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Review

Co-pyrolysis of biomass and waste plastics as a thermochemical conversion technology for high-grade biofuel production: Recent progress and future directions elsewhere worldwide

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ABSTRACT

Continuous growth of human population and industrialization has increased the energy demands all over the world and this has resulted in a number of energy related challenges including depletion of fossil fuels, environmental pollution, and shortage of electricity supply. These challenges made it imperative to develop and maximize the abundant renewable energy resources, particularly the biomass via upgrading thermochemical conversion routes such as co-pyrolysis. This review paper presents an overview of previous studies, recent advances, and future directions on co-pyrolysis of biomass and waste plastics for high-grade biofuel production particularly in China and elsewhere worldwide. This paper also discussed the advantages of the co-pyrolysis process, co-pyrolysis product yields, co-pyrolysis mechanisms of biomass with plastics, and synergistic effects between them during co-pyrolysis, as well as the effects of some operating parameters especially the biomass mixing ratio and pyrolysis temperature on co-pyrolysis yields. The result of this critical review showed that co-pyrolysis of biomass with waste plastics is more beneficial than the normal biomass pyrolysis alone, and that it is also a simple, effective, and optional solution to increase the energy security of a nation, achieve effective waste management, and reduce dependency on fossil fuels.

1. Introduction

Rapid depletion of fossil fuels (petroleum, coal, and natural gas) with the risk of energy and environmental challenges has drastically increased the development of alternative, sustainable, and renewable energy worldwide. According to Zhang et al. [1] the only way most countries, like China, can deal with the sharp conflict between rapid economic growth and high CO_2 emissions is by total transition to a low carbon and sustainable energy system. Also, according to Zhao et al. [2], China is facing a number of energy related challenges including the depletion of fossil fuels, environmental pollution, and a shortage of electricity supply owing to her rapid economic growth, large population, and high-speed industrial development with high CO_2 emissions. These challenges make it important to develop and maximize her abundant renewable energy resources such as the biomass, wind, hydropower, geothermal, and solar energy resources. Biomass is the only renewable energy source that can be converted into several forms of fuels—liquid (bio-oil), solid (char), and gas—with promising flexibility in production and marketing [3]. Biomass has been estimated to contribute somewhere between 15% and 50% of the world's primary energy consumption by the year 2050 [4]. Moreover, biomass as one of the world's largest sustainable energy sources [5], has numerous alternative energy resources existing in diverse forms worldwide and can be used to substitute the conventional fossil fuels due to its availability, innumerable economic and environmental benefits since it is a carbon source with CO_2 neutrality [6,7] Sources of biomass vary from one country to another with varying rates of accumulation, as a result of several factors which include, among others, geographical conditions and locations, population levels, levels of economic development, agricultural development, forest development, industrial growth, food demand, production and processing technologies, and lifestyle.

According to Yin [8] and Shen et al. [9], biomass is known to be the fourth largest energy system after coal, oil and gas, supplying, presently, approximately 14% of the world annual energy consumption. Therefore, the development and utilization of biomass have attracted worldwide attention [6,10–15]. In China, there are abundant biomass

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resources, and the theoretical value of biomass is about 5 billion tons. The Chinese government also pays much attention to biomass energy utilization, which has been listed as a key scientific research project in four national five-year plans consecutively, most especially, the seaweed biomass. Which due to its strong photosynthetic ability, fast growth, and suitability for large-scale artificial cultivation [16], has become the promising third generation source for biofuel/bioenergy production, and has a high potential to replace petrochemical fuel resources [17].

Generally, either the biochemical or thermochemical conversion methods are normally employed in converting biomass into useful energy. Results of research studies revealed that thermal conversion technologies such as direct combustion, gasification, pyrolysis, and hydrothermal liquefaction have recently gained more attention because they are much faster than the biological processes (e.g., anaerobic digestion, fermentation). Moreover, thermochemical technologies can be applied in production of energy from certain wastes, such as plastics, that cannot be broken down by the activities of microbes [18]. Among the thermal conversion processes, Demirbas [19] demonstrated pyrolysis as the most efficient and promising method which produces energy with high fuel-to-feed ratios. Therefore, pyrolysis has attracted considerable attention as one of the viable and promising ways for extracting energies from biomass, most especially, the pyrolysis oil. Pyrolysis oil (bio-oil) is the liquid product from the pyrolysis process which has potential for use as fuels or feedstock for many commodity chemicals. However, the oxygen content of the pyrolysis oil is high (about 35–60 wt%) [20–23], and has been identified to exist in several forms oxygenated compounds (e.g., acids, alcohols, aldehydes, esters, ketones, phenols, lignin-derived oligomers, etc.), and is mostly found as water [22].

