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# Effect of plastic waste types on pyrolysis liquid oil

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ABSTRACT

This paper aims to examine the effect of different plastic waste types such as polystyrene (PS), polyethylene (PE), polypropylene (PP) and polyethylene terephthalate (PET) on the yield and quality of produced liquid oil from the pyrolysis process. A small pilot scale pyrolysis reactor was commissioned for this purpose, and operated at optimum temperature and retention time of 450 °C and 75 min respectively. PS plastic waste showed maximum production of liquid oil (80.8%) along with least production of gases (13%) and char (6.2%) in comparison to other plastic types. Liquid oils from all plastic types contained mostly aromatic compounds with some alkanes and alkenes. Liquid oil from PS pyrolysis contained styrene (48.3%), ethylbenzene (21.2%) and toluene (25.6%). Pyrolysis liquid oils found to have ranges of dynamic viscosity (1.77–1.90 mPa s), kinematic viscosity (1.92–2.09 cSt), density (0.91–0.92 g/cm$^3$), pour point (−11(-60 °C)), freezing point (−15-(-65 °C)), flash point (28.1–30.2 °C) and high heating value (HHV) (41.4–41.8 MJ/kg) similar to conventional diesel, thus have potential as an alternative energy source for electricity generation. Upgrading of liquid oil using different post-treatment methods such as distillation, refining and blending with conventional diesel is required to make it suitable as a transport fuel due to presence of high aromatic compounds. The recovery of aromatic compounds especially styrene from pyrolysis oil can be a potential source of precursor chemical in industries for polymerization of styrene monomers.



## 1. Introduction

The consumption of plastic is increasing worldwide at an alarming rate of 4% per year due to its durability, light weight and low cost (Miandad et al., 2016a). In 2011, the total plastic waste production in the world was around 280 million tons (Sriningsih et al., 2014). Plastic waste is now one of the major components of municipal solid waste (MSW). It is a mixture of various plastic products, mainly made from low density polyethylene (LDPE), high density polyethylene (HDPE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC) and polyethylene-terephthalate (PET) plastics (Table 1). PE and PS are the most available plastic types among municipal plastic waste (MPW) (Onwudili et al., 2009).

Plastic waste is managed by different techniques including, reducing, reusing, recycling, waste-to-energy (WTE) and disposal at landfill sites (Ouda et al., 2016; Sadef et al., 2016). Conventional mechanical recycling techniques such as sorting, grinding, washing and extrusion can recycle only 15–20% of all plastic waste types (Nizami et al., 2015a). Beyond this level, the plastic becomes contaminated with materials like soil, dirt, aluminium foils, food wastes and paper labels (Nizami et al., 2015b). The uncontrolled incineration and open burning of plastic waste have caused air and waterborne pollutants (Miandad et al., 2016b; Rahmanian et al., 2015; Eqani et al., 2016; Munir et al., 2016). Therefore in recent years, various plastic-to-fuel (PTF) or WTE technologies such as gasification, pyrolysis, refuse derived fuel (RDF) and plasma arc gasification along with chemical recycling methods such as hydrolysis, methanolysis, glycolysis have gained significant attention for the management of MPW (Nizami et al., 2015a).

The pyrolysis of MPW is a promising WTE or PTF technology for the sustainable management of plastic waste along with production of liquid oil as a source of energy and char and gases as value-added products (Rehan et al., 2016a). The process involves thermal cracking of complex organic molecules or large chain hydrocarbons at elevated temperature (300–600 °C) into smaller molecules or short chain hydrocarbons (Sharma et al., 2014). The process is

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**List of acronyms and abbreviations**

| | |
|---|---|
| $CO_2$ | Carbon Dioxide |
| CO | Carbon Monoxide |
| FT-IR | Fourier Transform Infrared Spectroscopy |
| GC-MS | Gas Chromatography Coupled with Mass Spectrophotometry |
| HC's | Hydrocarbons |
| HDPE | High Density Polyethylene |
| HHV | High Heating Value |
| KACARE | King Abdullah City of Atomic and Renewable |
| KSA | Kingdom of Saudi Arabia |
| LCA | Life Cycle Assessment |
| LDPE | Low Density Polyethylene |
| MPW | Municipal Plastic Waste |
| MSW | Municipal Solid Waste |
| NOx | Oxides of Nitrogen |
| PE | Polyethylene |
| PET | Polyethylene Terephthalate |
| PP | Polypropylene |
| PS | Polystyrene |
| PTF | Plastic-to-Fuel |
| PWM | Plastic Waste Management |
| PVC | Polyvinyl Chloride |
| RDF | Refuse Derived Fuel |
| TGA | Thermogravimetric Analyzer |
| TIC | Total Ion Chromatogram |
| WTE | Waste-to-Energy |

completed in four steps, including initiation, transfer, decomposition and termination (Faravelli et al., 2001). Computer simulation models consider hundreds of possible reactions happening during thermal cracking of feedstock (Zhang et al., 2015). Therefore, the pyrolysis process depends on series of factors such as temperature, residence time, heating rates, feedstock composition and presence of moisture or toxic elements (Miskolczi et al., 2009).

