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Hydrothermal carbonization of medical wastes and lignocellulosic biomass for solid fuel production from lab-scale to pilot-scale

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A B S T R A C T

An alternative way has been proposed for the PVC-containing medical wastes valorization by co-hydrothermal carbonization (HTC) with lignocellulosic biomass. The organic-Cl in PVC can be converted to the inorganic-Cl via hydrolysis, defunctionalization, recondensation, and aromatization in the HTC process. Followed by the washing process with the condensed water, the inorganic-Cl with high water-solubility could be removed from the solid products (i.e. hydrochar). Lignin as a biomass component can significantly improve the dechlorination efficiency of PVC in the HTC process. Here, the dechlorination performance of lignocellulosic components is given as the following order: lignin > cellulose > hemicellulose. In addition, lignin can adjust the particle sizes of solid products by inhibiting the agglomeration in the order of lignin > hemicellulose > cellulose. In the pilot-scale HTC process, the addition of woodchips improves the dechlorination efficiency of hospital wastes (HW). The hydrochar particles with low-chlorine content and higher heating value could be used as a clean coal-alternative fuel.

1. Introduction

Plastic waste has become a major component of both industrial and municipal wastes due to the worldwide use of plastic products. Therefore, the disposal of plastic wastes is increasingly considered a major environmental issue. Recycling is by far the most sustainable method of plastic waste disposal. However, the variety of additives used in the manufacture of plastic goods results in separation and decontamination difficulties, which greatly limits the recycling of waste plastics. In addition, landfilling has become limited due to high population densities, high costs, and environmental concerns such as soil contamination and harmful influences on ecosystems [1]. However, although waste disposal by means of incineration possesses many advantages, including a high degree of destruction, reduction of land usage and the potential for energy recovery, thermal decomposition of the halogenated plastics can cause serious environmental problems such as toxic dioxin emission [2–4].

Polyvinyl chloride (PVC) is a major source of chlorine for chlorinated dioxin formation during the incineration of municipal wastes. When PVC waste is burnt, a lot of hydrochloric acid (HCl) can be generated; this can corrode the boiler tube and lead to the release of trace amounts of further harmful gases such as organo-halogen compounds, possibly causing pollution issues [5,6]. Recently, hydrothermal carbonization (HTC) as a novel thermal conversion process that can be used to convert waste streams into sterilized, value-added hydrochars, especially for the polymer-derived wastes including bio-wastes [7–13], and plastic wastes [14,15]. HTC as a kind of hydrothermal processing has been mostly used on bio-wastes recycling, but it is rarely reported on exploring the carbonization of plastic wastes or of utilizing HTC as a sustainable waste-to-energy technique [16]. Based on the processing conditions and the target products, hydrothermal processing can be classified into different fields of applications (Fig. 1). Main regions are HTC, liquefaction, and hydrothermal gasification. For instance, low-temperature hydrothermal processing (e.g., HTC) is often used

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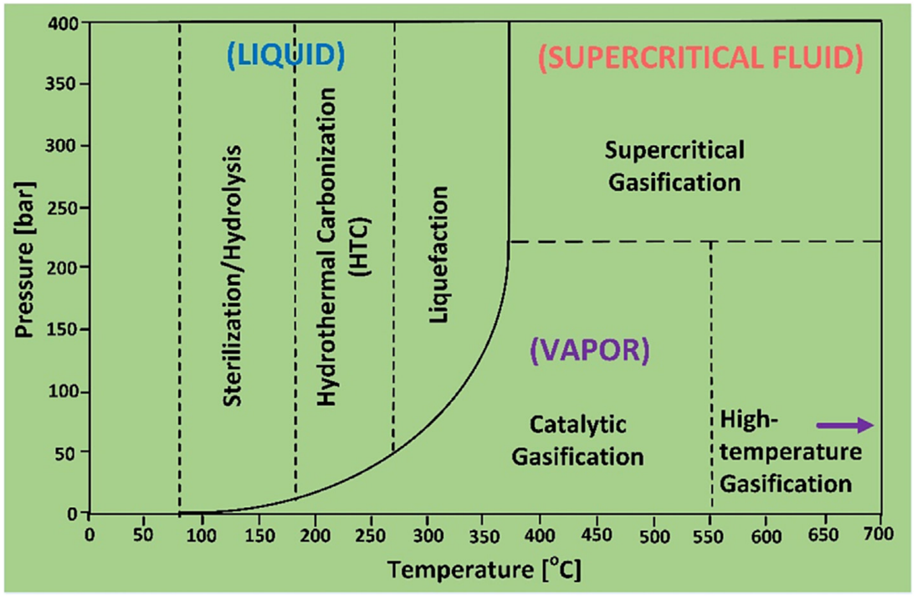

