Journal of Materials and
Environmental Sciences
ISSN : 2028-2508
CODEN : JMESCN

J. Mater. Environ. Sci., 2018, Volume 9, Issue 6, Page 1712-1721

https://doi.org/10.26872/jmes.2018.9.6.191

http://www.jmaterenvironsci.com

Engine Fuel Production from Waste plastic Pyrolysis (WPO) and Performance Evaluation in a CI engine with Diesel Blend

Ankit Verma[1], **Aditya Raghuvansi**[2], **M.A Quraishi**[3,4], **Jeewan V. Tirkey**[2*], **Chandrabhan Verma**[5]

[1, 4.] Centre for Energy and Resources Development, Mechanical Engineering, IIT (BHU), INDIA
[2] Department of Chemical Engineering, IIT (BHU) Varanasi
[3.]Center of Research Excellence in Corrosion Research Institute, King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabia
[4.]Department of Chemistry, IIT (BHU), INDIA
[5]Department of Chemistry, School of Chemical and Physical Sciences, Faculty of Natural and Agricultural Sciences, North-West University, Private BagX2046, Mmabatho 2735, South Africa
** Corresponding authors: jvtirkey@gmail.com, maquraishi.apc@itbhu.ac.in*

Received 30Apr 2017,
Revised 26Nov 2017,
Accepted 31Nov 2017

Keywords
- ✓ Transparent waste plastic
- ✓ Yield
- ✓ VCR,
- ✓ Power,
- ✓ Fuel consumption.

mumtaz.quraishi@kfupm.edu.sa
Phone: +213795290364;
Fax: +21329824945

Abstract

Plastic waste disposal throughout the world is creating problems and degrading the environment.Today transportation and electric power generation in rural areas mostly depend on fossil fuels. Such extensive use of fossil fuel is resulting in depleting it at an alarming rate. Hence, it is required to produce an alternative fuel to keep them running as well as minimizing waste disposal. Waste plastic pyrolysis oil is identified one of such good alternative. In this study, waste transparent plastic, used for packaging, is used for the conversion of fuel through pyrolysis process.It was observed that yield of plastic oil was approximately 65-70 %. However, a liquid yield affects heating rates and heat loss patterns in the reactor system. This paper also presents the effect of waste plastic pyrolysis oil in a diesel engine at various compression ratios with different load and blending with pure diesel (pure diesel, 10%, 20%, 30%, 40%) at constant engine revolution. The performance characteristics include engine brake power, brake thermal efficiency, specific fuel consumption and exhaust emissions. Experimental investigation shows that Plastic oil can be used to save the 40% diesel without loss of power, and its trend do not differ with variation in compression ratio.

1. Introduction

Energy, environment and economy areone of the major contributors for developing the country. Fossil fuels are depleting day by day, which results in rise of petroleum products prices around the globe. This indicatesrequirement of an alternative cheaper fuel to fulfil the need of transportation, 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 is a major problem as its non-biodegradable in nature. Plastic usage has become crucial part in today's world, because of their lightweight, durability, non-perishable nature, faster rate of production and flexibility in design and the demand of commodity [1,2]. In general, plastics are formed using petroleum products and consists of long hydrocarbon chains. These contain many additives such as colouring agents, anti-oxidants and stabilizers [3,4]. High-density polyethylene isa highly used plastic after poly vinyl chloride (PVC) and polypropylene (PP) [5]. Plastics are non-biodegradable polymers and remains more than 100 of years, adding significantly to the problem of waste management [6,7]. Moreover, the huge demand for plastic has created a large amount of plastic waste and itsconsequences are serious threat to the environment due to its disposal problems. The toxic substances released are causing a threat to vegetation, animal and human health and environment as a whole. In detail, burning of plastic wastes increase the risk of heart disease, aggravates respiratory ailments such as asthma and emphysema and cause rashes, nausea or headaches, and damages the nervous system [1]. According to a survey carried outin India, it found that annual consumption of plastic was nearly 8 million tonnes. Around 70% of this is recycled and remaining plastic waste is going as landfills [1,8].Wastage of energy is the recent trend in the selection of alternate fuels [9,10]. Fuels and its blend like alcohol, biodiesel, liquid fuels from plastics etc. are promising alternative fuels for the internal combustion engines [11]. As plastic is made of hydrocarbon, is cheap and easily available, and corresponding to tonnes of waste, leadsus to consider it as an alternative fuel for engine.This could be an important tool to save the environment as well as stop plastic wastes accumulation. Considering this fact, many authors [11-13] had worked on oil extraction from plastics as an alternative source of fuels for the diesel engines. Theyproved that WPO fuel is capable to run both SI and CI mode of an engine. There are many method to extract the waste plastic oil (WPO), among them pyrolysis process is the most common process to obtain the production of fuel.Author [14] produced WPO through waste plastic by initially crushing into small pallets,transferring to the reactor for thermal degradation wherein the absence of air it is heated to the range of 300–900 °C and plastic vapor forms, which being condensed and finally collected as WPO. Shafferina et al. [15] reviewed and suggested that the yield of WPO through pyrolysis process strongly depends upon types of plastic and selection of catalytic. Furthermore, the yield also depends on temperature and duration of reaction. Miandad et al. [16] revealed that as reaction time increase beyond 75 minute, yield decreases and tar content increases, also proposed that the optimum conditions for maximum liquid oil yield of 81% achieved at 450 ^{0}C temperature and 75 min reaction time.

Beside this, investigation of the optimum performance, emission and fuel consumption aspect of an internal combustion engine using WPO has similar importance. Panda et al., [12]experimentally observed that engine gives better performance up to 30%,while it may operate with maximum up to 50% waste plastic oil blended to diesel. The study shows a stable performance with brake thermal efficiency similar to that of diesel and its value is higher upto 80% of load.Also,observed that throughouttheexperiment, emissions are considerably higher than that of the diesel baseline. Anupet al. [17] concluded that petrol engine fuelled with waste plastic pyrolysis oil exhibits higher thermal efficiency up to 50% of the rated power for petrol engine. Viswanath et al. [8] performed experiment and revealed that the higher calorific value and more oxygen content of WPO significantly increases heat release rate than diesel, however possession of high viscosity with blends, leads to poor atomization,long ignition delay and combustion durationin compare to diesel at full load.In addition, Mani et al [6, 18] suggested that use of WPO, Ignition delay become longer by about 2.5^0 CA, NO_x is higher about 25%,CO 5% and Unburned hydrocarbon about 15%, and smoke reduced by about 40% to 50%. Ceyla et al. [19] also found the similar trend of emission. Injection timing for any CI engine plays major role for combustion and performance. Mani et al. [6] investigatedthat change from 23^{0}bTDCto retarded injection timing of 14^{0}bTDC lead to decrease oxides of nitrogen, carbon monoxide and unburned hydrocarbon. Viswanath et al. [20] experimentally investigated and found that brake thermal efficiency of blends are lower compared to diesel, but 25% blending shows similar performance to that of diesel.

