Performance and Emission Characteristics on Mixing of Waste Plastic and Tyre Pyrolysis Oil Blends With Diesel In a Single Cylinder 4-Stroke Diesel Engine With EGR

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Abstract: Energy consumption in the form of fossil fuels has increased continuously. Because of its light weight, easily carrying and low price, the modern world utilizes many components with waste plastic and tyres as a primary source. As a result of this, there is a problem of dumping waste plastics and tyres into land fields and municipal waste produces pollution problems. The latest trend towards converting waste into quality fuels is waste to energy. This present research work provides detailed information by using Exhaust Gas Recirculation based on experimental work using Waste plastic and Tyre pyrolysis oil blends with diesel. The experiment uses a single cylinder, four stroke, constant speed, water-cooled, direct injection VCR diesel engine. Experiments were performed using different blends of WPPO and WTPO blended with diesel to determine the performance and emission characteristics of a diesel engine using exhaust gas recirculation. The information obtained were evaluated for multiple parameters such as brake thermal efficiency, brake-specific fuel consumption, mechanical efficiency, and emission study such as carbon oxides, nitrogen oxides, and unburned hydrocarbons. Diesel was mixed with 5%, 10%, 15%, 20%, 25% and 30% by quantity of both WPPO and WTPO and named D100, B5-D95, B10-D90, B15-D85, B20-D80, B25-D75, and B30-D70, respectively. Among all the blends B20-D80 Blend has shown better engine performance and emission control. B20-D80 is taken as an optimum blend and EGR is taken on this blend to reduce emissions with 10 and 20 percent.

KEY WORDS **- Waste plastic and tyre pyrolysis oil, Exhaust Gas Recirculation, alternative fuels, diesel engine, pyrolysis, performance and emissions.**

I. Introduction

Energy, environment and economy are one of the main contributors to the country's development. Daily fossil fuels are depleting, resulting in rising prices of petroleum products around the globe. This shows the need for an cheaper alternative fuel to meet the transportation needs, and electric power generation in the rural area. On the other hand, waste product generated with growth of population and its management plays essential role to maintain economic and healthy country. Among many types of Solid waste, plastic waste and tyre waste is a major problem as its non-biodegradable in nature. Due to their lightweight, durability, non-perishability, quicker production rate and flexibility in design and commodity supply, plastic use has become a vital component of today's world[2,1]. **Hariram Venkatesan[1]**reported that, based on the experimental study into the combustion and performance features of a four-stroke DI compression ignition engine driven with straight diesel and waste plastic oil blends, the brake thermal efficiency showed small differences at low load but noticeable changes were observed at complete load (30.27%) which might be due to increased calorific value of PO blends and Mechanical efficiency was observed to have minimal impact on all fuel mixtures at all loads, but BSFC was reported to be higher for all non-load fuel mixtures and fuel consumption declined with load increases. **Ankit Varma[2]** researched the experimental inquiry on the addition of waste plastic oil resulting in increased brake thermal efficiency (BTE) and decreased specific fuel consumption. **Muhammed Qasim and Ansari[3]** conducted experimental study on a diesel engine operated with fuel blends extracted from a combination of Pakistani waste tyre oil and soybean oil biodiesel revealed that all the fuel blends tested showed reduced BTE, smoke emissions but increases the NOx emissions. **Ventaka subbaiah and Dr. B. Durga Prasad[4]** have been noticed that the greater deposition of plastic waste in the earth's pyrolysis cycle leads to a better transformation of plastic to effective hydrocarbon fuels such as petrol and diesel. The cost of manufacturing per liter of fuel reduces when compared to crude oil refining when performing this method effectively. This method showed an alternative way of generating fuel that could satisfy the worldwide demand for fuel due to enhanced fuel demand. The plastic oil blend[B20] generates the same power as diesel. Plastic oil indicates slightly greater emission values than diesel when absorbing the emission trait graphs. It is feasible to distinguish better fuel quality from the alteration in manufacturing such as pressure heating of the acquired crude type of fuel. If manufacturing is carried out effectively with defined parameters, quality fuel can be produced, this will take the place of standard diesel. **M.Mani[5]** conducted the test on Performance, Emission and Combustion Characteristics of a DI Diesel Engine Using Waste Plastic Oil and reviles that engine fuelled with waste plastic oil exhibits greater heat efficiency up to 75 percent of the rated energy smoke emission decreases by about 40 percent but CO, NOx emissions increase when the engine is operating at complete load circumstances. **Ioannis Kalargaris[6]** noted that the brake thermal efficiency of the engine was 3-4% smaller for PPO90 and 2-3% lower for PPO70 compared to diesel and all measured emissions (NOX, UHC, CO and CO2) were greater for PPO70 and PPO90 compared to all measured emissions (PPO70 and PPO90).

Dr. D. Subramanyam[7] researched the Performance Investigation of Diesel Engine Using Waste Plastic Pyrolysis Oil and Diesel Blends that Waste to Energy is the current trend that will concentrate on different research fields. Waste plastic oil blend (WPO20) brake thermal efficiency BTE 26.24 percent at 3.67 kw bp was higher than diesel (24.85 percent). Specific fuel consumption was slightly greater than diesel fuel consumption. Plastic oil's exhaust gas temperature with diesel blends is growing owing to longer plastic oil ignition delay. Carbon monoxide emissions increase with increased brake power under load circumstances at 3.67 kw. WPO15, WPO20, WPO30, WPO40 and WPO50 3.69, 3.63,3.72, 3.96, 4.18 and 4.18 percent. Carbon dioxide emissions from plastic oil blends with diesel rises significantly at WPO20 brake power 2.94 kw lower than diesel emissions owing to full fuel combustion. Hydro carbon emission plastic oil at all brake powers blends more than diesel emission. The emissions of 3.67 kw bp hc were 1606, 1610, 1609, 1614, 1616 and 1618 ppm for diesel, WPO15, WPO20, WPO30, WPO40, and WPO50 were 1606, 1610, 1609, 1614, 1616 and 1618 ppm. **Mitesh D.Paramar[8]** operates on Emission Analysis Of C.I Engine Using Tyre Pyrolysis Oil And Diesel Blend, suggesting that CO emissions are increased with TPO mix in exhaust emissions. The D75T25 mix provides the required impact. The emission of HC and CO and co2 decreases with the TPO blend and the optimum values of the D95T5 blend. With the rise in separate TPO blend D75T25, the emission of NOx and O2 provides the desire impact than other blends and desel. **Bhatt Prathmesh M[9]** done his research work on the suitability of tyre pyrolysis oil (tpo) as an alternative fuel for internal diesel engines and stated that scrap tyre pyrolysis develops oil that can be used as liquid fuels for industrial furnaces, foundries and boilers in energy plants owing to its greater heat, low ash, residual carbon and sulphur content. However greater density, Kinematic viscosity and Lower Cetane number of tyre oil indicates that the reaction of tyre oil in internal combustion engine can be studied by adding Tyre oil with DF in different proportions, maintaining the quality of the mixture by regulating the density and viscosity of the mixture in permissible ratios. Further improvement in fuel quality in terms of desulphurization, decrease of viscosity and fragrance contents and boost in the percentage of Cetane is needed by appropriate distillation of tire oil and use of suitable Cetane enhancer if tire oil is to be used as a fuel in the internal combustion engine. **R. Senthil Kumar[10]** investigated a DI naturally aspirated engine using tire pyrolysis oil-diesel blends as a biodiesel and realized that pyrolysis blends, brake thermal efficiencies are lesser than diesel. This may be due to reduced heating value and reduced pyrolysis combustion. Due to reduced viscosity, the rise in thermal efficiency for 50% compared to 75% can be ascribed to improved fuel atomization. Reduction in thermal efficiency by approximately 14 percent is greater than that of the other pyrolysis oil blends is eventually closer to blending the distilled method to fix the distinct aims and NOx values for 50 percent and 75 percent of the pyrolysis oil is lower than diesel and CO and HC emissions for diesel can be high owing to the existence of unsaturated oil. Smoke is greater than diesel for tyre pyrolysis blends. **Sk. Mohammad Younus[11]** researched the performance and emission attributes of Diesel Engine Fueled With Tyre Pyrolysis Oil & Diesel Blends with Additives and reported that Brake thermal efficiency improved with all blends compared to standard diesel fuel and Brake specific fuel consumption decreased with blends compared to diesel fuel. Compared to diesel, CO, CO2 and HC emissions are considerably reduced with the blends and lastly the blend TPE 20 demonstrates better efficiency compared to other blends (TP10,TP 20,TP 30,TPE 10&TPE 30) and diesel. **Pawan A R[12]** conducted his research work on the performance and emission characteristics of Tire Pyrolysis Oil (TPO) Blend with Diesel for Weird Composition and revealed that the engine's brake thermal efficiency decreases with increased concentration of TPO blend than diesel. Thermal efficiency for the operation of diesel fuel at varying loads. In case of TPO 10% blending, it's 22.47%. In the event of a 20% mix, that's 15.83%. It is 18.55 percent for 30 percent mix and the TPO-DF mix demonstrates greater BSFC value than diesel because of reduced TPO-DF blend calorific value. As the TPO-DF's BSFC load increases, it reduces. TPO-DF's mechanical efficiency improves as the load rises. The highest efficiency achieved is 21.64% for 10%. In the event of a 20% blend, it is 53.2%. And it's 49.7 percent in 30%. At greater loads, the CO emission is greater and grows with the blend proportion (TPO-DIESEL). Similarly, the HC emission is large for greater loads. The emission concentration is high in all load circumstances for the CO2 emission mix at 30%.

