Waste plastic oil as an alternative fuel for diesel engine – A Review

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Abstract— With increase in energy expenditure, stringent emission norms, depletion of petroleum fuels and undulate cost of petroleum products in India, it has become vital to use alternative fuels for diesel engines. The energy conversion from waste plastics has been an intelligent way to tackle the environmental pollution problem of waste plastic management in the landfills. Plastics being derived from petrochemical source has higher amount of hydrocarbon which yield oil with high calorific value. In this review, performance combustion and emission characteristics of diesel engine using neat plastic oil, blends of waste plastic oil and additives used with plastic oil as fuels are addressed. It is concluded that it is possible to use plastic oil derived from plastic wastes as an alternative fuel for diesel engines.

1. Introduction
In enhancing the standard of living of human beings, plastic plays a vital role. In one way plastic are quoted as key of innovation of many products and in various sectors with the rapid growth of population the demand for consumption of plastics has been increased. Global production of plastic has reached about  in 2016. On the other hand the continuous rising of plastic demand led to the growing in plastic waste accumulation in landfills. It takes billions of years for plastics to degrade naturally. This continuous disposal of plastic into landfills will cause serious and severe environmental pollution. Recycling method is considered as an alternative to minimize plastic waste. However recycling of plastics is a costlier and laborious process[1] as the plastic waste comprises of industrial and municipal wastes.

Although plastic recycling is able to reduce same amount of plastic waster, conversion of plastic waste into fuel as gained a lot of attention these days in order to meet the energy demand either due to the depletion of fossil fuels or due to the rapid rise in cost of producing petroleum fuel. Oil produced from plastic wastes is termed as waste plastic oil (WPO). Various methods have been adopted to produce WPO such as, pyrolysis mechanism, thermo chemical treatment and catalytic conversion. Out of these methods, pyrolysis mechanism has been found to be productive method of producing WPO.

Pyrolysis is the process of thermally degrading long chain polymer molecules into smaller and less complex molecules through heat and pressure [2]. During pyrolysis three major products are produced, which are oil, gas and char. Parameter such as pyrolysis temperature, type of reactor residence time type of catalyst used and type of fluidized gas and its flow rate influences the amount of WPO produced.
Many researchers have proclaimed that the physiochemical properties of WPO are similar to diesel and as such, WPO can be used on diesel engines either in neat form or can be blended with diesel with addition of additives. The present review focuses on the utilization of WPO as fuel and presents the performance and emission characteristics as used on diesel engine.

2. Engine performance and emission analysis

It is well said that utilization of WPO as fuel for diesel engine not only reduces the dependence on fossil fuel but also the waste management policies imposed all over the globe. The research established by Ioannis et al [3] with blends of WPO diesel in proportion of 25%, 50%, 75%, 90% and 100% revealed that brake thermal efficiency (BTE) of engine reduced by 2.5% at low load and 6.75% at 100% load as compared with diesel.

The physiochemical properties of WPO [4] presents that the viscosity of WPO is higher than diesel. The higher viscosity of WPO leads to longer ignition delay period [5] which in turn results in higher in cylinder pressure and higher net heat release rates [6]. Experimental investigations were carried out on CRDI engine by Ravi Shankar et al [7] to analyze the emission characteristics. The results indicated increase in NOx emission with increase in amount of WPO to diesel. As the oxygen content in WPO is higher than diesel with increase in proportion of WPO, the mean gas temperature inside the cylinder during combustion has increased with increase in NOx emission [8]. WPO combustion in oxygenated additive environment is found to be a feasible way in reducing NOx emission. Addition of DEE to WPO diesel blends has been experimented by[9] on a VCR engine. DEE, being a highly volatile liquid tends to reduce the viscosity of WPO and leads to better combustion. Addition of alcohol[10] to WPO-diesel engine blends has been found to be a superior technique to reduce smoke and increase NOx emission with increase in amount of 'n-butanol to WPO-diesel blends, HC and Co emissions escalated, Devraj et al [11] conducted experiments on diesel engine using WPO in neat form and blends with addition of DEE. It was found that brake specific fuel consumption with neat WPO is higher by 12% than diesel while with increase in NOx and HC emissions, CO emission reduced by 10.5% with DEE addition to WPO-diesel blends.