There are many investigation have been done with respect to deferent proportion of blends with conventional diesel and types of engines. Compression ratio (CR) of an engine plays important role to enhance the efficiency and overall performance however,its performance investigation is inadequate. The effects of CR along with variation of load and blends on the combustion characteristics, emission, and specific fuel consumption not been investigatedaltogether adequately. Therefore, the purposeof this work is to obtain optimum performance of WPO blends with conventional diesel. Experimental investigation was conducted and the effect of engine performance parametersas brake thermal efficiency, brake power, specific fuel consumption, emissions using WPO and diesel of various blends like B10, B20, B30, B40at different compression ratios and corresponding applied load were extensively studied.

2. Methodology

2.1 Fuel preparation by pyrolysis:

Waste plastic pyrolysis oil involves subjecting plastic to high temperature for the treatment of chemically decomposing of organic materials in absence of oxygen, otherwise it starts burning. During the process, initially plasticswastes have been cracked gently by adding catalyst, and the gases condensed in a series of condensers to give a low sulphur content distillated WPO. All this happens continuously to convert the waste plastics into fuel. The catalyst used in this system prevents formation of all the dioxins and Furans (Benzene ring). Figure 1 illustrates The laboratory scale pyrolysis setup consisted of a batch reactor sealed at one end and an outlet tube at the other end. An electric furnace used to provide heat to the reactor externally, and 20 gm of waste plastic sample was loaded in each pyrolysis reaction. The condensable liquid products (WPO) collected through the condenser and weighed.After pyrolysis, the solid residue left out inside the reactor and weighed. Reactionhave been carried out at different temperatures ranging from 400–500°C.The property of collected WPO was measured as shown in table 1.

2.2 Experimental setup

The experimental setup is shown in fig.2. The experimental setup consists of single cylinder, four stroke, multi-fuel, research engine connected to eddy current type dynamometer for loading. The engine specification: bore and stroke are 87.7 mm and 110 mm respectively, displacement volume 661cc, opening and closing of intake valve at 45^0 b TDC and 35.5^0 a TDC respectively, exhaust valve opening and closing at 35.5^0 b BDC and 4.5^0 a TDC respectively, Fuel injection timing 23^0bTDC at inlet manifold. The compression ratio can be varied without stopping the engine and without altering the combustion chamber geometry by specially designed tilting cylinder block arrangement.

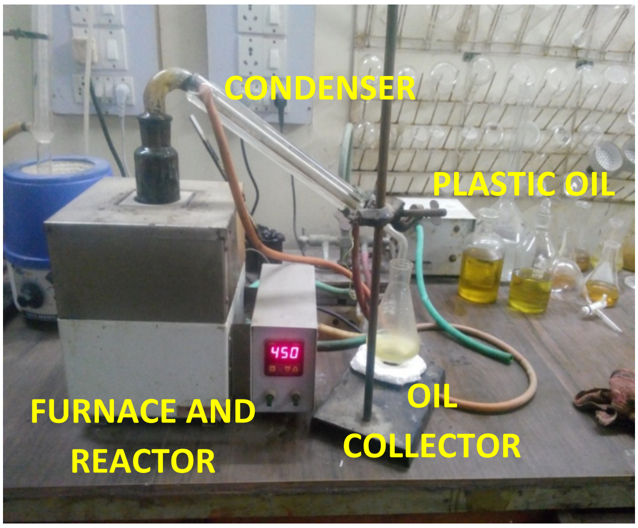

Fig. 1. Pyrolysis setup for WPO.

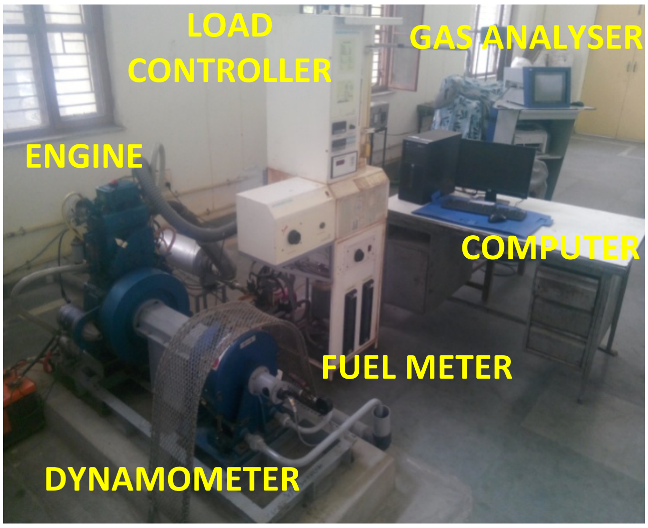

Fig. 2. Experimental set for engine performance.

Table 1: properties of waste plastic oil and diesel

Properties	Measuring Technique	B100(measured)	DIESEL(Pawar et al., 2013)
Density(kg/m^3)	Hydrometer cylinder	860	890
Calorific value (kJ/kg)	Bomb calorimeter	39500	42000
Flash point(°C)		36	>52
Fire point(°C)		41	>55

In Diesel mode fuel injection point and pressure can be manipulated for research tests. Air temp, coolant temp, Throttle position and trigger sensor are connected to Open ECU which control ignition coil, fuel injector, fuel pump and idle air. Set up is provided with necessary instruments for combustion pressure, Diesel line pressure and crank-angle measurements. These signals are interfaced with computer for pressure crank-angle diagrams. Instruments are provided to interface airflow, fuel flow, temperatures and load measurements. The setup has stand-alone panel box consisting of air box, two fuel tanks for duel fuel test, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and hardware interface. Rotametersare provided for cooling water and calorimeter water flow measurement. A battery, starter and battery charger is provided for engine electric start arrangement. The setup enables study of VCR engine performance for brake power, indicated power, frictional power, BMEP, IMEP, brake thermal efficiency, indicated thermal efficiency, Mechanical efficiency, volumetric efficiency, specific fuel consumption air fuel ratio, A/F ratio, heat balance and combustion analysis. Lab view based Engine Performance Analysis software package Enginesoft provided for on-line engine performance evaluation. All the experiments with different fuel ratios conducted for a constant engine speed of 1500 rpm and with varying CR and load on engine. Water flow through engine adjusted to 230 LPH and 90 LPH through calorimeter. Load varied from 0.0 kg to 12 kg corresponding to zero load to full load. All the performance and emission characteristics were determined by averaging 10 consecutive cycles. For exhaust gas, AVL DiTEST CDS 440 gas analyzer was used. The details of measuring equipment used and its accuracy level are listed in table-2.