Nomenclature

WPPO	Waste plastic pyrolysis oil
WTPO	Waste tyre pyrolysis oil
CO	Carbon monoxide
UHC	Unburnt Hydro Carbons
CO_2	Carbon dioxide
NOx	Oxides of nitrogen
DI	Direct Ignition
CI	Compression Ignition
PPM	Parts Per Million
EGR	Exhaust Gas Recirculation

11. PRODUCTION PROCESS OF WPPO AND WTPO

2.1 Pyrolysis

In the lack of oxygen, pyrolysis is usually described as the monitored heating method of a material. The macro-molecular structures of polymers are split into lower molecules and sometimes monomer units in plastics pyrolysis. Further degradation of these subsequent molecules is dependent on a number of different conditions including temperature, residence time, catalyst presence and other process circumstances. The response to pyrolysis can be performed with or without a catalyst. In a cylindrical chamber or reactor, plastic and tyre waste is continually handled. At 300^0C-500^0C the plastic and tyre is pyrolized.

2.1.1 Condenser

It cools the reactor's entire heated vapour. The cold water to pass through its exterior region enters and exits to the outlet through the inlet. This is used for vapour cooling. The gaseous hydrocarbons are condensed to about 30 – 35°C at a temperature of around 350°C.

2.1.2 Reactor

It is a 1000 mm long cylindrical stainless steel container with an inner diameter of 300 mm, an outer diameter of 320 mm secured on one end and an outlet tube on the other. Inside the reactor is put the entire cylindrical container. External heating is carried out from below the container and inside the reactor using the raw material such as Cole, wood, coke, etc. The reactor for lagging is produced of stainless steel, mild steel and clay. The reactor is heated at about 1450°C and higher temperatures.

2.1.3 Process Description

The method of thermal cracking is used to convert waste plastic into liquid fuel. For this specific experiment, only one sort of waste plastic is chosen, i.e. low density polyethylene. Waste plastic and tyre is collected and cleaned using liquid soap and water as strong smooth forms. Washed plastics and tyre are cut to a size of 3-5 cm to fit conservatively into the reactor. The experiment is performed with no vacuum applied during the thermal cracking process under a closed system. In a batch process system, we used polyethylene plastics of low density due to the relatively low conversion temperatures for these plastics. At the beginning of melting the waste plastics and Tyre, heat is applied from 100°C, the melted waste plastic and Tyre transform into liquid slurry when temperature increases gradually. When the temperature rises to 570°C, liquid slurry becomes vapour and then the vapour passes through a condenser unit. We obtain liquid fuel at the end of this phase. Between 100ºC and 250ºC about 20-30 percent of the fuel is gathered and then the next 40 percent is obtained when raised to 325ºC and the output is lastly finished when retained at 400ºC. Plastic parts are not and lastly when maintained at 400ºC the output is complete during the thermal cracking process. Plastic and Tyre pieces are not immediately broken down during the thermal cracking phase because plastics have distinct chain hydrocarbons. Only the straight chain hydrocarbon is applied in the starting mode heat. The temperature profile that slowly breaks this plastic and tyre carbon bond is further improved. The long chains molecules are dissolved step by step with the temperature rise.

111. ENGINE SETUP AND PROCEDURE

For experimental testing, Kirloskar single cylinder water cooled variable compression diesel engine fitted with EGR is used. To apply loads to the engine, the Eddy current dynamometer is connected to the flywheel. To inject the fuel, a 200 bar injection pressure is retained. The pressure of the cylinder is evaluated by the piezo-sensor installed on the head of the engine cylinder and the angle of the crank encoded on the fly wheel. The conventional engine is supplied with 0 to 25º BTDC injection point variation. The HC, CO, CO2, UBHC and NOX emissions are evaluated using the fire gas analyzer AVL-DIGAS 444. AVL smoke meter is used to measure the opacity of the smoke.

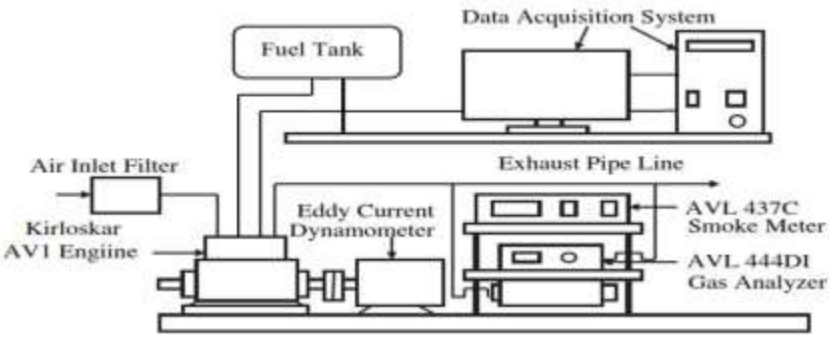

Figure 1: Schematic diagram of experimental set up

Figure 2: Complete Experimental engine setup

Engine make	VCR Engine test setup 1 cylinder, 4 stroke, Diesel with EGR (Computerized) engine
Type	Kirloskar, Type 1 cylinder, 4stroke Diesel, water cooled engine.
EGR	Water cooled, ss 304, Range 0-20%
Displacement	661 cc
Bore & Stroke	87.5 mm & 110 mm
Compression ratio	12 to 18
Fuel	Diesel &Petrol
Rated brake Power	3.5 KW
Rated Speed	1500rpm
Dynamometer	Eddy current, water cooled with loading unit
Ignition system	Compression Ignition
Injection point variation	0-25 deg BTDC
Connecting rod length	234mm
Software	"IC Engine software".

