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A study on synthesis of energy fuel from waste plastic and assessment of its potential as an alternative fuel for diesel engines

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ABSTRACT

The demand for plastic is ever increasing and has produced a huge amount of plastic waste. The management and disposal of plastic waste have become a major concern, especially in developing cities. The idea of waste to energy recovery is one of the promising techniques used for managing the waste plastic. This paper assesses the potential of using Waste Plastic Oil (WPO), synthesized using pyrolysis of waste plastic, as an alternative for diesel fuel. In this research work, the performance and emission characteristics of a single cylinder diesel engine fuelled with WPO and its blends with diesel are studied. In addition to neat plastic oil, three blends (PO25, PO50 and PO75) were prepared on a volumetric basis and the engine was able to run on neat plastic oil. Brake thermal efficiency of blends was lower compared to diesel, but PO25 showed similar performance to that of diesel. The emissions were reduced considerably while using blends when compared to neat plastic oil. The smoke and NO_X were reduced by 22% and 17.8% respectively for PO25 than that of plastic oil.

1. Introduction

Plastics are basically long hydrocarbon chained organic compounds synthesized from petroleum products. They have become highly popular in short time because of their unmatched usability, wide range of application, non-degradable nature and low cost. As per the estimate given by Plastic Europe, the global production of plastic has crossed 280 million tonnes in 2011 and it is increasing exponentially (Sriningsih et al., 2014). The ever increasing demand for plastic has also produced a huge amount of plastic waste and they pose a serious threat to the environment because of their disposal problems (Antony and Advaith, 2011; Sartorius, 2010). A survey report of the Central Pollution Control Board, India in 2012 shows nearly 5.6 million tonnes of plastic waste is generated annually in India. Out of this only up to 60% is recycled that means an astounding 6500 tonnes of plastic waste is going as landfills per day. In order to minimize the adverse environmental impacts, Plastic Waste Management was implemented for controlling and reducing the plastic waste generated.

Recycling, reusing, incineration and energy recovery are the major methods used in Plastic waste management (Syamsiro et al., 2014; Al-Salem et al., 2009). Energy recovery techniques convert the waste materials into energy which is a promising technique (Begum et al., 2012). The most commonly used method for energy recovery is thermal cracking (Pyrolysis). Pyrolysis process is one of the finest techniques for the conversion of mass to energy which gives liquid and gaseous products with high energy values (Buah et al., 2007). Previous researches reveal that thermal cracking yields liquid organic compounds similar to that of petroleum fuels as major product (Xuea et al., 2015; Sharmaa et al., 2014). The elementary procedure of pyrolysis is the thermal decomposition of long chained hydrocarbon compounds into smaller ones at elevated temperature in a non-oxidizing environment (Frigo et al., 2014; Aguado et al., 2007). Usually high temperature is required, in the range of 400–700 °C, in order to carry out the reaction (Frigo et al., 2014; Malkow, 2004). Maintaining such high temperatures during the entire time of reaction is difficult and dangerous. So catalysts are used for completing the reaction at a lower temperature range (Syamsiro et al., 2014; Luo et al., 2012).

The exponential growth in both population and industries has created a great demand for energy which is supplied mostly by petroleum fuels (Takasea et al., 2015; BP Statistical Review of World Energy, 2012). Because of the lavish consumption and continuous usage the fossil reserves are getting depleted rapidly. Also the exponential increase in the number of automobiles has created problems in the environment because of the emissions (Subramanian et al., 2005; Singh et al., 2014). These issues and the ever increasing price of crude oil have forced the world nations to look for alternate energy resources (Fraioli et al., 2014). The

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Nomenclature

PO	100% plastic oil	NO_X	oxides of nitrogen
PO25	25% plastic oil blended with diesel	UHC	Unburned Hydrocarbons
PO50	50% plastic oil blended with diesel	CO	carbon monoxide
PO75	75% plastic oil blended with diesel	SOC	start of combustion
BSEC	Brake Specific Energy Consumption	BSU	Bosch smoke unit
TDC	top dead centre		