Therefore, the major challenge associated with pyrolysis of biomass alone lies with the production of pyrolysis oil with high oxygen content, which results in a low calorific value, corrosion problems, and instability [24]. As a result, the bio-oil needs to be upgraded to overcome these challenges. According to literature reports of previous studies, different upgrading methods for oils (such as hydrogenation, hydrodeoxygenation (HDO), catalytic pyrolysis, catalytic cracking, steam reforming, molecular distillation, supercritical fluids, esterification, and emulsification), have been employed to eliminate the high oxygen content of the pyrolysis oil. Currently, two main pathways for upgrading the bio-oil exist: high-pressure hydrogenation processing and catalytic cracking [23–28]; and more recently, the co-pyrolysis of biomass with hydrogen-rich feedstock of higher fuel qualities (such as synthetic polymers) [29,30]. Fig. 1 presents an overview of the various techniques for upgrading pyrolysis oil; while Table 1 gives a comparison of co-pyrolysis technology with other upgrading techniques for pyrolysis oil in terms of operating conditions, reaction mechanism/process description, and technical feasibility. Co-pyrolysis is a simple and safe production process for high quality fuels since it does not bring in high-pressure hydrogenation; hence the hydrogen transfer may also be involved in the co-pyrolysis under ambient pressure conditions [31]. Thus, the co-pyrolysis process of biomass and plastics has been reported as an effective upgrading method that will not only increase the quantity of the oil produced but also improve its quality in terms of high calorific value [6], because the synthetic plastics are typically organic polymers derived mainly from petroleum products with high carbon and hydrogen contents, having little or no oxygen, and also offer a comparable high heating value (HHV) to conventional fossil fuels (diesel and gasoline). According to Zhou et al. [29], plastics with high hydrogen contents of about 14 mass % (such as polyethylene, polypropylene, and polystyrene), could donate hydrogen during co-pyrolysis with biomass which results in an increase and improvement in yield and quality of the oil produced respectively. Plastics are particularly attractive synthetic polymers, because they have a low recycling rate and most of them are non-biogradable. Moreover, waste plastics have constituted not only serious environmental problems but also a huge waste of fossil fuel resources considering their high-value chemicals and high energy density even though they have contributed

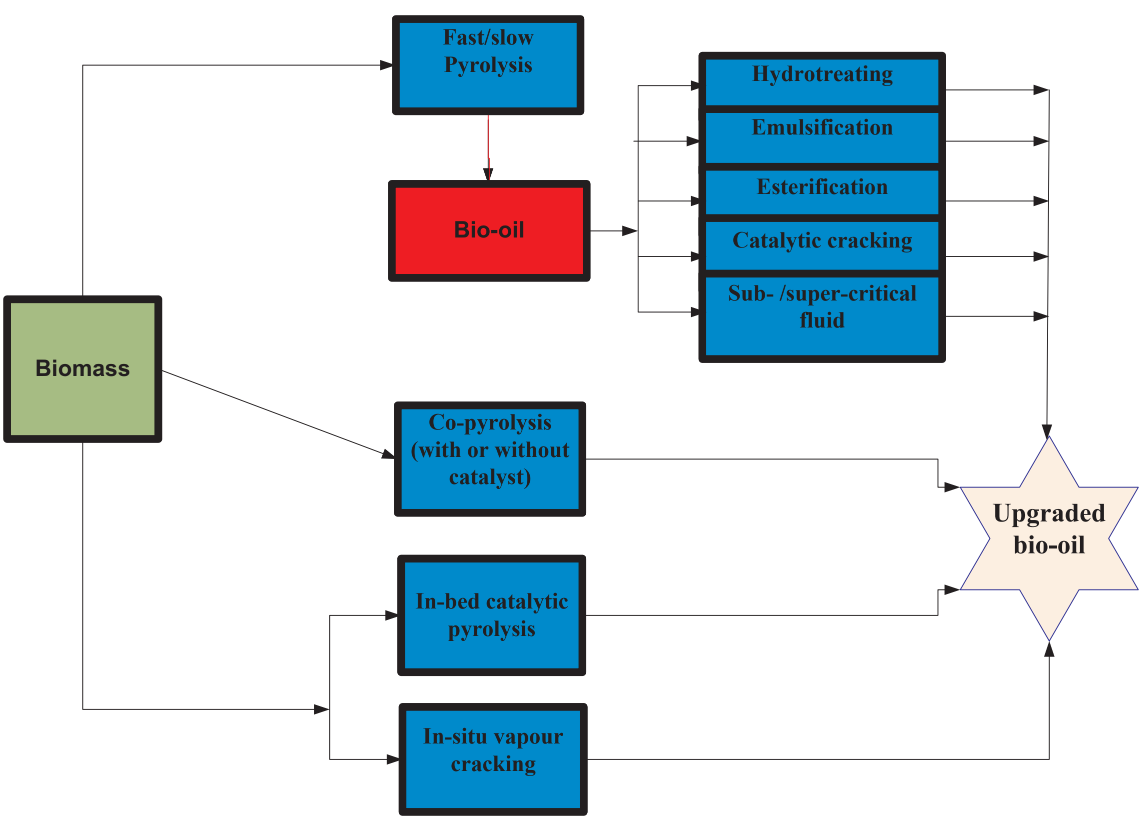

Fig. 1. Pyrolysis oil upgrading techniques.