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Review Paper

Waste plastic Pyrolysis oil Alternative Fuel for CI Engine – A Review

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Abstract

Environmental concern and availability of petroleum fuels have caused interests in the search for alternate fuels for internal combustion engines. Conversion of waste to energy is one of the recent trends in minimizing not only the waste disposal but also could be used as an alternate fuel for internal combustion engines. Waste plastics are indispensable materials in the modern world and application in the industrial field is continually increasing. In this context, waste plastics are currently receiving renewed interest. As an alternative, non biodegradable, and renewable fuel, waste plastic oil is receiving increasing attention. In the present paper waste plastic pyrolysis oil, waste plastic pyrolysis oil and its blend with diesel has been introduced as an alternative fuel. In this study, a review of research papers on various operating parameters have been prepared for better understanding of operating conditions and constrains for waste plastic pyrolysis oil and its blends fuelled compression ignition engine.

Keywords: Alternative fuel, diesel engine, waste plastic oil, performance, engine emission.

Introduction

Diesel engines are the most efficient prime movers, from the point of view of protecting global environment and concerns for long-term energy security it becomes necessary to develop alternative fuels with properties comparable to petroleum based fuels. Unlike rest of the world, India's demand for diesel fuels is roughly six times that of gasoline hence seeking alternative to mineral diesel is a natural choice. Alternative fuels should be easily available at low cost, be environment friendly and fulfill energy security needs without sacrificing engine's operational performance. Waste to energy is the recent trend in the selection of alternate fuels[1]. Fuels like alcohol, biodiesel, liquid fuel from plastics etc are some of the alternative fuels for the internal combustion engines. Utilization of biomass as alternative fuel for compression ignition engine has a great scope especially in developing and undeveloped countries.

Plastics have become an indispensable part in today's world, due to their lightweight, durability, energy efficiency, coupled with a faster rate of production and design flexibility, these plastics are employed in entire gamut of industrial and domestic areas hence plastics have become essential materials and their applications in the industrial field are continually increasing. At the same time, waste plastics have created a very serious environmental challenge because of their huge quantities and their disposal problems[2]. Waste plastics do not biodegrade in landfills, are not easily recycled, and degrade in quality during the recycling process. Instead of biodegradation, plastics waste goes through photo-degradation and turns into plastic dusts which can enter in the food chain and can cause complex health issues to earth habitants, through the thermal treatment on the waste plastic the fuel can be derive[3], by adopting the chemical process such as Pyrolysis can be used to safely convert waste plastics into hydrocarbon fuels that can be used for transportation[4].

Pyrolysis process for conversion of waste plastic into fuel

Pyrolysis is the chemical decomposition of organic substances by heating the word is originally coined from the Greek-derived elements pyro "fire" and lysys "decomposition". Pyrolysis is usually the first chemical reaction that occurs in the burning of many solid organic fuels, cloth, like wood, and paper, and also of some kinds of plastic. Anhydrous Pyrolysis process can also be used to produce liquid fuel similar to diesel from plastic waste.

Pyrolysis technology is thermal degradation process in the absence of oxygen. Plastic waste is treated in a cylindrical reactor at temperature of 300ºC – 350ºC. The plastic waste is gently cracked by adding catalyst and the gases are condensed in a series of condensers to give a low sulphur content distillate. All this happens continuously to convert the waste plastics into fuel that can be used for generators. The catalyst used in this system will prevent formation of all the dioxins and Furans (Benzene ring). All the gases from this process are treated before it is let out in atmosphere. The flue gas is treated through scrubbers and water/ chemical treatment for neutralization. The non-condensable gas goes through water before it is used for burning. Since the Plastics waste is processed about 300ºC - 350ºC and there is no oxygen in the processing reactor, most of the toxics are burnt. However, the gas can be used in dual fuel diesel-generator set for generation of electricity. The process of oil from waste plastics takes place as shown in figure 1.

