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Fluidized bed technology for biooil production: Review

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Abstract

Fast pyrolysis is an emerging technique by which a liquid product, biooil is formed. The fast pyrolysis can be done using various reactors such as fluidized bed reactors, transported and circulating fluidized bed reactors, ablative and vacuum reactors, tubular reactors, microwave pyrolytic reactors, auger system and rotating cone reactors. Among them fluidized bed system is a well understood technology and suited for the commercialization of fast pyrolysis. In this review, the process parameters in fluidized bed system that enhance the biooil production were reviewed. Utilization of various feedstocks for biooil production and the characteristics of biooil, which mainly affects the utilization were presented.

Keywords: Fast pyrolysis; Fluidized bed; Biooil.

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INTRODUCTION

Among the first generation biofuels vegetable oil, biodiesel and bioethanol are the important liquid fuels. It is mainly produced from edible oils and food crops. Due to the competition for food and fuel, the lignocellulosic residues are preferred widely for the fuel purpose. It can be converted into biofuels by thermo-chemical processes such as pyrolysis, gasification, combustion and liquefaction. The pyrolysis of biomass is an ancient energy technology that is becoming interesting again for the energetic utilization of bioresidues to produce liquid, solid and gaseous components. The yield and composition of these pyrolysis products depend on the composition of the feedstock and the pyrolysis conditions (temperature, residence time, pressure and heating rate). Low temperature process with long residence times at slow heating rates produce mainly charcoal and high temperatures mainly produce gaseous products. On the other hand, the short residence times, faster heating rates and moderate temperatures in the absence of oxygen favor a high yield of condensable vapours, which is called as biooil[1]. The fast pyrolysis produces typically 50–75% liquid bio-oil, 15–25% solid char and 10–20% permanent gases, depending on the biomass feedstock used[2] and the operating conditions[3].

For the fast pyrolysis, conditions are required such as medium temperatures, faster heating rates, short vapor residence times, purge gas flow rate and fast condensation of vapors to obtain a relatively high bio-oil yield[3]. As reported by Mohan et al.[2] the reactor is also a main component in fast pyrolysis system. Number of reactor designs have been developed to attain high liquid product. The reactors are categorized as fluidized bed reactors[4], transported and circulating fluidized bed reactors[5], ablative and vacuum reactors[6], tubular reactors[7], microwave pyrolytic reactors[8], auger system[2] and rotating cone reactors[9]. The reactors have been studied by many authors. Among them fluidized bed reactors, vacuum pyrolysis reactors and ablative reactors are available for the commercialization of biooil in the form of liquid fuel as reported by Scott et al.[10]. The fluidized bed system is a well understood technology that suitable for large scale applications.

Fluidized bed reactors have good solid-to-solids contact, good heat transfer, high specific heat capacity, good temperature control and distribution, large heat storage capacity and faster heating. In a fluidized bed pyrolyzer, a heated sand medium in a zero-oxygen environment quickly heats the feedstock, where it is decomposed into char, gas, vapors and aerosols, which exit the reactor by the conveying fluidizing gas stream. After exiting the reactor zone, the charcoal can be removed by a cyclone separator. The scrubbed gases, vapors and aerosols enter a quenching system where they are rapidly cooled using chillers. The syngas, residual biooil, aerosol droplets may be further scrubbed in an electrostatic precipitator to remove finer particulates and aerosols. The condensed bio-oil is collected and stored, and the non-condensable gas may be recycled or used as a fuel to heat the reactor.

PROCESS PARAMETERS

The process parameters that mainly affect the yield of liquid process in fluidized bed reactors are pyrolysis temperature (450-650°C), faster heating rates (100-1000°C s^{-1}), short vapor residence times (2-5 s), purge gas flow and fast condensation of vapours[3].

Heating Rate

The particle-heating rate and pyrolytic temperature are the major factors that limit the rate of pyrolysis reaction. Thermo-gravimetric analysis has been frequently used as a tool for the conditions of fast pyrolysis. It has been used to develop kinetic models of pyrolysis especially overall mass loss and the formation of char and volatile phases. Very high heating and heat transfer rates are used in fast pyrolysis that requires a finely ground feed. Heating rates of 100 to 1000°C s^{-1} are required[11]. Particle size is another parameter that affects the heat transfer and product distribution. Smaller feedstocks are needed (<2-3 mm) to ensure the high heat rate requirement.

Inert Bed Material

The biomass has to be fluidized to maintain the suspension condition in the reactor. It cannot be easily fluidized due to its irregular shapes. For proper fluidization, an inert bed material such as silica sand, alumina and calcite is used to facilitate fluidization of biomass. It also acts as a heat transfer medium in the reactor[12]. The mixtures of solid particles of different size and density tend to separate in vertical direction under fluidized condition. Pilar et al.[13] have studied the fluidization of solids with different particle sizes and densities.

Residence Time

Rapid heating produces intermediate pyrolysis condensable vapours. The residence time of the pyrolysis vapors is another important factor that determines the time available for vapor phase reactions, affecting the bio-oil yield. At lower gas flow rates and higher process temperatures of more than 550°C lead to the increase in residence time of vapors and support the possibility of secondary reactions such as thermal cracking, repolymerization and recondensation, respectively. Faster removal of the vapours leads to the immediate condensation, without undergoing any secondary reactions.

