

Investigation on Conversion of Municipal Plastic Wastes into Liquid Fuel Compounds, Evaluation of Engine Performance and Emission Characteristics

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Abstract

The present rate of economic growth is unsustainable without saving of fossil energy like crude oil, natural gas or coal. Thus mankind has to rely on the alternate/renewable energy sources like biomass, hydropower, geothermal energy, wind energy, solar energy, nuclear energy, etc. On the other hand, suitable waste management strategy is another important aspect of sustainable development. The growth of welfare levels in modern society during the past decades has brought about a huge increase in the production of all kinds of commodities, which indirectly generate waste. Plastics have been one of the materials with the fastest growth because of their wide range of applications due to versatility and relatively low cost, easy processability, light-weight, durability etc. There is a vast plastics waste stream that reaches each year to the final recipients creating a serious environmental problem. Again, because disposal of post-Consumer plastics is increasingly being constrained by legislation and escalating costs, there is considerable demand for alternatives to disposal or land filling. Advanced research in the field of green chemistry could yield biodegradable/green polymers but is too limited at this point of time to substitute the non-biodegradable plastics in different applications. Plastics have become a major threat due to their non-biodegradability and high visibility in the waste stream. Littering also results in secondary problems such as clogging of drains and animal health problems. The waste management methods such as landfill disposal, incineration, and recycling have failed to provide opportunities for the complete reuse of plastic waste. The Polymer Energy system uses a process called pyrolysis to efficiently convert plastics in to liquid fuel compounds. The system provides an integrated plastic waste processing system which offers an alternative to landfill disposal, incineration, and recycling-while also being a viable, economical, and environmentally responsible waste management solution. In this experimental analysis an attempt has been to investigate the conversion of municipal plastic wastes into liquid fuel compounds by using pyrolysis process, the performance studies on CI engine and to evaluate emission profiles HC, CO, NO_x and smoke for selected blends of Diesel-Plastic liquid fuels.

INTRODUCTION

The present rate of economic growth is unsustainable without saving of fossil energy like crude oil, natural gas or coal. Thus mankind has to rely on the alternate/renewable energy sources like biomass, hydropower, geothermal energy, wind energy, solar energy, nuclear energy, etc.

On the other hand, suitable waste management strategy is another important aspect of sustainable development. The growth of welfare levels in modern society during the past decades has brought about a huge increase in the production of all kinds of commodities, which indirectly generate waste. Plastics have been one of the materials with the fastest growth because of their wide range of applications due to versatility and relatively low cost, easy process-ability, light-weight, durability etc.

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The Polymer Energy system uses a process called pyrolysis to efficiently convert plastics in to liquid fuel compounds. The system provides an integrated plastic waste processing system which offers an alternative to landfill disposal, incineration, and recycling-while also being a viable, economical, and environmentally responsible waste management solution. In this experimental analysis an attempt has been to investigate the conversion of municipal plastic wastes into liquid fuel compounds by using pyrolysis process, the performance studies on CI engine and to evaluate emission profiles HC, CO, NO_x and smoke for selected blends of Diesel-Plastic liquid fuels.

Pyrolysis: Pyrolysis involves the degradation of the polymeric materials by heating in the absence of oxygen. The process is usually conducted at temperatures between 350 and 500°C and results in the formation of a carbonized char (solid residues) and a volatile fraction that may be separated into condensable hydrocarbon oil consisting of paraffins, isoparaffins, olefins, naphthenes and aromatics, and a non condensable high calorific value gas. The proportion of each fraction and their precise composition depends primarily on the nature of the plastic waste but also on process conditions.