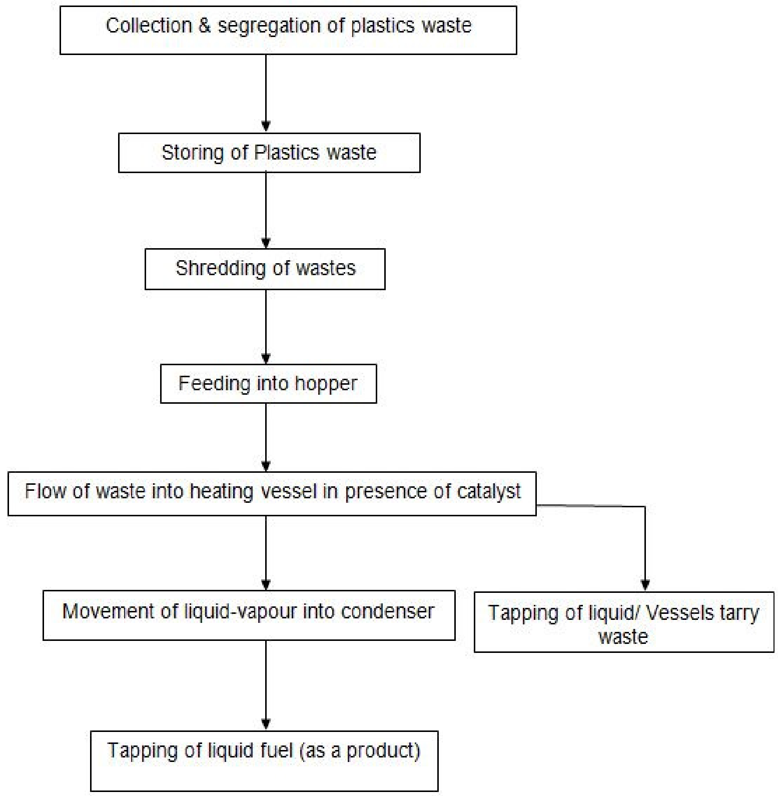

Figure-1
Conversion of Plastics waste into Liquid Fuel

Table-1
Properties of Waste Plastic Pyrolysis Oil and Diesel

Sr. No.	Properties	WPPo	Diesel
1	Density(kg/m^2)	793	850
2	Ash content (%)	<1.01%wt	0.045
3	Calorific value(kJ/kg)	41,800	42,000
4	Kinematicviscosity @ 40C (cst)	2.149	3.05
5	Cetane number	51	55
6	Flash point ^{o}C	40	50
7	Fire point ^{o}C	45	56
8	Carbon residue (%)	0.01%wt	0.20%
9	Sulphur content (%)	<0.002	<0.035
10	Pour point ^{o}C	-4	3-15

Performance characteristics

The various performance parameters such as brake thermal efficiency, brake Specific fuel consumption and exhaust gas temperature under study is summarized as follows.

Brake Thermal Efficiency: The experimental study on a single cylinder, four-stroke, air cooled DI diesel engine with waste plastic oil[5], Results the thermal efficiency is 28.2% at rated power for diesel and for the waste plastic oil it is 27.4%. Further the brake thermal efficiency of the waste plastic oil is closer to diesel up to 75% of rated power, beyond which it starts decreasing. At full load, the efficiency is higher for diesel fuel. This is due to the fact that at full load, the exhaust gas temperature and the heat release rate are marginally higher for waste plastic oil compared to diesel. An experimental study on waste plastic oil and diesel fuel blends in compression ignition engine[6] proved that the thermal efficiency is 28% at full load for diesel.

It is observed that the engine fueled with WPO10, WPO30, WPO50, WPO70 and WPO gives brake thermal efficiency of 28.2%, 27.95%, 27.42%, 26.5% and 27.4% respectively at full load. The total heat release for each WPO-DF blends is lesser than diesel. Hence, the brake thermal efficiency is lower for the WPO-DF blends than diesel. Because of the changes in composition, viscosity, density and calorific value of WPO-DF blends the brake thermal efficiencies of WPO-DF blends are low particularly at full load.

An experimental study on waste plastic oil with varying injection timing results the thermal efficiency is 28.2% at full load for standard injection timing and 32.25% for the retarded injection timing of the waste plastic oil, shown in (figure 2). Retardation of injection timing leads to fast start of combustion and combustion continues in the power stroke. This results in smaller peak heat release rate and increases effective pressure to do work. Consequently, the work output is high for retarded injection timing and therefore the brake thermal efficiency increases as the injection timing is retarded[7].