3. Results and Discussions

3.1 Brake Power

Figures 1.1, 1.2, 1.3 and 1.4 show the variation of brake power with respect load applied. It indicates that the Brake power increases with increase in load, which is due to increase in amount of fuel to maintain the constant RPM corresponding to load increase. These figures conclude that blending of waste plastic oil

(WPO) with pure diesel are very close trend with pure diesel corresponding to variation of load. Figures also indicate that plastic oil is safer to save the 40% diesel without loss of power, and its trend do not differ with variation in compression ratio.

Table 2. List of measuring equipment used.

Instrument	Measurement	Measurement Technique	Range	Accuracy
Tachometer	Engine speed	Magnetic Pick-up	1200-1500rpm	± 5rpm
Thermometer	Temperatures	K-Type Thermocouple	0-1200°C	± 2°C
Eddy current type Dynamometer	Load	Strain gauge type	0-50kg	± 0.1kg
Pressure Transducer	Pressure	Piezo sensor	0-5000psi	± 2psi
AVL DiTEST CDS 440 gas analyzer	Nitrogen oxides	Electrochemical sensor	0-5000ppm vol.	± 5 ppm vol.
	Carbon monoxide	NDIR	0-15% vol.	< 15.0 % vol.: ± 0,02 % vol.
	Carbon dioxide	NDIR	0-20% vol.	< 16.0 % vol.: ± 0, 3 % vol. ≥ 16.0 % vol: ± 5 % o.M.

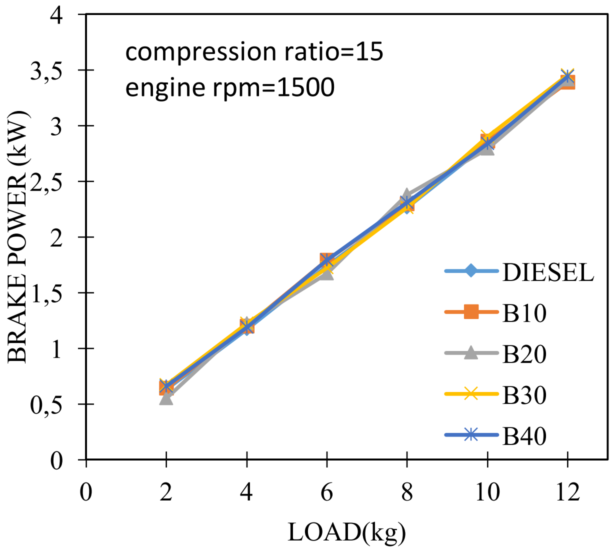

Figure1.1 Varation of brake power with load applied and blends

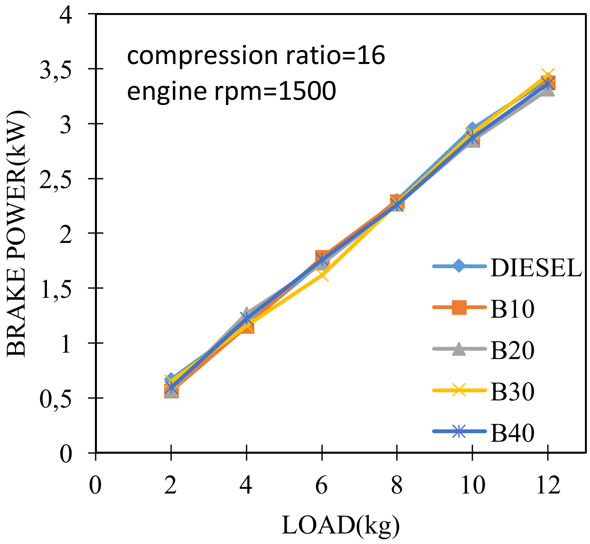

Figure1.2 Varation of brake power with load applied and blends

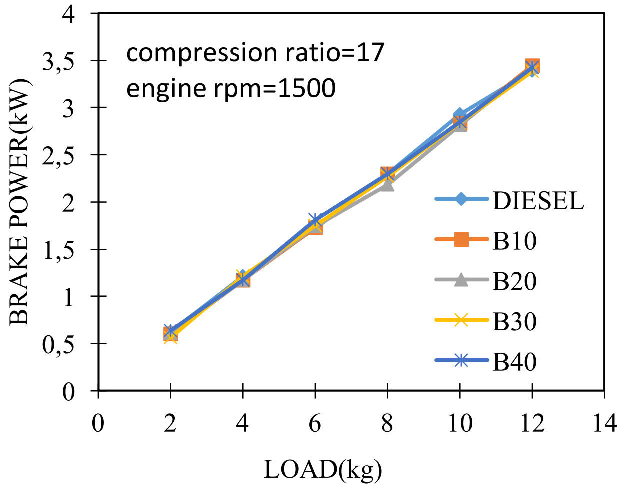

Figure1.3 Varation of brake power with load applied and blends

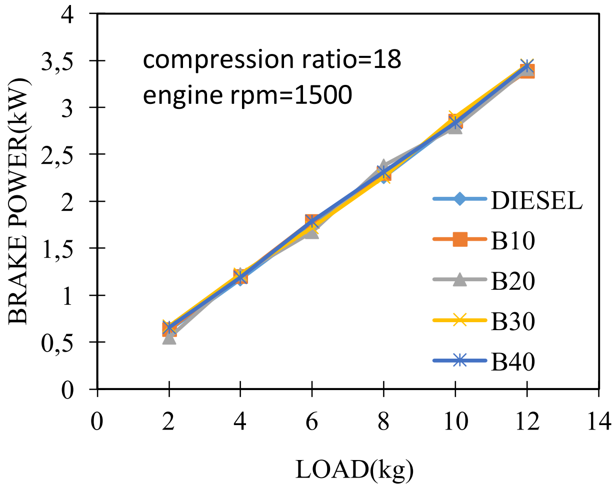

Figure1.4 Varation of brake power with load appied and blends

3.2 Brake thermal efficiency

Brake thermal efficiency (BTE) signifies how efficiently engine is capable to convert fuel into mechanical energy. Figures 2.1, 2.2, 2.3 and 2.4 illustrate the graphbetween the brake thermal efficiency and load applied from no load to full load corresponding to 0.0 to 12.00kg. It shows that the variation of brake thermal efficiency with compression ratio of 15, 16, 17 and 18. The brake thermal efficiency tends to be the same at lower load for all blends to the compression ratio of 15, 16 and 17, however, it varies for compression ratio 18.Brake thermal efficiency (BTE) increases with respect to increase in load, compression ratio, blending ratio up to 40%, and for all blend. However, the gap of BTE of diesel and blended fuels are deferent. Figure 2.1 shows maximum BTE at full load for diesel and B40 are 33.54% and 38.18% respectively at CR 15. Figure 2.2 shows that at maximum load BTE for diesel and B40 are 33.2% and 37.76% correspondingly at CR 16.at maximum load, BTE for diesel and B40 are 33.15% and 38.47% respectively at CR17. Figure 2.4 shows that at maximum load BTE for diesel and B40 are 33.33% and 38.7% at CR 18.This may be due to possession of higher calorific value of WPO and its blends with diesel then pure diesel (Panda et al.2016).

