 [6]. This reduction in compression ratio reduces the pre-injection thermodynamic state, resulting in increased ignition delays. The increased ignition delay increases the time for fuel and air mixing, allowing for attainment of premixed compression ignition combustion. EPA started imposing air emission regulations on heavy duty engines in 1985, to take effect in 1991, and then more stringent regulations in 1994. However, these initial regulations could be met with optimized combustion strategies, and improved combustion chamber design.

This work examines the interactions resulting from the application of a plastic diesel derived from plastic waste on a practical heavy-duty diesel engine system, with the aim of understanding their impact on emissions and performance. The goal of this experimental study is to assess the new fuel contributions to potential performance and efficiency penalties. Plasti diesel itself is a waste by product known to reduce the serious pollution threat to all most all the nation's world wide. An attempt is made to assess the combustion and performance phenomenon of plasti diesel fuel. Some tests were conducted with the neat diesel application to verify the delineation line to fix up the performance of the diesel engine designed for diesel fuel. Marginal changes in the performance in the wise of SFC and BSFC cannot decipher the nature of combustion exactly. That is the reason why an extensive investigation encompassing the performance, emissions is taken up to evaluate the engine under the new conditions of the fuel implementation.

The merits and the demerits of the plastic diesel fuel implementation with the neat diesel application are discussed. The fuel in the form of liquid hydrocarbons derived from plastic waste constitutes approximately 80% of total post consumer plastic waste in India and includes PET, LDPE, PVC, HDPE, PP, PS etc. into liquid fuel oil. The process adopted is based on random de-polymerization of waste plastics in presence of a catalyst into liquid fuel [7]-[10]. Fractional distillation was carried out by the author at his laboratory to convert the liquid hydro carbons to plastic diesel fuel at a temperature from 1600 c to 2600 c as suggested by the inventor and a dark yellow color diesel like fuel (PD) is derived by distillation with an approximate yielding of 30%. The distillation set up and the derived fuels are shown in the fig.1"[11,12].

Figure1. Experimental setup of fractional distillation to extract plasti diesel (PD) from liquid hydro carbons

II. EXPERIMENTATION

A. Experimental set up

"Direct Injection, Diesel engine is utilized for the experimentation. Experimentation is carried out at various engine loads (Engine Loading device is eddy current dynamometer) to record the cylinder pressure and finally to compute heat release rates with respect to the crank-angle. Engine performance data is acquired to study the performance and engine pollution parameters.

The smoke values in HSU, the exhaust gas temperatures and exhaust gas analysis of different components of exhaust gas are measured and compared and engine performance is analyzed for the parameters mentioned above with the implementation of blends of petro diesel with plasti diesel and with the blend of plasti diesel with cetane improver"[11,12].

Table 1. Specification Of The DI-Diesel Engine

Rated Horse power:	5 hp (3.73 kW)
Rated Speed:	1500rpm
No of Strokes:	4
Mode of Injection	Direct Injection
Injection pressure	200 kg/cm^2
No of Cylinders:	1
Stroke	110 mm
Bore	80 mm
Compression ratio	16.5:1

B. INDUS PEA 205, (Exhaust Gas Analyzer)

The PEA 205 [fig.2.1] measures the exhaust emissions such as Carbon Monoxide (CO), Carbon Dioxide (CO2), Hydro Carbon (HC), Oxygen (O2) and Nitric Oxide (NO) by means of Non-Dispersive infrared (NDIR) measurement.

Figure 2. INDUS PEA 205 Exhaust Gas Analyzer

C. Experimental Procedure

The experimentation is conducted on a single cylinder direct injection diesel engine operated at normal room temperatures of 280C to 330C The experiment was done with fuels diesel like fuel derived from plastic waste (PD) and Plastic Diesel fuel mixed with cetane improver(PDCI), Diesel oil in neat condition(ND) as well as with 20%, 40%, 60% and 80% blends of plastic diesel with petro diesel(B20,B40,B60,B80) at five discrete part load conditions namely No Load, One Fourth Full Load, Half Full Load, Three Fourth Full Load and Full Loads at fuel injection pressure 275 Kg/cm2 [Fig.2.a].

