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Research article

Experimental evaluation of a diesel engine fuelled by pyrolysis oils produced from low-density polyethylene and ethylene–vinyl acetate plastics

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ABSTRACT

Depletion of oil resources and increase in energy demand have driven the researchers to seek ways to convert the waste products into high quality oils that could replace fossil fuels. Plastic waste is in abundance and can be converted into high quality oil through the pyrolysis process. In this study, pyrolysis oils were produced from polyethylene (LDPE700), the most common used plastic, and ethylene–vinyl acetate (EVA900) at pyrolysis temperatures of 700 °C and 900 °C respectively. The oils were then tested in a four cylinder diesel engine, and the performance, combustion and emission characteristics were analysed in comparison with mineral diesel. It was found that the engine could operate on both oils without the addition of diesel. LDPE700 exhibited almost identical combustion characteristics and brake thermal efficiency to that of diesel operation, with lower NO_X, CO and CO_2 emissions but higher unburned hydrocarbons (UHC). On the contrary, EVA900 presented longer ignition delay period, lower efficiency (1.5–2%), higher NO_X and UHC emissions and lower CO and CO_2 in comparison to diesel. The addition of diesel to the EVA900 did not significantly improve the overall engine performance.

1. Introduction

Plastic consumption is increasing dramatically every year due to the relative low cost of production in comparison to other materials and convenience in use and application. In 2015, plastic production reached the 322 million tonnes worldwide and the 59 million tonnes in the European Union [1]. The disposal amount of the waste plastics has also been increasing and it has been considered as one of the major components of the municipal solid waste. Polyethylene is the most common plastic with global production of around 80 million tonnes per year and main application in plastic bags, toys, oil containers, bottles and wrapping foil for packaging [2]. Polyethylene is manufactured from the polymerisation of ethylene polymers with the addition of catalysts and it can be classified into two main categories: low density polyethylene and high density polyethylene. Polyethylene–vinyl acetate or ethylene–vinyl acetate (EVA) is a co-polymer of ethylene and vinyl acetate which represents the largest volume section of the ethylene co-polymer market [3]. The main uses of the EVA are in adhesives, sealants and coatings applications such as moulded automotive parts, flexible packaging, automobile bumpers, toys, flexible hoses and footwear components. Most of the plastics have very low degradation rate because of the molecular bonds of carbon, hydrogen and few other elements that make them very durable resulting in a serious environmental problem by landfilling them.

Plastic disposal can be reduced significantly if the waste plastics are managed efficiently at the end of their life. Mechanical recycling is a technique that applies sorting, grinding, washing and extrusion and can be used to recycle single polymer waste, which represent the 15–20% of the total waste plastics [4]. Chemical recycling or feedstock recycling can be used to treat significantly higher amount of waste plastics. Pyrolysis process is considered as a chemical recycling technique and it is a very promising technology for the waste plastics treatment [5–7]. Pyrolysis is a thermal degradation process that involves cracking of the complex organic molecules into smaller molecules and long hydrocarbon chains into shorter chains [8]. The process takes place in the absence of oxygen at elevated temperatures. The major products from the pyrolysis process are in liquid, gaseous and solid form while the amount of each product mainly depends on the feedstock composition and the pyrolysis process parameters such as temperature, residence time, heating rate and catalyst [9–11]. According to the literature review, the EVA pyrolysis

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Nomenclature

LDPE700	low density polyethylene oil produced at 700 °C
EVA900	ethylene-vinyl acetate oil produced at 900 °C
EVA900 75	75% EVA900 + 25% diesel fuel
NO_x	nitrogen oxides
CO	carbon monoxide
CO_2	carbon dioxide
HC	hydrocarbon
LHV	lower heating value
BMEP	brake mean effective pressure
IMEP	indicated mean effective pressure
COV_{IMEP}	coefficient of variation of IMEP
HRR	heat release rate
MFB	mass fraction burned
TDC	top dead centre
ϕ	equivalence ratio
BTE	brake thermal efficiency

has not been investigated in depth and the basic properties of the produced oil has not been reported yet [12–14]. On the other hand, the pyrolysis of polyethylene has been studied by various authors and the oil composition results suggest that is a promising fuel for power and heat generation [10,11,15-17].

