Experimental Study on the Effect of Inlet Air Temperature on Waste Plastic Pyrolysis Oil with Diesel Fuelled HCCI Combustion Engine

R. Jyothu Naik, K. Thirupathi Reddy

Abstract*: *The main aim of the paper is to investigate the, combustion, emission and performance characteristics of blended waste plastic pyrolysis oil (WPPO 5%, 10%, 15% and 20%) with diesel fuel based Homogenous Charge Compressor Ignition (HCCI) combustion engine. The experiments have been conducted on HCCI mode engine by varying the intake temperature (353K, 373K, 393K & 413K). WPPO is used to inject the intake manifold based on port-fuel injection methodology despite the fact of intake-air is heated by utilizing electric-heater for attaining stable HCCI functioning. From outcome results it is observed that the temperature of intake air has more pre-dominant effect on combustion, performance and emissions characteristics. The maximum thermal efficiency of WPPO-diesel fueled HCCI functioning is acquired as 45.12% at 413K with WPPO-5% blended with diesel. Formerly No_x were decrease for all blends and later slightly increases but smoke is negligible. However, the CO and UHC emissions are first increased and then decreased for the HCCI operation.

Index Terms*: *Emissions, HCCI, Inlet Air Temperature, Waste Plastic Pyrolysis Oil

I. INTRODUCTION

Now-a-days, the automobile industry pre-requisites the efficient technologies such as low fuel consumption for enhancement of ambient air-quality, energy security and minimized green-house gases. Consequently, engines and respective fuels faces two main challenges in transportation systems like fuel-economy and minimized emissions levels on extreme competitive economies. As rigorous constant emission laws, even as increased non-presence of primary energy sources, the implementation of advanced very attractive and surroundings approachable combustion systems, connected with bio-fuels are gradually turned into vital & later investigations which is essential carried in this area [1]. Various investigations are explored being started for developing novel combustion systems & bio-fuels concepts. Numerous research investigations are presently being started in the region of developing bio fuels and new combustion concepts. In internal combustion engines the HCCI is a new combustion concept.

The combustion engine of HCCI proffers the prominent merits at this point of ultra-low emissions & high efficiency. The demand for plastic is expanding step by step due to its profoundly attractive characteristics. In spite of these points of interest, the plastic waste produced is making huge numbers of natural intricacies. The tremendous interest for plastic has made a lot of waste plastic and it has turned into a typical waste material in all landfills. It makes such huge numbers of issues in arranging on account of their non-degradable nature.[2,3].

As indicated by a study completed in India in 2012 demonstrates roughly 5.6 million tons of plastic waste is created each year. Out of this 60% is reused that implies 6500 tons of plastic waste is going as landfills every day. For diminishing the unsafe impacts of plastic waste the vast majority of the nation's actualize reusing and burning [4] of the considerable number of methods utilized for reusing the waste plastic pyrolysis (chemical reusing) has considered as the most ideal path since it recuperates the vitality content in usable fluid or vaporous shape. Pyrolysis system is utilized as a vitality recuperation technique and gives fluid fuel as significant item like that of oil fills [5,6].

Ongoing investigations propose that plastic oil can specifically be utilized in diesel engines without any major modifications. The most attractive scheme are composition of homogeneous charge by utilizing mixing formation. Maurya et al. [1] did exploration different experiments regarding the port-fuel injection technique for composition homogeneous mixes. Several experimentation are carried by varying equivalence ratio (2.0-5.0) and the intake charge temperature (120-150^{0}c) at a defined speed 1500 rpm with a pre-defined end-goal to attain the stable HCCI ignition system. It indicates that the 120^{0}c, λ =2.5 given enhances the combustion-parameters and efficiency, with reduced NOx emissions.

Nathan et al. [7] conducts the experimentation on performance evaluation of acetylene fuels on HCCI based engine. This results the greater fuel transforming efficiencies and attractive range of BMEPs. And also reported, optimum EGR values used to control the inlet temperatures which increase the thermal brake efficiencies and external knock heat charges are evading. Ganesh.D.et al. [8] conducted experiments on HCCI based engines by using jatropha-methyl easter fuel. The respective cooled EGR methods are developed to regulate the pre-on ignition of JME vapor-air blended. The attained results intimated the 72% of smoke and 81% of Nox emissions are reduced. Harisankar Bendu et al. [9] explore the experimentation on HCCI engines with the injection of port-fuel as ethanol.

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R. Jyothu Naik, Ph.D Research Scholar Department of Mechanical Engineering, Jawaharlal Nehru Technological University Anantapur, Ananthapuramu, Andhra Pradesh, INDIA.