Table 1, Test Engine specifications

3.1 Test procedure

This research focuses on the use of WPPO and WTPO as fuel in the conventional diesel direct injection (DI) engine. Some of these two biodiesel characteristics are closer to diesel oil. As a result, wppo and wtpo biodiesel are selected as an alternative fuel and it is experimented in a DI diesel engine along with the application of EGR with 10% and 20% to explore the maximum possible diesel replacement. However, since the combination of these two biodiesel mixed with diesel has a increases engine performance.

We used these wppo and wtpo oil by reducing its viscosity. Also engine will be made to run with blends of diesel and wppo and wtpo biodiesel consisting of 5%, 10%, 15%, 20%, 25% and 30% in to the diesel fuel along with EGR 10% and 20%.

BLENDS	BLENDS PROPORTIONS
B5-D95	2.5% WPPO + 2.5% WTPO + 95% Diesel
B10-D90	5% WPPO + 5% WTPO + 90% Diesel
B15-D85	7.5% WPPO + 7.5% WTPO + 85% Diesel
B20-D80	10% WPPO+ 10% WTPO + 80% Diesel
B25-D75	12.5% WPPO + 12.5% WTPO + 75% Diesel
B30-D70	15% WPPO + 15% WTPO + 70% Diesel
B20-D80	10% EGR
B20-D80	20% EGR

Table 2: Blending proportions table

IV. PROPERTIES OF DIESEL, WPPO, WTPO AND ITS BLENDS

S.No	Fuel	Density (kg/m^3) at 30^0c	Kinematic viscosity(cst) at 30^0c	Specific gravity	Flash point ^0c	Fire point ^0c	Calorific value kj/kg	Cetane number
1	Diesel	840	2.02	0.84	43	45	42000	55
2	WPPO	830.55	2.04	0.830	37	40	44340	52
3	WTPO	920.35	2.23	0.92	38	41	42600	58

Table 3: Physical properties of diesel, waste plastic pyrolysis oil, waste tyre pyrolysis oil.

S.No	Fuel	Density (kg/m^3) at 30^0c	Kinematic viscosity(cst) at 30^0c	Specific gravity	Flash point ^0c	Fire point ^0c	Calorific value kj/kg
1	B5-D95	843	1.98	0.843	35	37	42750
2	B10-D90	841	1.332	0.841	37	40	43100
3	B15-D85	841.5	1.296	0.8415	37	40	43480
4	B20-D80	841	1.248	0.841	37	40	43500
5	B25-D75	841	1.480	0.841	37	41	43930
6	B30-D70	841.1	1.4006	0.8411	37	42	44300

Table 4: Physical properties of biodiesel mixtures

V. RESULT AND DISCUSSIONS

5.1 Performance Analysis

5.1.1 Brake specific fuel consumption:

Figure 3 shows the differences in brake-specific fuel consumption of various blends with regard to brake energy. The plot reveals that the BSFC is diminishing as the load increases. The BSFC obtained 0.39 kg / kw-hr, 0.366 kg / kw-hr, 0.361 kg / kw-hr, 0.36 kg / kw-hr, 0.34 kg / kw-hr, 0.36 kg / kw-hr, 0.38 kg / kw-hr for diesel fuels, B5-D95, B10-D90, B15-D85, B20-D80, B25-D75, B30-D70 respectively under maximum load conditions. BSFC's percentage variation of all diesel blends at varying load conditions is declining at 0.938 percent, 0.925 percent, 0.923 percent, 0.871 percent, 0.924 percent and 0.974 percent. For the B20-D80 blend, which is 0.34 kg / kw-hr, the minimum brake-specific fuel consumption is achieved, i.e. 0.871 percent reduces with diesel fuel at 10 kg load. The BSFC for B20-D80 is obtained lower compared to all fuel blends, but for B5-D95, B30-D70, the BSFC is closer to diesel. Figure 4 shows the brake-specific fuel consumption effect of exhaust gas recirculation. The plots reveal that as the EGR percentage increased brake-specific fuel consumption due to dilution of clean air with exhaust gas resulting in poor oxidation, combustion and lower power output, more fuel is needed to produce the same power output as diesel fuel. Compared to other fuel blends, BSFC for B20-D80 with 20 percent EGR is observed to be higher for the entire load range. It may be due to greater calorific value and reduced blending fuel viscosity. The BSFC is 0.39 kg / kw hr, 0.34 kg / kw hr, 0.34 kg / kw hr and 0.4 kg / kw hr at full load conditions. BSFC's percentage variation on diesel at distinct EGR percentages is 0.871%, 0.871% and 1.025% respectively.