Figure 3. Experimental setup

The fuel consumption for the PD, PDCI, PD20, PD40, PD60, PD80 fuel runs and for the petro diesel is measured at all defined loads both with U-tube manometer and fuel Rota meter. The heat release rate values are derived from the pressure- crank angle signatures by a suitable computer program.

III. RESULTS

A. Performance analysis of blends of Plastic Dieselwith petro Diesel at 275bar Pressure

Figure 3 and Figure 4 show the brake specific fuel consumption and brake thermal efficiency at 275bar. The S.F.C of plastic diesel-100(PD) at full load is 0.4904 kg/kw-hr where as for plastic diesel-20 it is 0.379kg/kw-hr. There is no much deviation in the fuel consumption for plastic diesel at 275 bar pressure.

The brake thermal efficiency also shows the same trend. The efficiency of plastic diesel-20 and plastic diesel-40 are equal and it is very near to the efficiency of diesel at 200 bar pressure.

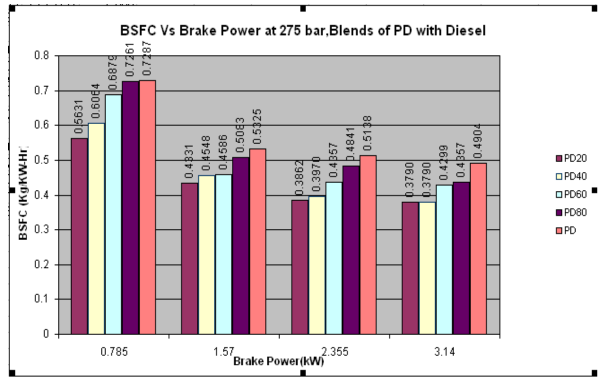

Figure 4. Brake Specific fuel Consumption Vs Brake power graph at 275bar Pressure with Blends of Plastic Diesel with Neat Diesel at various loads

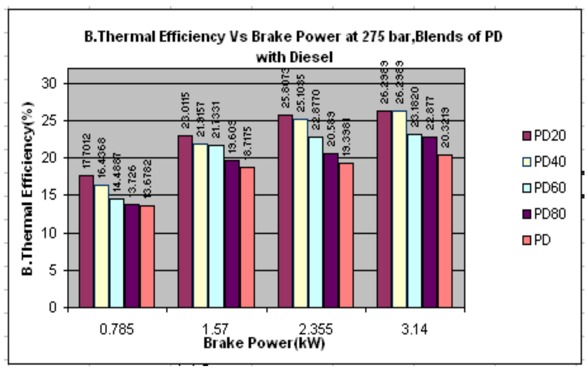

Figure 5. Brake Thermal Efficiency Vs Brake power graph at 275bar Pressure with Blends of Plastic Diesel with Neat Diesel at various loads

B. Combustion Analysis of blends of Plastic Diesel with Petro Diesel at 275 bar Pressure

For Further increase of injection pressure to 275 bar, the peak pressure rise moves towards the TDC (Figure 5). It shows the better evaporation and homogenization that leads to better combustion. As a result, the starting of combustion is also earlier than the previous cases. In case of 100% plastic diesel, combustion begins at 360^0 of crank angle with 275 bar injection pressure where as in the case of 200 bar or 250 bar injection pressures, ignition starts at 364^0 of crank angle. But the combustion of 100% plastic diesel at 275 bar injection pressure is irregular in the after combustion zone. 80% of plastic diesel shows the incomplete combustion. As a result peak pressure is dropped. At 275 bar injection pressure, plastic diesel-20 or plastic diesel-40 shows the better combustion.

Similar reflections can be observed in the HRR (Figure 6). Plastic diesel-20 shows the less fluctuation during the combustion. But in all the other cases, the HRR is non-uniform and irregular. More irregularity can be observed in case of plastic diesel-40, plastic diesel-60 and 100% plastic diesel application. Plastic diesel-80 shows the incomplete combustion, it may be the experimental error.

