**BEST: International Journal of Humanities, Arts,**
**Medicine and Sciences (BEST: IJHAMS)**
**ISSN (P): 2348-0521, ISSN (E): 2454-4728**
**Vol. 3, Issue 10, Oct 2015, 149-158**
**© BEST Journals**

# PRODUCTION OF WASTE POLYETHYLENE BAGS IN TO OIL AND STUDIES PERFORMANCE, EMISSION AND COMBUSTION CHARACTERISTICS IN DI DIESEL ENGINE

**P. SENTHILKUMAR[1] & G. SANKARANARAYANAN[2]**

[1]Department of Mechanical Engineering, Velammal Institute of Technology, Chennai, Tamil Nadu, India

[2]Department of Mechanical Engineering, Sree Sastha Institute of Engineering and Technology,
Chennai, Tamil Nadu India

## ABSTRACT

Fast demanding of conventional fossil fuels, rising costs and environmental issues are the major problems for alternate fuel. On the other hand waste plastic poses very serious environmental challenges because of their disposal problems all over the world. The oil obtained by pyrolysis of waste plastics and analyzed properties of the oil were found that it has properties similar to that of diesel. It can be utilized as an alternate fuel for diesel engine without any modifications to the engine which results, Oxides of nitrogen (NOx) was higher by about 17ppm and carbon monoxide (CO) increased by 0.07% for waste plastic oil (WPO) operation compared to diesel. Unburnt Hydrocarbon (UBHC) was higher by about 14ppm and Smoke increased at full load with WPO compared to diesel. The exhaust gas temperature (EGT) was higher at all loads compared to diesel.

**KEYWORDS:** Waste Plastic Oil, Pyrolysis Process, Diesel Engine, Performance, Emission

## INTRODUCTION

Higher thermal efficiency and simplicity of handling are the reasons behind wide acceptance of diesel for numerous industries like, automobile, agricultural and power generation sectors. For the moment, in the past four decades the demand of oil derived fuels had been enormously increased due to the enhancement of automotive vehicles usage, this tends to increase the economy value of the fossil fuel. Also rising of an air pollution caused by burning of fossil fuels intensifies to search for alternative fuels for the internal combustion engines to ensuring energy security and solving environmental issues. Plastics have become an essential part in today's world due to their lightweight, durability, energy efficiency, coupled with a faster rate of production and design elasticity. At the same time, waste plastics have created very serious environmental challenges due to their huge quantities and disposal problems. Pyrolysis process is a better method for converting waste plastics into plastic oil because of their advantages such as self-governing feedstock, least amount of waste produced, low pressure operation and high conversion efficiency in the order of 80% **[1]** Plastics are non-biodegradable polymers mostly containing carbon, hydrogen, and few other elements like nitrogen. Due to its non-biodegradable nature, the plastic waste contributes significantly to the problem of waste management. According to a nationwide survey which was conducted in the year 2000, approximately 6000 tonnes of plastic waste were generated every day in India, and only 60% of it was recycled, the stability of 40% could not be disposed off. Today about 129 million tonnes of plastics are produced annually all over the world, out of which 77 million tones are produced from petroleum **[2]**. Most of the plastics are recycled and occasionally they are not done so due to not have of sufficient market value of the waste plastics not recycled about 45% is polyethylene, with most of them in containers and packaging.

## MATERIALS AND METHODS

### Production of Waste Plastic Oil

Pyrolysis is a thermal degradation process in the absence of oxygen, performed to obtain waste plastic oil by using silica alumina as a catalyst. The experimental layout of pyrolysis process is shown in **Figure 1.** Different sizes and shapes of waste plastics were collected and crushed with shredder for ease of handling the process. Waste plastics fine crushed were fed in a reactor chamber. The copper coil placed around the burning chamber is heated and maintained at a temperature range of 320$^0$C-500$^0$C for 3-4 hours duration. At this high temperature, waste plastic gets vaporized and passes through the condenser devices. Because of the cold water present in the condenser, latent heat transfer occurs by condensing the waste plastic vapour**[3].**The condensed waste plastic vapor is then stored in the oil collector in the form of plastic oil. The pyrolysis process involves the breakdown of large molecules to smaller molecules. From the pyrolysis treatment the following output products were collected: Waste Plastic Oil – 75% to 90% (mixture of petrol, diesel and kerosene), Gas – 5% to 20% and Residual coke – 5% to 10% **[4].**