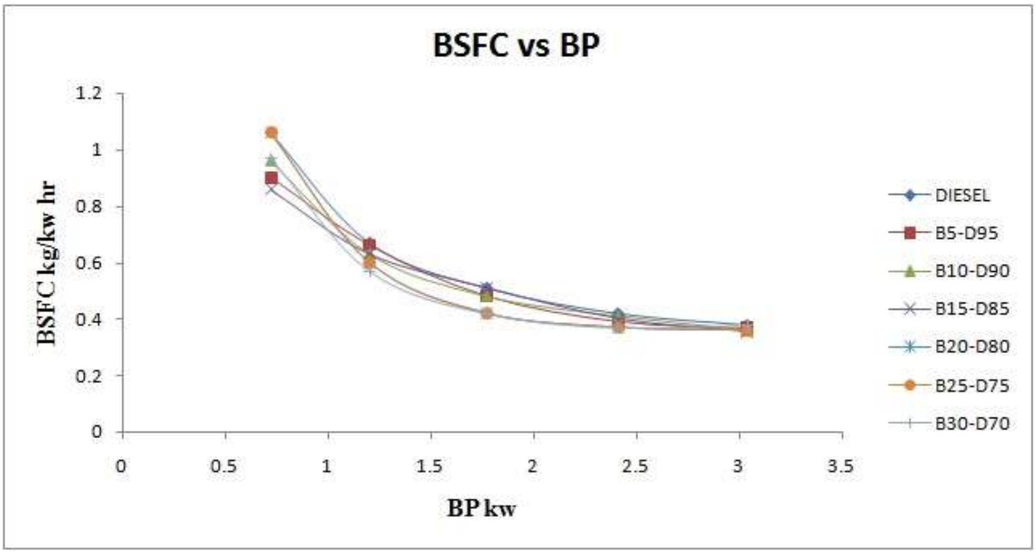

Figure 3: Variation of BSFC with Brake power

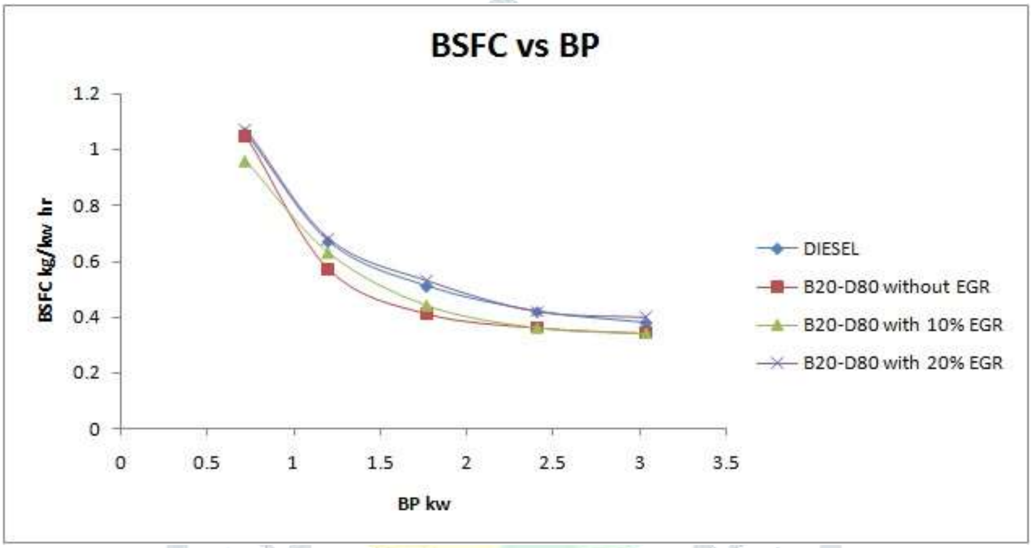

Figure 4: Variation of BSFC with Brake power for various EGR percentages

5.1.2 Brake thermal efficiency (BTE)

The Brake Thermal Efficiency Variations regarding Brake Power as shown in the figure 5. The brake thermal efficiency generally improves with increased load. As the load increases the brake power also increases and decreases the bsfc and heat loss which improves the brake thermal efficiency. Brake thermal efficiency is 22.08 percent, 23.45 percent, 23.68 percent, 23.18 percent, 24.73 percent, 23.78 percent and 22.67 percent for fuel blends such as Diesel, B5-D95, B10-D90, B15-D85, B20-D80, B25-D75, B30-D70 respectively, from graphs at 10 kg load conditions the percentage variation of Brake thermal efficiency of all diesel blends at different load conditions is increased by 1.062%, 1.072%, 1.049%, 1.12%, 1.076% and 1.02%. The maximum brake thermal efficiency for the B20-D80 blend is 24.73 percent, i.e. 1.12 percent higher than diesel fuel, and blends such as B25-D75 and B30-D70 decreased as compared to B20-D80 due to an increase in the percentage of WPPO and WTPO in diesel fuel. Figure 6 demonstrates the brake thermal efficiency impact of exhaust gas recirculation. With the increase in the EGR flow rate, the brake thermal efficiency decreases marginally. The brake thermal efficiency is 22.08 percent, 24.73 percent, 23.63 percent and 21.25 percent for fuel blends such as diesel, B20-D80 without EGR, B20-D80 with 10 percent EGR and B20-D80 with 20 percent EGR, from the chart at 10 percent load condition we absorbed. The decrease in brake thermal efficiency is due to elevated percentages of EGR resulting in a deficiency in the concentration of oxygen in the process of combustion and a greater substitution of hot air from exhaust gases. Higher exhaust gas flow rate decreases the average combustion temperature in the combustion chamber resulting in reduced brake thermal efficiency at all loads. The percentage variation in engine thermal efficiency of all blends at distinct diesel EGR rates is 1.12%, 1.070% and 0.96% respectively.

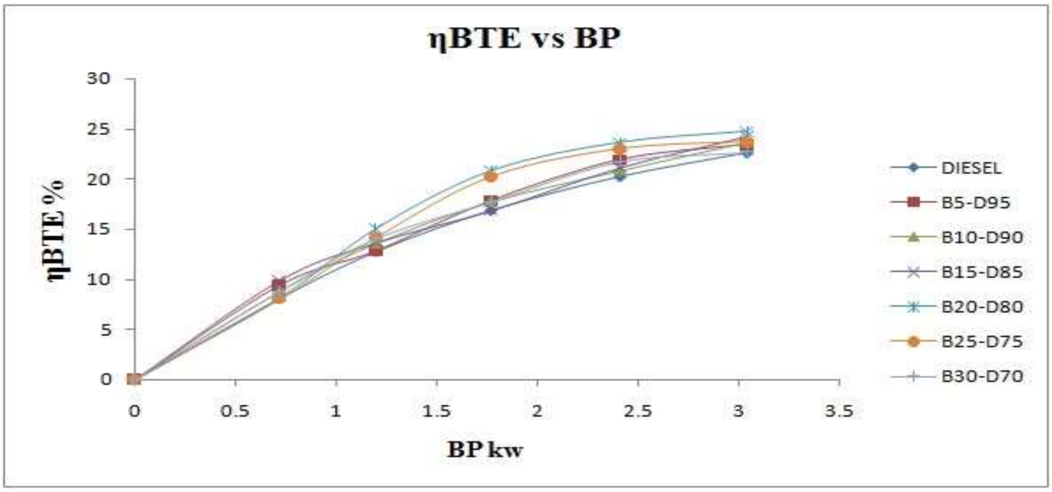

Figure 5: Variation of BTη with Brake power

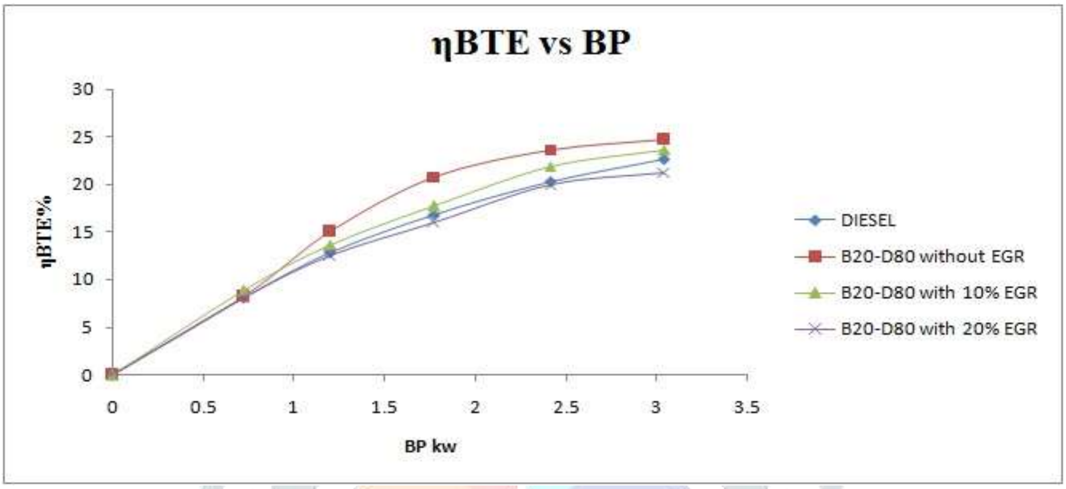

Figure 6: Variation of ηBTE with Brake power for various EGR percentages

5.1.3 Mechanical Efficiency (Mechη)

Mechanical efficiency is the measure of the engine's useful work with fuel and energy input. The figure 7 demonstrates mechanical efficiency differences for all fuel mixtures under different load conditions. From the graph it is observed that with increasing loads for pure diesel to all blends, there is an increase in mechanical efficiency. At 10 kg load conditions, the Mechanical Efficiency for fuel blends such as Diesel, B5-D95, B10-D90, B15-D85, B20-D80, B25-D75, B30-D70 were 52.50 percent, 53.47 percent, 53.52 percent, 53.71 percent, 54.10 percent, 54.32 percent and 56.94 percent for the fuel blends like Diesel, B5-D95, B10-D90, B15-D85, B20-D80, B25-D75, B30-D70 respectively. The percentage variation in the mechanical efficiency of all diesel blends at different load conditions is increased by 1.018%, 1.019%, 1.023%, 1.030%, 1.034% and 1.08%. The mechanical efficiency is improved from the Diesel fuel to the Blend B30-D70 due to rises in the blending ratios. The maximum mechanical efficiency is achieved by 56.94 percent in the blend B30-D70 i.e. 1,08 percent higher than diesel. Figure 8 shows the effect of recirculating exhaust gas with respect to brake power on mechanical efficiency. As we all know, it is the measure of the engine's useful work with fuel and energy input. The figure shows a declining nature of mechanical efficiency while increasing the flow of exhaust gasses into the engine cylinder by varying the EGR proportion for the B20-D80 fuel mix by 10% and 20%. Due to poorer atomization of fuel blends with exhaust gases, the reason for decreasing mechanical efficiency. We observed readings such as 52.5 percent, 54.1 percent, 52 percent and 50.8 percent for fuel blends such as diesel, B20-D80 without EGR, B20-D80 with 10 percent EGR and B20-D80 with 20 percent EGR respectively at 10 kg load conditions.