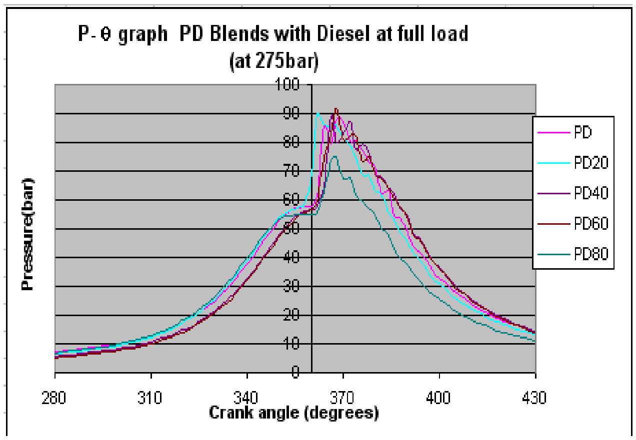

Figure 6. P-θ Graph at full load with Blends of Plastic Diesel with Neat Diesel, at 275bar Pressure

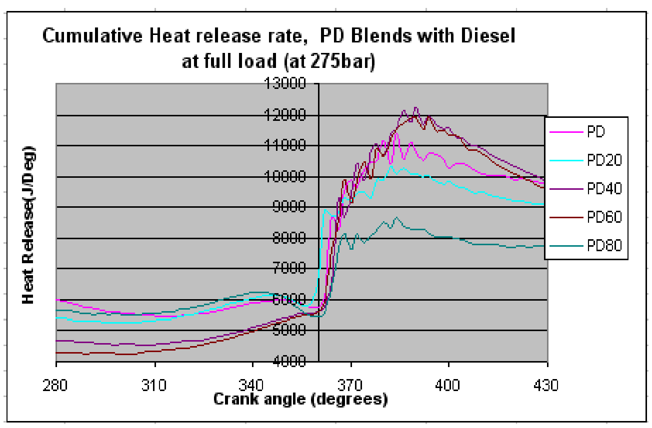

Figure 7. Cumulative Heat Release Rate Vs Crank Angle graph, at full load, with Blends of Plastic Diesel with Neat Diesel, at 275bar Pressure

C. Analysis of Emission Parameters of Blends of Plastic Diesel with Petro Diesel at 275 bar Pressure

On increase of injection pressure burning of the fuel after combustion is reduced gradually. The gradual decrement of this phase leads to reduction of exhaust gas temperature for plastic diesel-100(PD) (Figure 7). So the variation is negligible from 250 bar to 275 bar injection pressure. This can be observed from the table 2[11,12].

Table 2.

Table 2: Exhaust Gas Temperatures for Plastic Diesel-100				
At full load	At 200 bar	At 250 bar	At 275 bar	At 300 bar
P.D-20	505^0C	318^0C	272^0C	291^0C
P.D-100(PD)	574^0C	301^0C	305^0C	303^0C

As a result of drop in exhaust gas temperatures and increased rate of reaction in the premixed zone, it results in decrease of NOx at 275 bar at full load (Figure 8). At part load operation, the variation of NOx with different blends is negligible. But at the full load operation from plastic diesel-20 to 100% plastic diesel, it shows gradual increase in the NOx. This is clear evidence that for plastic diesel-20, the burning is proper and most of the hydrocarbon portion burnt in the earlier portion of burning. For HC, CO they are negligible at particular load, but these values are lower than the previous operation figure 9 & figure 10. The CO2 emissions have no significant variations with respect to increase in the injection pressure figure 11. From the smoke graph figure 12, reduction of particulate matter can be observed due to better combustion.

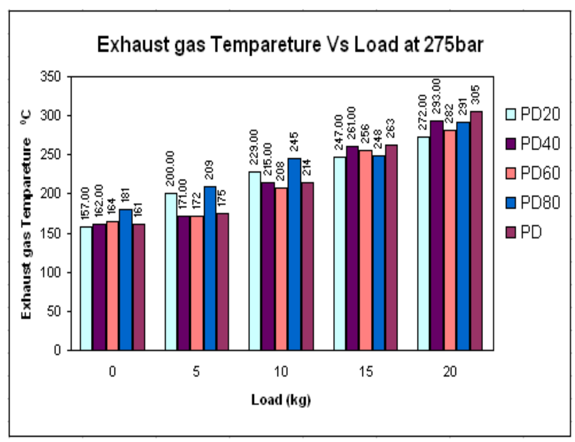

Figure 8. Exhaust Gas Temperature Vs Load graph with Blends of Plastic Diesel with Neat Diesel, at 275bar Pressure