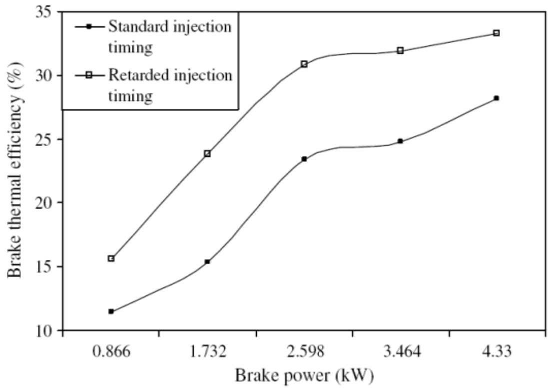

Figure-2
Variation of brake thermal efficiency with brake power

Experimental works on waste plastic oil with exhaust gas recirculation in direct injection diesel engine indicate that the brake thermal efficiency decreases with increase in EGR flow rate. For diesel operation the efficiency varies from 11.5% at 20% load to 27.4% at full load where as in the case of waste plastic oil operation without EGR it ranges from 14.5% at 20% load to 30.9% at full load. At full load the brake thermal efficiency decreases with increase in EGR flow rate. It is 30.1% with 10% EGR while with 20% EGR the efficiency is 29.8%. The reduction in brake thermal efficiency is due to high EGR percentages that results in deficiency in oxygen concentration in combustion process and larger replacement of air by the exhaust gases. Higher flow rate of exhaust gases reduces the average combustion temperature in the combustion chamber resulting in reduction in brake thermal efficiency at all the loads[8].

Brake specific fuel consumption: Brake specific fuel consumption measures how efficiently an engine is using the fuel supplied to produce work. it is inversely proportional to thermal efficiency, The brake specific fuel consumption for the waste plastic oil varies from 0.574 g/kWh at no load to 10.297 g/kWh at full load for standard injection timing, and it varies from0.514 g/kWh at no load to 0.235 g/kWh at full load for retarded injection timing[5]]. An experimental study on diesel engine with blends of diesel-plastic Pyrolysis oil shows that the BSFC was found to increase with load for WPPO 50, WPPO 70 and diesel fuel. As the load increases, BSFC decreases for all fuel blends. At full load, WPPO blends show the specific fuel consumption higher than the diesel. The main reason for this could be that percent increase in fuel required to operate the engine is less than the percent increase in brake power due to relatively less portion of the heat losses at higher loads[9].

Exhaust gas temperature: Experimental study on diesel and waste plastic oil in direct injection diesel engine shows that the exhaust gas temperature varies from 221^{o}C at no load to 417^{o}C at rated power for diesel and for the waste plastic oil it varies from 240^{o}C at no load to 450^{o}C at rated power. The increase in exhaust gas temperature with engine load is clear from the simple fact that more amount of fuel was required by the engine to generate the extra power needed to take up the additional loading it is also find that the fuel air ratio is higher in the case of waste plastic oil compared to diesel at all loads.

This result in higher exhaust gas temperature in the case of waste plastic oil compared to diesel[5]. An experiment study on waste plastic oil and diesel fuel blends in compression ignition engine proved that the exhaust gas temperature increases with load because more fuel is burnt to meet the power requirement. It seen that in the case of WPO operation, the exhaust gas temperature ranges from 240^{o}C at low load to 450^{o}C at full load whereas in the case of DF operation it ranges from 221^{o}C at low load to 417^{o}C at full load. For WPO 10 and WPO 30, at full load the exhaust gas temperature marginally increases to 420^{o}C and 424^{o}C respectively shown in figure 3[6].

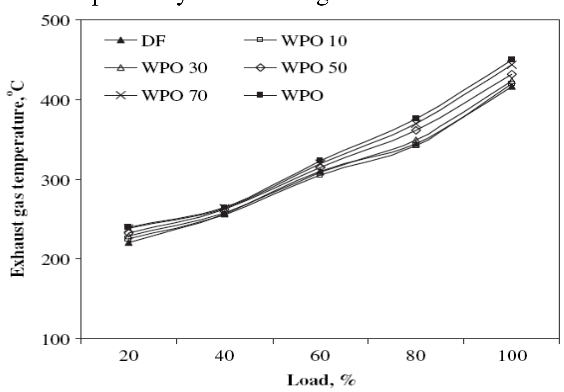

Figure-3
Variation of exhaust gas temperature with load

The exhaust gas temperature for WPO 50 varies from 232^{o}C at low load to 432^{o}C at full load. In the case of WPO 70, the exhaust gas temperature varies from 238^{o}C at low load to 444^{o}C at full load. Higher exhaust gas temperature in the case of WPO compared to DF is due to higher heat release rate. Also In the case of WPO, the fuel spray becomes finer and effective combustion takes place.