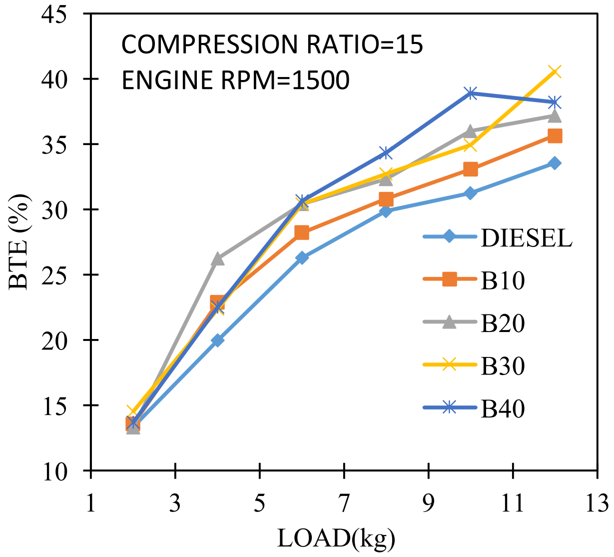

Figure 2.1 Variation of brake thermal efficiency with Load and blends

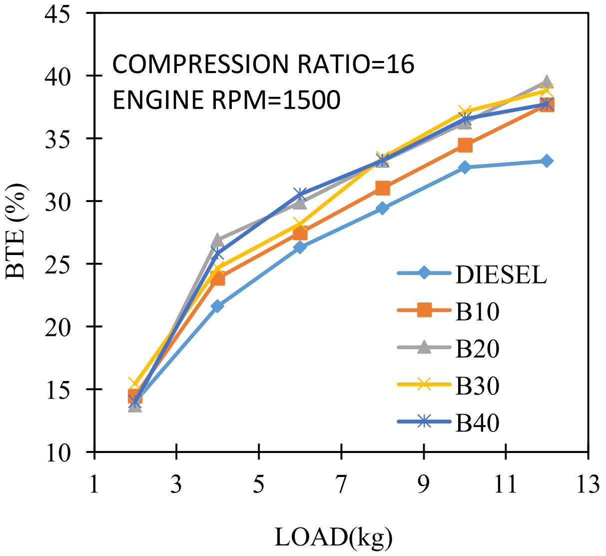

Figure 2.2 Variation of brake thermal efficiency with Load and blends

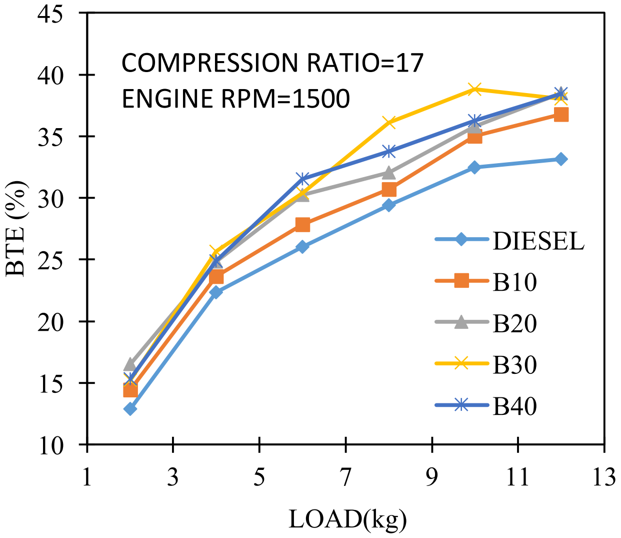

Figure 2.3: Variation of brake thermal efficiency with Load and blends

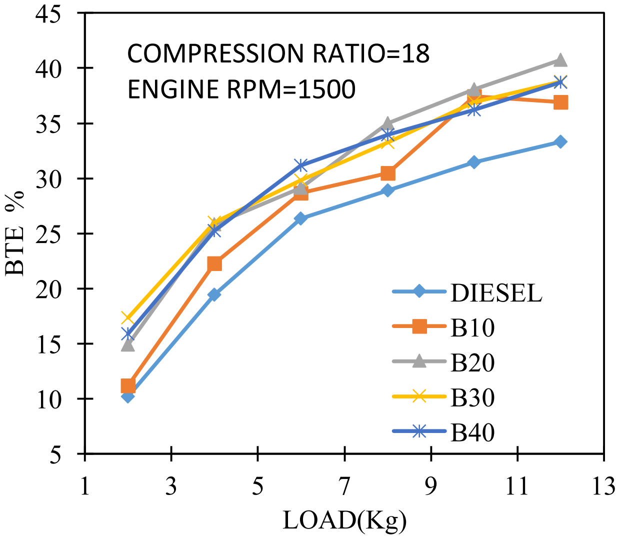

Figure 2.4: Variation of brake thermal efficiency with Load and blends

3.3 Specific fuel consumption

Figures 3.1, 3.2, 3.3 and 3.4represents about the variation of brake specific fuel consumption (BSFC) with respect to different load applied in kg up to full load equivalent to no load - full load, and compression ratio of 15, 16, 17 and 18. These graph prove that as the load increses, BSFC decreases continously for all blendes and to all comprssion ratio. This is because, when the load increases temperature inside the clylinder increases, reduces delay period, total combustion timing increases and result proper combustion of fuel. It can also be noticed that trend of falling BSFC corresponding to load applied is almost same for pure diesel and B40 blend, however it differs for lesser ratio of blend and lower load.The variation in BSFC at maximum load for diesel and B40 is 0.26 ±0.04 kg/kWh. Moreover, compression ratio 17 and 18 providelesser BSFC of B40 blend at low load in comarasion to CR 15 and 16.These trends of BSFC is all because of possesing high calorific value of WPO and better combustion toward higher compression ratio.