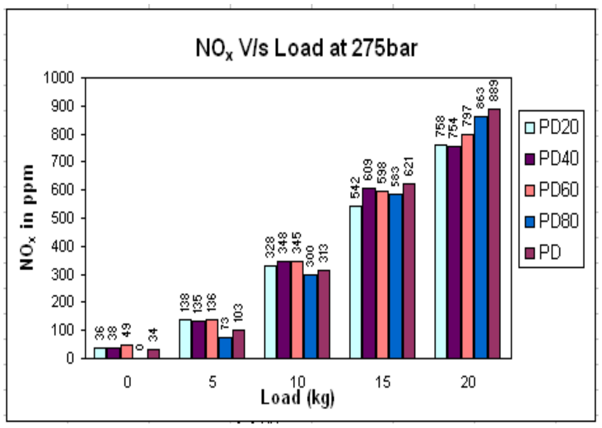

Figure 9. Nitric oxide Vs Load graph with Blends of Plastic Diesel with Neat Diesel, at 275bar Pressure

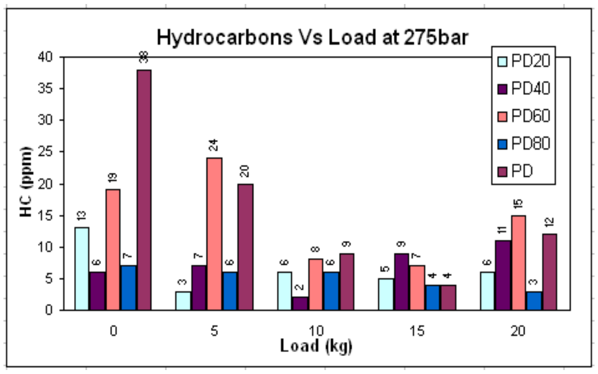

Figure 10. Hydrocarbons Vs Load graph with Blends of Plastic Diesel with Neat Diesel, at 275bar Pressure

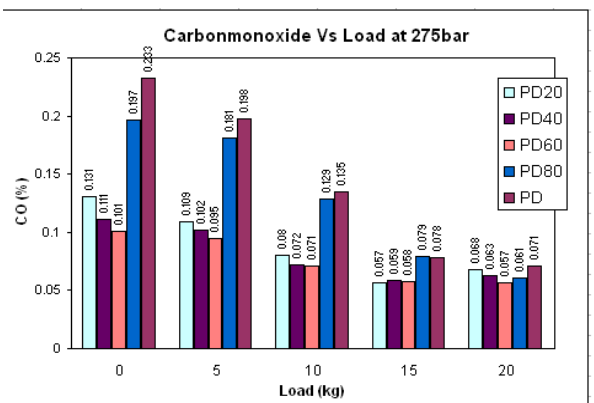

Figure 11. Carbon monoxide Vs Load graph with Blends of Plastic Diesel with Neat Diesel, at 275bar Pressure

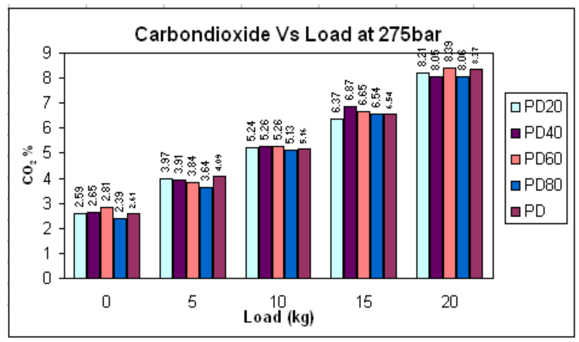

Figure 12. Carbon dioxide Vs Load graph with Blends of Plastic Diesel with Neat Diesel, at 275bar Pressure