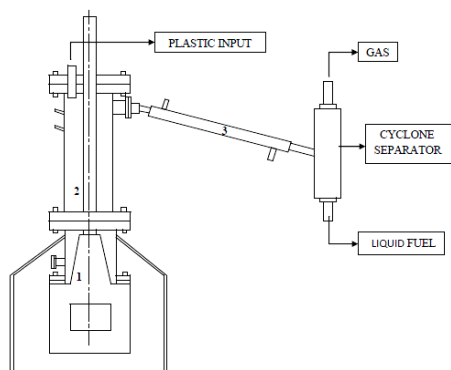


Figure 1: Experimental apparatus

1. Combustion chamber
2. Reactor
3. Condenser



Figure 2: Firing system



Figure 3: Liquid product

Figure 1 shows, the experimental apparatus. The design of the apparatus was deliberately kept simple, in line with the aim of the project to develop a recycling approach based on basic technology. The apparatus was designed to operate at high temperatures and atmospheric pressure. The details of firing system and liquid product obtained shown in Figure 2 and Figure 3 respectively.

ENGINE TEST

The common rail direct injection system in which the fuel injection pump is tuned to pressurize the Biodiesel more than the recommended value of diesel which is up to 1200 bar and with preheater arrangement in the fuel line and in the common rail gave a good result in the trial. The fuel is injected into the combustion chamber at ultrahigh pressures of up to 1200 bar to ensure more complete combustion for cleaner exhaust gas. The higher pressure that the common rail technology makes available is up to 1200 bar.

Test rig specification

Table 1: Engine specifications

Engine Type	CRDI Diesel engine
Capacity	1248cc
Bore	74 mm
Stroke	75.5 mm
Power	75ps@4000rpm
Torque	190Nm@2000rpm
Compression Ratio	17.6:1



Figure 4: Control unit

The details of Control unit to monitor the power and exhaust emissions are shown in Figure 4 and Figure 5 respectively.



Figure 5: CRDI diesel engine



Figure 6: Exhaust gas analyzer

AVL DIGAS 444 D gas analyzer as shown in Figure-6, it is used to measure HC, CO, CO₂, O₂ and NO_x emissions. A non-dispersive infrared measurement for HC, CO and CO₂ emissions while for NO_x and O₂ electrochemical measurement method is given in the exhaust analyzer.



Figure 7: Smoke meter

Smoke meter is used to measure the smoke opacity of the present test engine (Figure 7, in the measurement chamber of a defined measurement length). The opacity is the extinction of light between light source and receiver. The engine exhaust gas is fed into a chamber with non-reflective inner surfaces.

RESULTS AND DISCUSSION

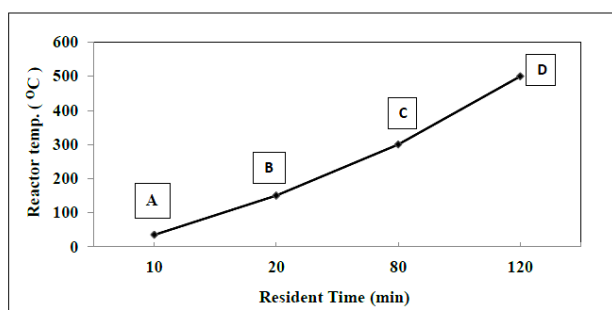


Figure 8: Typical temperature and resident time profiles in thermal process.

For the first few minutes after an experiment is started, temperatures in the reactor system remain unchanged. This is because the furnace is heating up and little energy reaches the reactor. After few minutes (point A) shown in Figure 8, heat transfer to the reactor begins and the temperatures in the reactor start to increase. At the point B the solid plastic starts to melt and considerable energy is taken up in the liquid phase in the form of latent heat [6]. By further increasing in temperature at point C up to 300°C after 80 minutes, some noncondensable gas and heavy oils are comes out from the reactor. These noncondensable gases are reuses to heat the pyrolysis unit. At the final stage point D, temperature is reaches up to 500°C.

Analysis of liquid fuel yields from catalytic pyrolysis process

In catalytic pyrolysis, increases the gaseous product yields. Under lower temperatures and lower resident time than thermal pyrolysis process, much higher gaseous product yield is observed in the presence of a catalyst. Vapour gets further cracked due to the presence of catalysts. The reactions of catalyst with vapour enhance the yields of gaseous product and formation of carbon residue than thermal pyrolysis process. At point A heat transfer to the reactor begins and the temperatures in the reactor start to increase. At the point B the solid plastic starts to melt and considerable energy is taken up

in the liquid phase in the form of latent heat. By further increasing in temperatures at point C up to 2500° C after 50 minutes, some non condensable gas and heavy oils are comes out from the reactor. These non condensable gases are reuses to heat the pyrolysis unit. At the final stage point D, temperature is reaches up to 4500° C.

