MATEC Web of Conferences 45, 03002 (2016)
DOI: 10.1051/matecconf/20164503002

Performance and Emission Studies of a SI Engine using Distilled Plastic Pyrolysis Oil-Petrol Blends

Kareddula Vijaya Kumar[1], Ravi Kumar Puli[1], A. Swarna Kumari[2] and P. Shailesh[3]

[1] Dept. of Mechanical Engineering, National Institute of Technology, Warangal, TS-506004, INDIA
[2] JNTUK/ MED, Kakinada, INDIA
[3] MCET, OU/MED, Hyderabad, TS-500001, INDIA

Abstract. In the present work, an experimental investigation is carried out to evaluate the use of plastic oil derived from waste plastic which used in a Spark Ignition engine. Experiments are conducted, the measured performance and emissions of plastic oil blends at different proportions are compared with the baseline operation of the SI engine running with gasoline fuel. Engine performance and exhaust gas emissions such as carbon monoxide, total unburned hydrocarbons, carbon dioxide and oxides of nitrogen are measured. From the experiments it is observed that 50% Distilled Plastic Pyrolysis Oil (50%DPPO) exhibits the substantial enhancement in brake power, brake thermal efficiency and reduction in brake specific fuel consumption running at full load conditions among different blends and pure petrol. There is also noticed decrement of carbon dioxide and unburned hydrocarbons emissions at the same blend. The experimental result shows that plastic oil shall conveniently be used as a substitute to gasoline in the existing SI engines without any modifications.

1 Introduction

Increasing industrialization, urbanization and changes in the pattern of human life, will accompany the process of economic growth but at parallel causes for increasing quantities of environmental wastes leading to increased threats to it. Developing countries like India depends heavily on oil import. From the last two decades research around the world is concentrating on alternative energy generation techniques, it is the high time to generate the energy by alternative sources. Alternative fuels for both spark ignition and compression ignition engines have become very imperative owing to increased environmental protection concern, need to reduce dependency on petroleum products and even socioeconomic aspects. The past three and half decades are witnessed for an explosive growth of the plastic utilization across world. The production of synthetic polymers represented by polyethylene (PE), polypropylene (PP), polystyrene (PS), and polyvinyl chloride (PVC). These plastics are widely used in many important day to day applications such as clothing, household appliances and in automotive products and aerospace. While we enjoying the conveniences that plastics can provide, the treatment of waste plastic becomes an unavoidable and imminent issue.

In this context, it is urgent need to search a safety and effective ways to recycle waste plastics. Recently new ways of environmental friendly waste plastic recycling have been of interest, and among them, the use of waste plastics as a supplementary fuel has attracted interest of many researchers. Mehdi et al. [1] reviewed the PVC wastes and suggested chemical recycling is the best process for the environmental pollution problems and addressed several recent separation and recycling problems. Mitsuhara et al. [2] attention is also focused on using oil derived from waste plastics in diesel engines. Williams et al. [3] investigated the diesel engines are the most preferred power plants due to their excellent driveability and higher thermal efficiency. Naima et al. [4] had investigated alternative fuels for internal combustion engines by using waste plastics, waste engine oil and waste cooking oil. The properties of the oil derived from these three types of oils were analysed and compared with the diesel fuel. Moinuddin Sarker, et al. [5] used stainless steel reactor to produced hydrocarbon vapors from waste thermoplastics. Plastics are non-biodegradable polymers mostly containing carbon, hydrogen and few other elements which were the root cause for the plastic waste management and environmental issues [6-8]. Many researchers are investigated the usage of waste plastic oil and waste tyre oil as an alternative fuel for diesel engine. Shanmuga Vadivel et al. [9] are investigated the performance and emission characteristics of Nano engine running on plastic oil with gasoline blends. Their results shows an increase in brake thermal efficiency for the blends when compared to that of gasoline fuel. [10-12] were run the diesel engine blended with plastic oil to evaluate the performance and emission characteristics without any engine modifications, their investigation clears that the plastic oil is alternate fuel for diesel engine. [13-17] are experimentally investigated on a diesel engine using waste plastic oil and tyre oil blends with exhaust gas recirculation. Their results shows that plastic and tyre oil blended engines suffers with high NO_x emission, which can deduced by using exhaust gas recirculation. Vijaya Kumar et al. [18] had investigated the performance and emission characteristics of diesel engine with three hole injector by using tyre oil blends and their results shows that 20% tyre oil blend was given better performance compared with diesel and other blends at all injections pressures. [19-22] are conducted experiments on diesel engine fuelled with tyre pyrolysis oil blended at different proportions to evaluate the performance and emissions with and without ethanol. [23, 24] are investigated the performance, emission and combustion studies using distilled tyre pyrolysis oil blends on diesel engine without any engine modification. However, very little work has been done to test their use in high-speed diesel engines. The main objective of this research is derived from the literature review, analyze the engine performance, combustion and emission characteristics of petrol engine fuelled with distilled waste plastic oil blends with petrol fuel. The crud waste plastic oil prepared from the pyrolysis process was carried out the batch distillation apparatus. This distilled plastic oil blended with gasoline at different volume fractions and the performance and emission characteristics was carried out on 4stroke single cylinder kerlosker petrol engine without any engine modifications.