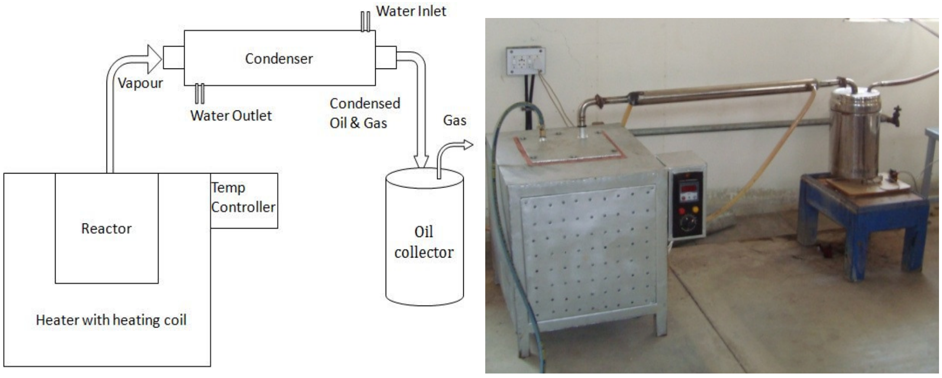

**Figure 1: Experimental Setup of Pyrolysis Process**

The properties of waste plastic oil compared with diesel are given in Table 1.

**Table 1: Properties of Diesel, Waste Plastic Oil**

| Properties | Protocol | Diesel | WPO Oil |
|---|---|---|---|
| Density@15$^0$C kg/m$^3$ | IS1448,P16 | 860 | 835 |
| Kinematic viscosity @40$^0$C (cSt) | ASTM D445 | 2.107 | 3.254 |
| Flash point $^0$C | IS1448,P20 | 50 | 41 |
| Fire point $^0$C | IS1448,P20 | 56 | 49 |
| Gross calorific value (KJ/kg) | IS1448,P25 | 42500 | 43388 |
| Cetane number | IS1448,P9 | 50 | 48 |

### Experimental Setup

An experimental setup of 4.4 KW single cylinder, air cooled, direct injection diesel engine is shown in **Figure 2**.U-tube pressure gauge was fitted with anti-pulsating drum to observe the mass flow rate. A specification of the test engine is shown in **Table 2**. AVL software was used for combustion data analysis and DAQ card placed in between the computer and the engine converts the recorded analog signal into a digital value. The AVL 365C angle encoder was attached to the engine to measures the crank angle for different piston positions. AVL Pressure transducer GH14D was used to indicate the pressure level in the combustion chamber.K-2 type thermocouple was used to measure the exhaust gas temperature. The test engine coupled with electrical dynamometer to apply load on the engine. Electrical Dynamometer consists of the electrical power bank, which applies 0%, 25%, 50%, 75%, 100% load on an engine and it is controlled with the aid of ammeter and voltmeter. The engine was connected to the computer (PC-IV) to record and analyze the output data. The combustion parameters such as cylinder pressure, instant heat release rate and ignition delay were evaluated. AVL Digas 444 exhaust gas analyzer was used to measure engine emissions such as $NO_x$, UBHC and CO. Smoke opacity of the exhaust gas was measured with the use of AVL 437C smoke meter.