K. Thirupathi Reddy, Professor of Mechanical Engineering Rajeev Gandhi Memorial College of Engineering & Technology, Nandyal, A.P. INDIA.

From the attractive results, it is started at 170ºC, the maximized range of thermal brake efficiency and combustion efficiency of ethanol was carried.

As well as, definite the smoke and NOx emissions are decreased slightly. Agarwal et al. [10] shown experiments on HCCI based engine fuelled with methanol and ethanol and by varying the temperatures of intake air. This outcome results are stated with that, ethanol & methanol components are good alternate for petro-fuels. Singh [11] explore different experiments regarding injection methodology of port fuel for defining homogeneous mixes.

The experiments is acquires by changing the temperature ranges of intake charge (160^0c, 180^0c and 200^0c) and EGR ratio (0% EGR, 10% and 20% EGR)) at various loads. The results exposed that the increasing intake charge temperature decreased HC and CO emissions but more NOx emissions at maximum load. S. Gowthaman et al. [12] investigates the experimentation with various temperature ranges of inlet charge (80ºC to 120ºC). It should be reported that, CO, HC and emissions are decreased but with increasing charge temperature about 100°C, higher the specific fuel consumptions. This investigation was indicated the impact of intake temperature of WPPO blended with diesel HCCI engine operation. In this reason, a DI based diesel engine is changed over the HCCI mode with a Port fuel injection (PFI) of waste plastic pyrolysis oil. By reason of an appropriate time taking for mixing through suction as well as, compression strokes, a total homogeneous charge was ready. The combustion, emission and performance characteristics of HCCI based engine is investigated in this paper.

II. EXPERIMENTAL METHODOLOGY

Fig. 1: Photographical view of experimental setup

A 4-stroke, water cooled, single cylinder, direct injection Kirloskar engine is converted into HCCI engine. External mixture formation technique (Port Fuel Injection system) was adopted. Fig1. Shows the photographical view of experimental setup and Fig2.0 shows the photographical view of Air Pre-heater. Experiments were conducted on both the conventional and HCCI mode engine by using the waste plastic pyrolysis oil blended with diesel fuel. The bio diesel fuels are blended at WPPO-5%, WPPO-10%, WPPO-15% and WPPO-20% ratios. One end of the engine shaft coupled with eddy current dynamometer to apply the loads. The inlet and outlet temperature and combustion were measured by using the thermometer coupled with digital display. Smoke and gas analyzer were used to measure the exhaust gases like Nox, HC, CO and smoke. By varying the engine load through dynamometer were observed the combustion, emission, performance characteristics of the bio diesels. The properties of waste plastic pyrolysis oil are illustrated in Table 1. The engine parameters are illustarted in Table 2. Accuracy and operating range of instruments used in the present study with their uncertainties listed in Table 3.

Fig. 2: Photographical view of Air pre-heater

Table 1: Properties of diesel, waste plastic pyrolysis oil

Properties	**Diesel**	**WPPO**
Color	orange	black
Specific gravity at 30^0c	0.88	0.822
Kinematic viscosity at 40^0c	2.0	2.3
Calorific value	46300	42100
Flash point	>51	37
Fire point	>55	40
Cetane Number	55	52

Table 2: Experimental Engine parameters

Rated power	3.50 kW
Bore x stroke	87.50 mm x 110.00 mm
Displacement	661.45 (cc)
Rated speed	1500 rpm
Compression ratio	18:1
Cooling method	water
Intake valve closing/opening	35° ABDC/4.5° BTDC
Exhaust valve closing/opening	4.5° ATDC/35° BBDC

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Table 3: Uncertainties of the instruments used

Instrument used	Range		Accuracy	Uncertainties (%)
Gas analyzer	NOx	0-5200 ppm	±40 ppm	±0.5
	CO	0-10%	±0.03%	±1
	UHC	0-3000 ppm	±10 ppm	±1
Smoke meter	0-100% opacity		±0.9	±1
EGT indicator	0-800^{0}c		±1^{0}c	±0.14
Pressure transducer	0-110 bar		±0.2	±0.2
Speed sensor	0-10000 rpm		±10 rpm	±1
Crank angle encoder	0-720^0 CA		±0.4^0	±0.01
Charge amplifier			±1	±0.1
Load indicator	250-5500 w		±10	±0.2

