Renewable and Sustainable Energy Reviews 59 (2016) 1246–1268

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

By-products recycling for syngas cleanup in biomass pyrolysis – An overview

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A R T I C L E I N F O

Article history:
Received 5 September 2015
Received in revised form
27 December 2015
Accepted 13 January 2016
Available online 30 January 2016

Keywords:
Biomass gasification
Tar removal
Bio-char
Bio-oil
Catalytic reforming

A B S T R A C T

Bio-char and bio-oil have a potential to be used for gas cleaning in biomass pyrolysis/gasification. On one hand, tar in producer gas could be removed by physical treatment, such as oil absorption and char adsorption; on the other hand, tar could be eliminated by chemical treatment, such as catalytic conversion over char-supported catalysts. This paper reviewed the recent progress in gas cleaning especially for tar removal during biomass pyrolysis/gasification by using the by-products (i.e. bio-char, bio-oil, low-viscosity tar). In general, bio-char could effectively adsorb the light tar compounds such as volatile organic compounds (VOCs), while bio-oil is normally benefit for the absorption of heavy tars. Additionally, catalytic reforming is considered as one of the promising alternatives for the removal of tars, because it converts the tars into the additional gas products. Bio-char could be used as a carbon catalyst or support with fair performance in tar removal. It is noteworthy that the char-supported catalysts could be gasified to recover energy of char without the need of frequent regeneration after deactivation. Furthermore, the carbon-based catalysts derived from bio-chars could be urgently developed for the removal of contaminants including NH_3, H_2S and tar simultaneously in the producer gas from the real biomass gasification processes.

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http://dx.doi.org/10.1016/j.rser.2016.01.077
1364-0321/

1. Introduction

1.1. Bio-energy

Biomass is carbon based and is composed of a mixture of organic molecules containing hydrogen, usually including atoms of oxygen, often nitrogen and small quantities of other atoms, including silica, alkali, alkaline earth and heavy metals. Biomass is a renewable energy resource derived from biological sources, such as energy crops, agricultural residues, forestry residues, algae and municipal solid wastes. Biomass utilization is recognized as one of the most promising solutions for current energy and environmental problems. Alternative renewable energy technologies such as hydropower energy, solar energy and wind power, which often suffer from the intermittent power generation issue, are less reliable in term of security of supply. Meanwhile, biomass is the only renewable energy source that could be converted into liquid fuels and used as feedstock in chemicals synthesis [1]. For instance, the biomass power generating industry in the United States, consisting of approximately 11,000 MW of summer operating capacity actively supplying power to the grid, can produce about 1.4% of the U.S. electricity supply. Fig. 1 illustrates the trends of the top five countries in generating electricity from biomass. It suggests that the electricity generated from biomass significantly increase, especially for China, therefore requiring a further development of biomass utilization for electricity and biofuels.

1.2. Pyrolysis/gasification of biomass

Thermochemical processes including combustion, pyrolysis and gasification can convert biomass into the useful bio-energy (i.e., fuel gas, bio-oil) and bio-char. Biomass pyrolysis or gasification is recognized as one of the most promising technologies for producing sustainable fuels that could be used for power generation systems or syngas applications. For instance, biomass pyrolysis at relative higher temperatures could produce the bio-char, bio-oil and syngas for boiler and power generation (Fig. 2). Moreover, the proportion of the derived products, to some extent, depends on pyrolysis temperature and other conditions. Compared with the partial oxidative gasification process, the inert pyrolysis of biomass has low process efficiency, but can produce fuel gas with a high heating value [2]. Pyrolysis can be divided into three subclasses; slow pyrolysis, fast pyrolysis and flash pyrolysis [3]. The main operational parameters are summarized in Table 1. Significantly, gasification of biomass has several environmental merits over fossil fuels, namely lower emission of CO_2 and other flue gases, such as H_2S, SO_2, NO_x [3–7]. Biomass gasification is a thermochemical process in which biomass undergoes the incomplete combustion to yield a gas product referred to syngas that mainly consists of H_2, CO, CH_4, CO_2, and N_2 (if air or N_2 is used as the carrier gas) in various proportions. Biomass pyrolysis or gasification has considerable advantages compared to the direct combustion. The main reasons are that it can convert the low-value feedstocks to high quality combustible synthesis gas, which can be not directly burned for electricity generation but turned into liquid transportation fuels [8].

Processes occurring in biomass gasification are often distinguished: drying and devolatilization, volatile and char combustion, and gasification and tar reforming with steam and CO_2. These processes can be identified in certain spatial regions in fixed bed gasifiers [9]. As for biomass pyrolysis illustrated in Fig. 3, during transient heating of the solid particle, temperature increases locally, leading first to the evaporation of moisture (drying stage) and then to the progressive release of pyrolytic volatiles (*primary pyrolysis stage*). The primary volatiles are produced from the thermal scission of chemical bonds in the biomass individual constituents, which are cellulose, hemicellulose, lignin and extractives, and comprise permanent gas species (*e.g.,* CO_2*, CO,* CH_4) with the condensable species at ambient conditions (i.e., some organic compounds and water). Although each of the biomass constituents decompose at faster rates in different temperature ranges, the primary pyrolysis stage is complete at lower

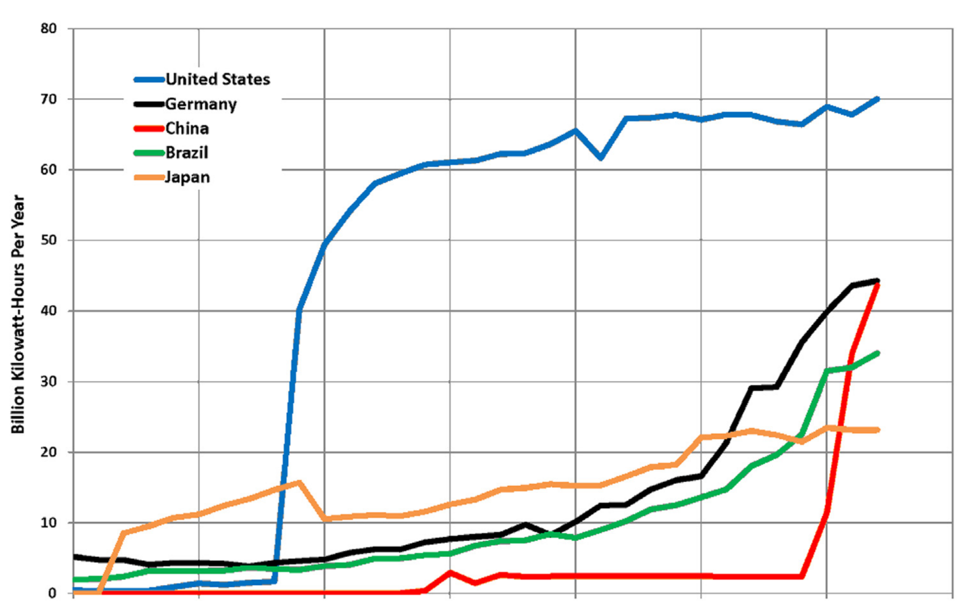

Fig. 1. Trends in the top five countries generating electricity from biomass.