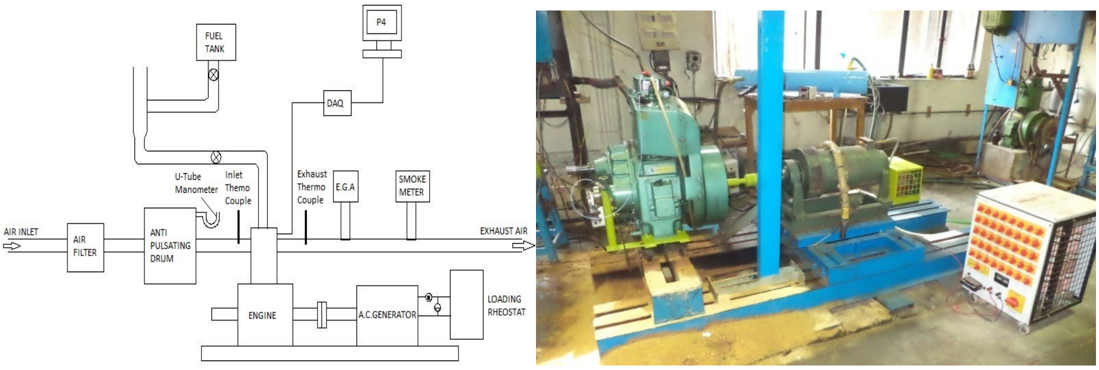

**Figure 2: DI Diesel Engine Experimental Setup**

**Table 2: Single Cylinder DI Diesel Engine Specifications**

| Particulars | Specifications |
|---|---|
| Name of the manufacturer | Kirloskar TAF-1 |
| Bore and stroke | 87.5mm, 110 mm |
| Number of cylinder | 1 |
| Rated speed | 1500 rpm |
| Rated Brake power | 4.4 kW |
| Displacement volume | 661.45 cc |
| Cooling system | Air-cooled |
| Compression ratio | 17.5:1 |
| Nozzle opening pressure | 200 bar |
| Orifice diameter | 13.6mm |
| Co efficient of discharge | 0.6 |
| Injection timing | $23^0$bTDC |

## Error Analysis and Uncertainties

Error analysis is performed to identify the accuracy of the measuring instruments. Errors can occur due to many factors which include environmental conditions, calibration, observation, instruments and test planning. The instruments and their percentage uncertainties of $NO_x$, HC, CO, $CO_2$, $O_2$, Exhaust gas temperature (EGT) and smoke opacity were given in **Table 3.**

Percentage of uncertainty present in the experiment is = square root of ((uncertainty of pressure transducer)$^2$ + (uncertainty of angle encoder)$^2$ + (uncertainty of $NO_x$)$^2$ + (Uncertainty of HC)$^2$ + (uncertainty of CO)$^2$ + (uncertainty of $CO_2$)$^2$ + (uncertainty of $O_2$)$^2$ + (uncertainty of smoke opacity)$^2$ + (uncertainty of K-2 thermocouple)$^2$ + (uncertainty of stop watch)$^2$ + (uncertainty of manometer)$^2$ + (uncertainty of burette)$^2$) = square root of $((0.01)^2 + (0.2)^2 + (0.2)^2 + (0.2)^2 + (0.3)^2 + (0.2)^2 + (0.3)^2 + (1)^2 + (0.2)^2 + (0.2)^2 + (2)^2 + (1.5)^2)$ = square root of (7.6701) = ±2.769%.

**Table 3: List of Instruments and Its Range, Accuracy and Percentage Uncertainties**

| Instrument | Measuring Range | Accuracy | Percentage Uncertainties |
|---|---|---|---|
| AVL pressure transducer GH14D | 0-250 bar | ±0.01 bar | ±0.01 |
| AVL 365C Angle encoder | - | $\pm 1^0$ | ±0.2 |
| AVL digas 444 (five gas analyzer) | | | |
| $NO_x$ | (0-5000ppm vol) | <500ppm vol: ±50ppm vol<br>≥500ppm vol: ±10% | ±0.2 |
| HC | (0-20000ppm vol) | <200ppm vol: ±10 ppm vol<br>>200ppm vol:±5% | ±0.2 |
| CO | (0-10% vol) | <0.6% vol: ±0.03% vol<br>>0.6% vol: ±5% | ±0.3 |
| $CO_2$ | (0-20% vol) | <10% vol: ±0.5% vol<br>> 10% vol: ±5% vol | ±0.2 |
| $O_2$ | (0-22% vol) | <2% vol: ±0.1% vol<br>≥2% vol: ±5% vol | ±0.3 |
| AVL 437C smoke meter | | | |
| Smoke intensity | (0-100%) | ±1% | ±1 |
| K-2 thermocouple | $(0\text{-}1250^0C)$ | $\pm 1^0C$ | ±0.2 |
| Digital stop watch | - | ±0.2s | ±0.2 |
| U-tube Manometer | - | ±1mm | ±2 |
| Burette | 1-30cc | ±0.2cc | ±1.5 |