The scientific literature shows that in most of the pyrolysis studies, resin/virgin plastic or processed plastics were used as a feedstock, mostly in small scale reactors (Syamsiro et al., 2014; Adnan and Jan, 2014; Sriningsih et al., 2014; Miandad et al., 2016a; Ciliz et al., 2004). While, the interest in pyrolysis of real MPW has gained significant attention in recent years (Lee, 2012; Chen et al., 2014; Zeaiter, 2014). The focus of these studies were to increase the quantity of pyrolysis liquid oils along with establishing the carbon chain composition of the produced liquid oil (Sharuddin et al., 2016; Ates et al., 2013; Demirbas et al., 2016). However, the quality of pyrolysis liquid oils, from mixtures of different plastic types, in terms of their properties such as density, viscosity, high heating value (HHV), flash point, and cold flow properties (i.e. pour point and freezing point) along with their comparison with conventional diesel properties is seldom reported (Lee et al., 2015; López et al., 2011; Miandad et al., 2016a). Moreover, the recovery of aromatic compounds such as styrene, ethylbenzene and toluene from pyrolysis liquid oils produced from MPW and their potential applications' studies have been limited (Bozkurt et al., 2016; Shah and Jan 2014; Sarker and Rashid, 2013; Miandad et al., 2016b; Siddiqui and Redhwi, 2009), which was the focus of this study.

The Kingdom of Saudi Arabia (KSA) is one of the major plastic producers in the world with annual plastic generating capacity of around 6 million metric tons (Anjum et al., 2016). The average life span of about 40% of the consumed plastic is less than a month (Siddiqui and Redhwi, 2009). As a result, it is the second largest waste stream (upto 17.4%) of MSW in KSA (Nizami et al., 2016). Moreover, excessive quantities of plastic waste are generated every year due to serving of meals in disposable plastics to millions of pilgrims in the holiest cities of Makkah and Madinah (Nizami et al., 2015c; Nizami et al., 2016; Miandad et al., 2016c).

In KSA, neither WTE facilities exist to convert plastic waste into energy, nor have the plastic waste types been characterized for their potential role as an energy recovery feedstock (Nizami et al., 2016). Therefore, this study aims to examine the effect of different plastic waste types such as PS, PE, PP and PET on the yield and quality of produced liquid oil. A small pilot scale pyrolysis reactor was commissioned for this purpose with total capacity of 20 L. The plastic waste types were used as a feedstock, individually as well as in mixtures. The potential application of liquid oil in generating energy or as a source of transport fuel and for recovery of aromatic compounds especially styrene was evaluated in detail. Moreover, the potential usage of char in various environmental applications was also highlighted.

## 2. Materials and methods

### 2.1. Feedstock preparation and reactor startup

The collected feedstock samples for the present study were consist of disposable plates, grocery bags, and juices or drinking cups that were mainly made of PS, PE, PP and PET plastic types respectively. These plastic types were selected as they are the major components of MPW found in KSA. The collected samples were used individually and in mixture of a 50/50%, 50/25/25%, and 40/20/20/20% ratios. Feedstock was crushed to small pieces (around 2 $cm^2$) to get the homogeneous mixture.

A small pilot scale pyrolysis reactor was commissioned and used for the conversion of plastic waste into liquid oil and char (Fig. 1). The reactor was made of stainless steel and covered with a loop of an electric heater that allows to achieve a maximum temperature of 600 °C. The height of the reactor was 360 mm with 310 mm diameter and a capacity of 20 L (Table 2). A tube type condenser with a length of 860 mm coupled with a water chiller was installed at the end of catalytic reactor. Organic vapors produced within the heating chamber at high temperature were condensed into liquid oil in the condenser. Water circulating chiller with a coolant was used to decrease the temperature of condenser for the maximum condensation of organic vapors into liquid oil in the condenser. The condensed organic vapors (liquid oil) were collected from the oil collector assembly at the bottom of the system. While the uncondensed products (gases) coming from same liquid oil pipe were exhausted outside (Fig. 1).

### 2.2. Experimental setup and scheme

In all of the experiments, 1 kg of feedstock for each plastic type was used in the pyrolysis reactor individually and in mixture form. The reactor was heated from room temperature to 450 °C using a heating rate of 10 °C/min. A retention time of 75 min was used for all experiments (Table 3). These optimum conditions of 450 °C and 75 min for pyrolysis process were determined by Thermogravematric analysis (TGA) of the used plastic types under controlled conditions together with safety considerations of using