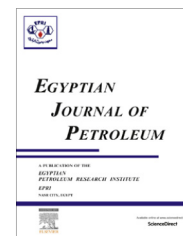




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FULL LENGTH ARTICLE

Wax co-cracking synergism of high density polyethylene to alternative fuels



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Abstract Attempts have been made to understand the thermal degradation of high density polyethylene (HDPE) and their combined co-cracking using different ratios of HDPE and petroleum wax under nitrogen atmosphere. We have conducted the experiments using HDPE as the raw material and petroleum wax as co-feed by at 400 and 450 °C reaction temperatures. The product distribution was noted along with reaction time of 0.5–3 h for the degradation. Thermal gravimetric analysis (TGA) technique was used to measure the weight change of the feedstock as a function of temperature and time. Differential scanning calorimetry (DSC) was used to determine the degradation temperature. Products were characterized using gas chromatography (GC) and infrared spectroscopy (FTIR), some other standard physical methods were used to determine the main properties of the liquid products. Results show that the mixed plastic-wax samples could be converted into gases, gasoline, and middle distillate depending upon the composition of feed polymer/wax ratio. It was found that the products mostly consisted of paraffin and olefin compounds, with carbon numbers of C₁–C₄, C₅–C₉ and C₁₀–C₁₉ in the case of gases, gasoline and middle distillate respectively.

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1. Introduction

Plastics are one of the most widely used materials due to their various advantages and numerous applications in our day to day life. Plastic production has increased by an average of

almost 10% every year on a global basis since 1950. HDPE is the third largest commodity plastic material in the world, after polyvinyl chloride and polypropylene in terms of volume. The increased demand and production of HDPE has led to the accumulation of large amounts in the final waste stream due to its low useful life [1–4]. Various techniques for the treatment of waste polymers have been investigated to complement existing landfill, incinerating and mechanical recycling technologies. Ideally, it would be desirable to convert the waste into a

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value-added product [5–7]. Pyrolysis is one method of reducing plastic wastes [8–9]. It should allow us to recycle back some of the stored energy within the plastic wastes. Pyrolysis uses high-temperatures to break polymer structures into smaller hydrocarbon molecules in an oxygen free atmosphere. The process can handle plastic waste, which cannot be efficiently recycled by other recycling processes and operates without the need of air and generates no pollutants since it is conducted in a closed system. A plant developed by recycling technologies treats mixed plastic waste and provides all the usual advantages of the combined heat and power system [10]. Considerable demand exists for affordable technology that can use environmentally sound methods to extract value from waste that would otherwise be sent to a landfill. The plant is designed to be positioned at the end of a plastic sorting line that already removes material that is not going to be economically recycled, using it instead to provide the electricity and heat needed to recycle the plastics that will be. This avoids the use of virgin fossil fuel in the recycling process, as well as the transport of plastic waste to landfill or as refuse derived fuel to mass-burning facilities. Mixed plastic waste is shredded, the tramp metal removed and the waste is then dried and stored in a bunker. This prepared material is then fed constantly into a pyrolysis reactor where, in the absence of oxygen, the long hydrocarbon chains that form the polymers are thermally cracked into compounds of shorter chain lengths, which exit the chamber as hot gas. The issue with using waste material as a fuel is, of course, that its constituents can vary dramatically, so the quality of the fuel produced also tends to be variable. To combat this problem the system uses a reactor management module to continually adjust the conditions in the reactor to even out such variations. By constantly monitoring the gas being produced the operating parameters can be adjusted to enhance the fuel properties [11–12].

In this work, high-density polyethylene (HDPE) plastic was chosen as used plastic with the objective of optimizing the liquid product yield at a reaction temperature of 400 and 450 °C for a residence time 0.5–3 h under N₂ atmosphere in a batch reactor. The effects of HDPE/wax ratio on the yield of liquid and gaseous products were studied. The physical properties of the pyrolytic oil such as specific gravity and viscosity were studied. The chemical compositions of the pyrolytic oil products were investigated using analysis.

2. Experimental

2.1. Materials

Waste HDPE was purchased from the Garbage collected place, Manshiat Naser. El – Dewaka, Cairo, Egypt. Light paraffin wax used was obtained from Alexandria Petroleum Company. The characteristics of HDPE raw material and wax feed stock are summarized in (Table 1).

2.2. Pyrolysis experiment

The pyrolysis experiments were carried out in nitrogen atmosphere, using a high pressure magnetically stirred batch autoclave (Parr model 4575) with an inner volume of 500 ml and heated by a digital controller, at a temperature of 400 and 450 °C, initial hydrogen pressure of 100 psi. A typical run

Table 1 Characterization of HDPE raw material and paraffin wax.

| Characteristics | Method | HDPE | Paraffin wax |
|---|------------|----------|-----------------|
| Density, gm/cm ³ | ASTM D4052 | 0.950 | ASTM D1505 0.84 |
| Average molecular weight, g mol ⁻¹ | | 250,000 | 440 |
| Melting point, °C | | 130 | 62 |
| Refractive index | | 1.541 | 1.45 |
| Tensile strength | ASTM D638 | 3300 psi | – |

100 g of the sample was placed into the reactor, which was then sealed. The system was heated at a rate of 20°Cmin⁻¹ up to 450 °C and maintained there for 0.5–3 h at a speed of 200 rpm. The stirring and heating of the autoclave were shut down then left to cool overnight. Gas and liquid samples were collected and analyzed by gas chromatography.

Thermal cracking experiments were carried out using different HDPE-paraffin wax mixtures prepared with relative proportions within the ratio 50/50, 75/25, 82.5/12.5 respectively and also for HDPE alone.

The conversion and yield are defined according to the following:

$$\text{Conversion(wt\%)} = \frac{\text{feed} - \text{residue}}{\text{feed}} \times 100$$

$$\text{Yield(wt\%)} = \frac{P}{\text{feed}} \times 100$$

where *P* represents the oil or gas.

2.3. Characterizations

Thermogravimetric analysis TGA of the waste HDPE sample was carried out with a Perkin–Elmer apparatus. TGA was used to study the weight loss vs. temperature, and to determine the reaction temperature range. A known weight of the sample was heated in a silica crucible at a constant heating ratio of 20 °C/min operating in a stream of nitrogen with a flow rate of 20 ml/min from 30 °C to 600 °C. DSC analysis was done in a Perkin–Elmer differential scanning calorimeter under a flow of nitrogen (flow rate 20 ml min⁻¹). Samples (5–10 mg) were sealed in aluminum pans and heated at a heating rate of 10 °C min⁻¹, and cooled at the same rate. The melting and crystallization temperatures are reported as average values with standard deviations.

Fourier transform Infrared spectroscopy FTIR of the obtained pyrolysis oil was performed with ATI Mattson infinity series apparatus, Model 960 M0009 with resolution of 4 cm⁻¹, in the range of 400–4000 cm⁻¹.

The components of the gaseous products were analyzed using a Varian CP-3800 GC equipped with two detectors:

1. Thermal Conductivity Detector TCD for analysis of non-organic gases, which were separated in a 7 ft Hysep Q, molecular sieve packed stainless steel column.
2. Flam Ionization Detector FID for C₁–C₅ hydrocarbon separated in a 60 meter (capillary) DB-1 silicon oil fused silica by using helium as carrier gas at 50 °C and 5 min hold (injector and detector) temperature of 150 and 250 °C,

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