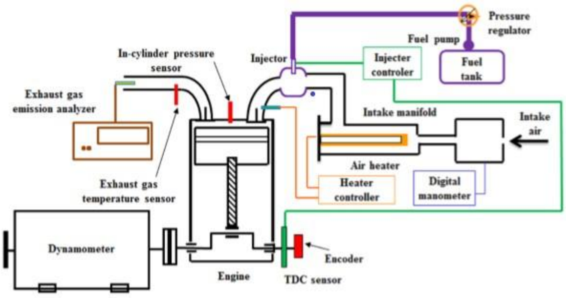


Fig. 3: Schematic diagram of the experimental setup

III. RESULTS & DISCUSSIONS

A. Effect of inlet charge temperature on Cylinder Pressure and Heat Release Rate

Fig. 4 shows the effect on temperature of intake charge on the rate of heat release and cylinder pressure of WPPO blend with diesel based HCCI working and makes comparisons with diesel at maximum load range. It is cleared, that the pressure data on cylinders of WPPO blend with diesel based HCCI is greater than diesel functioning at maximum load. To start the combustion of WPPO blend with diesel happens earlier by 1-2^0 CA than that of diesel because of intake temperature is high in the entire load conditions. The combustion HCCI engine of WPPO blend with diesel shows the maximized reaction rates increased due to temperature of intake air. The higher peak pressure and the earlier SOC are caused by the increase temperature of WPPO blend with diesel. The higher peak pressure of cylinder at 100% as full-load is observed to be about 58 bars and a impact is found at 373K also, the misfire occurrence is observed at 413K.The ignition rate is very high in HCCI, as burning happens at the same time to the entire cylinder charge. Temperature and species concentration are depended by combustion rate. From the figure1 it is observed that the WPPO blend with diesel HCCI operation shows a single stage heat release rate compared to the diesel HCCI operation.

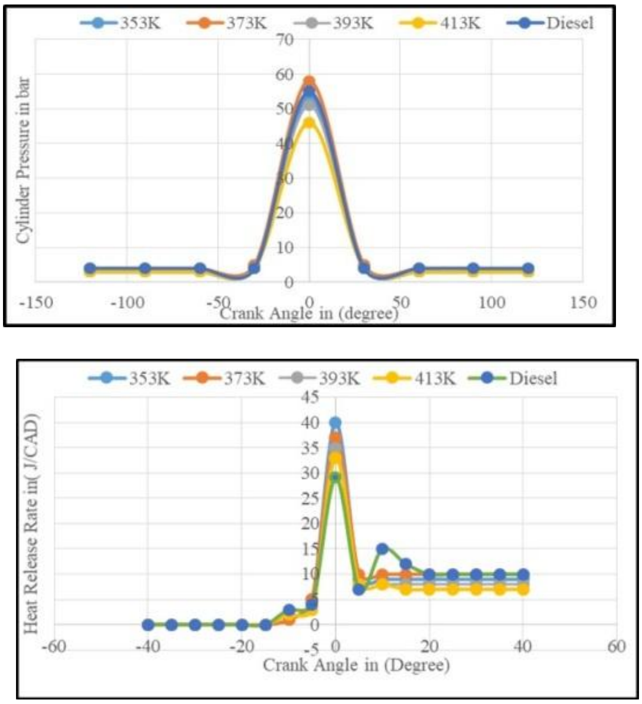
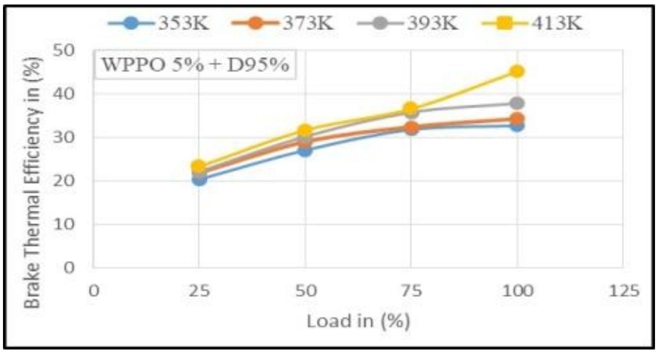


Fig. 4: Effects of intake charge temperature on Cylinder Pressure and Heat Release Rate

B. Effect of inlet charge temperature on Brake Thermal Efficiency

Fig.5 shows the effect of intake charge temperature on Brake thermal efficiency of HCCI engine for selected fuel blends operation at different loads. The increasing the load conditions increase the brake thermal efficiency also. The lower BTE is found that the lower rates of engines due to retarded start of combustion in HCCI engine the heat losses are lower because of LTC, combustion time is less, better mixture homogeneity is causes to less soot formation. The higher combustion temperatures and high HRR are affected by the advance start of combustion. Hence the surfaces of the cylinder and piston are increased by heat loss therefore the net work done is decreases. Meanwhile the start of combustion leads to low combustion efficiency due to lower LTC and increased emissions. The higher thermal efficiency for WPPO-diesel fueled HCCI functioning is found to be 45.12% at 413K with WPPO-5%with diesel.