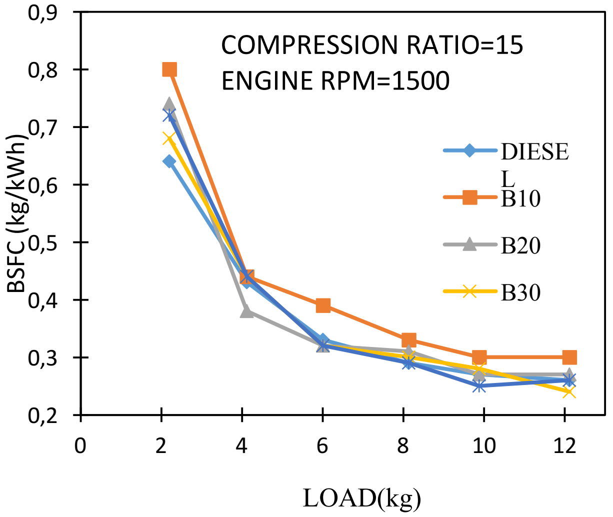

Figure 3.1: Variation of BSFC with Load and Blends

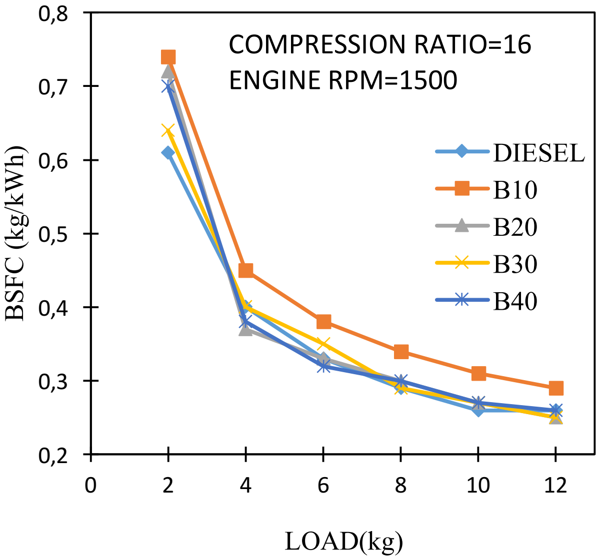

Figure 3.2: Variation of BSFC with Load and Blends

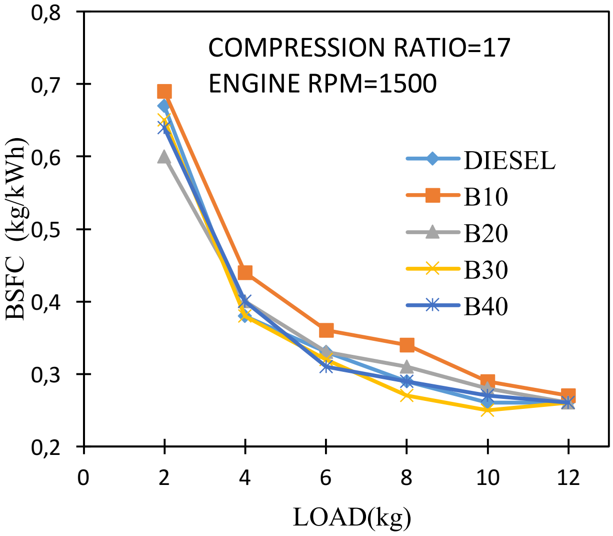

Figure 3.3: Variation of BSFC with Load and Blends

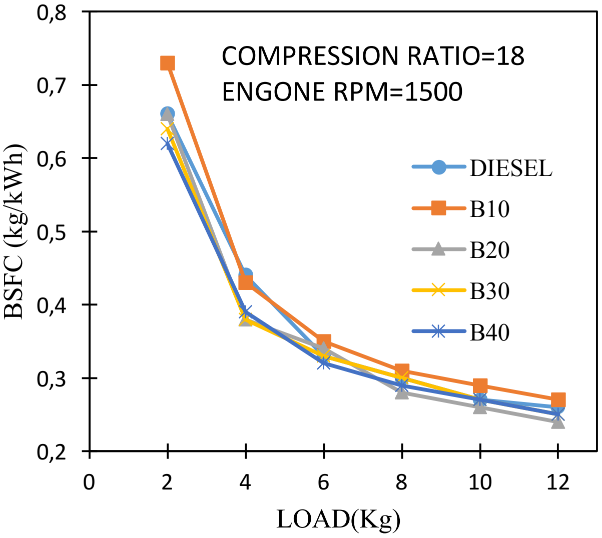

Figure 3.4: Variation of BSFC with Load and Blends

3.4 CO emissions

A toxic gas Carbon monoxide (CO) emitted from the engine, measured at tail pipe corresponding to variation of load, and at compression ratio of 15,16,17 and 18 are shown in the figures 4.1, 4.2, 4.3 and 4.4 respectively. The CO produced during the combustion due to lack of oxygen, poor air entertainment, mixture preparation and incomplete combustion (Heywood, J.B., 1984). It observed that Carbon monoxide (CO) decreases with increase in load, blend ratio up to 40% of WPO, and compression ratio. CO emissions decreases continously for all blendes, and the value of emission in volume percentage for B40 and pure diesel at maximum load are0.04 and 0.03 , 0.03 and0.02, 0.02 and 0.02,0.03 and 0.01 coresponding to CR15,16,17,and 18 respectevely. The reson behind decreased CO emission may be due to increase in combustion efficiency and better mixing. It can be noticed that the decresed in the value of CO emission with increse in load, blending ratio, and compression ratio fall are in the range of 0.13 to 0.01 volume percentage.