Fig. 1. Application fields of hydrothermal processes [17].

as a sterilization step within fermentation processes to inhibit that bacterial cultures reach the environment. Starting from temperatures of about 100 °C and more likely from above 180 °C HTC is applied to produce the solid products for different purposes [17]. The HTC process has proven to reach energy yields of more than 80% for woody biomass in the pilot scale [18]. The energy yield of a HTC conversion process represents how much of the energy-content of the starting material is converted to the solid product. Therefore, the HTC-process is expected to be a future energy-efficient way to convert wet biomass to solid fuels [7,19,20].

Typically, HTC of biomass is achieved in water at elevated temperatures (180–250 °C) under saturated pressures (e.g., 2–10 MPa). It has been reported that the chemical transformations of lignocellulosic model compounds under pressure in the HTC process, particularly cellulose, pentoses/hexoses (glucose and xylose), starch, and phenolic compounds (as illustrated in Fig. 2) [21]. The initial reaction occurring as biomass heated up in water is the hydrolysis of cellulose to glucose, which is the decisive difference to thermochemical conversion [8]. The hydrolysis provides way to homogeneous reactions in an aqueous solution, which are not limited by heat and mass transfer. Same holds true for the destruction of lignin to its main product phenol. In the HTC of organic matrice (e.g., PVC), significant decomposition processes include hydrolysis as the initial step, followed by defunctionalization such as dehydration and decarboxylation, and finally recondensation and aromatization [15]. It was proven that organic chlorine in PVC could be effectively converted to inorganic chlorine via the HTC process at high temperatures (>250 °C) and high pressures, e.g., subcritical or supercritical process [14,15].

In the previous work, municipal solid wastes (MSW) including PVC were pretreated by the HTC process at relatively lower temperatures (around 210 °C) [22–25]. The solid products could be used as coal alternative fuels with low chlorine content. The purpose of this work is to treat the PVC wastes by the HTC at a lower temperature (210 °C). The lignocellulosic components (e.g., cellulose, xylan, and lignin) will be applied and studied, in terms of the dechlorination performance and the solid particle size distribution. Noteworthy, it is the first time to study the washing process by recycling the condensed water. As a case study, the co-HTC process of PVC wastes, e.g., hospital wastes (HW) with woodchips will be preliminary studied for the solid hydrochar fuel production in a pilot-scale plant.

2. Materials and methods

2.1. Feedstocks

In the lab-scale process, the feedstock of PVC (Cl content: 57%) was purchased from *Wako Pure Chemical Industries, Ltd*. PVC was ground in a planetary ball mill to pass a 0.25-mm screen. The lignocellulosic model compounds such as lignin, cellulose, hemicellulose (e.g., xylan) were blended with PVC in the HTC process. In the pilot-scale process, the complex feedstocks of the PVC wastes (i.e., hazardous HW) were collected by the specific containers, which cannot be directly touched by researchers. The HW mainly contained the PVC medical products along with waste clothes, paper, tissue and organs. Therefore, the total-Cl content cannot be accurately given. The total-Cl content in the HW was assumed as 57% to identify the effect of woodchips on the PVC dechlorination. In addition, cellulose, hemicellulose, and lignin were the three main components in woody biomasses, so the bio-waste of woodchip (<1 mm) is employed. The hemicellulose, cellulose and lignin were determined following the procedure reported by Allen et al. [26]. The carbohydrate composition of the woodchip is mainly composed of cellulose (48.2%), lignin (25.8%) and hemicellulose (16.5%).

2.2. The HTC processes of medical wastes

The lab-scale HTC processes were conducted in an autoclave reactor (volume: 500 ml) with an electronic heater, which was coupled with a motor stirrer [27]. PVC (5 g) was blended with lignocellulosic biomass component (5 g) by the ball-milling for 10 min. The solid mixture (10 g) dissolved in the distilled water (20 g) were fed to the HTC reactor. As the temperature increasing, the water steam can be generated automatically. In this study, the holding time was controlled at 30 min as the reactor temperature increase to the target value (210 °C). The primary solid products were further treated by the washing process.

The pilot-scale HTC apparatus was mainly composed of HTC