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Review

Recent progress in the direct liquefaction of typical biomass

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ABSTRACT

Energy from biomass, bioenergy, is a promising source to replace fossil fuels in the future, as it is abundant, clean, and carbon dioxide neutral. Thermochemical liquefaction of biomass is widely investigated as a promising method to produce one kind of liquid biofuel, namely bio-oil. This review presents the recent research progress in the liquefaction of typical biomass from a new perspective. Particularly, this article summarizes five aspects of related work: first, the effect of solvent type on the liquefaction behaviors of biomass; second, the effect of biomass type on the liquefaction behaviors of biomass; third, the liquefaction of biomass in sub-/super-critical ethanol; fourth, the liquefaction of biomass in organic solvent–water mixed solvents; fifth, the liquefaction of sewage sludge. Meanwhile, the research advance in the migration and transformation behavior of heavy metals during the liquefaction of sewage sludge was also summarized in this review. This review can offer an important reference for the study of biomass liquefaction.

Contents

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1. Introduction

It is believed that the climate change is currently the most pressing global environmental problem. Hundreds of millions of people could lose their lives and up to one million species could become extinct if the average global temperature increases by more than 2 °C. It is widely accepted that using fossil fuels has caused global warming [1,2]. On the other hand, the world has been confronted with an energy crisis due to the depletion of finite resources of fossil fuels [3]. Global energy crisis and environmental pollution, derived from the massive use of conventional fossil fuels, have led to a move towards alternative, renewable, sustainable, efficient and cost-effective energy sources with less emission. Some of the most notable alternative sources of energy capable of replacing fossil fuels include: water, solar and wind energy, and biofuels [4].

Biofuels are generated from renewable resources such as agricultural crops, woody and herbaceous biomass, and waste materials, which are renewable annually or in several years [5]. Biofuels are broadly classified as primary and secondary biofuels. The primary biofuels are used in an unprocessed form, primarily for heating, cooking or electricity production such as fuelwood, wood chips and pellets, etc. The secondary biofuels are produced by processing of biomass, e.g. ethanol, biodiesel, dimethyl ether (DME), etc. [6]. Biomass can be converted to biofuels via two main types of processes: thermo-chemical and bio-chemical/biological processes [7]. Generally, thermo-chemical processes have higher efficiency than bio-chemical/biological processes in terms of the shorter reaction time required (a few seconds or minutes for thermo-chemical processes vs. several days, weeks or even longer for bio-chemical/biological processes) and the superior ability to degrade most of the organic compounds [8].

Thermochemical conversion processes mainly include combustion, pyrolysis, gasification, and liquefaction [8–11]. Liquefaction is a low-temperature (250–400 °C) and high-pressure (5–20 MPa) thermochemical process during which the biomass is converted into three products, i.e. a bio-oil fraction (target product), a gas fraction and a solid residue fraction, in water or another suitable solvent [12–14]. As depicted in Fig. 1, the basic reaction pathways for the liquefaction of biomass can be described as: (i) depolymerization of the biomass into biomass monomers; (ii) decomposition of biomass monomers by cleavage, dehydration, decarboxylization and deamination, forming light fragments of small molecules, which are unstable and active; (iii) rearrangement of light fragments through condensation, cyclization and polymerization, leading to new compounds [8,15–17].

In recent years, there has been a continuing increase in the number of research work concerning the liquefaction of biomass. And some related review papers focusing on the advances in biomass liquefaction have also been published. The liquefaction of biomass in water has been extensively reviewed by Peterson et al. [13], Toor et al. [15], Tekin et al. [18], Kang et al. [19] and Toor et al. [20]. The effect of process parameters on the liquefaction of biomass has been widely reviewed by Akhtar and Admin [21] and Behrendt et al. [22]. Pan [23] reviewed the synthesis of resin products from the liquefaction biomass in organic solvents. The hydrothermal catalytic liquefaction of biomass is detailedly summarized by Yeh et al. [24] and Tekin and Karagöz [25]. Pavlovič et al. [26], Ruiz et al. [27] and Knez et al. [28] introduced the hydrothermal liquefaction of agricultural and food processing wastes, agriculture residues and marine biomass, organic wastes and byproducts, respectively. Elliott et al. [29] described the recent results in hydrothermal liquefaction of biomass in continuous-flow processing systems. Xu et al. [30] discussed the liquefaction of biomass in hot-compressed water, alcohols and alcohol–water co-solvents.

Although the liquefaction of biomass has been widely studied in various conditions, these investigations cannot be directly compared due to the difference in the separation of products and definition of the liquid product (bio-oil). To understand the effect of solvent/biomass type on the liquefaction behaviors, all the liquefaction experiments must be carried out at identical conditions [31,32]. Therefore, researchers specially designed and carried out many liquefaction studies to discuss the effect of solvent/biomass types on the liquefaction behaviors of biomass. To the best of our knowledge, there is no related review literature published, focusing on discussing and analyzing above work. Meanwhile, the liquefaction of biomass in ethanol has not been systematically summarized in related review literature, too. Although the liquefaction of biomass in alcohol-water co-solvents has been introduced in an edited book [30], the information is limited. As respects to the liquefaction of sewage sludge, there are few related reviews.

The aim of this review is to summarize the above mentioned work in the hope of providing some new information for the liquefaction of biomass. Specifically, this review mainly focuses on five aspects of related work. We firstly covers those work devoted to investigating the liquefaction behaviors of one biomass in different solvents at identical conditions in Section 4.1. Next, Section 4.2 describes the work devoted to studying the liquefaction behaviors of different biomasses at identical conditions. Section 4.3 and Section 4.4 focus on the application of sub-/super-critical

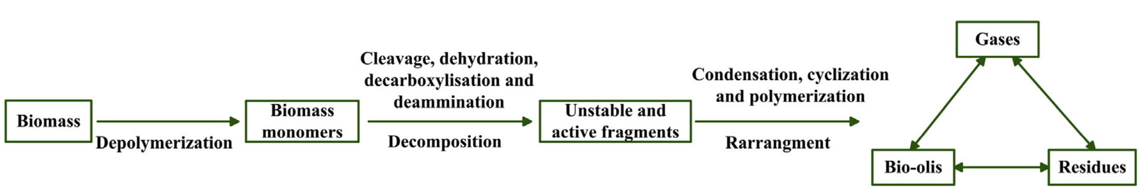

Fig. 1. The basic reaction pathways for the liquefaction of biomass.