1.1 Preparation of Plastic Pyrolysis Fuel

The production method for the conversion of plastics to liquid fuel is based on the pyrolysis of the plastics and the condensation of the resulting hydrocarbons are shown in Fig. 1. Pyrolysis refers to the thermos-chemical process for conversion of waste plastic by heating the feed stock at high temperature in absence of air which produces gaseous products which is them condensed to give liquid fuels consisting of pyrolytic oil or liquid oil.

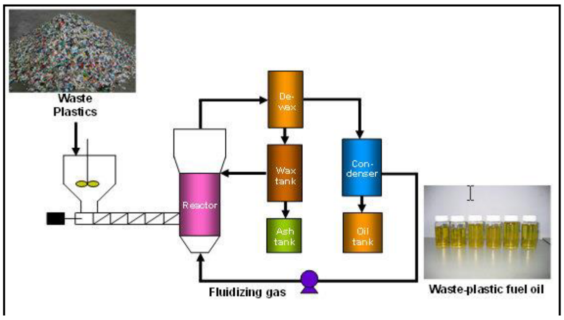

Figure 1. Pyrolysis process of waste plastics

Waste plastic is treated before feed in to the reactor. The feed stock passed to hopper through mills and send in to reactor by the hot screw conveyor. In reactor waste plastic is subjected to high temperature and low pressure by the hot gasses coming from combustion chamber where they will decompose at 450°C to 550°C. Vapors, gasses and char products are generated and they passed through cyclone filter. The char is collected at the ash tank and gasses are send to condenser. In the condenser heat from this gasses is utilized to generate steam. The steam can used to generate the power as by product. So, that the plastic vapors are gets condensed in the condenser. The condensate oil is separated and used to further transformation, the non-condensable gasses are feed back to the reactor as fluidized gasses. Almost 70-80% of gaseous products are converted in to liquid fuels providing a good quantity of liquid fuel which then can be enhanced.

1.2 Reducing Viscosity of Plastic Pyrolysis Oil

The plastic oil which obtained by the pyrolysis method has some disadvantages such as high viscosity, low volatility, gumming effect and carbon residue. So, that the demerits impose a negative impact on the engine performance, emissions durability. Therefore, before using they as fuels the viscosity of the plastic oil have to be reduced. One interesting method to reduce the viscosity of the plastic oil and also to improve the spray formation so as to use them in the spark ignition engines are distillation. This process applied for petrol and diesel grade fuel production process. Fig. 2, distillation apparatus is used for to remove the impurities from basic fuel and increase the volatility of fuel. After distillation volatility of fuel is increase, it helps to homogenization of air fuel mixture in case of SI engine carburetor itself and also avoid logging of fuel impurities in filter or in nozzle holes.

Figure 2. Batch distillation apparatus

Waste plastic to fuel was use for further distillation process and making petrol grade fuel. Distillation column was use for distillation process. Distillation process set up different columns with different temperature profile like low boiling point fuel to high boiling point fuel. Petrol grade fuel collected from fractional column and temperature range was 90°C to 160°C. This fuel hydrocarbon compound also heavier and this fuel are not igniting. Collected petrol grade fuel percentage was about 42% and rest of all other fractional fuel percentage was 58% including diesel grade fuel and light gas also. Fractional distillation process was also generating some light gases. Plastic pyrolysis fuel to different fuel by using fractional distillation column used for heat applied with different column temperature wise and fuel break down into shorter into longer chain wise and come out into different fraction column then collected into separate container.