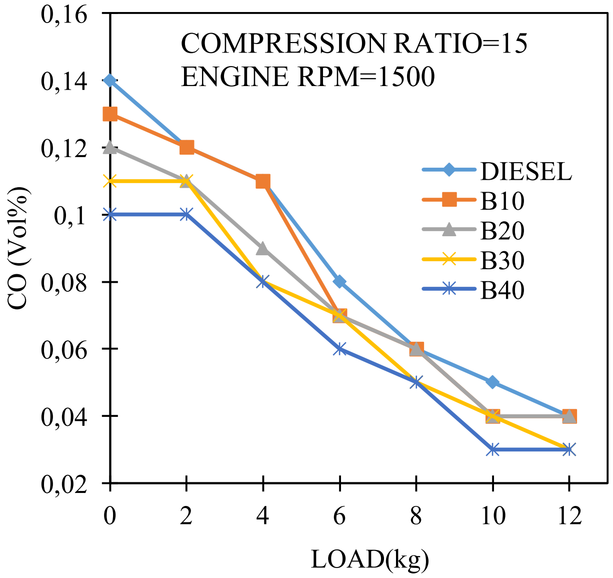

Figure 4.1: Variation of CO with Load applied and Blends

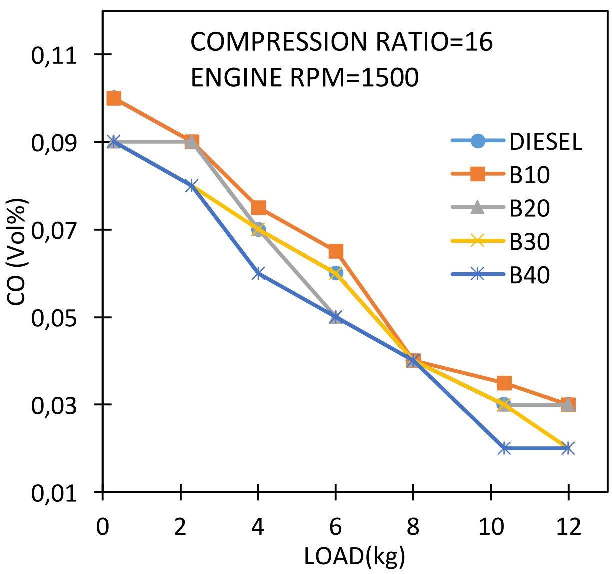

Figure 4.2: Variation of CO with Load applied and Blends

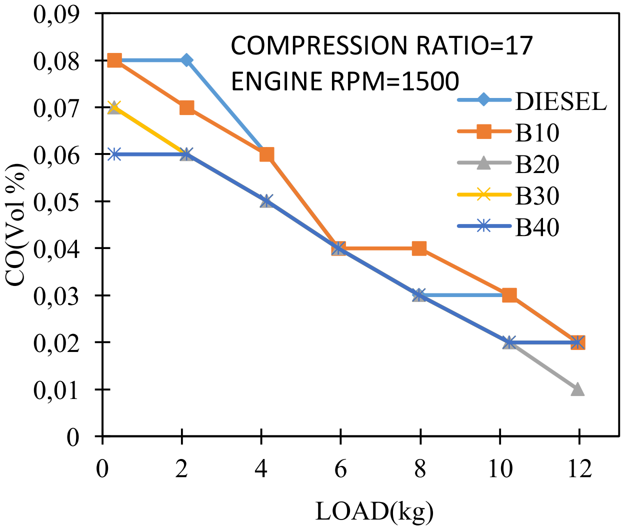

Figure 4.3: Variation of CO with Load applied and Blends

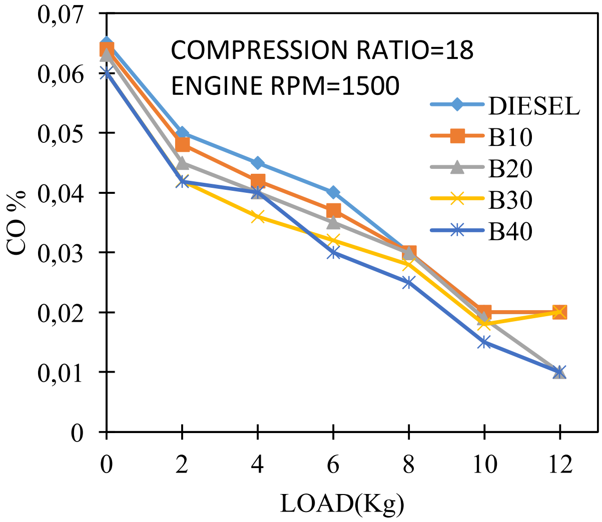

Figure 4.4: Variation of CO with Load applied and Blends

3.5NOx emissions

NOx emission at the exhaust tail of an engine have been measured in parts per million (ppm) for different blends of WPO with pure diesel and with the variation of compression ratio (CR) from 15-18 are plotted as function of load in figures 5.1, 5.2, 5.3 and 5.4.The reason of NOx formation is mainly due to availability of oxygen, reaction time and higher temperature during combustion. Figures depict that NOx emission increases upto 10 kg (80% load) and decreases thereafter for the compression ratio 15 and 16, however, increasing trend of NOxis continue for CR 17 and 18 throughoutthe load range. It can be observed that NOx emission of B40is very closedto pure diesel at lower load up to the 50% and higher for further increased load for all CR.Increasing of NOx with load and blends incrementmight be due to higher heat released and higher combustion temperature. Moreover,could be due to longer ignition delay owing to the presence of long chain carbon compounds in WPO (Panda et al., 2016).Figure show that at maximum load NOxemission for diesel and B40 is 316ppm and 282ppm respectively for CR 15, 321ppm and 294ppm for CR 16, 382ppm and 305ppm for CR 17 and 472ppm and 468ppm for CR 18.Which indicates NOx emission is proportional to the CR increase, along with load and all blends.

3.6 CO_2emissions

Increasing tendency of CO_2 emission corresponds to the complete combustion, however CO emission shows incomplete combustion. CO_2 emission decreases corresponding to increasing thermal efficiency.CO_2 exhaust emission measured at exhaust tail at different blends (B10,B20,B30,B40) and compression ratio (15,16,17 and 18) with respect to load applied are shown in figures 6.1, 6.2, 6.3 and 6.4.