Determination of calorific value

The calorific value of a fuel is the quantity of heat produced by its combustion at constant pressure and under normal conditions. Calorific value determined by using bomb calorimeter shown in Figure 9.



Figure 9: Bomb calorimeter

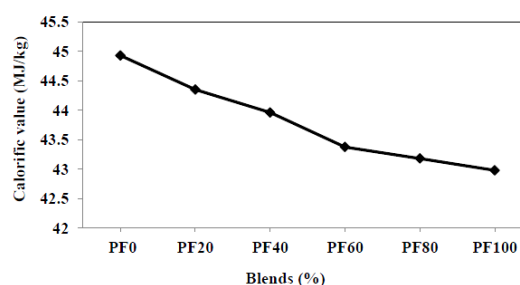


Figure 10: Variation of calorific value for different percentages of plastic liquid fuel blends

Figure 10 shows the variation of calorific value for various percentages of plastic liquid fuel blends. Here we observe that there is no too much difference between the calorific value of diesel and plastic liquid fuel. As the percentage of plastic liquid fuel increases the calorific value decreases slightly i.e. the calorific value of pure diesel is higher when compared to plastic liquid fuel and its blends.

ENGINE PERFORMANCE AND EMISSIONS CHARACTERISTICS

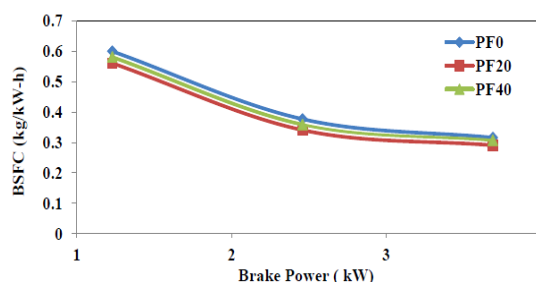


Figure 11: variation of brake specific fuel consumption (BSFC) with BP

The rate of fuel consumption divided by the rate of power production is termed as Brake specific fuel consumption. Brake specific fuel consumptions descend from lower to higher Brake power level. At higher BP the brake specific fuel consumption decreased. Figure 11 shows the variation of brake specific fuel consumption (BSFC) with BP for PF20, PF40 and diesel fuel. As the BP increases, BSFC decreases for both diesel and plastic fuel blends.

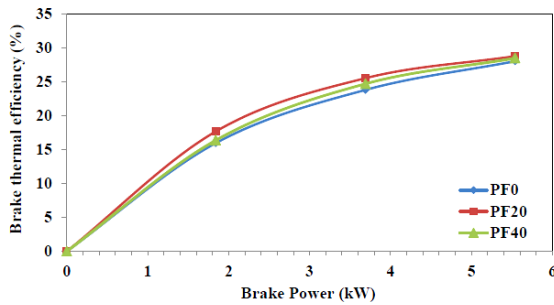


Figure 12: Variation of brake thermal efficiency with brake power at 1500rpm

The variation of brake thermal efficiency with BP is shown in Figure 12 can be observed from the Figure that the brake thermal efficiency is 28.03% at maximum BP for diesel and for the PF20 it is 28.78% and for PF40 it is 28.47%. It is clear that the brake thermal efficiency of PF20 is maximum as compared to diesel and PF40. Plastic fuel blend is a mixture of hydrocarbons varying from C10 to C30 having both low and heavy fractions with aromatics and oxygen. This results in smaller peak heat release rate and increases effective pressure to do work. Consequently, the work output is high and therefore the brake thermal efficiency increases. Another reason for higher brake thermal efficiency is better and complete combustion of fuel due to the oxygen present in the plastic fuel blends.

