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Transportation fuel from plastic: Two cases of study

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ABSTRACT

Synthesis of liquid fuels from waste is a promising pathway for reducing the carbon footprint of transportation industry and optimizing waste management towards zero landfilling.

The study of commercial plants that conduct pyrolysis of plastics from post-consumer recycled materials and directly mine from old landfills without any pre-treatment has revealed two cases that show the feasibility of manufacturing transportation fuels via these methods.

Pyrolysis oil, consisting of almost 26% hydrocarbons within the gasoline range and almost 70% within the diesel range, is upgraded to transportation fuel in the existing refinery. A batch operating plant is able to deliver relatively good quality pyrolysis oil from post-consumer plastic waste, owing to the catalyst employed. Simple distillation was also evaluated as an alternative and cheaper upgrading process into transportation fuels, meeting EN590 diesel and ISO8217 marine fuel standards.

Even though the two installations are outside the European Union, they represent good examples of the "circular economy" concept envisaged by the European Union via its ambitious "Circular Economy Package [1]", providing real world data for comparison with other experimental and lab results.

1. Introduction

There is increasing worldwide attention towards the synthesis of liquid fuels from waste streams to reduce the carbon footprint of transportation industry and optimize waste management towards zero landfilling. European Union directive 2009/28/CE sets common targets among member states to use renewable energy in transportation and promote "advanced biofuels" or "2nd generation biofuels" to meet those targets without the drawbacks associated with traditional biodiesel and bioethanol from food crops. Plastic waste is a promising source of cheap and abundant feedstock for fuel synthesis via thermochemical conversion, assuming the produced fuels meet the technical specifications prescribed by regulations. A plethora of papers have been published on the pyrolysis of plastic, where the produced pyro-oil, which is in a liquid state, might be used as a fossil fuel substitute or as a crude oil replacement (e.g. Aguado et al., 2006; Blazso et al., 2006; Buekens et al., 1998; De Marco et al., 2005; Demirbas et al., 2004; Onwudili et al., 2009; Lovett et al., 1997; Oku et al., 2005; Shioya et al., 2005; Zhou et al., 2006). Pyro-oil might also be used for the synthesis of chemicals (Kaminsky et al., 1999; Oku, 2005) and co-processed with traditional oil in refineries (Fogassy et al., 2010; Mercade et al., 2010; de Miguel Mercader et al., 2011). However, these are mainly academic studies (Buekens et al., 1998; Buekens, 2006).

In 2009, the Division of Technology of UNEP (United Nations Environmental Programme) issued a publication, entitled "Converting Waste Plastic into a Resource", where waste plastic is defined as "one of the most promising resources for fuel production because of its high heat of combustion and its increasing availability in local communities" (UNEP, 2009). In the document, a number of technologies for plastic pyrolysis are presented, indicating great effort from industry and the private sector to develop cost-effective solutions. Few of those technologies have reached commercial scale operation and most of them are still in the pilot phase, mainly for research and developmental purposes (Al-Salem et al., 2009; Butler et al., 2011; Roy et al., 2001; Scheirs et al., 2006; Zadgaonkar, 2006). Pyrolysis of plastics derived from municipal solid waste and from end-of-life tires has been investigated to determine the extent to which feedstock composition and contaminants can affect oil yield and quality (Wu et al., 1993; Lopez et al., 2010; Miskolezi et al., 2005; Panda et al., 2010; Pinto et al., 1999; Rofiqul et al., 2008; Roy et al., 1999). However, very few cases involving commercial-scale plants have been described in the literature, and those cases are almost exclusively located in Japan (Okuwaki et al., 2006; Shioya et al., 2005) or China (Yuan, 2006), meaning that the industry still needs real case examples to be engaged in this field.

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[1] In a circular economy waste and resource use are minimized, and when a product reaches the end of its life, it is used again to create further value.

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The disposal of waste in landfills has been going on for decades, while the recycling of material has only recently begun gathering momentum. Old landfills represent huge stocks of plastic, which are relatively easy to recover and are virtually untapped as a resource for energy. Often neglected is the consideration that even recycled plastic will eventually end up in an incinerator or landfill, as plastic cannot be recycled endlessly, unlike metals for example.

Preliminary results on INSER's proprietary process of fuel synthesis from plastic waste was presented at the Venice 2012 Symposium and its technical feasibility was proven. The advantages of direct conversion to liquid fuels, a technique for upgrading oil, and the idea of using plastic stored in old landfills were also suggested in 2012 (Faussone, 2012).

Landfills, as reservoirs for material extraction, have become a viable option only recently (Krook et al., 2012), and strategic policy decisions are still needed to for it to reach full potential (Jones et al., 2013). Examples of waste-to-energy technology applications are essential to develop this opportunity (Bosmans et al., 2013) and drive political will towards this option. Waste extracted from old landfills is incinerated as a measure of environmental remediation in Sweden (Hogland et al. 2004) and investigated as recyclable feedstock in the Netherlands (Van de Zee et al., 2004). Simulations have been conducted on the viability of manufacturing refuse-derived fuel (RDF), suitable for the incineration of aged waste material (Bosmans et al., 2014; Danthurebandara et al., 2015; Zhou et al., 2014).