notion of using alternate resources for petroleum fuels has gained its significance since the energy crisis of 1970. A lot of researches are being carried out in the field of alternative energy and in this category most of the researchers suggest the use of biodiesels because of their similar physiochemical properties with that of diesel (Mofijur et al., 2013; Kaimal and Vijayabalan, 2015; Lin et al., 2011; Hoekman et al., 2012). Among the different fuels available, plastic oil produced by pyrolysis process has become the center of attention because of its dual benefit of recovering energy from waste materials and reducing the environmental problems caused by waste plastic. Studies using plastic and tire pyrolysis oil is in utilizing them as an additive for reducing the viscosity of heavy oils in heavy duty marine engines (Mani et al., 2009). Recently, researchers have reported the success in utilizing the pyrolysis oil as a fuel in diesel engines and suggested that the properties of plastic pyrolysis oil are comparable to that of diesel fuel (Kaimal and Vijayabalan, 2015; Mani et al., 2011). Even though the pyrolysis oil has been used as fuel in diesel engines, the performance and emission characteristics are much inferior to diesel fuel (Kaimal and Vijayabalan, 2015; Murugan et al., 2009). However, only a few works have been carried out to study the effects of their use in light duty compression ignition engines. So in this present work, a detailed investigation is carried out to evaluate the performance and emission characteristics of waste plastic oil and its blends with diesel in a diesel engine and to assess its potential as an alternate fuel for high speed compression ignition engines.

2. Materials and methods

2.1. Plastic oil synthesis by pyrolysis

In this research work, the waste plastic materials (HDPE) were gathered from the city landfills and cut into pieces of approximately the same size (0.5–1 cm^2). The impurities in the plastic chips were then removed by repeated washing and the moisture content is completely dried with the help of an oven. A custom made pyrolysis reactor of 40 cm diameter and 60 cm height was used for carrying out the reaction. A 10% by weight of coal and 1% by weight of Silica catalyst were fed into the reaction chamber along with the plastic chips. The reactor was fed with a mixture of 750 g of HDPE plastic chips, 70 g of coal and 7 g of silica in a single feed. The reaction chamber was made inert by supplying nitrogen at a constant rate of 8 L/min. The reaction temperature inside the chamber was maintained in the range of 350–400 °C with the help of a temperature controller and the reaction was allowed to carry out for 4 h continuously at atmospheric pressure. Pyrolysis process yielded plastic oil (80% by weight of input), solid coke residue (15% by weight) and gaseous fractions (5% by weight) which is a mixture of propylene, iso butane, ethane and small amounts of methane. 1.3 kg of HDPE waste plastic was required to produce 1 kg of waste plastic pyrolysis oil.

All the gaseous products from this process are condensed to either liquids or non-condensable products by passing it through the water chamber before it is let out. Most of the toxins are either burned out in the lack of oxygen or reduced in the presence of a catalyst. The oil was also distilled, to remove any of the remaining impurities, before using in the engine. The properties of diesel and plastic oil are given in Table 1.

2.2. Experimental setup

A DI diesel engine generating 3.7 kW at a rated speed of 1500 RPM was used for performing the experiment. Table 2 gives the specifications of the engine and the graphic representation of the test setup is depicted in Fig. 1.

The investigation was carried out on the engine using diesel neat plastic oil and its blends with diesel. No adjustments or modifications were done on the engine setup throughout the experiment. The engine was electrically loaded with a rheostat. A pressure transducer was attached to the cylinder head to obtain the pressure signals from the combustion chamber. The crank angle and TDC data were acquired using a precision encoder. The signals from both the encoder and the pressure transducer were given to KISTLER charge amplifier. The amplified signals were collected with the help of a data acquisition system and fed to the computer. The average of 100 cycles of pressure crank angle data was recorded to avoid variability and error. The gaseous emissions (UHC, CO and NO_X) in the exhaust were obtained with the help of AVL Digas 444 infrared gas analyzer and smoke levels were recorded with the help of AVL 437C smoke meter. The engine was started using the diesel fuel and was switched to plastic oil after attaining steady state. The fuel tank was fully emptied by running the engine before using a new fuel. The injection system of the engine was cleaned and calibrated after every test run.

3. Results and discussion

3.1. Basic composition of the plastic oil

The oil produced by the pyrolysis process was analyzed with mass spectrometry technique. The basic composition of the plastic pyrolysis oil is given in Table 3. From the table it can be seen that more than 70% of the fuel is constituted by smaller chains of

Table 1
Properties of plastic oil and diesel.[a]

Properties	Test standard	Diesel	Plastic oil
Density at 15 °C (g/cc)	ASTM D 1298	0.84	0.83
Kinematic viscosity (cSt) at 40 °C	ASTM D 445 04e	2.15	2.64
Calorific value (kJ/kg)	ASTM D 240 02	43,500	44,200
Cetane number	ASTM D 613 05	54	50
Flash point (°C)	ASTM D 93	45	40
Fire point (°C)	–	48	44
Cloud point (°C)	ASTM D 2500	3	2
Ash content (wt%)	ASTM D 482	0.001	0.002
Sulfur content (wt%)	ASTM D 4249	0.01	0.025
Water by distillation (vol%)	ASTM D 95	–	0.05

[a] Values measured.

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