Hydrothermal treatment of plastic waste within a circular economy perspective

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Introduction and motivation

Plastic wastes have posed serious threats to the environment, including a decrease in soil nutrient effectiveness and agricultural production as well as emerge of ecological instability [1]. Continues industrial development, increasing energy requirements, efforts to mitigate serious health issues mainly focusing on COVID-19 are directly related to the use of plastic-based materials. To efficiently resolve the issue of increasing energy, wind turbines with an average life cycle of 20- 25 years are playing their role effectively. So first major wave of wind turbines installed in the 1990s with almost 14,000 blades with complex composition is needed to be recycled in 2023 [2]. Solar panels that are also used as alternative energy sources are threatening to produce 80 million tonnes of waste at the end of 2050 with Polymethyl methacrylate (PMMA) as a major constituent [3]. According to Global analysis of healthcare waste in the context of COVID-19**,** more than 141 million kits have the potential to produce 2650 tonnes of waste plastic, and on other hand, 8.1 billion doses of vaccine producing 144,000 tonnes of waste mainly consist of syringes and safety boxes have been shipped from March 2020 to November 2021 [4]. All the known plastics are high molecular weight polymers so posting the serious threats to the environment in the following ways: 1- reducing the agricultural land production by disturbing the soil function, 2- driving the high mortality of animals due to both marine and land ecosystems disturbances caused by plastic waste, 3- producing the micro-plastics and inducing ecological security [5]. So, keeping this serious situation in mind development of an effective strategy for the useful disposal of this plastic waste is a need of time.

Increased environmental constraints and depletion of natural resources demand effective processing and disposal of ever-increasing solid waste. The most commonly used technique is landfilling which involves high site costs and complex materials like plastic and other composites that required thousands of years to degrade [6]. The presence of microplastics reduces the amount of dissolved nitrogen and phosphorus essential for crops growth thus affecting soil nutrient effectiveness, in addition the pores of the root cell wall are blocked resulting decrease intake of water resulting in the reduction of plants output [7]. Biological degradation is another technique in which microbes degrade the waste materials in aerobic or anaerobic environments, but plastic requires pre-treatment before undergoing this type of degradation [8].

Energy utilization of plastic by converting it into fuel is an effective way of plastic disposal. For this purpose, different thermal treatments including incineration, co-gasification with biomass, and pyrolysis have been adopted but all these techniques required high-temperature degradation of materials that result in greenhouse gas emissions and carcinogenic volatile emissions.[9], [10]. During the pyrolysis process in addition to pre-drying, the solid waste is heated in an anaerobic atmosphere at elevated temperatures 500^{o}C to 700^{o}C to generate C5-C20 aromatic and aliphatic liquid fuels [11]. This high temperature always requires high energy consumption making the process less feasible.

While on other hand hydrothermal treatment is the process that involves heating of plastic at comparatively low temperatures under subcritical or supercritical conditions of water to generate high purity oils process involve the high-pressure container with the applied pressure range of 7-30 MPa [12]. Production of the required product and its yield is highly dependent on applied temperature and residence time. With the increase of temperature above 300^{o}C and residence time above 60 minutes yield of aromatic hydrocarbons increases with the subsequent decrease of aliphatic hydrocarbons [13]. An advancement of hydrothermal liquefaction is oxy-liquefaction of plastic at a temperature of 150-310^{o}C under the flow of oxygen at a pressure determined by stoichiometric conditions keeping in view that the total pressure is in the range of 20-150 bar [14]. In comparison with other techniques, hydrothermal treatment is a less energy-intensive process with less greenhouse gas emissions and has higher technology readiness level. It also provides an opportunity to recover the resources from waste so it's a change in fundamental approach "waste treatment" alone to "waste treatment and resource recovery" [15].

The aim of the paper is identification of important parameters that have a significant effect on required product yield and recovery of useful resources from plastic waste in the frame of the circular economy paradigm.

Results and discussion

The process was carried out at high temperatures of 200-350°C and pressure of 20-40 bar in a Parr 4650 batch reactor with a capacity of 500 ml with the addition of an oxidizing agent (O_2 or H_2O_2) to obtain oxidative conditions.

The results shows that the conditions of the oxidative liquefaction process of waste plastics have the main but not the only statistically significant influence on the phase and chemical composition of the obtained products. Moreover it was observed that it is possible to determine such conditions and process variables which promote a narrow group of chemical compounds such as short-chain carboxylic acids (C_1-C_5) and short-chain fatty acids (C_6-C_{21}).

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