Fluidization Velocity and Inert Atmosphere

The minimum fluidization velocity is a function of types of particles and their relative concentrations. Pilar et al.[13] have concluded that no satisfactory equations are available for predicting the minimum fluidization velocity for mixture of biomass and bed material. The minimum fluidization velocity can be obtained by pressure drop experiments[14]. Geldart et al.[15] proposed a Hausner ratio of smaller than 1.25 are easily fluidized, while powders with Hausner ratios higher than 1.4

could pose fluidization issues. The fast pyrolysis would be conducted in an inert atmosphere like N_2 and He. The pyrolysis gas can also be used for this purpose. It mainly consists of CO, CO_2, CH_4, H_2 and some other light hydrocarbons[2,4]. CO_2 is a mild oxidative atmosphere and CO and H_2 are the strong reductive atmospheres. Such reactive atmospheres may significantly influence yields and quality of products[16].

BIOOIL STUDIES

Asadullah et al.[5] produced biooil from jute stick in fluidized bed reactor at 300-600°C. The maximum yield of 66.7% was obtained at 500°C. Zhang et al.[17] produced biooil from corncob of particle size 0.5-4 mm in fluidized bed reactor without and with HZSM – 5 zeolite catalyst. Four different N_2 flow rates as 1.2, 2.3, 3.4 and 4.5 l min^{-1} were used at the temperatures of 400, 500, 550, 600 and 700°C. The maximum yield of biooil thus obtained was 56.8% at 550°C with a gas flow rate of 3.4 l min^{-1}. They also reported that the presence of catalyst increased the yields of non-condensable gas, water and coke.

He et al. [18] carried the biooil production in fluidized bed reactor of 5 kg h^{-1} located at Lowa state University center using switch grass at 5, 10 and 15% moisture contents at 450, 500 and 550°C. They reported that the moisture content of the feedstock and temperature caused large variations in bio-oil yield. Fluidized bed flash pyrolysis of Jatropha oil cake (0.3–1.18 mm) was carried out at 350-550ºC with a nitrogen gas flow rate of 21 to 40 l min^{-1}. The maximum oil yield of $64.25\%_{wt}$ was obtained at a nitrogen gas flow rate of 30 l min^{-1} while using particle size of 0.7–1.0 mm at 500 ºC. Calorific value of the pyrolysis oil was 19.66 MJ kg^{-1} [19].

Islam et al. [20] obtained a biooil yield of $48\%_{wt}$ from sugarcane at 450°C for a particle size of 0.42-0.60 mm at a gas flow rate of 30 l min^{-1}. Heo et al.[21] studied the fast pyrolysis of waste furniture sawdust in a fluidized bed reactor (150 g h^{-1}) at 400-550°C with N_2 as the purge gas. The maximum biooil yield of 58.1% was achieved at 450°C with a particle size of 0.7 mm. Sawdust with large particles (1.3 mm) produced less biooil comparing with a particle size of 0.3 mm. Heo et al.[22] investigated the fast pyrolysis of Miscanthus in a fluidized bed reactor. Process conditions were varied for temperature (350–550°C), particle size (0.3–1.3 mm), feed rate and gas flow rate. The highest bio-oil yield of $69.2\%_{wt}$ was observed at 450°C, which correspond to the end of the thermal composition of hemicellulose and cellulose. Duman et al.[23] studied the fast pyrolysis of cherry seed and shells in a fluidized bed reactor of 100 g h^{-1} capacity at 400, 500 and 600°C using silica sand as a bed material with a N_2 gas flow of 11 l min^{-1}, where the residence time of vapour in the reactor was about 1-2 s. The yield of condensate was high at 500°C.

Chen et al.[24] tested the biooil production in a fluidized bed system constructed at Shanghai Jiao Tong University with a biomass throughput of 1-5 kg h^{-1} at 500°C. The biooil yield was 60.5% with a water content of 64.41%. pH and calorific value of the biooil was 2.84 and 22.06 MJ kg^{-1}, respectively. Comparatively they checked the electrostatic precipitator and ceramic filter to filter the pyrolytic vapour. The yield of biooil was 60.5 and 57.3% when using hot vapour filter and cyclone, respectively. Salema et al.[8] studied the microwave induced pyrolysis of oil palm in a fluidized bed reactor with a microwave power of 450 W with a N_2 flow of 20 l min^{-1}. Abdul et al.[25] obtained a maximum liquid of $45\%_{wt}$ using tamarind seeds at 400°C at a gas flow rate of 6 l min^{-1} with a running time of 30 min. Zhang et al.[26] studied the fast pyrolysis in a fluidized bed reactor using various pyrolysis gas components namely N_2, CO_2, CO, CH_4 and H_2. The CO atmosphere gave the lowest liquid yield of 49.6% compared to highest 58.7% obtained with CH_4. Use of carbon containing carrier gases (e.g. CO, CO_2 and CH_4) favors the deposition of the polymerizing compounds on the surface of the bed materials, whereas H_2 takes part in the reactions via a completely different route, which produces less coke.

Products and Up Gradation

Bio-oil contains a very complex mixture of oxygenated hydrocarbons and a noticeable fraction of water issued from both the biomass and pyrolysis reactions[3.] Their direct applications as fuels are limited by the presence of high oxygen content, acidity, high viscosity, corrosion and thermal instability. Therefore, bio-oils must be upgraded before they can be used in gasoline or diesel engines to avoid the release of ash and alkali metals during combustion. One of the most effective methods to improve the quality of bio-oil is to reduce oxygen content in the presence of a catalyst[27] and developing an efficient char removal system[28].

CONCLUSION

Fast pyrolysis has a great potential in converting biomass into energy dense liquids that can be transported easily. The bio-oil is considered to be an alternative of crude petroleum oil and as a source of clean energy or to produce value added products. However, the technology needs development in order to produce bio-oil in a technically and economically feasible way, which is environmental friendly and sustainably accepted.

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