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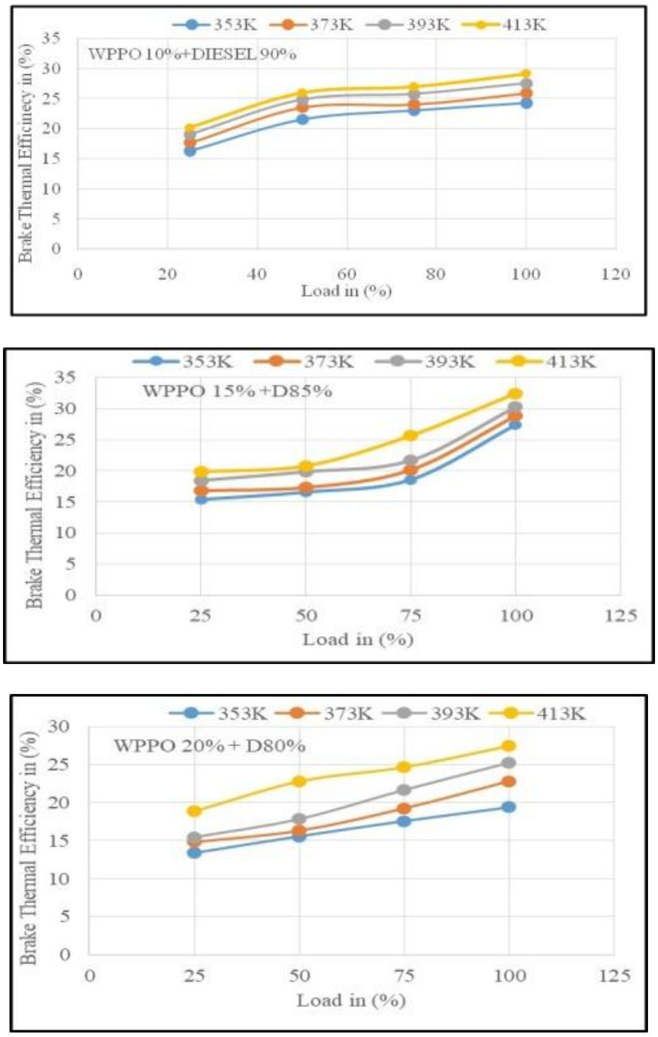

Fig. 5: Effect of intake charge temperature on Brake thermal efficiency of fuel blends at different loads

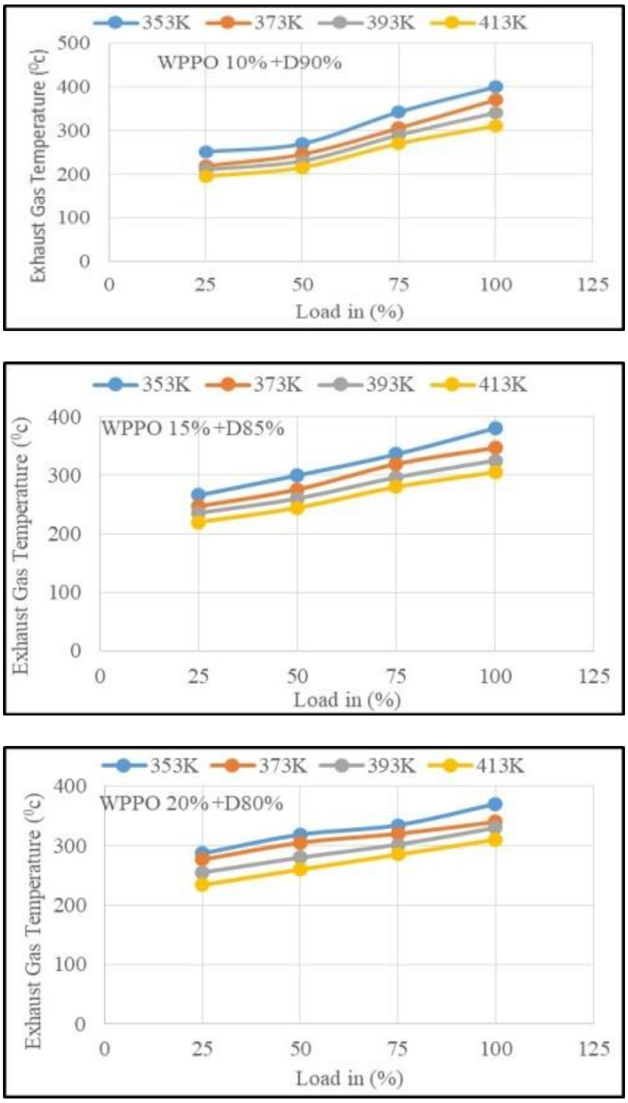

Fig. 6: Effect of intake charge temperature on Exhaust Gas Temperature of fuel blends at different loads