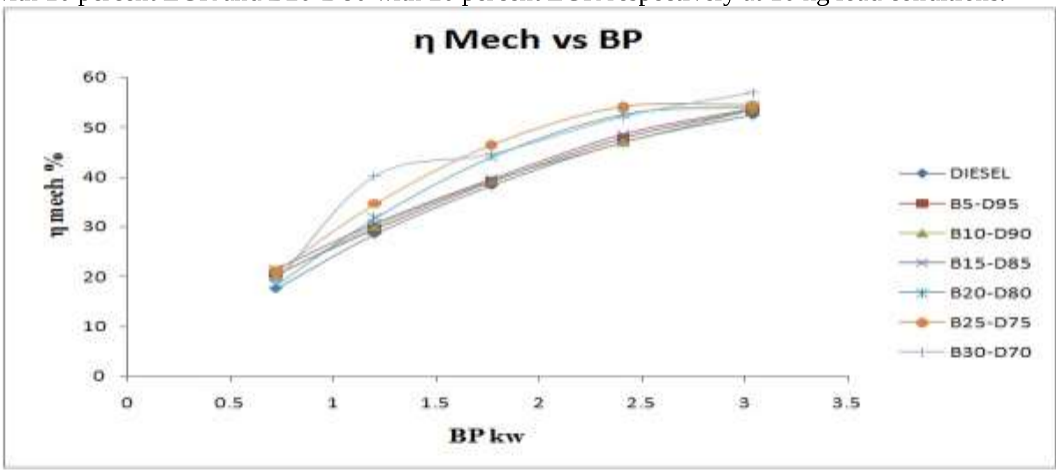

Figure 7: Variation of Mechη with Brake power

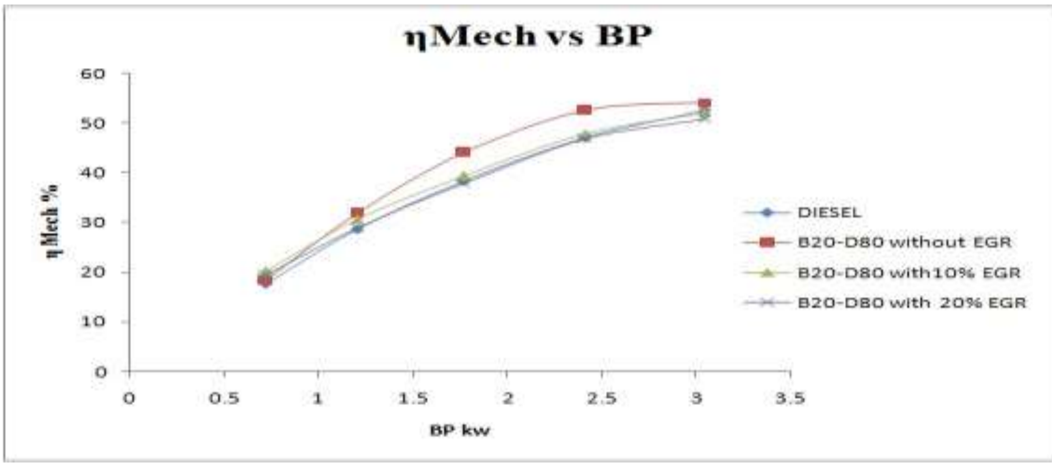

Figure 8: Variation of ηMech with Brake power for various EGR percentages

5.2 Emission Analysis

5.2.1 Oxides of nitrogen emissions (NO_X):-

The figure 9 shows the variation of oxides of nitrogen with distinct blends at varying brake power. The increase in temperature causes the formation of nitrogen oxides in the exhaust. But in this case the engine temperature is equivalent to standard diesel for B15-D85 and B20-D80 and the blend B30-D70 is nearer to diesel. This is due to the fact that pyrolyzed fuel has more oxygen content than conventional diesel fuel, although the engine temperature is less. This provides surplus oxygen, resulting in excess nitrogen oxide release. That's why we got excess NOX emissions. It is represented from the graph that all non-diesel blends such as B5-D95, B10-D90, B15-D85, B20-D80, B25-D75 and B30-D70 produce higher NOX emissions. Among them, B25-D75 and B30-D70 produce NOX emissions, i.e. 479 ppm and 442 ppm, which is much closer to diesel fuel and the B5-D95 blend, provides maximum NOX emissions, i.e. 534 ppm. Figure 10 shows the variation at different EGR conditions of NOx emissions with brake power. NOx emissions reduced through the use of the exhaust gas recirculation method. This is because the intake charge is diluted and the flame temperature decreased. NOx emissions were found to be 423ppm, 509ppm, 438ppm and 403ppm at 10 kg load conditions for diesel, B20-D80 without EGR, B20-D80 with 10% EGR and B20-D80 with 20% EGR respectively.