## RESULTS AND DISCUSSIONS

### Brake Thermal Efficiency

**Figure 3** shows the variation of the BTE with respect to load for diesel fuel and WPO. The BTE is 24.96% at full load for diesel and for the waste plastic oil it is 22.61%. It is clear that the lower BTE of the WPO at all load conditions compared to that of diesel. At full load, the exhaust gas temperature and the heat release rate are marginally higher for waste plastic oil compared to diesel. This may result in higher heat losses and lower brake thermal efficiency in the case of waste plastic oil blend. **[5]**

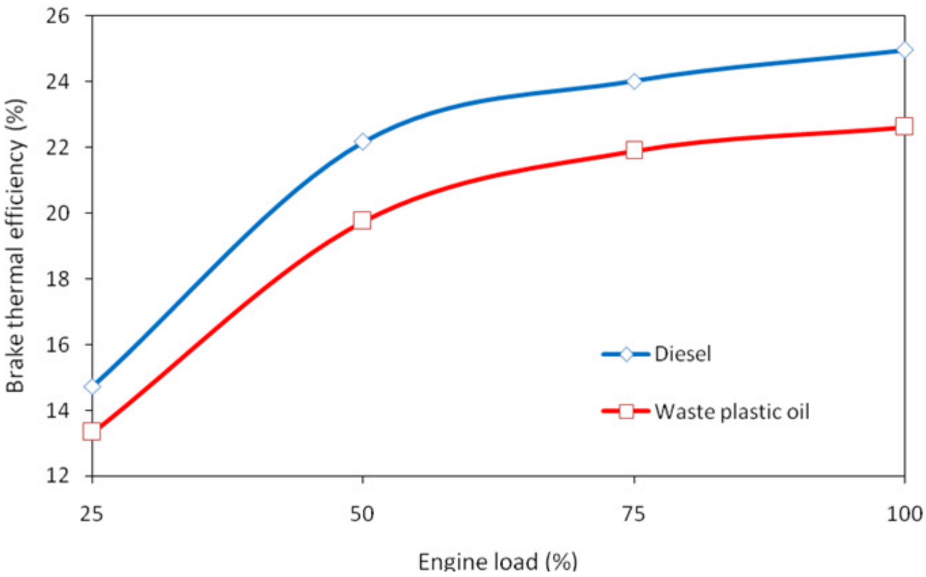

**Figure 3: Variation of Brake Thermal Efficiency vs. Engine Load**

## Brake Specific Fuel Consumption

**Figure 4** shows the curve between Brake Specific Fuel Consumption with the load. This figure reveals that pure diesel has the BSFC (brake specific fuel consumption) of 0.5749 kg/kW h at 25% load and 0.3527 kg/kW h at full load. For WPO, the value is 0.6217 kg/kW h at 25% and 0.3668 kg/kW h at full load. At high speeds of the engine, the differences between BSFC values of fuel become smaller, due to the short combustion period in spite of the increased fuel amount. The variation in brake specific fuel consumption with load for different fuels shows decline with increase in load.

