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Review

Catalytic pyrolysis of plastic waste: A review

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ABSTRACT

This paper reviews the progress and challenges of the catalytic pyrolysis of plastic waste along with future perspectives in comparison to thermal pyrolysis. The factors affecting the catalytic pyrolysis process such as the temperature, retention time, feedstock composition and the use of catalyst were evaluated in detail to improve the process of catalytic pyrolysis. Pyrolysis can be carried out via thermal or catalytic routes. Thermal pyrolysis produces low quality liquid oil and requires both a high temperature and retention time. In order to overcome these issues, catalytic pyrolysis of plastic waste has emerged with the use of a catalyst. It has the potential to convert 70–80% of plastic waste into liquid oil that has similar characteristics to conventional diesel fuel; such as the high heating value (HHV) of 38–45.86 MJ/kg, a density of 0.77–0.84 g/cm^3, a viscosity of 1.74–2.5 mm^2/s, a kinematic viscosity of 1.1–2.27 cSt, a pour point of (−9) to (−67) °C, a boiling point of 68–352 °C, and a flash point of 26.1–48 °C. Thus the liquid oil from catalytic pyrolysis is of higher quality and can be used in several energy-related applications such as electricity generation, transport fuel and heating source. Moreover, process by-products such as char has the potential to be used as an adsorbent material for the removal of heavy metals, pollutants and odor from wastewater and polluted air, while the produced gases have the potential to be used as energy carriers. Despite all the potential advantages of the catalytic pyrolysis, some limitations such as high parasitic energy demand, catalyst costs and less reuse of catalyst are still remaining. The recommended solutions for these challenges include exploration of cheaper catalysts, catalyst regeneration and overall process optimization.

Contents

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1. Introduction

The municipal solid waste (MSW) is one of the chronic environmental, health and economic problems in most developing countries (Nizami et al., 2016). The high generation rate of MSW (up to 1.3 billion tons per year) in developing world is the result of both rapid increase in population and urbanization along with raised living standards (Nizami et al., 2015a; Martinot et al., 2002). In last few decades, millions of people have shifted from rural to urban areas in many parts of the world (Nizami et al., 2015b). Currently half of the world's population lies within urban areas (Tacoli, 2012). Moreover, according to a United Nation (UN) report, the 3.9 billion current urban population will increase to 6.3 billion by 2050, with a 90% increase only in urban areas of Africa and Asia (UN, 2014).

MSW can be a valuable source of biomass, recycled materials, energy and revenue if properly and wisely managed (Nizami et al., 2015a; Miandad et al., 2016a). However, many of the municipalities within the developing world do not have sufficient technical and economical capasities to treat and dispose MSW in an eco-friendly manner (Tacoli, 2012). The Kingdom of Saudi Arabia (KSA) is facing the same problem with MSW management, like other developing nations (Ouda et al., 2016). MSW is generated at an alarming rate of around 15 million tons per year and is estimated to double (30 million tons) by 2033. Plastic waste is the second largest waste stream (up to 17.4%) of MSW in KSA (Nizami et al., 2015a, 2016).

Plastic waste has become an indelible component of MSW, as being used in a wide range of products due to its durability, light weight and low cost (Serrano et al., 2002; Aguado et al., 2007). In 2011, the total world plastic waste production was around 280 million tons that was estimated to further increase with a rate of 4% by 2016 (Sriningsih et al., 2014). Plastic waste is the mixture of different plastic products that are predominantly made from low density polyethylene (LDPE), high density polyethylene (HDPE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC) and polyethylene-terephthalate (PET). PE and PS plastics are the main components of municipal plastic waste (Onwudili et al., 2009).

The plastics are mostly non-biodegradable and remain in the environment for hundreds of years (Ashworth et al., 2014). Conventional recycling methods such as sorting and grinding can recycle only 15–20% of total plastic waste (Khan and Kaneesamkandi, 2013; Siddiqui and Redhwi, 2009). The energy recovery technologies such as thermal and catalytic pyrolysis, gasification and plasma arc gasification are receiving more attention as alternative methods of plastic waste recycling (Nizami et al., 2015a; Ouda et al., 2016; Miandad et al., 2016b). Pyrolysis process converts plastic waste into liquid oil, solid residue (char) and gases at high temperatures (300–900 °C) via thermal decomposition. However, there are certain limitations with the conventional thermal pyrolysis, where the whole process is temperature-dependent (Sadaf et al., 2015; Tahir et al., 2015). The liquid oil from thermal pyrolysis may contain impurities and residues (Borsodi et al., 2011). Moreover, the thermal pyrolysis of PE type plastics such as HDPE and LDPE along with PP are difficult to conduct due to their crossed chain hydrocarbon structures (Achilias et al., 2007). Therefore, catalytic pyrolysis is being developed to overcome the problems of thermal pyrolysis (Lopez et al., 2011a).

A range of catalysts have been utilized, including Red Mud (Lopez et al., 2011a), FCC (Lee, 2009), ZSM-5 (Lopez et al., 2011a), HZSM-5 (Hernandez et al., 2007), Y-zeolite (Lee, 2012), Fe_2O_3 (Sarker and Rashid, 2013), Al_2O_3, $Ca(OH)_2$ (Sarker et al., 2011a,b) and natural zeolite (Syamsiro et al., 2014), in catalytic pyrolysis to improve the quality of liquid oil (Wang and Wang, 2011). The catalysts increase the lighter fractions in the liquid oil such as gasoline (Lerici et al., 2015), and decrease the overall process energy-inputs (Lopez et al., 2011a). For instance, the use of ZSM-5 catalyst decreased the impurities such as solid residue, sulphur, nitrogen, and phosphorous in the produced liquid oil (Miskolczi et al., 2009). It is also reported that the use of catalysts with a high BET surface area allows more contact between reactants and the catalyst surface, resulting in an increased rate of cracking reaction to produce more gases than liquid oil (Syamsiro et al., 2014).

Although substantial research is underway to explore different types of catalysts and their dynamic role in the pyrolysis process and its products, but a comprehensive review on what has been achieved in the catalytic pyrolysis of plastic waste, the challenges and limitations of this process, and what the future directions are, hasn't been widely-published