C. Effect of inlet charge temperature on Exhaust Gas Temperature

Fig.6 represents the certain variations of EGT with engine load for waste plastic pyrolysis oil blend with diesel-HCCI operation. As the results, for certain intake temperatures are estimated. But the EGT goes to reduces based on intake temperatures, when the intake temperatures are increased the start of combustion is very advanced nature due to faster reaction rates and chemical kinetics. A pre-start of ignition with small combustion duration affects with greater connective heat transfer.

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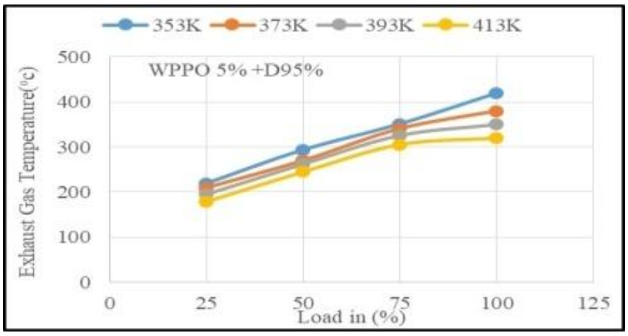

D. Effect of inlet charge temperature on No_x Emissions

Fig.7 shows the difference of the Nox Emissions for the different fuel blends like WPPO-5%, WPPO-10%, WPPO-15% and WPPO-20% with different load conditions in HCCI engine. From the figure it is noticed that the No_x emissions are increase with the engine load for the WPPO fuelled with diesel HCCI engine due to high combustion temperature of the burned gases. High No_x emissions are caused by maximizing the resident time of combusted gases which are highly affected by increasing the temperature intake due to pre-start of ignition. At 100% load condition, the maximized Nox emissions are investigated for WPPO-diesel based fuel of HCCI working at 413K charge temperature.

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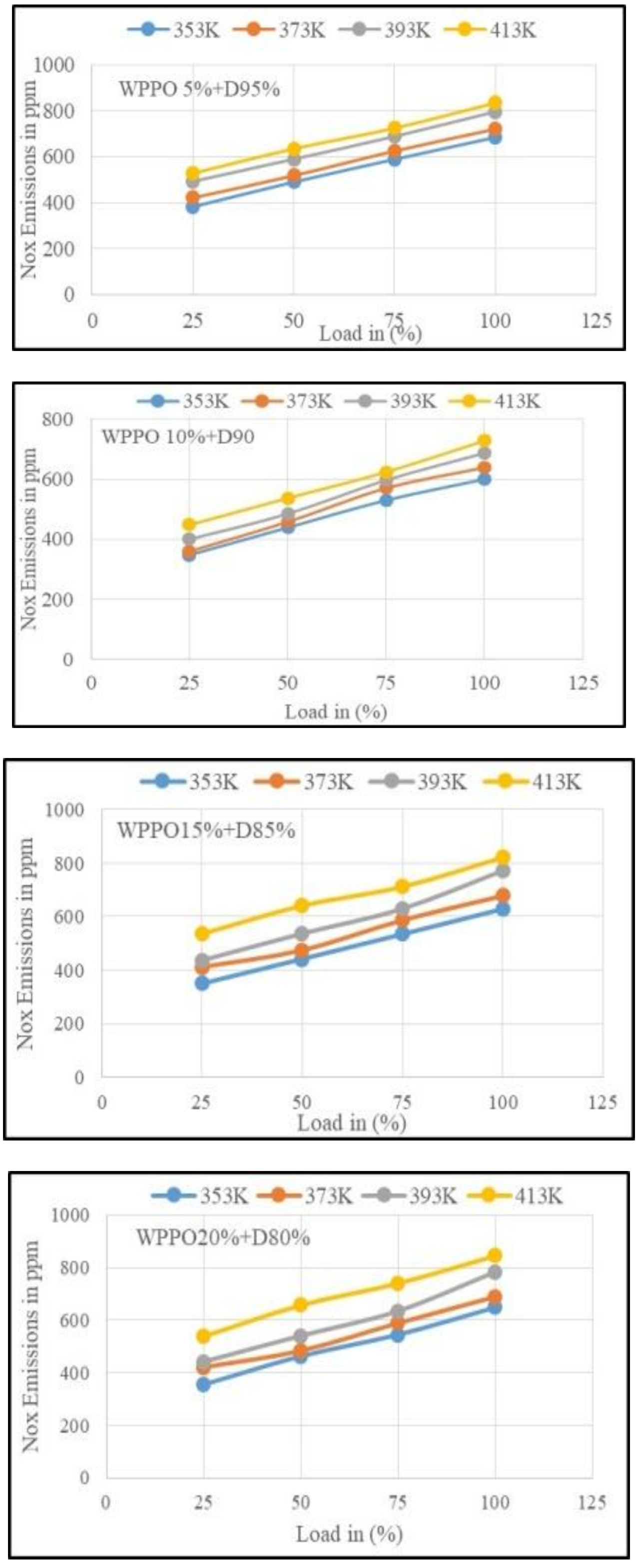