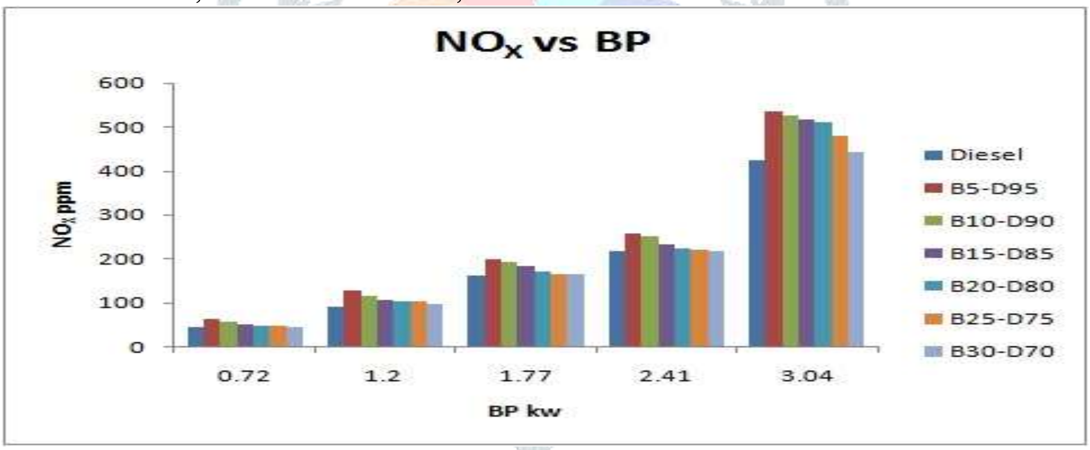

Figure 9: Variation of NO_X emissions with Brake power

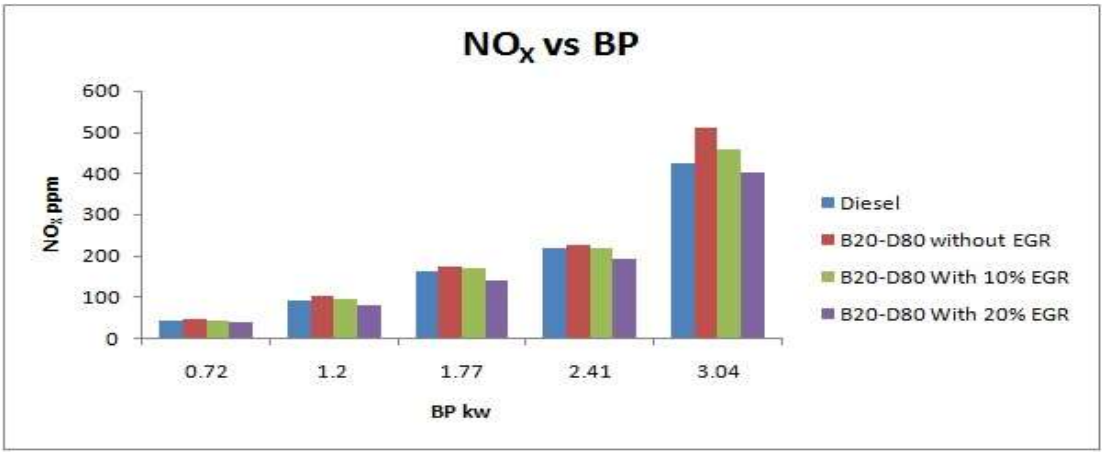

Figure 10: Variation of NOx with Brake power for various EGR percentages

5.2.2 Carbon monoxide emissions:-

Carbon monoxide (CO) is a slightly less dense, colorless, odorless, and tasteless gas than air. When found in levels to above 35 ppm, it is poisonous to hemoglobin animals (both invertebrates and vertebrates, including humans). The figure 11 compares the emissions of carbon monoxide (CO) with the brake power. In practice, when there is incomplete fuel burning, carbon monoxide can be seen in the exhaust. There is an aromatic presence in both WPPO and WTPO for the acquired pyrolysis oil. This compound doesn't exhibit complete combustion The blend B25-D75 and B30-D70 yield greater CO emissions from the graph at distinct load conditions and the B20-D80 yields lower CO percent by volume compared to all blends and diesel due to the oxygen needed for complete combustion. The CO emissions acquired for the blends such as Diesel, B5D95, B10D90, B15D85, B20D80, B25D75 and B30D70 are 0.12%, 0.12%, 0.12%, 0.13%, 0.11%, 0.14% and 0.14%. Figure 12 demonstrates the variation of CO emissions with brake power at various EGR conditions. There is an increase in CO emissions owing to a decrease in the air-fuel ratio when exhaust gas is circulated. The CO emissions for diesel, B20-D80 without EGR, B20-D80 with 10% EGR and B20-D80 with 20% EGR were found to be 0.12% vol, 0.11% vol, 0.125% vol and 0.15% vol respectively at 10 kg load conditions.

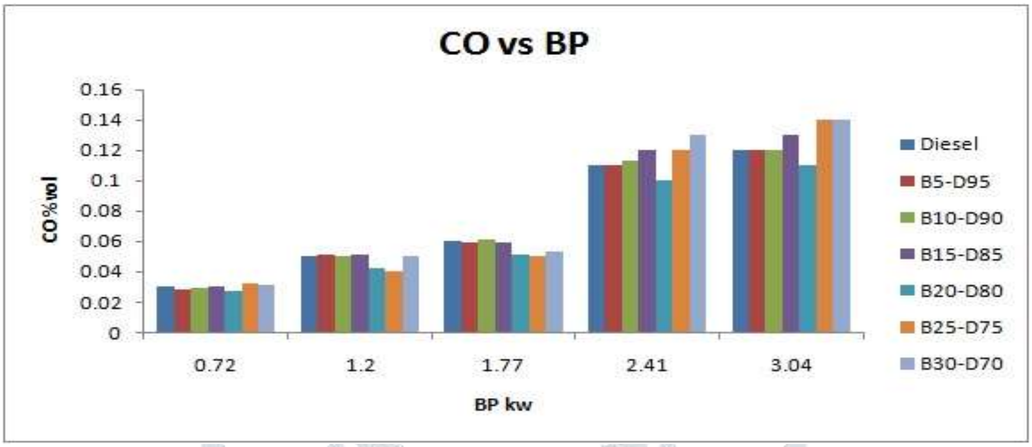

Figure 11: Variation of CO emissions with Brake power

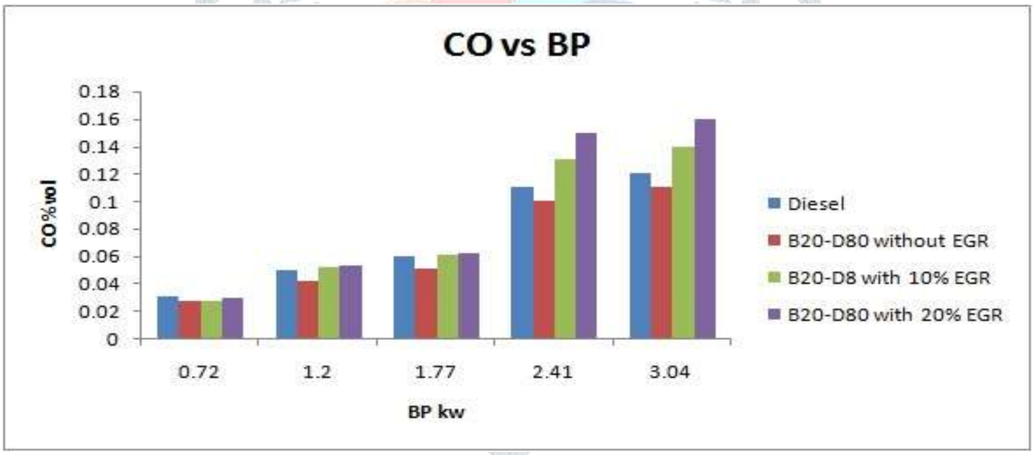

Figure 12: Variation of CO with Brake power for various EGR percentages

5.2.3Carbon dioxide emissions:-

In the figure 13, the variation of carbon dioxide with brake power is represented for various blends. Only when complete combustion occurs carbon dioxide be seen in engine exhaust due to having of adequate oxygen. The oils we used WPPO and WTPO may have excess oxygen. This leaves excess oxygen that ultimately releases big amounts of exhaust carbon dioxide. In fact, carbon dioxide in the diesel engine was seen as pollution along with lived green house gas. The Blend 30-D70 and Diesel emits a lower CO2 emission of about 5.84 percent and 6.1 percent from the graph under different load conditions, whereas the B20-D80 blend gives 6.62 percent of the CO2 emissions due to more oxygen weight in the fuel that makes the fuel completely burn than other fuel mixtures. Figure 14 demonstrates the variation in CO2 emissions at distinct EGR conditions with Brake power. Carbon dioxide is the main constituent of the recirculation of exhaust gas because it has higher heat absorbing capacity and serves as heat absorbing agent in the combustion process. The CO2 emission level for diesel, B20-D80 without EGR, B20-D80 with 10% EGR and B20-D80 with 20% EGR was found to be 6.1% vol, 6.62% vol, 6% vol and 5.8% vol respectively at 10 kg load circumstances. This is due to the instability of combustion and oxygen deficiency, which causes CO2 to decrease and CO emissions to rise.