Emission characteristic

Internal Combustion engine emissions have been major contributor to air pollution regulated pollutants are carbon monoxide (CO), NOx, and unburned fuel or partly oxidized HC. Which are summarized as follows.

Unburned hydrocarbon: Unburned hydrocarbon emissions consist of fuel that is incompletely burned. The term hydrocarbon means organic compounds in the gaseous state, solid hydrocarbons are part of the particulate matter. Typically, unburned hydrocarbons are a serious problem at light loads in CI engines[10]. At light loads the fuel is less to impinge on surfaces, but because of poor fuel distribution, large amounts of excess air and low exhaust temperature, lean fuel–air mixture regions may survive to escape into exhaust. An experimental study on waste plastic oil shows that, unburned hydrocarbon varies from 0.598 g/kWh at no load to 0.147 g/kWh at full load for standard injection timing, and it varies from 0.314 g/kWh at no load to 0.0336 g/kWh at full load for retarded injection timing. Further at the retarded injection timing reduces the unburned hydrocarbon emissions. Decreased flame quenching thickness is the reason for the reduction in unburned hydrocarbons[7]. Unburned hydrocarbon varies from 0.431 g/kWh at 25% of rated power to 0.1389 g/kWh at rated power for diesel. In the case of waste plastic oil it varies from 0.4393 g/kWh at 25% of rated power to 0.147 g/kWh at rated power shown in (figure 4)

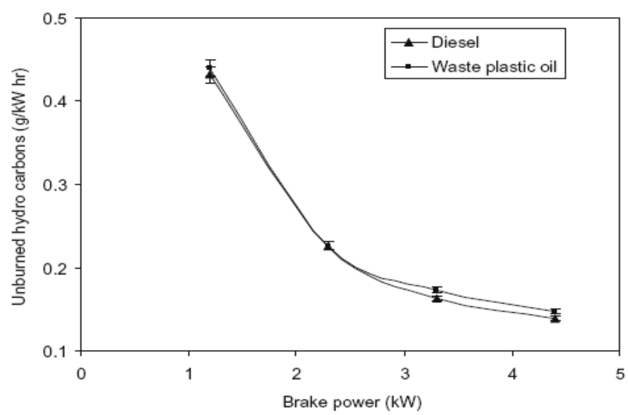

Figure-4
Variation of unburned hydrocarbon with brake power

It is noticed that the concentration of the hydrocarbon of waste plastic oil is higher than diesel; the reason behind increased unburned hydrocarbon in waste plastic oil may be due to higher fumigation rate and non-availability of oxygen relative to diesel. At lighter loads due to charge homogeneity and higher oxygen availability, the unburned hydrocarbon level is less in the case of waste plastic oil, whereas at higher load ranges due to higher quantity of fuel admission, unburned hydrocarbon increases[5].

Nitrogen oxides (NOx) emission: An experimental study on waste plastic oil and diesel fuel blends in compression ignition engine indicate that[7], the concentration of NOx varies from 12.15 g/kW h at low load to 7.61 g/kW h at full load for DF and from 14.68 g/kW h at low load to 8.23 g/kW h at full load for WPO. For WPO 10, it varies from 12.16 g/kW h at low load to 7.75 g/kW h at full load. It was also observed that NOx varies from 12.6 g/kW h at low load to 7.9 g/ kW h at full load for WPO 30 and for WPO 50 it varies from 12.8 g/ kW h at low load to 8.01 g/kW h at full load. In the case of WPO 70, NOx varies from 12.96 g/kW h at low load to 8.1 g/kW h at full load. The reason for the increased NOx is higher heat release rate in the case of WPO. WPO is a higher aromatic content fuel with ring structure. Fuels with ring structure tend to have a higher adiabatic flame temperature which results in higher heat release rate[11].

Due to higher heat release rate, the in-cylinder temperature would also increase with increase in WPO concentration in the WPO-DF blend this is the reason for higher NOx formation in the case of WPO-DF. Experimental work on waste plastic oil with exhaust gas recirculation in direct injection diesel engine indicate that the NOx emission in the case of diesel operation ranges from 14.36 g/kWh at 20% load to 8.1 g/kWh at full load and for waste plastic oil operation without EGR it ranges from 14.63 g/kWh at 20% load to 8.56 g/kWh at full load shown in figure 5[8].