Fig. 7: Effect of intake charge temperature on Nox Emissions of fuel blends at different loads

E. Effect of inlet charge temperature on CO Emissions

Fig.8 shows the effect of intake charge temperature on CO Emissions of HCCI engine for selected fuel blends operation at different loads. LTC is causes by the inadequate oxide temperatures of certain gas, results the development of CO emissions in HCCI based engines. The decrease in the CO emission is found with increase engine load because of increase in temperature of cylinder to peak level. The low CO emission are also occurred due to advanced start of ignition while greater CO emissions are attained due combustion phasing as very late cases. The CO emission is higher when the temperature ranges of lower air-intake as (353K) and loads due to misfiring. The load limit treated as low of the WPPO-Diesel based fueled HCCI functioning is authorized by CO emissions.

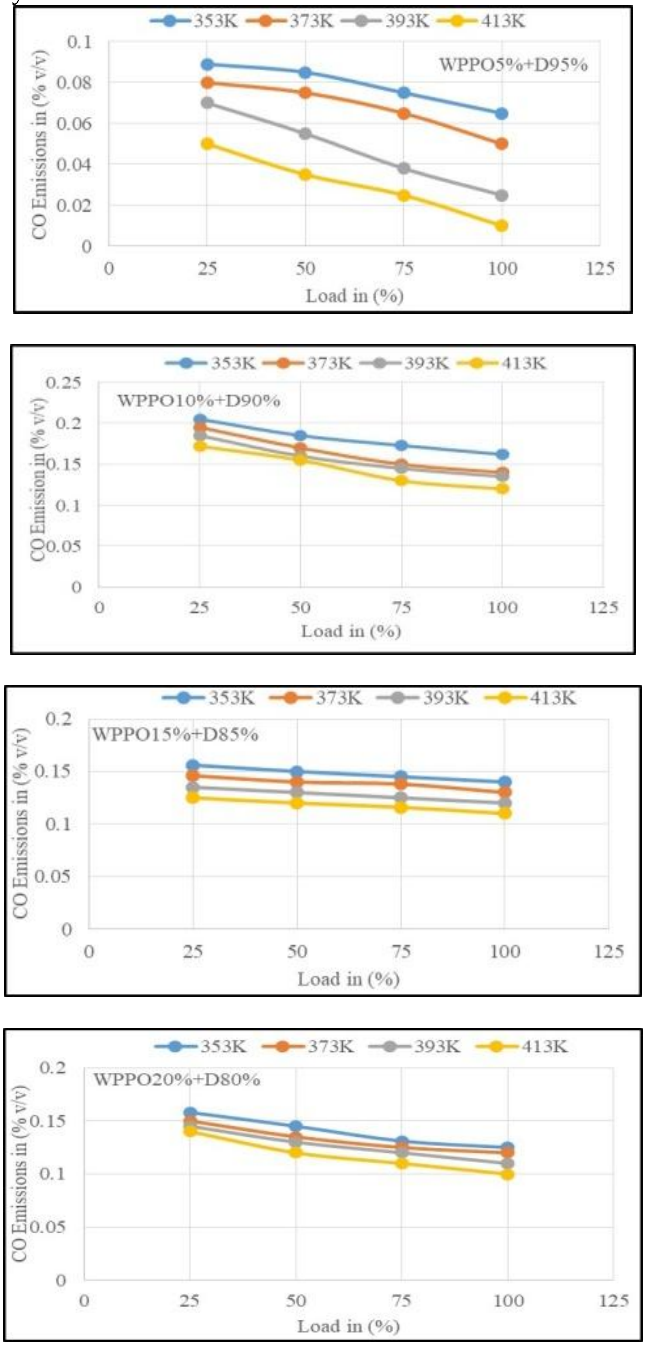

Fig. 8: Effect of intake charge temperature on CO Emissions of fuel blends at different loads