The constitutes of plastic wastes influence the composition of WPO. Ceylagunger [12] produced WPO from waste polyethylene alone. Blends of WPO with diesel in proportions of 5%, 10%, 15%, and 20% were tested on 4cylinder diesel engine at varying speeds with 5% WPO test fuel, the power output increased by 1.6% and reduction in CO emission by 20.63% was observed. Another property that influences the combustion process is the cetane number. WPO produced by [13] showed lower cetane number than diesel which in turn resulted in reduction in brake power and torque. Series of experiments conducted by Kaimal et al [14-17] using WPO on diesel engine showed mixed results in terms of emission. The analysis revealed that the pyrolysis temperature range influence a lot in the quality of oil produced and in turn in fluencies the emission characteristics. They also reported that the addition catalyst in pyrolysis process enhance the reaction time and yield of WPO. Senthil and sanknarayanan [18] emulsified WPO with span 80 and tween. The results of their experimental investigation revealed that with emulsification, NOx emission reduced substantially by 32%, the characteristics of WPO blends was studied by[19], disclosed that the aromatic nature of WPO is higher than diesel. Achyut panda [20] investigated the effect of kaoline catalyst in producing WPO and carried out tests on diesel engine with
blend percentage of 10%, 20%, 30%, 40% and 50%. The results revealed that BTE for all blends of WPO was higher than diesel up to 80% load and at 100% load BTE got deteriorated.

Mani et al [21-24] explored most of the avenues of utilizing WPO in neat and blend form such as advancing and retarding fuel injection timing and adopting EGR. It is showed that 75% of liquid hydrocarbon can be obtained on mass basis from plastic wastes. Heat release rate increased by 24.5% without EGR at full load. Table 1 lists the detailed summary of previous studies that demonstrated the use of WPO and its blends as fuel.