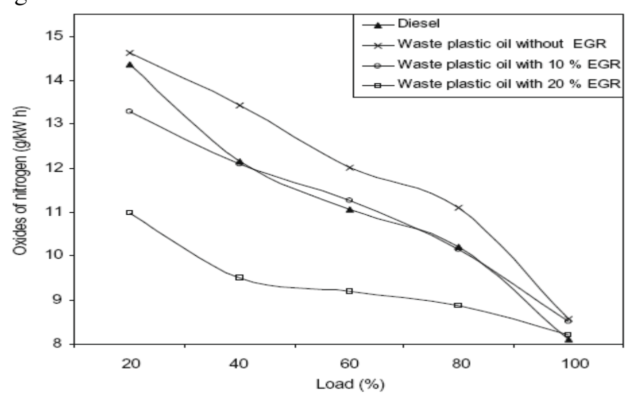

Figure-5
Variation of oxide of nitrogen with load for various EGR percentages

It is observed that from 10% to 20% EGR, at 20% load, the NOx reduces from 13.3 to 10.97 g/kWh whereas in case of full load it reduces from 8.51 to 8.2 g/kWh. The reduction in NOx emission with increase in EGR percentage may be due to the presence of inert gas (CO_2 and H_2O) in the EGR. These gases absorb energy released by combustion, which reduces the peak combustion temperature in the combustion chamber, and also it replaces the oxygen in the combustion chamber. As a result of reduction in temperature and oxygen, the NOx reduces.

Carbon mono-oxide (CO) and CO_2 emission: Generally, CI engine operates with lean mixtures and hence the CO emission would be low. 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. The experiment performed on a single cylinder, four-stroke, air cooled DI diesel engine with waste plastic oil[5]. Finds that the concentration of CO emission varies from 14.14 g/kWh at 25% of rated power to 5.75 g/kWh at rated power for diesel, whereas it varies from 18.51 g/kWh at 25% of rated power to 6.19 g/kWh at rated power for waste plastic oil. Here the CO emission of waste plastic oil is higher than diesel. The reason behind increased CO emission is incomplete combustion due to reduced in-cylinder temperatures.

Experimental work on waste plastic oil with exhaust gas recirculation in direct injection diesel engine[8] indicate that the At 20% load the concentration of CO2 in waste plastic oil without EGR is found to be 1510 g/kWh compared to 1475 g/ kWh with 10% EGR and 1359 g/kWh with 20% EGR. The CO2 concentration decreases with increase in EGR percentages. At full load the CO2 concentration in waste plastic oil without EGR is found to be 794.39 g/kWh compared to 763.588 g/kWh with 10% EGR and 659 g/kWh with 20% EGR. This is due to the instability in combustion and deficiency of oxygen that makes the CO concentration to increase and CO2 concentration to decrease.

Conclusion

Based on the reviewed paper for the performance and emissions of waste plastic Pyrolysis oil , it is concluded that the waste plastic Pyrolysis oil represents a good alternative fuel for diesel and therefore must be taken into consideration in the future for transport purpose. Further it is concluded that, i. Engine was able to run with 100% waste plastic oil. ii. Engine fueled with waste plastic oil exhibits higher thermal efficiency up to 75% of the rated power. iii. Brake thermal efficiency of the engine fueled with waste plastic oil with retarded injection timing is found to be higher. iv. At full load the brake thermal efficiency decreases with increase in EGR flow rate. v. At the full load the Bsfc is higher WPPO blends show the specific fuel consumption higher than the diesel. vi. The exhaust gas temperature for plastic oil is higher than diesel. vii. Unburned hydrocarbon emission is higher by about 15% than that of diesel; with the retarded injection timing it can be reduced. viii. The NOx emission in waste plastic oil varies from 14.63 to 8.56 g/ kWh without EGR compared to 10.97–8.2 g/kWh with 20% EGR. The NOx emission reduces with increase in EGR percentage, due to the presence of higher heat capacity gases that reduces the peak combustion temperature. ix. CO emission increased by 5% in waste plastic oil compared to diesel operation. x. The CO2 concentration decreases with increase in EGR percentages, due to instability in combustion.

Nomenclature

Abbreviation	Meaning
BSFC	Brake specific fuel consumption
CI	Compression Ignition
CO	Carbon Monoxide
CO_2	Carbon dioxide
DF	Diesel fuel
EGT EGR HC	Exhaust gas temperature Exhaust gas recirculation Hydrocarbon
NOx	Nitrogen oxide
WPPO10	10%Waste plastic oil with diesel
WPPO30	30% Waste plastic oil with diesel
WPPO50	50% Waste plastic oil with diesel
WPPO70	70% Waste plastic oil with diesel

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