F. Effect of inlet charge temperature on Unburned Hydrocarbons (UHC) Emissions

Fig. 9 shows the effect of intake charge temperature on UHC of HCCI engine for selected fuel blends operation at different loads. The in-completion of ignition of hydro-carbon fuels are indicated based on formation of UHC emissions in intended HCCI based engine due to LTC.

The temperature at combustion is very lower near by the walls of combustion region due to heat losses. Extreme parts of UHC emissions increases from combustion regions. It is very clear that maximizes the temperatures of intake charge and load set-ups are decreased by the UHC emissions due to increased equivalent level with load.

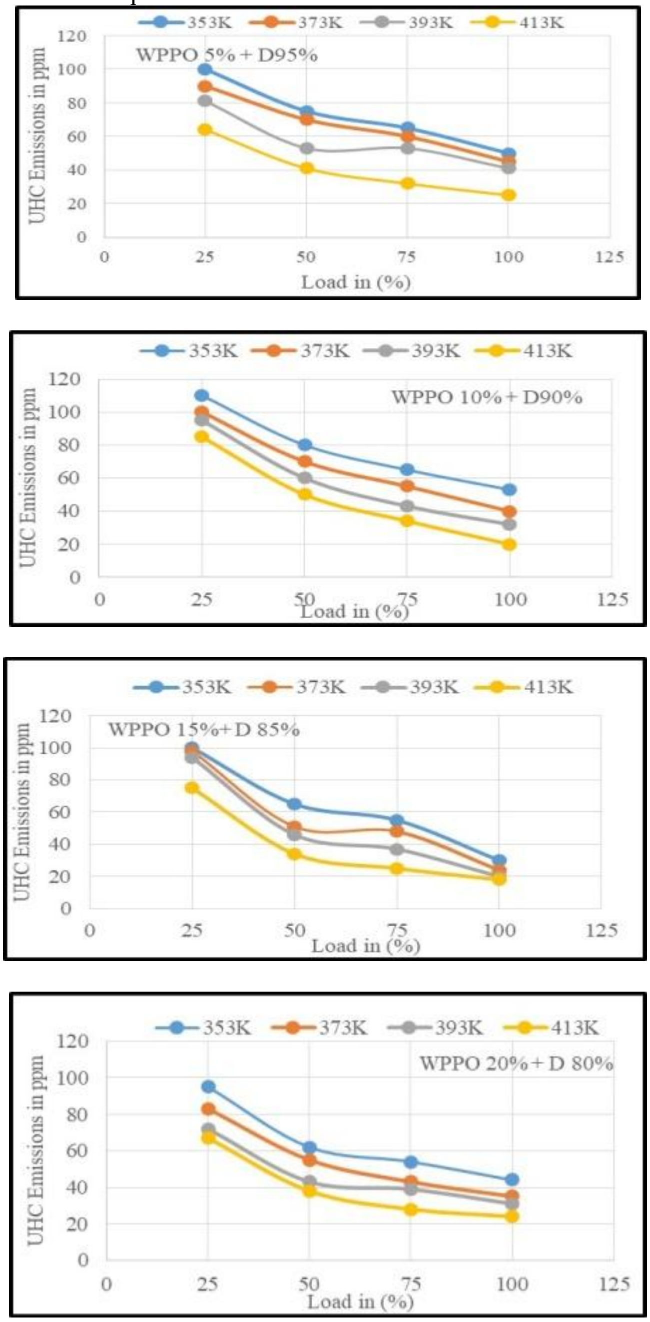

Fig. 9: Effect of intake charge temperature on UHC of fuel blends at different loads

G. Effect of inlet charge temperature on Smoke Opacity

There are three factors that affect the smoke formation in diesel engine.

1. Absence of oxidation temperature
2. Solid carbon in the fuel
3. For mixture composition, a short-time is needed.

From the fig. 10 it is noticed that the decrease in nature of smoke emission is found for increase in the engine load and intake charge temperature. At full load, WPPO-20% and at 413K the smoke emission is negligible due to composition of high grade homogeneous mixes with maximized ignition delay. The intake temperature and load causes to decrease the smoke emissions. It requires high resident time burned gases and oxidation temperature, smoke emission noticed to be negligible at 413K, full load and WPPO-20%. Be that as it may, at higher load ranges as a result of non-availability of adequate air and abnormal combustion there was a noticeable white smoke emission.