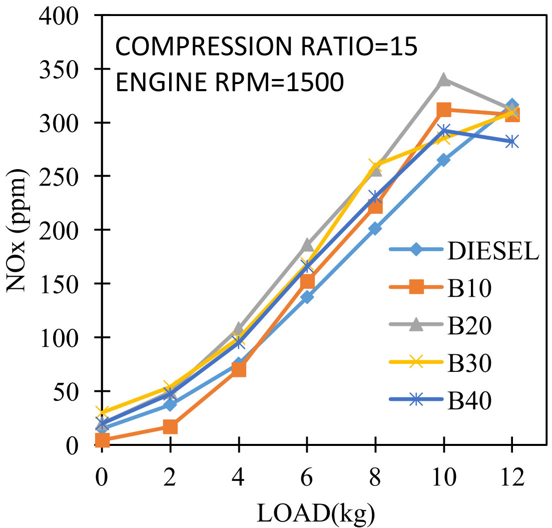

Figure5.1: Variation of NOx with Load and Blends

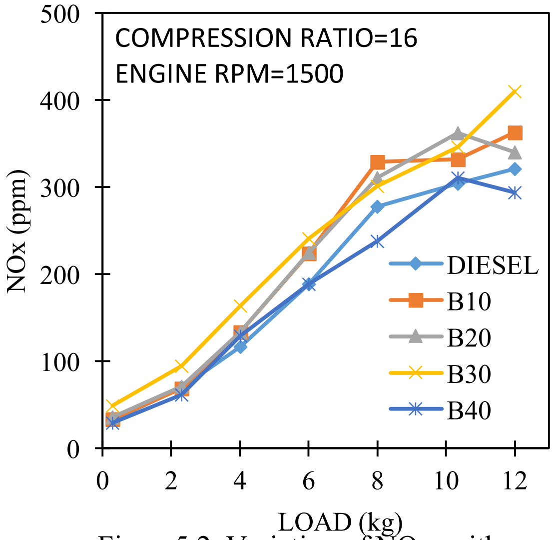

Figure5.2: Variation of NOx with Load and Blends

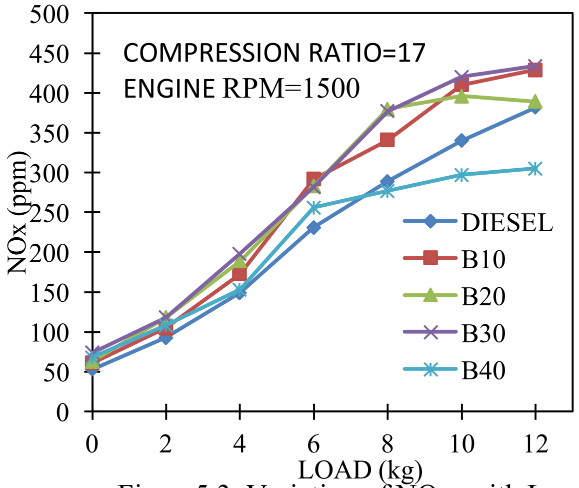

Figure5.3: Variation of NOx with Load and Blends

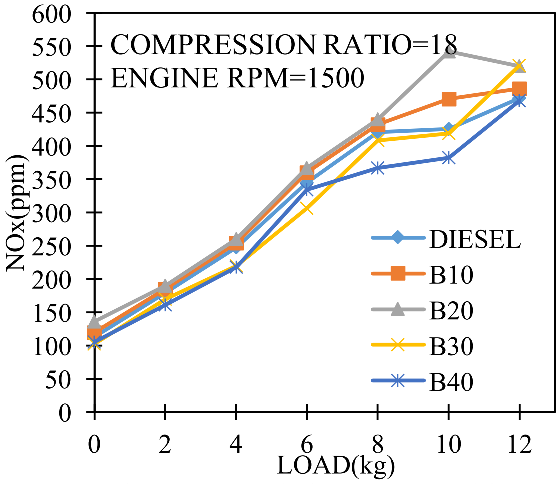

Figure5.4: Variation of NOx with Load and Blends

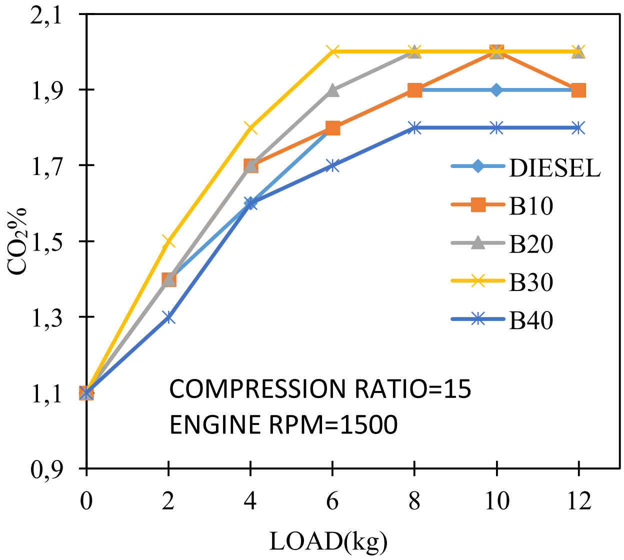

Figure 6.1: Variation of CO_2 with Load and Blends

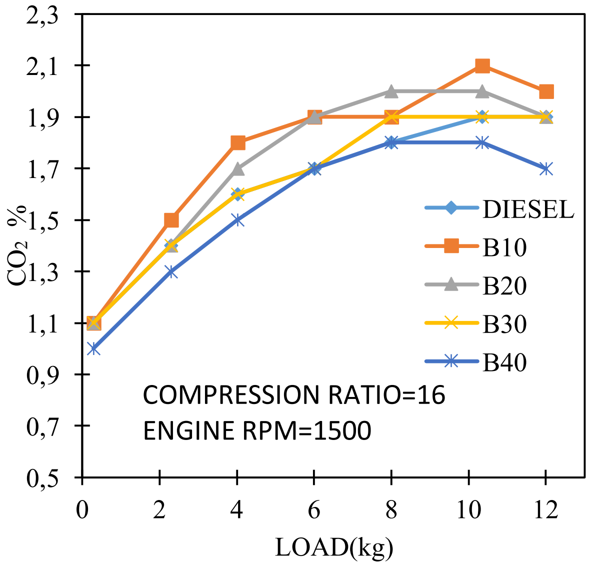

Figure 6.2: variation of CO_2 with Load and Blends

Figures illustrate that CO_2 emission of B40 is lower for all compression ratios, when compared with diesel. CO_2 emissions increase with respect to load for all blends, and at maximum load, emission for diesel and B40 is almost same as 1.9% and 1.8% respectively at CR 15, 1.9% and 1.7% respectively at CR 16, 2.1% and 2.1% respectively at CR 18. The average emission of CO_2 increases sharply up to the 60% to 70% (8-10 kg) of load and further slows down. This indicates that after 60% load engine gives better performance, although CO2 emission is high.

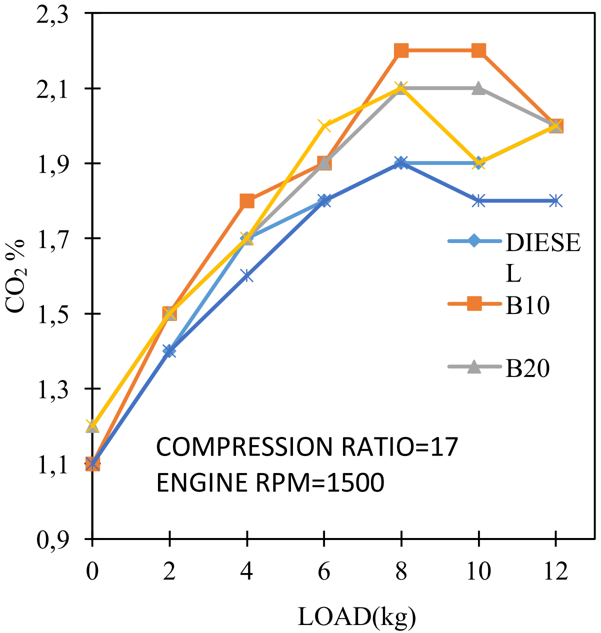

Figure6.3: Variation of CO_2 with Load and Blends

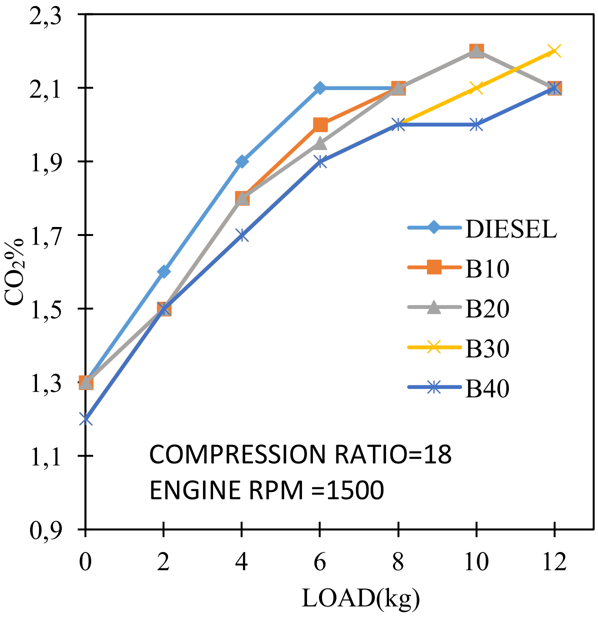

Figure 6.4 Variation of CO_2 with Load and Blends

4. Conclusion

An intensive experimental study was conducted on a single cylinder 4-stroke diesel engine to appraise the effects of performance and exhaust emission operating with WPO and its blends with diesel. The following conclusions are drawn from the experimental study