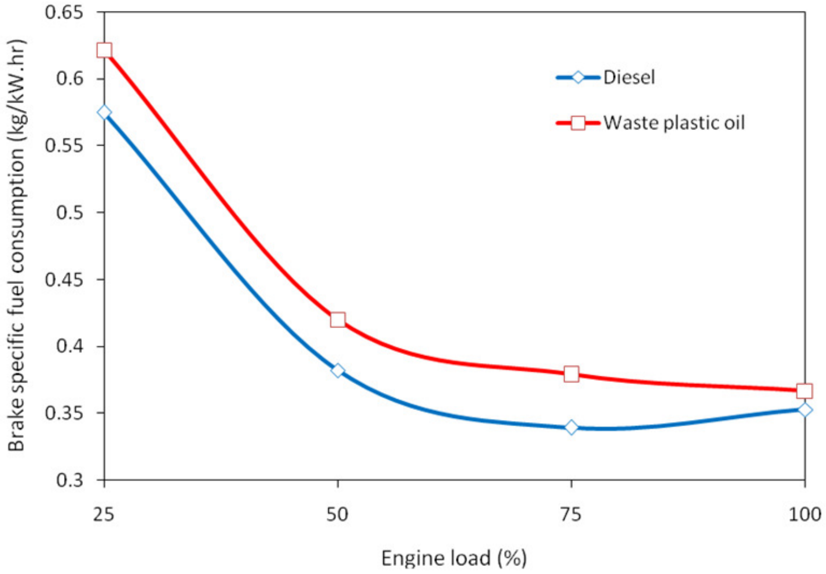

**Figure 4: Variation of Specific Fuel Consumption vs. Engine Load**

## Exhaust Gas Temperature

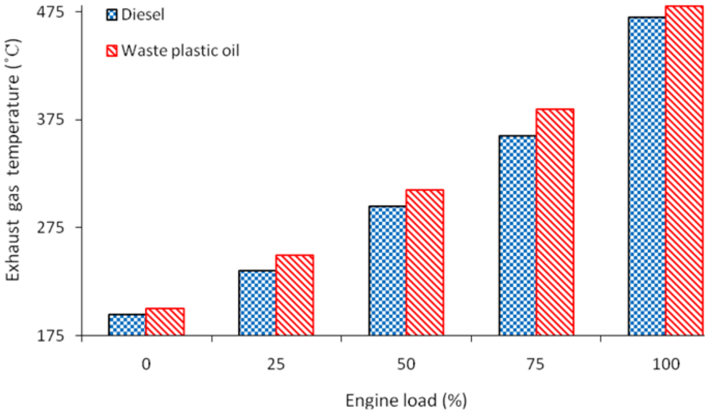

**Figure 5: Variation of Exhaust Gas Temperature vs. Engine Load**

The variation of exhaust gas temperature with brake power is shown in **Figure 5**. The exhaust gas temperature varies from 195 ˚C at no load to 470˚C at rated power for diesel whereas in the case of waste plastic oil it varies from 200 ˚C at no load to 480 ˚C at rated power. The reason for increase in exhaust gas temperature with engine load that more amount of fuel was required by the engine to generate the extra power needed to take up the additional loading. **[6]** In addition to high oxygen content, waste plastic oil usually contains constituents that have higher boiling points than diesel. This resulted in higher exhaust temperatures.

## Unburned Hydrocarbon

The variation of UBHC with brake power for tested fuels is shown in **Figure 6.** UBHC consists of fuel that is incompletely burned. UBHC varies from 22 ppm at 25% of rated power to 34 ppm at rated power for diesel. In the case of WPO it varies from 38 ppm at 25% of rated power to 48 ppm at rated power. From the results, it can be

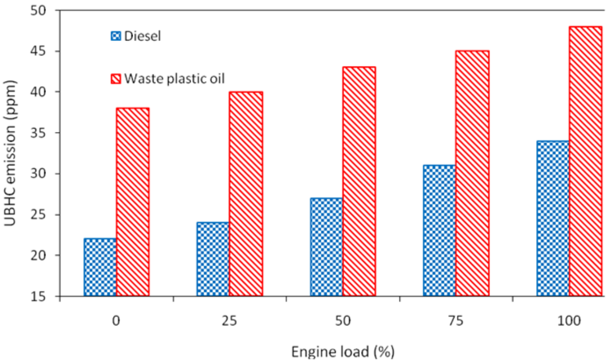

**Figure 6: Variation of HC Emission vs. Engine Load**

Noticed that the concentration of the hydrocarbon of waste plastic oil is marginally higher than diesel. The reason behind increased UBHC in WPO may be due to higher fumigation rate

## Oxides of Nitrogen

**Figure 7** shows the comparison of nitrogen oxides with load. NOx emission increases with increase in load from 104 ppm at low load to 668 ppm at full load condition for diesel and from 112 ppm at low load to 685 ppm at full load for WPO. It was observed that the NOx emission increases with increase in load for WPO compared to diesel. The reason for the increased NOx in WPO compared to diesel may be plastic oil contains some oxygenated hydrocarbons which promote better combustion and thus the formation of NOx in exhaust. The oxides of nitrogen in the emissions contain nitric oxide (NO) and nitrogen dioxide ($NO_2$). Nitrogen oxide is formed as a result of the oxidation of nitrogen in the air during burning of the air-fuel mixture in the combustion chamber. In the formation of nitrogen oxides, the predominant factors are the air/fuel ratio and the environment temperature. In the case of adequate burning the temperature rises and, consequently, more free oxygen atoms combine nitrogen; this, in turn, increases the formation rate of nitrogen oxide.**[7]**