Little data are available on commercial installations, and even less or no data are available on pyrolysis applied to waste extracted from old landfills on a commercial scale. Besides, no similar report on industrial pyrolysis plastic installations containing explicit comparison between produced oil and official transportation fuel standards is available in literature.

This study presents two cases involving the transformation of plastic waste into liquid fuels by pyrolysis plants. Both plants, one operating in continuous mode and the other in batch mode, adopt some of the technical solutions outlined in 2012. Both plants use mixed plastic waste as feedstock, sourced either from postconsumer recycling or directly from an old landfill. In our opinion, due to the nature of feedstock used, these two examples represent the "state of the art" of fuel synthesis from the waste stream. Even though these plants are not located in the European Union, they represent a perfect example of what the European Union is trying to promote via its ambitious "Circular Economy Package", a set of rules to stimulate Europe's transition towards a circular economy, which will boost its global competitiveness, foster sustainable economic growth, and generate new jobs.

The data presented have been obtained from real operations and must be considered as an attempt to provide the scientific community with industrial studies to compare with academic experimental results. Data on plants' emissions in the atmosphere were not available therefore no information to this respect is provided in this work.

2. Materials and methods

2.1. First case of study: Pyrolysis plant in South East Asia

The plant was designed and commissioned on its current design in 2014; it is semi-continuous; plastic loading is continuously performed by means of a modified extruder. After a fixed number of working hours, the ash and residues are extracted by means of a water-jacked screw without cooling down the reactor. Then, the loading starts again and the cycle continues. With this approach, a typical ash extraction is performed after 48 h of operation and lasts less than 1 h after a 4-h "cook off" period (a condition where the reactor is kept hot without loading new feedstock). This procedure allows the complete pyrolysis of the latest loaded feedstock.

The capacity of the plant is about 5–7 tons/day of raw feedstock. Plastic is collected from a nearby old landfill. The landfill, closed as a dump site several years ago, literally became a mining site where the compacted waste/soil is dug and the plastic is extracted by separating it using a rotary screen. It is then transported to the plant site in large bags of approximately 80 kg each with about 6% moisture and used as it is without any pre-treatment.

Pyrolysis products are selectively condensed and stored for further refining. Fig. 1 shows the scheme of fractional condensation. Two different fractions, albeit condensed and collected separately, are mixed again and sent to a refinery for hydrogenation upgrading. This latter approach is also used elsewhere (Okuwaki et al., 2006) in a commercial plant in Japan. Gas generated from pyrolysis is used to self-sustain the process occurring in dedicated gas burners, and therefore, the energy recovery in the oil is only calculated to be approximately 50% of the total energy present in the feedstock.

Refining consists mainly of hydrogenation (mainly for heteroatom removal) and fractional distillation, and the end products are transportation fuels, both in the gasoline and diesel range. This

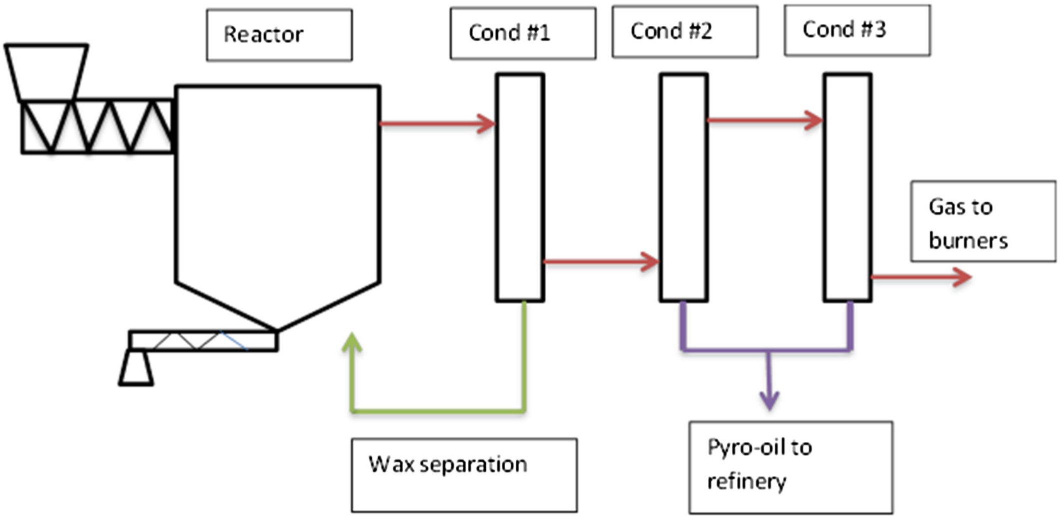

Fig. 1. Simplified fractional condensation scheme.