Oxides of Nitrogen:

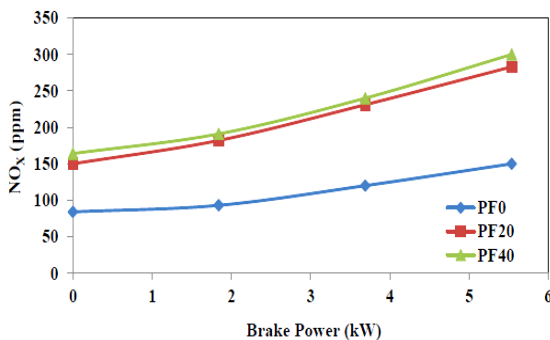


Figure 13: Variation of oxides of nitrogen with brake power at 1500rpm

The oxides of nitrogen in the emissions contain nitric oxide (NO) and nitrogen dioxide (NO₂). The formation of NO_x is highly dependent on cylinder temperature, oxygen concentration and residence time for the reactions to take place. Figure 13 shows the comparison of oxides of nitrogen with BP. It can be noticed that the NO_x emission higher in the plastic fuel blends at speed 1500rpm. NO_x varies from 84ppm to 150ppm for diesel, from 150ppm to 283ppm for PF20 blend

and for PF40 it varies from 164ppm to 300ppm. The reason for increased NO_x is due to the higher heat release rate and higher combustion temperature.

Exhaust Gas Temperature:

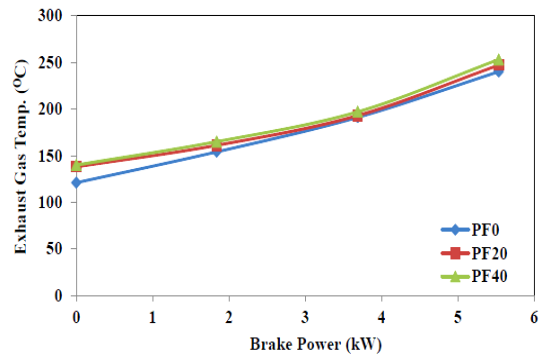


Figure 14: Variation of exhaust gas temperature with brake power at 1500rpm

Figure 14 depicts the variation of exhaust gas temperature with BP at various load conditions. It is observed that the exhaust gas temperature increases with BP because more fuel is burnt to meet the power requirement. It can be seen that in the case of PF20 and PF40 operation, the exhaust gas temperature ranges from 138 °C to 247 °C and 140°C to 253 °C respectively whereas in the case of diesel operation it ranges from 121°C to 240°C. Higher exhaust gas temperature in the case of plastic fuel blends compared to diesel is due to higher heat release rate. It may also be due to the oxygen content of the plastic fuel blends which improves combustion.

CONCLUSION

In the present work Polymer Energy system, which uses a process called pyrolysis to efficiently convert plastics into liquid fuel compounds. The conversion of municipal waste plastics to liquid hydrocarbon fuel was carried out in thermal and catalyst degradation. This method is superior in all respects (ecological and economical). By adopting this technology, efficiently convert weight of municipal waste plastics into 65% of useful liquid hydrocarbon fuels without emitting any pollutants. It would also take care of hazardous plastic waste and reduce the import of crude oil. Depletion of non-renewable source of energy such as fossil fuels at this stage demands the improvements of this technique. Engine test carried out with plastic liquid fuel blends which are obtained from the municipal waste plastic pyrolysis process. The results shows, better engine performance than diesel fuel operation.

The fuel consumption of the engine was somewhat lower as compared to diesel fuel operation and brake thermal efficiency increases with PF20, PF40 blends operation.

The emissions of engine like carbon monoxide (CO), hydrocarbon (HC) and nitrogen oxide (NO_x) is increases when the engine runs with plastic fuel blends.

The ability to recover valuable product and/or energy from wastes plastics. Perfect solution for waste plastic management. Raw material readily available for the process. Waste plastic pyrolysis liquid fuel can be used alternate fuel to the diesel.

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