In the present study distillate of the plastic oil is obtained in the same boiling range of petrol (90-160^{o}c). The oil is obtained by pyrolysis come distillation is shown in the below Fig. 3.

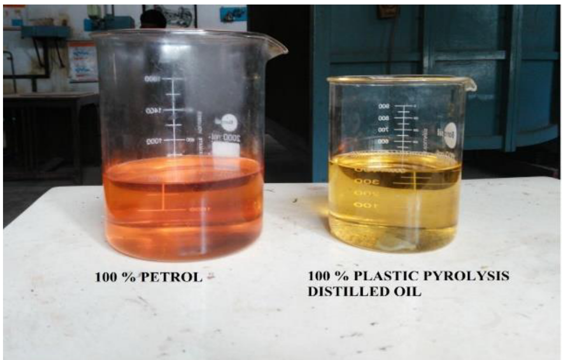

Figure 3. Pure distilled plastic oil and Petrol

Table 1: Basic properties of fuels

S. No.	Characteristics	Petrol	PPO	DPPO
1	Specific Gravity @ 40^{o}C	0.720	0.820	0.780
2	Kinematic Viscosity m^2/sec @ 40^{o}C	0.5 x 10^{-6}	2.52 x 10^{-6}	0.7 x 10^{-6}
3	Calorific Value (kJ/kg)	43953	42808	46817
4	Density @ 40^{o}C (kg/m^3)	720	820	780

As the derived plastic fuel from the waste plastic after pyrolysis and distillation catches fire in room temperature itself, so flash and fire point is not valid for the arrived fuel as same like as petrol. And the extraction from the distillation i.e. plastic fuel slightly having more calorific value compare to that of gasoline, and also having density more than that of the gasoline. Some of the properties of the petrol, plastic pyrolysis oil (PPO) and distilled plastic pyrolysis oil (DPPO) are compared in table 1.

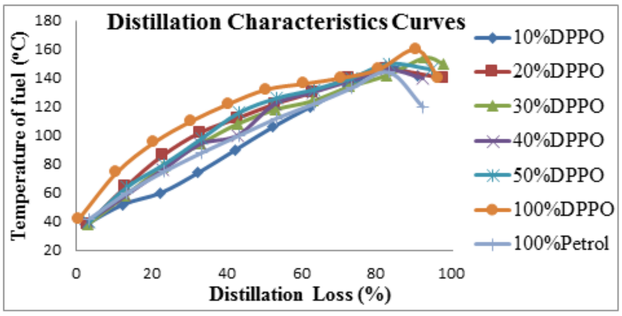

Figure 4. Volatility variation in petrol and DPPO blends

The tendency of a fuel to vaporize is also characterized by determining a series of temperatures at which various percentages of the fuel have evaporated (boiling temperatures), as described in ASTM D86, Test Method for Distillation of Petroleum Products. The temperatures at which 10 percent, 50 percent, and 90 percent evaporation occurs are often used to characterize the volatility of gasoline.The distillation characteristics curves of the petrol and plastic fuel as well as the different blends are shown in Fig. 4. From Fig. 4, it can be observed that the volatility property is more in the plastic pyrolysis distilled oil blends compared to the 100% petrol.

1.3 Preparation of Plastic Oil Blend

The basic properties of DPPO-PF were measured and compared with conventional petroleum fuels. The Carbon content are higher for DPPO than petrol fuel. In the present work 10%DPPO, 20%DPPO, 30%DPPO, 40%DPPO and 50%DPPO of DPPO was blended with petrol fuel on volume basis and observed for 15 days to check for any separation. No such separation was noticed. DPPO blended with PF is indicated as 10%DPPO. For example, 10%DPPO blended with 90% PF is denoted as 10%DPPO.

1.4 Experimental Setup

The Test rig comprises of the following apparatus and the layout is shown in Fig. 5,

- Petrol engine
- Electrical Dynamometer
- Burette setting with fuel consumption pipe and fuel tank
- Air and fuel supplied to engine
- Gas analyzer and Display

The test rig consists of single cylinder, 4-stroke, air-cooled petrol engine coupled to a electrical dynamometer, which acts as a loading device. A six channel temperature indicator provided to measure the temperature at various points of the test rig.

