Fuel 179 (2016) 368–375

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Thermal degradation of polyethylene waste and jute fiber in oxidative environment and recovery of oil containing phytol and free fatty acids

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HIGHLIGHTS

- A self designed reactor for the effective thermal degradation of polyethylene waste.
- All the thermal degradation experiments were performed in oxidative environment.
- The recovered oil was screened against SV, AV, EV, % glycerol and % FFA.

ARTICLE INFO

Article history:
Received 1 October 2015
Received in revised form 19 January 2016
Accepted 4 April 2016
Available online 8 April 2016

Keywords:
Thermal degradation
Waste polyethylene
Jute fiber
Oxidative environment
Reactor
Fatty acids

ABSTRACT

The thermal degradation of the mixture of waste HDPE & LDPE defined as WPB, in the ratio of 3:1 by wt% and the mixture of jute, HDPE & LDPE defined as JFWPB in the ratio of 1:3:1 by wt%, was carried out in a self designed, laboratory scale, stainless steel reactor in the oxidative environment. The reactor was heated up to 180 °C with a heating rate of 1 °C/min, by using the digital temperature controller. The recovered liquid yield from WPB was reported less than 5% which had been improved upto 56% with JFWPB. The comparatively FTIR analysis of both the samples revealed that unsaturated hydrocarbon fragments were transformed in to the oxygenated products which were confirmed by GC/MS analysis and identified as a phytol, free fatty acids and silica derivatives by using NIST library. The saponification value, acid value, ester value, % free fatty acids and % glycerol for Oil_{JFWPB} was found close to the coconut oil.

1. Introduction

With the help of waste to energy (WTE) technology, the municipal solid waste (MSW) could be used as a raw material for the production of sustainable energy. The world plastic production has been reached up to the 280 Metric tons [1] and United States individually produces 250 million tons of municipal solid waste (MSW) [2] which generates various ecological problems. Pyrolysis is one of the most important WTE technologies through which it is possible to transform solid waste plastic into oil like substance. Pyrolysis is the thermal break down of polymer at elevated temperature in the absence of oxygen and produces condensable liquid product having good heating value. It was reported that on pyrolysis by mixing of biomass with plastic waste the yield of pyrolysis-oil was much improved than the pyrolysis oil produced from biomass and plastics pyrolyzed individually [8]. Co-pyrolysis of different plastics with different biomass such as Karanja & Niger seeds [3], red oak [4], rice husk [5], almond shell [6], oil shell [7], pine cone [8], wood biomass [9], forestry biomass wastes [10], and lignocellulosic materials [11] has been studied widely.

Jute fibers are 100% bio-degradable, recyclable, environmental friendly and extracted from the bark of the jute plant (*Corchorus oliotorus*). Jute fibers have strength, low cost, durability, versatility

Abbreviations: HDPE, high density polyethylene; LDPE, low density polyethylene; WPB, waste plastic blend; JFWPB, jute fiber waste plastic blend; wt%, weight percentage; FTIR, Fourier Transform Infrared; GC/MS, Gas Chromatography Mass Spectrometry; °C/min, degree centigrade/minute; NIST, National Institute of Standards and Technology; WTE, waste to energy; MSW, municipal solid waste; CIPET, Central Institute of Plastic Engineering and Technology; mm, millimeter; kW, kilowatt; mg, milligram; g, gram; Oil_{WPB}, oil recovered by waste plastic blend; Oil_{JFWPB}, oil recovered by jute fiber waste plastic blend; cm, centimeter; % T, percentage transmittance; $FTIR_{WPB}$, Fourier Transform Infrared Spectrum by waste plastic blend; $FTIR_{JFWPB}$, Fourier Transform Infrared Spectrum by jute fiber waste plastic blend; µl, microliter; SV, saponification value; ASTM, American Society for Testing and Materials; AV, acid value; % FFA, percentage free fatty acids; EV, ester value; TG, thermo gravimetric; DTG, derivative thermo gravimetric; approx., approximately.

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http://dx.doi.org/10.1016/j.fuel.2016.04.004
0016-2361/

and basically used in the making of shopping bags, carpets and rugs. Jute does not produce toxic gases on burning and also possesses good insulating and antistatic properties, as well as having low thermal conductivity and moderate moisture retention. Jute is an annual crop grown in South Asia and specifically a product of India and Bangladesh this crop is not able to grow in European countries because jute needs tropical rainfall, warm weather and high humidity. About 95% of world jute is grown in these two South Asian countries. Annual output in the last decade ranges from 2.5 to 3.2 million tons. India and Bangladesh account for about 60% and 30%, respectively of the world's production [12].

The aim of this research work is to design a cost effective method for the degradation of polyethylene waste into an energy source and also to recover a low cost fuel with good heating value for various domestic as well as industrial applications.

2. Experimental

2.1. Materials

To achieve the aim, waste, useless plastic buckets made up of high density polyethylene (HDPE) and shopping carry bags made up of low density polyethylene (LDPE) were collected from various domestic sources and characterized by Central Institute of Plastics Engineering and Technology (CIPET) Bhopal, India and then these collected samples were prepared for the experiments by washing it using tap water, cleaning it by using cotton cloth, drying it under the sunlight and then shredding into small pieces of size 3×3 in. The natural fibers of Indian origin such as jute, flax, hemp and sisal were purchased from the local area market and washed with the help of distilled water to remove unwanted particles and dried under the sunlight for a week and then allowed to chop and sieved using, British Sieve Size No. 14.