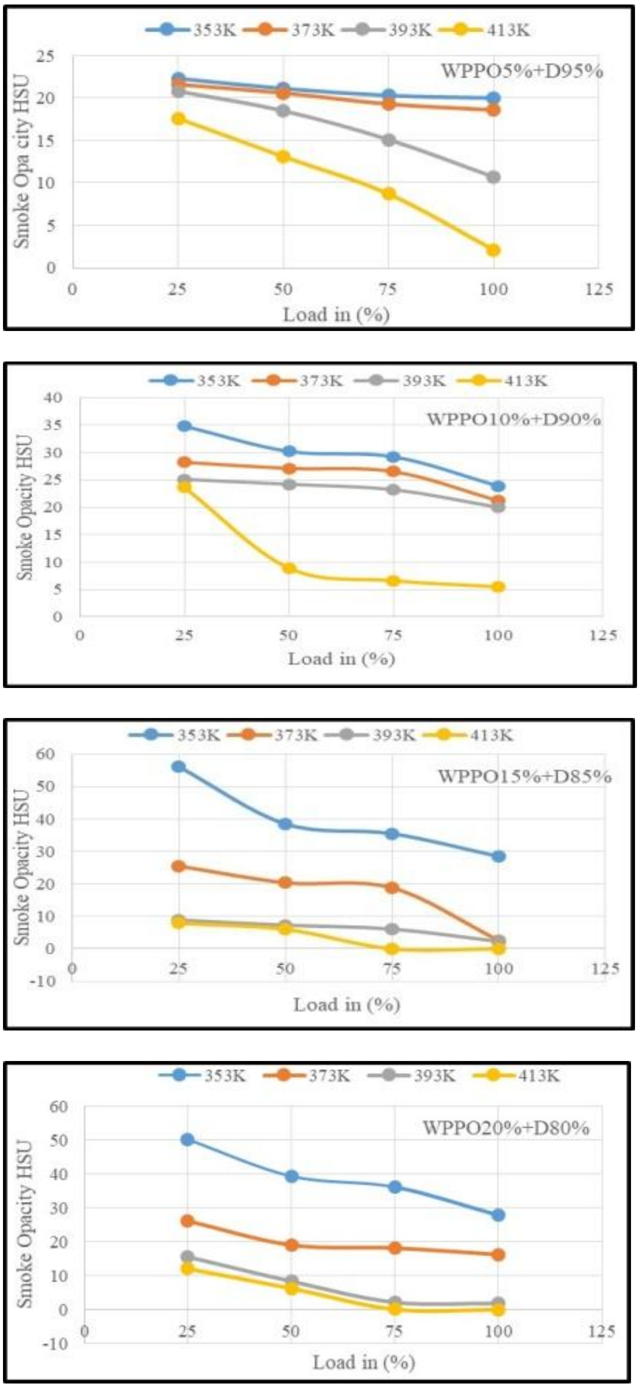

Fig. 10: Effect of intake charge temperature on Smoke opacity of fuel blends at different loads

IV. CONCLUSION

WPPO blended with diesel used effectively for the HCCI and results were analyzed which are presented as follows

- Because of larger deposition of plastic wastes in the earth surface pyrolysis process shows better conversion of plastics in to useful hydro carbon fuels like petrol, diesel.

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- On efficiently doing this process the production cost per liter fuel decreases when compared to crude oil refining. Because of increased fuel demand this process illustrations an alternative way of producing fuel which can able to meet the global fuel demand.
- Advance start of combustion and decreased in EGT were more affected by increase in inlet air temperature.
- HCCI limited by the operating regime. Combustion noise limited by the higher load and the CO emissions are limited by the lower load.
- Maximum thermal efficiency for the WPPO-5% blended with diesel HCCI operation observed as 45.12% at 413K inlet temperature.
- For the HCCI operation smoke emission was observed below 0.1% that is almost negligible.
- The carbon monoxide and unburned hydrocarbons emission were much higher for HCCI engine than DI diesel engine
- The biodiesel fuelled HCCI engine has lower CO emission because of higher oxygen molecule present in the cylinder during the combustion process. The level of CO and UHC emission was decreased with increase the inlet air temperature.
- By using Low Temperature Combustion method that is HCCI operated with biodiesel has advantageous with respect to engine performance and combustion compared to conventional engine.

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