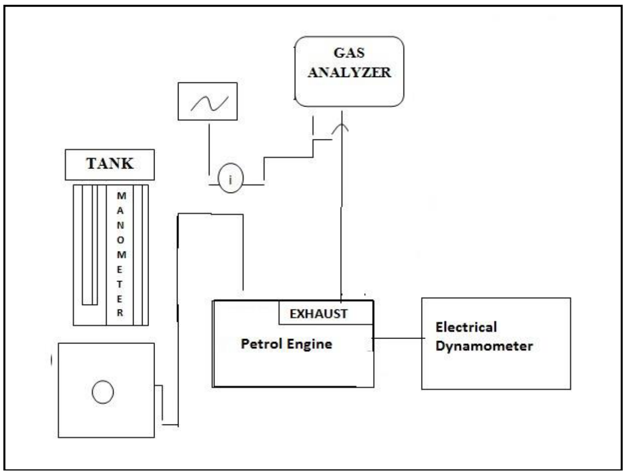

Figure 5. Layout of the Experimental Set up

The engine is complete with carburetor, governor, exhaust silencer, etc... a 2.2 KVA capacity, single phase, DC Generator is coupled on a strong iron base plate with bank (fin type resistor) arrangement a panel board consisting of main switch, voltmeter, ammeter to measure the power output. A fuel tank of about 5 liters capacity, a 100cc x 0.1cc burette and a three way cock arrangement. A silencer is fitted to the exhaust pipe to reduce the noise level to a minimum. A single phase panel board arrangement consisting of a digital ammeter and voltmeter and single phase main switch. All this above instruments with panel board are mounted on the M.S. Fabricated stand. The speed of the engine is measured by the use of non-contact type digital tachometer.

1.5 AVL Gas Analyzer

The purpose of the AVL gas 444 is to measure the relative volumes of certain gases constituents in the exhaust gas of motor vehicles has shown in Fig. 6. These gases are carbon monoxide, carbon dioxide, hydrocarbons, and oxygen nitric oxide. The air fuel ratio is calculated from the CO, CO_2, HC and O_2, constituents and displayed. The Liquid crystal display shows the constituents of the gas once the gas is allowed to flow in. It is a standard output device for the AVL gas 444. The functional keys serves for various purposes such as to fine filter helps in removal or separation of water which enters into meter with tested gas. This prevents the damage of the machine. Frequently the filter has to be replaced depends on the manufacturer catalogue. The water inlet allows the gas from the engine exhaust into the machine. The exhaust gas probe takes a sample of gas from the exhaust tail pipe of the vehicle and carries it to the gas analyzer via exhaust gas hose. The important elements that are present on the back side are condensate outlet, ventilator and fan, sensors rpm and oil temperature RS 232 connection and power supply.

Figure 6. AVL Gas Analyzer

2 Results and Discussion

2.1 Engine Performance Characteristics

2.1.1 Brake Specific Fuel Consumption

Brake specific fuel consumption of an engine is defined as the rate of fuel consumption per unit power produces. This is an important performance parameter as it determines the mileage of the vehicle. It can be seen from the Fig. 7, that the BSFC of the engine decreased with increase in load and also BSFC decreased with increase in the proportion of plastic oil in the blend. Density and calorific values of the blend increases with increases in the plastic proportion as the plastic oil is denser than petrol and also have higher calorific value.

2.1.2 Brake Thermal Efficiency

Fig. 8, shows the variation of brake thermal efficiency with load for various blends. Brake thermal efficiency increased with increase in load with the rate of variation decreasing with increase in load acting. For the 1/6th, 1/3rd and 1/2 load conditions the brake thermal efficiency of 50%DPPO is more than the pure Petrol, after half load condition the brake thermal efficiency is fall and again raised at the full load conditions.