2.2. Methods

2.2.1. Experimental procedure

In this work the mixture of jute fiber, HDPE and LDPE in the ratio of 1:3:1 and the mixture of HDPE and LDPE in the ratio of 3:1, by wt% were heated up to 180 °C with a heating rate of 1 °C/min. All the experiments were performed in the oxidative environment and the yield of recovered oily substance from both the samples were compared and then analyzed by using Fourier Transform Infrared Spectroscopy and Gas Chromatography Mass Spectrometry. The saponification value, acid vale, ester value, free fatty acids and % glycerol for recovered oil were determined and compared with different vegetable oils. For the effective thermal degradation, a laboratory scale, stainless steel reactor was self designed. This reactor system consisted of a vertical, stainless steel, air tight chamber with 500 mm of height and 200 mm of inner diameter, a heating source of 2 kW was placed below the reactor and to sense the temperature inside the reactor a 'J' type thermocouple was fitted at the bottom of the reactor and the heating source and thermocouple were merged to the digital temperature controller and this entire setup was set to heat up with the heating rate of 1 °C/min, to achieve the temperature upto 180 °C. A specially designed collector to collect liquid product was connected to the exhaust of the reactor by using rubber tubes. This collector works on the principle that liquids are heavier than the gases so the liquids settled into the bottom while gases are lighter than the liquids so shifted to the water tank. The actual picture of the reactor represented in Fig. 1. The % yield of liquid, solid residue and gaseous products were determined by using Eqs. (1)–(3) [13].

$$\%\ \text{yield of liquid} = \frac{\text{Weight of recovered liquid}}{\text{Total weight of mixture}} * 100 \qquad (1)$$

$$\%\ \text{yield of solid residue} = \frac{\text{Weight of solid residue}}{\text{Total weight of mixture}} * 100 \qquad (2)$$

$$\%\ \text{yield of gaseous products} = 100 - [\%\ \text{yield of liquid} + \%\ \text{yield of solid residue}] \qquad (3)$$

2.2.2. Thermo gravimetric analysis

Approx. 10 mg sample of jute fiber, HDPE and LDPE was heated from room temperature to 700 °C at a heating rate of 5 °C/min, in a NETZSCH TG 209 F1 thermo gravimetric analyzer and the inert atmosphere was created by flowing of nitrogen gas with the rate of 100 ml/min.

2.2.3. Thermal degradation experiments

All the thermal degradation experiments were performed inside the self designed reactor in oxidative environment with different types of easily available natural fibers in Indian markets such as jute, flax, hemp and sisal. The mixture of polyethylene was prepared by mixing shredded HDPE and LDPE in the ratio of 3:1 by wt% and 1 ratio of different natural fiber by wt% was added to the mixture of shredded polyethylene waste and the final amount of each reaction mixture was 500 g.

2.2.4. Nomenclature of the samples and products

The mixture of waste HDPE and LDPE was designated as WPB and the mixture of jute, HDPE and LDPE was designated as JFWPB. The recovered oily substance by WPB and JFWPB was designated as Oil_{WPB} and Oil_{JFWPB} respectively.

2.2.5. Fourier Transform Infrared Spectroscopy

The FTIR analysis of recovered oily substance was carried out in Shimadzu IR Affinity-1. NaCl cell was used for sample holding inside the instrument and cell thickness was 0.025 mm, total scan

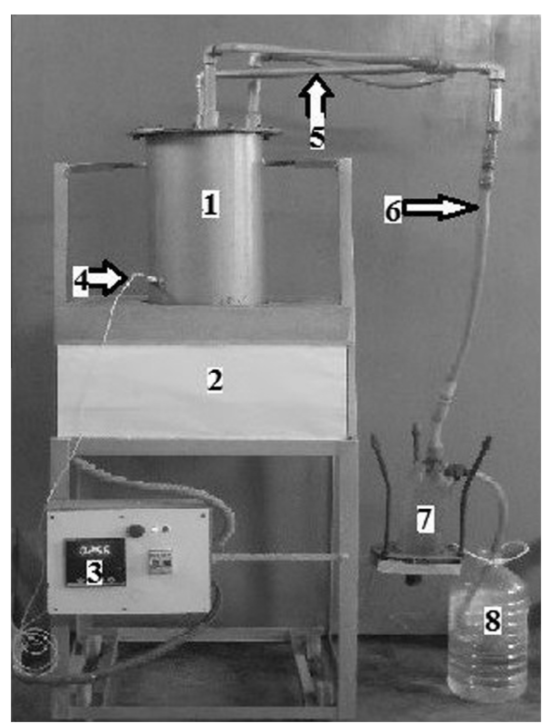

Fig. 1. The actual picture of the experimental setup. 1: Stainless steel reactor, 2: heating source, 3: digital temperature controller, 4: 'J' type thermocouple, 5: exhaust pipe from reactor to collector, 6: connecting rubber tubes, 7: specially designed collector, 8: water tank, respectively.