Table 1: Summary of previous investigations

| Ref No. | Blend   | EM | BTE | BSFC | NOx | HC  | CO  | CO2 | HRR | Smoke | EGT | Cylinder Pressure | Remarks                                                                 |
|---------|---------|----|-----|------|-----|-----|-----|-----|-----|-------|-----|-------------------|--------------------------------------------------------------------------|
| [3]     | PPO     | ↓  | ↑   | ↓   | ↑   | =   | ↑   | ↑   | ↑   | ↑     | ↑   |                  | A blend of 60%-70% PPO at 80-90% load is good                           |
| [5]     | PPO 25  | ↓  | ↑   | ↓   | ↑   | ↑   | ↑   | ↑   | ↑   | ↑     | ↑   |                  | 5% and 10% EGR can be selected as optimum value                           |
| [5]     | PPO 50  | ↓  | ↑   | ↓   | ↑   | ↑   | ↑   | ↑   | ↑   | ↑     | ↑   |                  | 10% EGR                                                               |
| [5]     | PPO 75  | ↓  | ↑   | ↓   | ↑   | ↑   | ↑   | ↑   | ↑   | ↑     | ↑   |                  | 15% EGR                                                               |
| [5]     | PPO 100 | ↓  | ↑   | ↓   | ↑   | ↑   | ↑   | ↑   | ↑   | ↑     | ↑   |                  | 20% EGR                                                               |
| [6]     | LFLP3   | ↑  | ↓   | ↓   | ↓   | ↓   | ↓   | ↓   | ↓   | ↓     | ↓   |                  | LFLP3 is better than diesel                                            |
| [7]     | PO10    | ↓  | ↑   | ↑   | ↑   | ↑   | ↑   | ↑   | ↑   | ↑     | ↑   |                  | PO can be used in pure form with little modifications to the engine    |
| [7]     | PO20    | ↓  | ↑   | ↑   | ↑   | ↑   | ↑   | ↑   | ↑   | ↑     | ↑   |                  |                                                                        |
| [8]     | WPPO 5  | ↑  | ↓   | ↓   | ↓   | ↓   | ↓   | ↓   | ↓   | ↓     | ↓   |                  |                                                                        |
| [8]     | WPPO 10 | ↑  | ↓   | ↓   | ↓   | ↓   | ↓   | ↓   | ↓   | ↓     | ↓   |                  |                                                                        |
| [8]     | WPPO 15 | ↑  | ↓   | ↓   | ↓   | ↓   | ↓   | ↓   | ↓   | ↓     | ↓   |                  |                                                                        |
| [8]     | WPPO 20 | ↑  | ↓   | ↓   | ↓   | ↓   | ↓   | ↓   | ↓   | ↓     | ↓   |                  |                                                                        |
| [9]     | P 2.5   | =  | ↑   | =   | ↑   | =   | ↑   | ↑   | ↑   | ↑     | ↑   |                  |                                                                        |
| [9]     | P 7.5   | ↓  | ↑   | ↑   | ↑   | ↑   | ↑   | ↑   | ↑   | ↑     | ↑   |                  |                                                                        |
| [9]     | P 12.5  | ↓  | ↑   | ↑   | ↑   | ↑   | ↑   | ↑   | ↑   | ↑     | ↑   |                  |                                                                        |
| [9]     | P 100   | ↓  | ↑   | ↑   | ↑   | ↑   | ↑   | ↑   | ↑   | ↑     | ↑   |                  |                                                                        |
| [10]    | CR 12   | =  | ↑   | =   | ↑   | =   | ↑   | ↑   | ↑   | ↑     | ↑   |                  |                                                                        |
| [10]    | CR 16   | =  | ↑   | =   | ↑   | =   | ↑   | ↑   | ↑   | ↑     | ↑   |                  |                                                                        |
| [10]    | CR 20   | =  | ↑   | =   | ↑   | =   | ↑   | ↑   | ↑   | ↑     | ↑   |                  |                                                                        |
| [10]    | D50WP040B10 | = | ↑   | =   | ↑   | =   | ↑   | ↑   | ↑   | ↑     | ↑   |                  |                                                                        |
| [10]    | D50WP090B20 | = | ↑   | =   | ↑   | =   | ↑   | ↑   | ↑   | ↑     | ↑   |                  |                                                                        |
| [10]    | D50WP020H30 | = | ↑   | =   | ↑   | =   | ↑   | ↑   | ↑   | ↑     | ↑   |                  |                                                                        |
| [10]    | WPO     | =  | ↑   | =   | ↑   | =   | ↑   | ↑   | ↑   | ↑     | ↑   |                  |                                                                        |
| [11]    | WDO5    | =  | ↑   | =   | ↑   | =   | ↑   | ↑   | ↑   | ↑     | ↑   |                  |                                                                        |
| [11]    | WDO10   | =  | ↑   | =   | ↑   | =   | ↑   | ↑   | ↑   | ↑     | ↑   |                  |                                                                        |
| [11]    | WPE 5   | =  | ↑   | =   | ↑   | =   | ↑   | ↑   | ↑   | ↑     | ↑   |                  |                                                                        |
| [13]    | CPE 5   | =  | ↑   | =   | ↑   | =   | ↑   | ↑   | ↑   | ↑     | ↑   |                  |                                                                        |
| [13]    | WPDF    | ↑  | =   | =   | ↑   | =   | ↑   | ↑   | ↑   | ↑     | ↑   |                  |                                                                        |
| [14]    | PO      | =  | ↑   | =   | ↑   | =   | ↑   | ↑   | ↑   | ↑     | ↑   |                  | Engine can be run using 100% PO                                         |
| [14]    | RME     | =  | ↑   | =   | ↑   | =   | ↑   | ↑   | ↑   | ↑     | ↑   |                  |                                                                        |
| [15]    | PO25    | =  | ↑   | =   | ↑   | =   | ↑   | ↑   | ↑   | ↑     | ↑   |                  |                                                                        |
| [15]    | PO50    | =  | ↑   | =   | ↑   | =   | ↑   | ↑   | ↑   | ↑     | ↑   |                  |                                                                        |
| [15]    | PO75    | =  | ↑   | =   | ↑   | =   | ↑   | ↑   | ↑   | ↑     | ↑   |                  |                                                                        |
3. Conclusion

With faster depletion of petroleum fuels and environmental consequences, the use of alternative fuels has become invariably important. It is concluded that, waste plastic oil indeed is found to be a potential alternative fuel wherein the waste management along with energy crisis could be addressed. This review is limited to analyze the performance combustion and emission characteristics of diesel – plastic oil blends on diesel engine. However, there are other issues such as kinetics of plastic oil, effects of combustion improvers and engine modifications that are to be considered for in depth analysis of combustion using plastic oil blends.
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