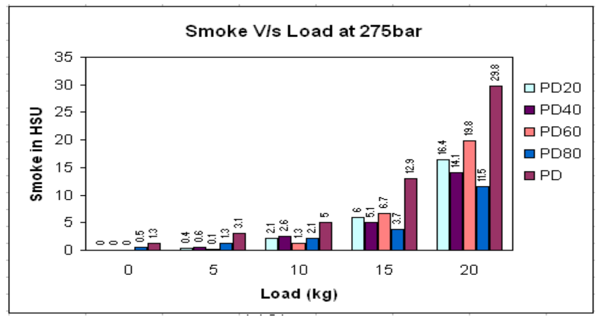

Figure 13. Smoke Value Vs Load graph with Blends of Plastic Diesel with Neat Diesel, at 275bar Pressure

D. Performance analysis of Plastic Diesel with Cetane Number Improver at 275 bar Pressure

In the operation of the engine at 275 bar injection pressure and with PDCI, the SFC is further decreased (Figure 13). The SFC at 275 bar at full load is 0.4554. It is 4.6% less than the consumption at 200 bar pressure. At part load operation there is no much variation. Even in the brake thermal efficiency, similar reflection can be observed. An improvement of 1% can be observed with cetane improver (Figure 14).

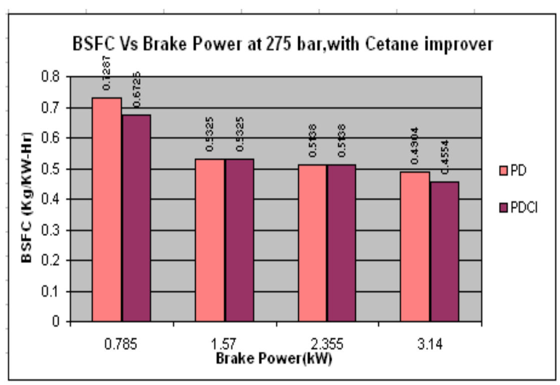

Figure 14. Brake Specific fuel Consumption Vs Brake power graph at 275bar Pressure at Plastic Diesel with Cetane Number Improver, at various loads.

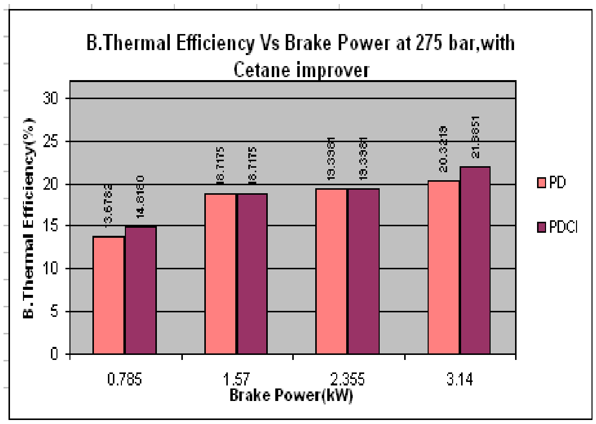

Figure 15. Brake Thermal Efficiency Vs Brake power graph at 275bar Pressure at Plastic Diesel with Cetane Number Improver, at various loads.

E. Combustion analysis of Plastic Diesel with Cetane Number Improver at 275 bar Pressure

At 275 bar injection pressure, p-θ curve rise is very uniform (Figure 15). As a result of CI the delay period is lowered and uniform pressure rise is consistent. The peak pressure obtained at 3680 of crank angle and its value is equal to the diesel i.e 90.6 bar. The combustion duration is also improved. The gradual rise of pressure leads to uniform development of torque. The Figure 16 shows the HR with PDCI which is gradual and major heat is released below 4000 of crank angle.

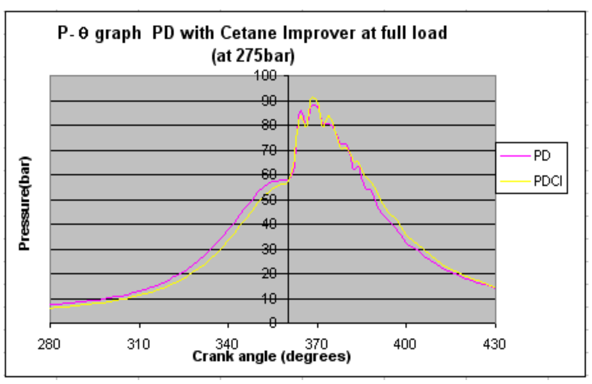

Figure 16. P-θ Graph at full load, Plastic Diesel with Cetane Number Improver, at 275bar Pressure