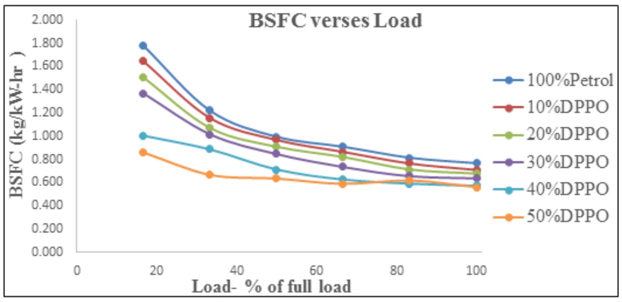

Figure 7. Variation of Brake Specific Fuel Consumption with Load

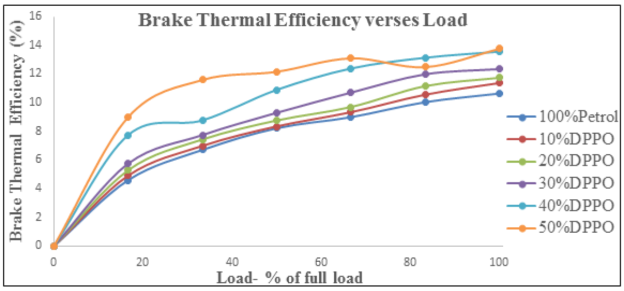

Figure 8. Variation of Brake Thermal Efficiency with Load

2.2 Engine Emission Characteristics

2.2.1 Carbon Monoxide

From Fig. 9, it can be observed that, CO emissions increased with increase in load reached the maximum at 4th or 5th load and there after slightly decreased. CO emissions are due to incomplete complete combustion of fuel either due to inadequate oxygen or flame quenching. In the present study as the engine is equipped with a carburetor to supply fuel to the engine cylinder, fuel air mixture might not be homogenous throughout the cylinder. CO emissions increased marginally with increase in the proportion of the plastic oil in bend.

2.2.2 Oxides of Nitrogen

NO_x emissions increases with increase in the peak cylinder temperature. Peak cylinder temperature increases with increase in load. NO_x emissions also varies with air fuel ratio, but in petrol engine air fuel ratio does not vary much with load. From Fig. 10, it can be observed that

NO_x emissions increased with increase in load as predicted.

2.2.3 Unburnt Hydro Carbons

Fig. 11, shows the variation of unburnt hydro carbon emissions with load for all blends. Unburnt hydro carbon emissions decreased with increase in the proportion of plastic oil in bend. Whereas CO emissions increased with increase in the plastic oil content in blend. In-cylinder temperature is a key factor in determining unburned HC and CO emissions characteristics. Lower temperatures generally cause higher emissions of unburned HCs and CO, however there are certain temperature ranges where HC emissions increase while CO decreases. An important consideration for the HC and CO emissions characteristics is the hot ignition and CO to CO_2 Oxidation threshold temperatures. Prior research has shown that the rapid breakdown of H_2O_2 leading to hot ignition for HC fuels begins at roughly 1000 K. CO-to-CO_2 oxidation requires temperatures of at least 1500 K.