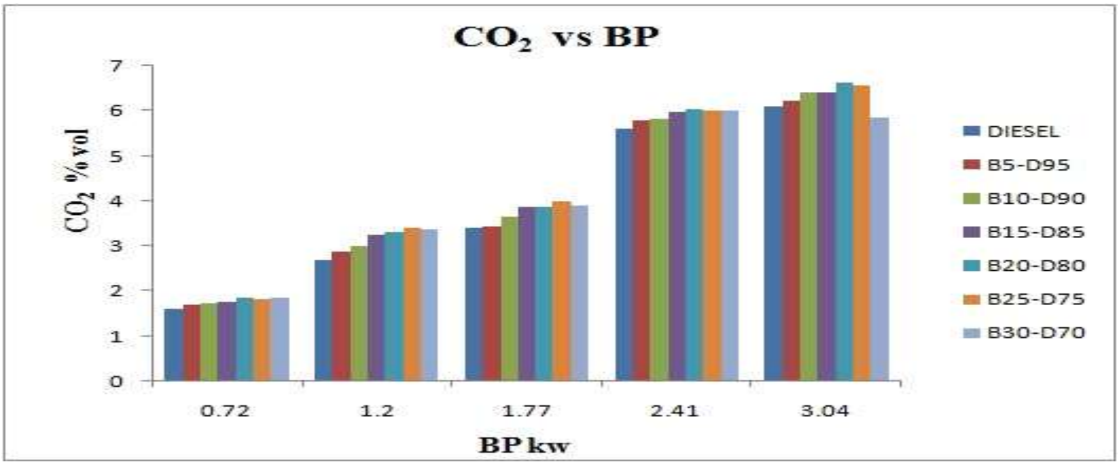

Figure 13: Variation of CO_2 emissions with Brake power

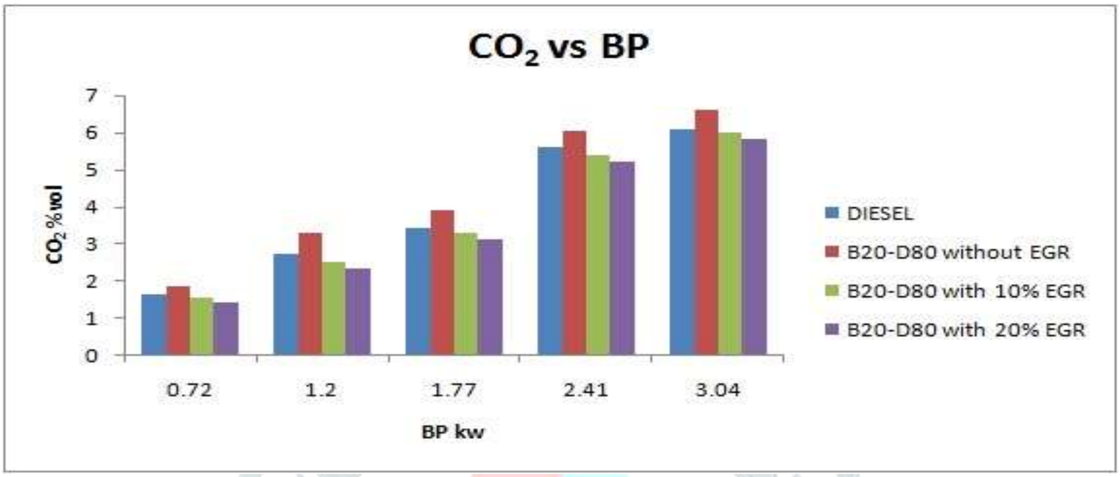

Figure 14: Variation of CO_2 with Brake power for various EGR percentages

5.2.4 Unburnt Hydrocarbons emissions (UHC):-

The figure 15 shows the variation of unburned hydrocarbons with different blends at different brake power. It is generally possible to see hydrocarbons in the exhaust when the fuel has a higher number of cetane and there is not enough combustion. Compared to standard diesel, the cetane number of WPPO and WTPO pyrolyzed oil is lower, hence the level of combustion rises and hydrocarbon emissions reduces. From the graph it is noted that all non-diesel blends such as B5-D95, B10-D90, B15-D85, B20-D80, B25-D75 and B30-D70 produce lower UHC emissions. The B15-D85 and B20-D80 emit less UHC emissions, i.e. 36 ppm and 35 ppm, among them. Figure 16 demonstrates the variation in CO2 emissions at distinct EGR conditions with Brake power. The changes in unburned hydrocarbons follow a near trend with an rise in EGR leading to increased emissions of HC. The CO2 emission levels for diesel, B20-D80 without EGR, B20-D80 with 10% EGR and B20-D80 with 20% EGR respectively were found at 10 kg load conditions as 55ppm, 35ppm, 38ppm and 44ppm. The graph shows that with the increase in EGR concentration HC emissions increase but not up to diesel fuel emissions. The reasons for this exhaust emission are due to the decrease of oxygen in the inlet with EGR in the engine cylinder responsible for HC emission formation.

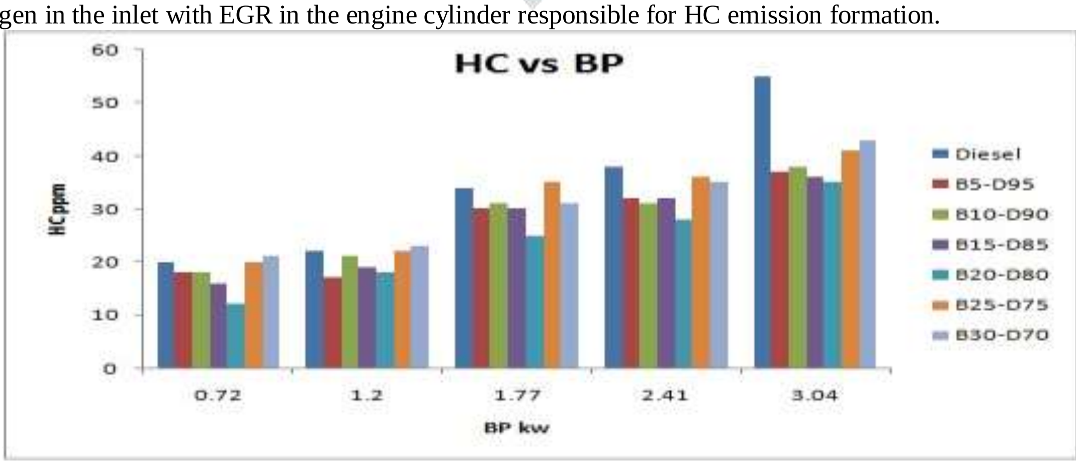

Figure 15: Variation of HC emissions with Brake power

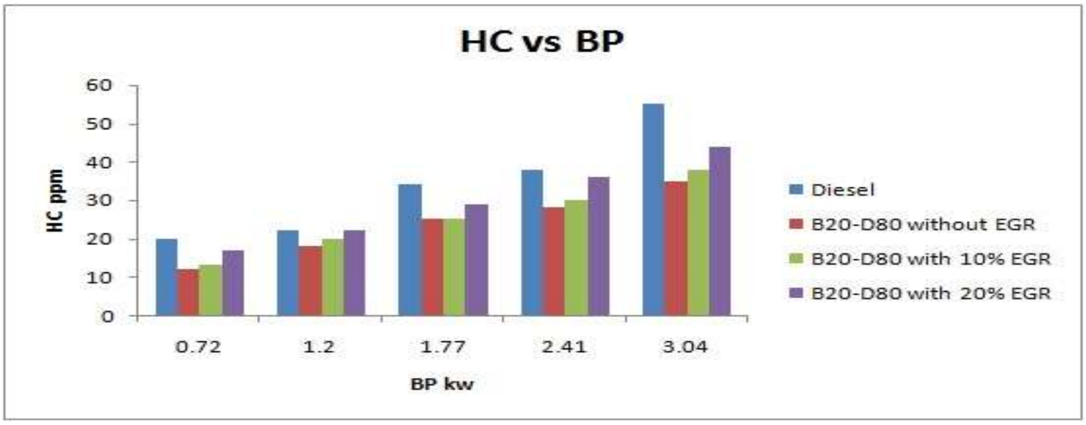

Figure 16: Variation of HC with Brake power for various EGR percentages

5.2.5 Smoke Opacity:-

Opacity of smoke rises with load rises. Figure 17 demonstrates a graph plotted between the opacity of smoke and the engine brake power fuelled with blends i.e. Diesel, B5-D95, B10-D90, B15-D85, B20-D80, B25-D75 respectively, and B30-D70. In general, smoke opacity of diesel fuel is greater than other fuels. Due to more oxygen content, smoke opacity reduces with an rise in the percentage of the mixture. The minimum opacity for smoke is in the blend B15-D85 (47.8BSU) while considering the fuel and the maximum in the blend B25-D75 (68.6BSU). Opacity of smoke in diesel fuel is noted at 71.8 BSU. It can be observed that the amount of smoke opacity is smaller than diesel for all blends. The reason for the reduced smoke is the availability of oxygen within the engine cylinder with premixed and homogeneous charge well before the start of combustion. The other reasons for decreased smoke are higher combustion temperature, longer combustion duration and rapid flame propagation. Figure 18 shows the variation of Brake power with smoke emissions under various EGR conditions. It also improves smoke pollution by raising the proportion of EGR. Smoke emissions for diesel, B20-D80 without EGR, B20-D80 with 10% EGR and B20-D80 with 20% EGR were found at 10 kg load conditions as 71.8 BSU, 65.4 BSU, 67.9 BSU and 72.5 BSU respectively. The rise in concentration of smoke is due to partial exhaust gas replacement of air resulting in instability of combustion.