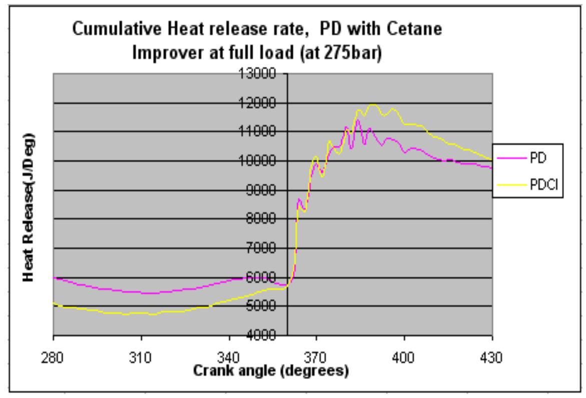

Figure 17. Cumulative Heat Release Rate Vs Crank Angle graph, at full load, Plastic Diesel with Cetane Number Improver, at 275bar Pressure

F.Analysis of Emission Parameters of Plastic Diesel with Cetane Number Improver at 275 bar Pressure

At 275 bar injection pressure the exhaust gas temperatures are further decreased with PDCI operation. Around 1500C drop in temperature (Figure 17) is observed. As a result of decrease in the exhaust gas temperature, rapid reaction rate and decrease in size of fuel droplet, 'NOx' show less value at this operating condition (Figure 18). The values of HC and Co at this operating condition are very low (Figure 19 and Figure 20) which show the better combustion. The CO2 has no significant difference at particular load with 275 bar injection pressure (Figure 21). As a result of improved quality of fuel and saturated condition, PDCI shows very low particulate matter emissions (Figure 22).

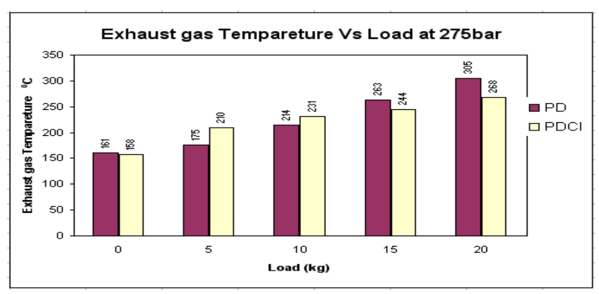

Figure 18 Exhaust Gas Temperature Vs Load graph, Plastic Diesel with Cetane Number Improver, at 275bar Pressure

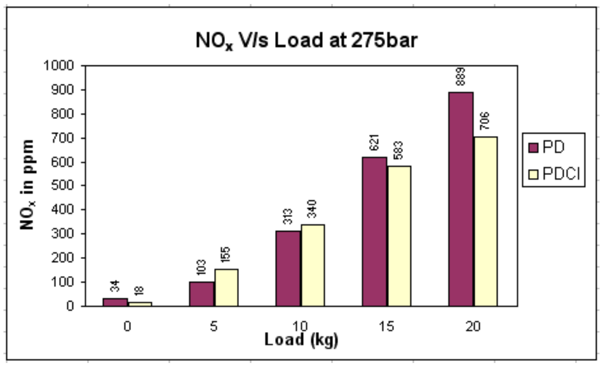

Figure 19. Nitric oxide Vs Load graph, Plastic Diesel with Cetane Number Improver, at 275bar Pressure

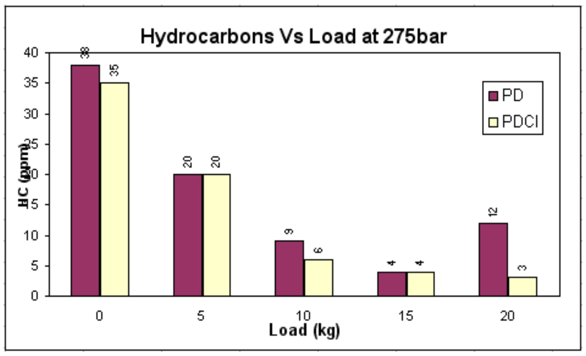

Figure 20. Hydrocarbons Vs Load graph, Plastic Diesel with Cetane Number Improver, at 275bar Pressure