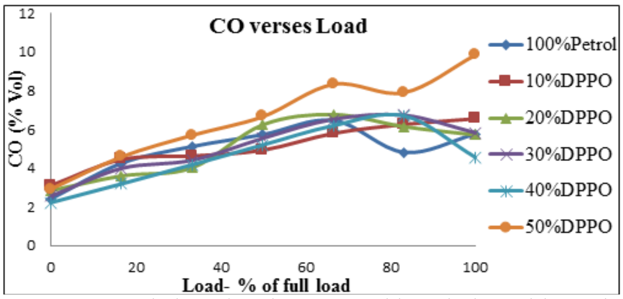

Figure 9. Variation of Carbon Monoxide emission with Load

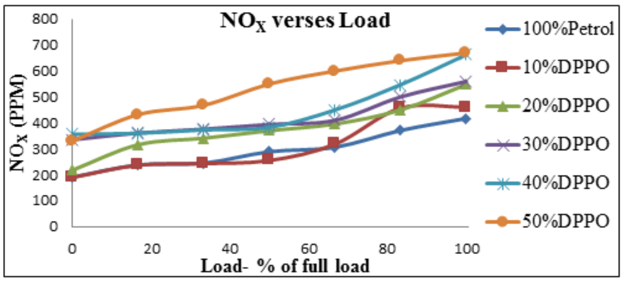

Figure 10. Variation of Oxides of Nitrogen emission with Load

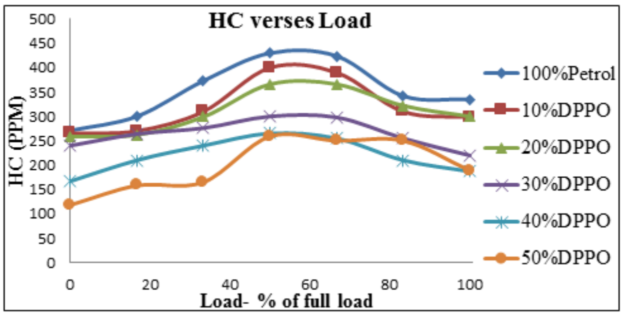

Figure 11. Variation of Unburnt Hydro Carbon emissions with Load

In the present study as the plastic oil has more calorific value than petrol, engine temperatures might be higher when the engine is operated with plastic oil. The HC and CO emissions exhibited an opposite trend with increase in plastic oil content in blend. This might be due to in-cylinder temperatures being near or below the H_2O_2 breakdown temperature, where radicals released from rapid H_2O_2 breakdown cause HC molecules to break down to form CO . When the temperatures are near or below 1000 K, partial oxidation of HCs into CO does not occur thereby causing higher emissions of HCs and lower emissions of CO.

3 Conclusions

Plastic pyrolysis distilled fuel is tested on the SI engine and the performance and emissions characteristics are compared with the different blends and the following observations are made.

- Plastic oil obtained from the pyrolysis of a plastic waste can be used as a fuel in petrol engine by obtaining the distillate in the temperature range of petrol.
- Petrol and plastic pyrolysis distilled fuel can be readily blended without any precautions or the methods as both their viscosity and density are of in the same range.
- It is observed that the distillation characteristics of both petrol and plastic pyrolysis distilled fuel are more or less similar.
- The basic specific fuel consumption of the engine fuelled with 50%DPPO is 26.84 % lesser than that of the engine fuelled with sole petrol at full load.
- The brake thermal efficiency of the engine with 50%DPPO is 19% higher than that of the sole petrol operation.
- The CO emissions in 50%DPPO are 1.7 times more than that of the engine fuelled with the 100% Petrol.
- The unburnt hydrocarbons are 43.58% lesser in the 50%DPPO engine operation compared to the sole petrol operation.
- The NO_x emissions are 1.6 times more in the 50%DPPO compared to that of the engine with 100% petrol as fuel.

In the view of performance, experiments can run beyond 50% distilled plastic pyrolysis oil without any engine modification, but while considering in NO_x emissions, they are proportionately increasing with the percentage of distilled plastic pyrolysis oil compared to 100% petrol. Which should be consider as per EPA regulation.

References

1. Mehdi Sadat-Shojai, Gholam Reza Bakhshandeh, Recycling of PVC wastes, Elsevier, Polymer Degradation and Stability, **96**, 404-415, (2011).
2. Mitsuhara Y, Soloiu VA, Nakaishi Y, Application of new fuel produced from waste plastics and heavy oil to diesel engine, Transaction of the Japan Society of Mechanical Engineers, **67**, 2618-2624, (2001).