Internal combustion engines and especially diesel engines are preferable for power generation from alternative fuels due to their high efficiency, excellent durability, less demanding exhaust emission regulations and fuel quality [18]. The use of polyethylene pyrolysis oil in diesel engines has only been investigated at low blend ratios with diesel fuel, showing promising results for use of higher blend rates. More specifically, Gungor et. al. [19] conducted a research on a four-cylinder diesel engine using the oil that derived from the pyrolysis of high density polyethylene (HDPE) blended with diesel at 5% blend ratio (95% diesel + 5% HDPE oil by volume). The investigation on HDPE showed lower brake thermal efficiency and cetane number (i.e. longer ignition delay period) and higher carbon dioxide and nitrogen emissions than diesel operation. Another research on low density polyethylene (LDPE) oil (10%) blended with diesel (90%) revealed similar ignition delay period with diesel, lower efficiency and nitrogen oxides emissions and higher unburned hydrocarbons, carbon monoxide and carbon dioxide emissions [20]. Finally, Kumar et. al. [21] investigated the effect of fuelling a twin cylinder diesel engine with HDPE oil with blends up to 40% with diesel. The results showed higher nitrogen oxides, unburned hydrocarbons and carbon monoxide emissions and lower carbon dioxide and brake thermal efficiency than diesel performance.

Table 1
Produced gas composition.

Component	Quantity (v/v %)	
	LDPE700	EVA900
Hydrogen	16.1	14.4
Oxygen	<1.0	<1.0
Nitrogen	4.9	2.8
Methane	32.1	33.8
Carbon monoxide	28.8	27
Carbon dioxide	16.6	20.3
Ethylene	<0.1	<0.1
Ethane	0.3	0.6
1,3 butadiene	<0.1	<0.1
Benzene	0.9	0.5
Toluene	0.3	0.6

What has not been investigated yet in diesel engines is the use of LDPE oil in high blend rates and without diesel. Moreover, the properties of an oil that derives from the pyrolysis of EVA have not been reported and the use of EVA oil in diesel engines has not been evaluated yet. In the present work, the use of EVA and LDPE oils in a diesel engine are evaluated and compared with diesel fuel operation. To accomplish this aim, the oils properties were determined and the engine combustion, performance and emission characteristics were analysed.

2. Materials and methods

2.1. Conversion process and fuel properties

Low density polyethylene (LDPE) and ethylene–vinyl acetate (EVA) were used as feedstocks and converted into high quality oils via the fast pyrolysis process. The schematic layout of the pyrolysis plant that was used is shown in Fig. 1, whereas its operational information is given in our previous work [22]. The conversion chamber temperature for the pyrolysis of the EVA was maintained at 900 °C while for the LDPE was set at 700 °C. LDPE was also converted at pyrolysis temperature of 900 °C but the produced oil was too viscous and preheating was required in order to reduce the viscosity and use it as fuel in a diesel engine. This result is in accordance with other studies, which have also reported that pyrolysis of polyethylene produced high viscosity oils [7,15,23].

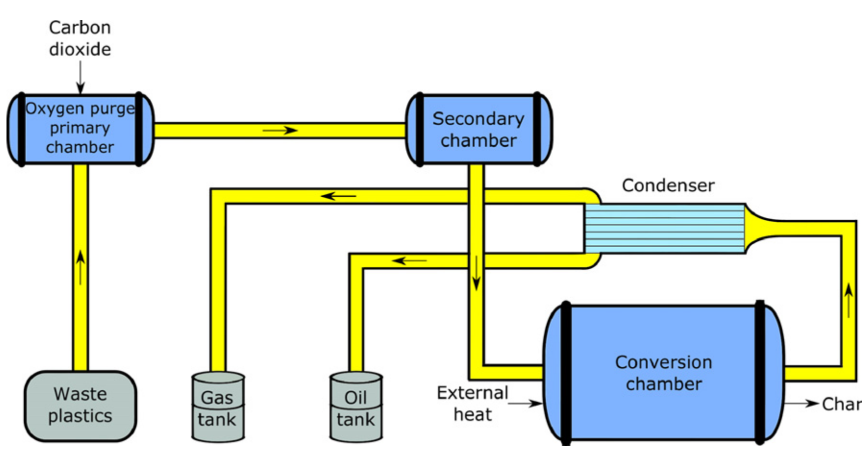

Fig. 1. Schematic layout of the pyrolysis process.