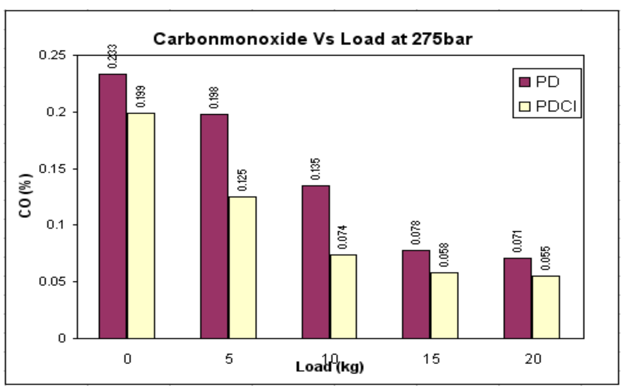

Figure 21. Carbon monoxide Vs Load graph, Plastic Diesel with Cetane Number Improver, at 275bar Pressure

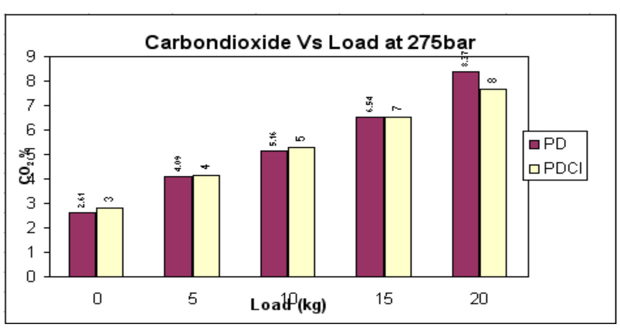

Figure 22. Carbon dioxide Vs Load graph, Plastic Diesel with Cetane Number Improver, at 275bar Pressure

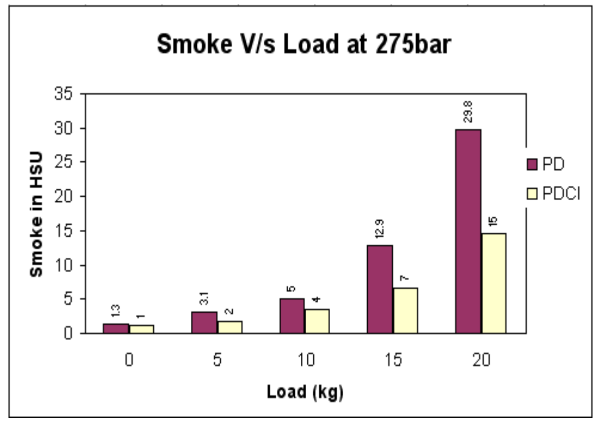

Figure 23. Smoke Value Vs Load graph, Plastic Diesel with Cetane Number Improver, at 275bar Pressure

IV. CONCLUSIONS

Direct implementation of plastic diesel at 200 bar injection pressure leads to poor B.S.F.C and Brake thermal efficiencies. It also caused for generation of higher amount of CO and HC in the exhaust gas and heavy deposits of carbon in the engine cylinder. The reasons for poor combustion quality of plastic diesel are higher viscosity and lower cetane number. Plastic diesel also contains higher amounts of sulphur which leads to acid rains. Blends of plastic diesel, with diesel lowers the viscosity and leads to good improvement in brake thermal efficiency. Plastic diesel 20 gives the 25.568 brake thermal efficiency at 200 bar injection pressure [11,12]. The cetane number improver gives better ignition quality and PDCI gives uniform heat release during the combustion. As a result of adding of CI, the improvement in the brake thermal efficiency is very low, but it gives smooth burning of fuel. Increase of injection pressure leads to reduction of fuel droplet size there by the surface area of the fuel droplets increases for the given volume of the fuel. As a result, vaporization, homogenization and rate of reaction with oxygen can be improved. Higher injection pressures such as 275 bar give better thermal efficiency and low pollutants. The combination of plastic diesel blends and increase of injection pressure lead to decrease of fuel viscosity and decrease of fuel droplet size. Pollutants are also low at this pressure. The cetane number improver gives better ignition quality and PDCI gives uniform heat release during the combustion.

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