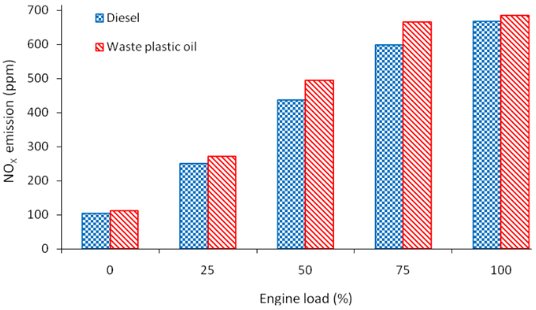

**Figure 7: Variation of $NO_X$ Emission vs. Engine Load**

## Carbon Monoxide

Carbon monoxide emission is mainly due to the lack of oxygen, poor air entrainment, mixture preparation and incomplete combustion during the combustion process. CO emission is toxic and must be controlled. It is an intermediate product in the combustion of a hydrocarbon fuel, so its emission results from incomplete combustion.

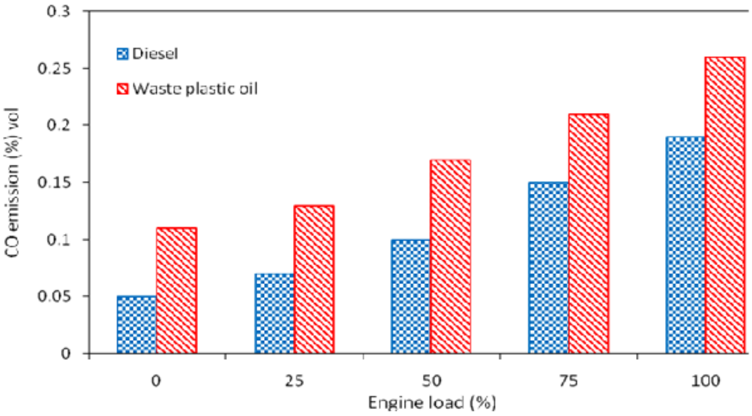

**Figure 8: Variation of CO Emission vs. Engine Load**

The variation of carbon monoxide with load is shown in **Figure 8.** The CO emission varies from 0.05 %vol at low load to 0.19 %vol at full load for diesel and from 0.11 %vol at low load to 0.26 %vol at full load for WPO. The results show that CO emission of waste plastic oil is higher than diesel especially at higher load. The reason behind increased CO emission is incomplete combustion due to absence of oxygenated compounds in waste plastic oil. The drastic increase in CO emission at higher loads is due to higher fuel consumption.**[8]**

### Smoke Intensity

Smoke is nothing but solid soot particles suspended in the exhaust gas. **Figure 9** shows the variation of smoke with load for diesel and WPO. Smoke varies from 5.5 % at low load to 51.1 % at full load for diesel whereas for WPO it varies from 12.3 % at low load to 55.2 % at full load. It can be noticed that the smoke for WPO is higher than that of diesel. This is due to the non-availability of homogeneous charge inside the engine cylinder. Lower combustion temperature, reduced duration of combustion and rapid flame propagation may also be the reasons for higher smoke intensity **[9].** However, at higher load ranges due to non-availability of sufficient air and abnormal combustion there was a visible white smoke emission.

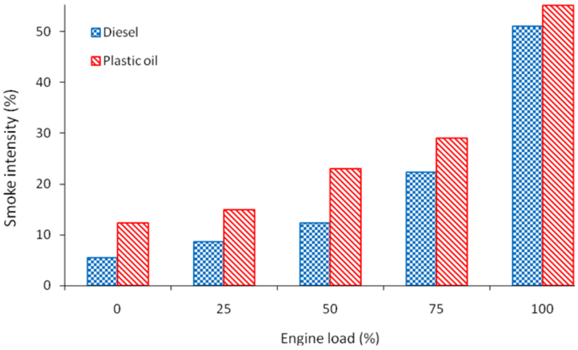

**Figure 9: Variation of Smoke Intensity vs. Engine Load**

### Heat Release Rate

The comparison of heat release rate for WPO blends and diesel operation at full load is shown in **Figure 10.**

Diesel shows lower heat release rate during the initial stage and longer combustion duration at full load. It can be observed that the maximum heat release rate of 71.5621 J/ CA is recorded for diesel. In the case of WPO, the maximum heat release rate is 91.933 J/ CA.