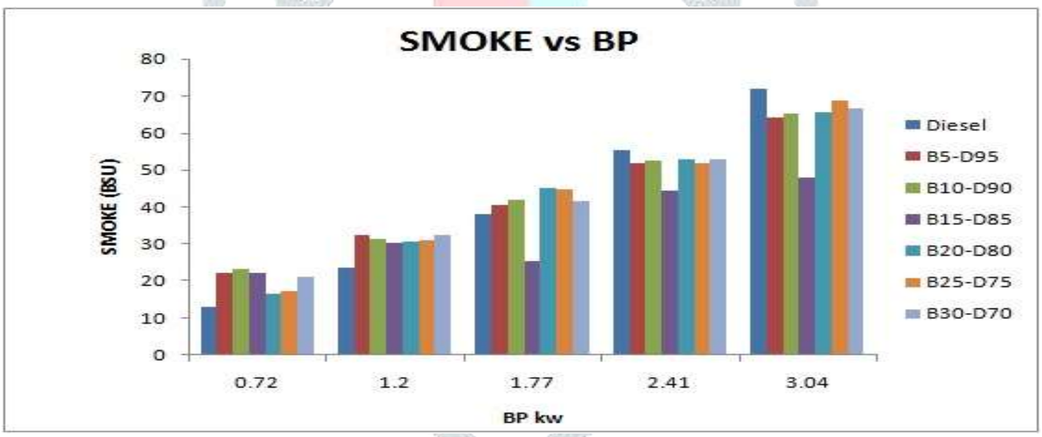

Figure 17: Variation of Smoke opacity with Brake power

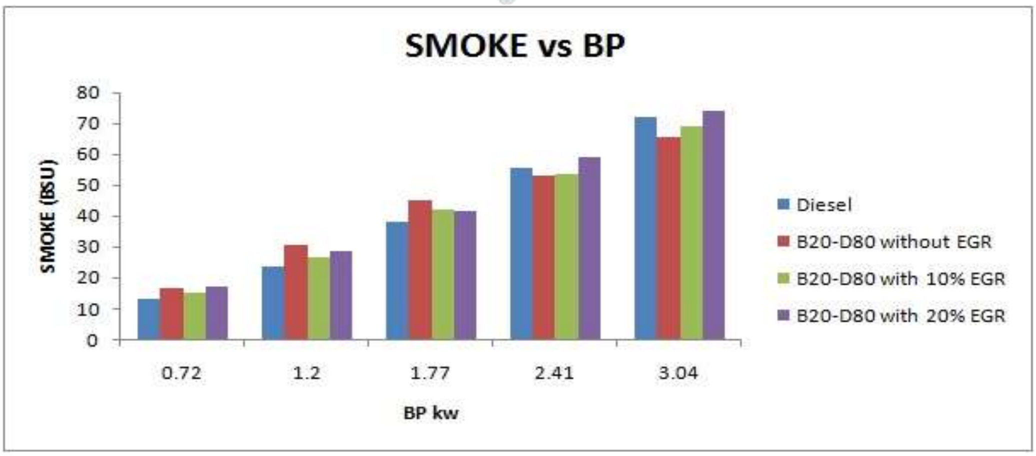

Figure18: Variation of Smoke opacity with Brake power for various EGR percentages

VI. CONCLUSION

Based on the experimental performance and emission characteristics of a four-stroke single-cylinder VCR diesel engine fuelled with straight diesel and mixtures of waste plastic pyrolysis oil and waste tyre pyrolysis oil with diesel in a mixing ratio of D100, B5-D95, B10-D90, B15-D85, B20-D80, B25-D75 and B30-D70 respectively and for B20-D80 Blend, EGR is used of about 10% and 20% the following conclusions were drawn:

1. The physio-chemical characteristics of WPPO and WTPO such as kinematic viscosity, density, dynamic viscosity, flash point, fire point and calorific value of all diesel blends were found.
2. The engine's brake thermal efficiency improves as the blending proportions increase from B5-D95 to B20-D80 and subsequently reduces for B25-D75 to B30-D70. The maximum brake thermal efficiency of the B20-D80 mix is 24.73% and the minimum for Diesel (D100) is approximately 22.08%. By using EGR Brake thermal efficiency decreased.
3. Brake-specific fuel consumption reduces with load increases from B5-D95 to B20-D80 in all blending ratios and increased later for B25-D75 to B30-D70. At the B20-D80 blend, the minimum brake specific fuel consumption is 0.34 kg / kw-hr and a maximum value of 0.39 kg / kw-hr is obtained. And the BSFC improved by 20% by using EGR.
4. The mechanical efficiency increased with increase in fuel blends from diesel, B5-D95 to B30-D70. The maximum mechanical efficiency is obtained at blend B30-D70 is 56.94% and minimum values is obtained at Diesel fuel of about 52.50%.
5. The CO emission decreases with increase in the blending proportions where as at higher loads the CO emission is increased for the blends B25-D75, B30-D70 i.e. 0.14 ppm. The minimum CO emissions occurred at B20-D80 blend of about 0.11 ppm.
6. Because of presence of oxygen content in both WPPO and WTPO the CO_2 emissions is more for all blending proportions than the diesel fuel. B20-D80 blend gives 6.62% of CO_2 emissions.
7. The UHC emissions decrease with increase in the blending proportions. The blendB20-D80 and B15-D85 gives lesser UHC emissions of about 35 ppm and 36 ppm than other fuel blends.
8. The increase in temperature causes the formation of nitrogen oxides in the exhaust. But in this case the engine temperature is equivalent to standard diesel for B15-D85 and B20-D80 and the blend B30-D70 is nearer to diesel. Among all the blends B25-D75 and B30-D70 yield NOX emissions, i.e. 479 ppm and 442 ppm, which is much nearer to diesel fuel and the B5-D95 blend yields maximum NOX emissions, i.e. 534 ppm.
9. In general, smoke opacity of diesel fuel is greater than other fuels. Due to more oxygen content, smoke opacity reduces with an rise in the percentage of the mixture. For the blend B15-D85 and B20-D80 of approximately 47.8 BSU and 65.4 BSU, the minimum smoke opacity is acquired while considering the fuel. The diesel fuel smoke opacity is noted at 71.8 BSU. The B20-D80 blend provides less opacity smoke than diesel.
10. EGR reduced NOx emissions than all other fuel blends.
11. By increasing EGR concentration the CO, HC and SMOKE emissions increased when compared with all the other blends.

As a result, the B20-D80 is chosen as an optimum mixture owing to better results and can be used as a replacement for diesel fuel.

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