3. Williams PT, Williams EA, Interaction of plastics in mixed plastics pyrolysis, J. Energy Fuels, **13**(1), pp 188-196, (1999).
4. Naima K and Liazid A, Waste oils as alternative fuel for diesel engine: A review, Journal of Petroleum technology and Alternative fuels, Vol. **4**(3), pp. 30-43, (2013).
5. Moinuddin Sarker, Mohammad Mamunor Rashid, Mohammad Molla and Ashiquz Zaman, Conversion of Municipal Waste Plastic into Liquid Hydrocarbon Fuel Using a Stainless Steel Reactor, JESE A 1, 721-726, ISSN: 1934-8932, (2012).
6. Mani M, Nagarajan G, Influence of injection timing on performance, emission and combustion characteristics of a DI diesel engine running on waste plastic oil. Energy, **34**, 1617-1623, (2009).
7. Soloiu A, Yoshihara Y, Hiraoka M, Nishiwaki K, Mitsuhara Y, Nakanishi Y, The investigation of a new diesel produced from waste plastics, Eco-Technology Research Center, ISME, (2000).
8. Hai VP, Nishida O, Fujita H, Harano W, Toyoshima N, Iteya M, Reduction of NOx and PM from diesel engines by WPD emulsified fuel, SAE 2001-01-0152, ISSN: 01487191, (2001).
9. T. Shanmuga Vadivel, P. Balashanmugam, T Sivakumar, Performance and emission characteristics of Nano engine running on Plastic oil extract, International Journal of Scientific Research (IJSR), Vol. **3**, Issue 7, ISSN: 2277-8179, (2014).
10. Jane Pratoomyod, Krongkaew Laohalidanond, Performance and Emission Evaluation of Blends of Diesel fuel with Waste Plastic Oil in a Diesel Engine, International Journal of Engineering Science and Innovative Technology (IJESIT), Volume **2**, Issue 2, ISSN: 2319-5967, (2013).
11. M. Mani, C. Subash, G. Nagarajan, Emission and combustion characteristics of a DI diesel engine using waste plastic oil. Applied Thermal Engineering, **29**, 2738-2744, (2009).
12. Senthilkumar Tamilkolundu, Chandrasekar Murugesan, The Evaluation of blend of Waste Plastic Oil- Diesel fuel for use as alternate fuel for transportation. 2nd International Conference on Chemical, Ecology and Environmental Sciences (ICCEES'2012), April 28-29, Singapore (2012).
13. Mani M, Nagarajan G, Sampath S, An experimental investigation on a DI diesel engine using waste plastic oil with exhaust gas recirculation. Fuel **89**, 1826-1832 (2010).
14. M Paul Daniel, KareddulaVijaya Kumar, B Durga Prasad, Ravi Kumar Puli, Performance and Emission Characteristics of Diesel Engine Operated on Plastic Pyrolysis Oil with exhaust gas recirculation, IJAE, DOI: 10.1080/01430750.2015.1086677.
15. M Paul Daniel, KareddulaVijaya Kumar, B Durga Prasad, Performance and Emission Characteristics of Diesel Engine Operated on Tyre Pyrolysis Oil with exhaust gas recirculation, IJAE, May 2015, DOI: 10.1080/01430750.2015.1023837.
16. Kareddula Vijaya Kumar, Ravi Kumar Puli, Monika Dixit, D Ravi Chandra, Performance and Emission Evaluation of Tyre Oil blended with Diesel Fuel in Compression Ignition Engine, ICEE-2014, December 2014, JNTUH Kukatpally, Hyderabad, India.
17. Kareddula Vijaya Kumar, Ravi Kumar Puli, A Veeresh Babu, J.A. Ranga Babu, Performance and Emission Evaluation of Plastic Oil blended with Diesel Fuel in Compression Ignition Engine, ICEE-2014, December 2014, JNTUH Kukatpally, Hyderabad, India.
18. K. Vijaya Kumar, Dr. Ravi Kumar Puli, D. Ravichandra, K. Abhishek, Investigation on a CI Engine Fuelled with blends of Waste Tyre oil, Third International Conference on Advances in Mechanical, Aeronautical and Production Techniques (MAPT), April 2015, Malysia.
19. Mr. Hirenkumar M Patel, Prof. Tushar M Patel, performance analysis of single cylinder diesel engine fuelled with pyrolysis oil- diesel and its blend with Ethanol, International Journal of Engineering Research & Technology (IJERT), Vol. **1**, Issue 4, ISSN: 2278-0181, (2012).
20. Jinang M.Patel, Krunal J. Patel,Vatsal V. Patel, Kalpesh V. Vaghela, Investigates that Performance studies of Tire Pyrolysis Oil blends with Diesel Fuel, International Journal of Engineering and Advanced Technology (IJEAT), Volume-**3**, Issue-2, ISSN: 2249–8958, (2013).
21. Murugan. S, M.C. Ramaswamy, G. Nagarajan, Assessment of pyrolysis oil as an energy source for diesel engines, Fuel Processing Technology, **90**, 67-74, (2009).
22. Merchant, A.A., and Petrich, M.A., Pyrolysis of Scrap Tires and Conversion of Chars to Activated Carbon, American Institute Chemical Engineering Journal, Vol. **39**, 1370-1376, (1993).
23. Murugan. S, M.C. Ramaswamy, G. Nagarajan, Performance, emission and combustion studies of a DI diesel engine using distilled tyre pyrolysis oil-diesel blends, Fuel Processing Technology, Elsevier, **89**, 152-159, (2008).
24. Murugan. S, M.C. Ramaswamy, G. Nagarajan, A comparative study on the performance, emission and combustion studies of a DI diesel engine using distilled tyre pyrolysis oil–diesel blends, Fuel **87**, 2111-2121, (2008).