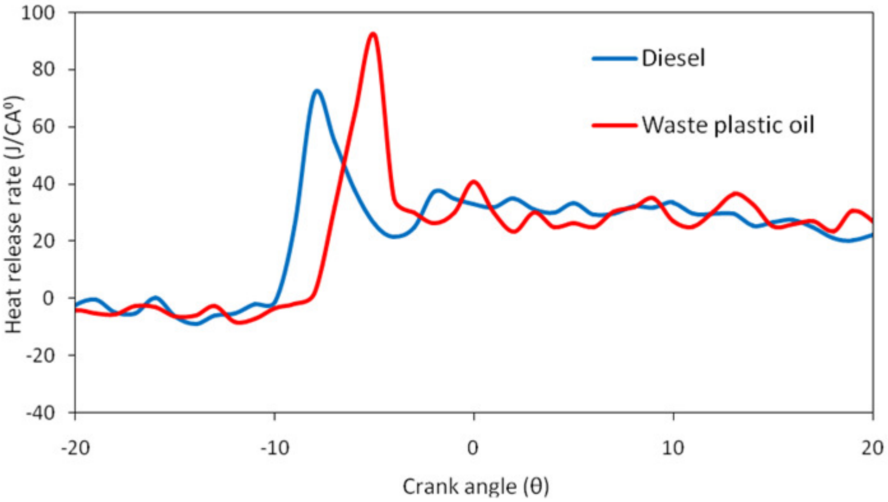

**Figure 10: Variation of Heat Release Rate vs. Crank Angle**

The maximum heat release in WPO compared to diesel is due to its longer ignition delay. The burning rate in the diffusion combustion phase is controlled by the availability of combustible fuel air mixture.

## CONCLUSIONS

Waste plastic oil exhibits a higher cylinder peak pressure compared to diesel because of evaporation of waste plastic oil inside the cylinder by absorbing heat from the combustion chamber. The heat release rate with waste plastic oil is higher compared to diesel fuel due to better combustion. From the experimental investigation the following conclusions were drawn,

- Brake Thermal efficiency, decreased by about 2.35% with WPO operation at full load compared to diesel.
- NOx emission is 17 ppm higher for WPO operation than diesel at full load.
- UBHC emission for WPO operation is about 14 ppm higher than diesel at full load.
- CO emission for diesel operation is about 0.07% lesser than waste plastic oil at full load.
- Smoke emission increased by about 4.1% in the case of WPO compared to diesel at full load.

## ACKNOWLEDGMENTS

Author sincerely thanks Sri Venkateswara College of engineering for offering the setup of IC engine for experimental studies.

## REFERENCES

1. A.V Bridgewater and G.V.C Peacocke(2000), Fast pyrolysis process for biomass. Renewable and sustainable energy reviews. 41–73.

2. Phong Hai Vu, Osami Nishida, Hirotsugu Fujita, Wataru Harano, Norihiko Toyoshima, Masami Iteya, Reduction of NO x and PM from diesel engines by WPD emulsified fuel, SAE Technical Paper 2001-01-0152

3. Mr. Rajesh Guntur et al (2011). Experimental evaluation of a Diesel Engine with blends of Diesel-Plastic Pyrolysis, International Journal of Engineering Science and Technology 30975-5462.

4. M. Mani, C. Subash, G. Nagarajan, Performance, emission and combustion characteristics of a DI diesel engine using waste plastic oil. Applied Thermal Engineering 29 (2009) 2738–2744.

   doi:10.1016/j.applthermaleng.2009.01.007

5. Jerzy Walendziewski, Continuous flow cracking of waste plastics, Fuel Process. Technol. 86 (2005) 1265-1278.

6. Kim D, Shin S, Sohn S, Choi J, Ban B. Waste plastics as supplemental fuel in the blast furnace process: improving combustion efficiencies. J Hazar Mate B 2002;94:213–22.

7. Zhu L, Cheung CS, Zhang WG, Huang Z. Combustion, performance and emission characteristics of a DI diesel engine fueled with ethanol-biodiesel blends. Fuel 2011;90:1743–50.

8. S. Murugan, M.C. Ramaswamy, G. Nagarajan, Tyre pyrolysis oil as an alternate fuel for diesel engines, SAE Paper 2005-01-2190

9. Agarwal Avinash Kumar. Biofuels (alcohols and biodiesel) applications as fuels internal combustion engines. Journal of Energy and Combustion Science 2007; 33:233-71.