1. The use of Waste Plastic Oil blended fuel in a diesel engine causes improvement in engine performance and exhaust emissions. Plastic oil is save to use till 40% blended with diesel without loss of power, and its trend do not differ with variation in compression ratio.
2. Waste Plastic oil addition results in the increase of Brake Thermal Efficiency (BTE) and decrease in the specific fuel consumption. BTE for diesel and B40 are 33.33% and 38.7% at CR 18 at maximum load. The BSFC reduces with increase in CR. The variation in BSFC observed at maximum load for diesel and B40 is 0.26 ±0.04 kg/kWh at CR 18.
3. Waste plastic oil addition results in significant reduction in exhaust emissions. Carbon monoxide (CO) decreases with increase in load, increase in blend ratio up to 40% of WPO and increase in compression ratio. NOx emission of B40 is very closed to pure diesel at lower load up to the 50% and higher for further increased load for all CR. CO_2 emission of B40 is lower for all compression ratios, when compared with diesel. CO_2 emissions increase with respect to load for all blends, and at maximum load emission for diesel and B40 are almost same.

References

1. K.S. Rinku Verma, Vinoda, M. Papireddy, A.N.S. Gowda, Toxic Pollutants from Plastic Waste- A Review. *Procedia Environmental Sciences*. 35(2016) 701–708.
2. M. Z. H. Khan, M. Sultana , R. Al-Mamun M. , M. R. and Hasan, 2016. Pyrolytic Waste Plastic Oil and Its Diesel Blend: Fuel Characterization, Journal of Environmental and Public Health. Article ID 2016 (2016)1-6.
3. S.H. Hamid, M.B. Amin, A.G. Maadhah, Handbook of polymer degradation. New York: Marcel Decker; 1992.
4. P.T. Williams, E.A. Williams, Interaction of plastics in mixed plastics pyrolysis. *Energy Fuels,* 13 (1990) 188–96.

5. S.Kumar, R. Prakash, S. Murugan, R.K. Singh, Performance and emission analysis of blends of waste plastic oil obtained by catalytic pyrolysis of waste HDPE with diesel in a CI engine. *Energy Conversion and Management*, 74 (2013) 323–31.
6. M. Mani, Subash, C. G. Nagarajan, Performance, emission and combustion characteristics of a DI diesel engine using waste plastic oil. *Applied Thermal Engineering,* 29 (2009) 2738–2744.
7. R. Miandad, M.A. Barakat, S. Asad, Aburiazaiza ,M. Rehan, A.S. Nizami Catalytic pyrolysis of plastic waste: A review, *Process Safety and Environmental Protection,* 102 (2016) 822–838.
8. Viswanath K. Kaimal, P. Vijayabalan, A detailed study of combustion characteristics of a DI diesel engine using waste plastic oil and its blends. *Energy conversion management* 105 (2015) 951 – 956.
9. S. Murugan, M.C. Ramaswamy and G. Nagarajan, The use of tyre Pyrolysis oil in diesel engines. Waste Management of tyre Pyrolysis oil in diesel engines. *Waste Management*, 28 (2008) 2743-2749.
10. Younus, S. K. Mohammad, V. Kumar, Ranjith, Rao, Y.V. Hanumantha, Performance and Emissions Characteristics of Diesel Engine Fueled With Tyre Pyrolysis Oil & Diesel Blends with Additives. *International Journal of Engineering Science Invention,* 2 (2013) 32-37.
11. R. P. Harshal, M. L. Shailendra, Waste plastic Pyrolysis oil Alternative Fuel for CI Engine. *Research Journal of Engineering Sciences.*2 (2013) 26-30.
12. P, Achyut, S. Murugan, R.K. Singh, Performance and emissions characteristics of diesel fuel produced from waste plastic oil obtained by catalytic pyrolysis of waste polypropylene, Energy soures, Part A; *Recovery utilization and environmental effects*, 38 (2016) 568-576.
13. J. Ankit, P. Tushar,R. Gaurav, Effect of Varying Load on Performance and Emission of C.I. Engine Using WPO Diesel Blend. IOSR *Journal of Mechanical and Civil Engineering*. 12 (2015) 37-44.
14. S. Ananthakumar, S. Jayabal, P. Thirumal, Investigation on performance, emission and combustion characteristics of variable compression engine fuelled with diesel, waste plastics oil blends. *Brazilian Society of Mechanical Sciences and Engineering*. 39 (2017) 19-28.
15. S. Dayana A. Sharuddin, F. Abnisa, W. W. M. Ashri Daud,A.K. Mohamed, A review on pyrolysis of plastic wastes. *Energy Conversion and Management*. 115 (2016) 308–326.
16. R. Miandad, A.S. Nizami, M.Rehan, M.A. Barakat, M.I. Khan, A. Mustafa, I.M.I. Ismail, J.D. Murphy, Influence of temperature and reaction time on the conversion of polystyrene waste to pyrolysis liquid oil. *Waste Management*. 58(2016) 250–259.
17. T. J. Anup, Vilas Watwe, Waste Plastic Pyrolysis Oil as Alternative For SI and CI Engines. *International Journal of Innovative Research in Science, Engineering and Technology*. 3(2014) 14681-14687.
18. M. Mani, G. Nagarajan, S. Sampath, Characterisation and effect of using waste plastic oil and diesel fuel blends in compression ignition engine, *Energy,* 36 (2011) 212-219.
19. C. Güngör, H. Serin, M. Özcanlı, S. Serin, K. Aydın, Engine Performance and Emission Characteristics of Plastic Oil Produced from Waste Polyethylene and Its Blends with Diesel Fuel. *International Journal of Green Energy,* 12 (2015) 98–105.
20. V. K. Kaimal , P. Vijayabalan, A study on synthesis of energy fuel from waste plastic and assessment of its potential as an alternative fuel for diesel engines, *Waste Management*, 51 (2016) 91–96.

.

(2018) ; http://www.jmaterenvironsci.com