Valorization of Clean as well as Waste Biomass into Chemicals and Catalysis

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Abstract:

Biomass is an important feedstock for the renewable production of fuels, chemicals and energy as a result conversion of clean as well as waste biomass into chemicals is becoming famous. Biomass is a renewable, carbon-neutral resource, and fuels derived from biomass usually burn more cleanly than fossil fuels. Various processes can be used to convert biomass to energy includes fermentation, anaerobic digestion, transesterification, gasification, pyrolysis. Catalysis is most important technology for valorization of biomass; offers numerous benefits including lower energy requirements, catalytic versus stoichiometric amounts of materials, increased selectivity, decreased use of processing and separation agents and allows for the use of less toxic materials.

Keywords: Biomass, fermentation, transesterification, gasification, pyrolysis.

Introduction:

Biomass is an important feedstock for the renewable production of fuels, chemicals and energy; indeed, the only renewable source of liquid transportation fuels is currently obtained from biomass. With the depletion of fossil fuels as a source for fuels, chemicals and energy; the fraction of energy and chemicals supplied by renewable resources such as biomass can be expected to increase in the foreseeable future. Indeed, several governments have recently passed legislation mandating increases in the gross domestic energy and chemical production from renewable resources, especially biomass [1]. Several kinds of biomass can be converted to fuel and chemicals. Examples are wood and wood waste, agricultural crops, agricultural waste, litter from animal feedlots, waste from food processing operations and sludge from water treatment plants. Biomass is typically composed of 75-90 wt% sugar polymers, the other 10-25 wt% being composed mainly of lignin. Other biomass components, which are generally present in minor amounts include triglycerides, sterols, alkaloids, resins, terpenes, terpenoids and waxes [2].

Biomass can be converted by thermal or biological routes to a wide range of useful forms of energy including process heat, steam, motive power, electricity, liquid fuels, chemicals and synthesis gas. The biomass can be burned, transformed into a fuel gas through partial combustion, transformed into a biogas through fermentation, converted to bioalcohol through biochemical processes, converted to biodiesel, pyrolyzed into a bio-oil or transformed into a syngas from which chemicals and fuels can be synthesized [3]. This paper will review the various conversion processes to convert biomass into value added chemicals by using homogeneous and heterogeneous catalyst.

Biomass Conversion Processes:

The conversion of biomass to chemical products involves several steps. Typically, biomass conversion routes begin with pretreatment in case of cellulosic and grain biomass and extraction of oil in case of oilseeds. Then the cellulosic or starch containing biomass undergoes fermentation (anaerobic or aerobic), gasification or pyrolysis. The oil in oilseeds is transesterified to obtain fatty acids. These conversion processes are reviewed in the following sections.

Biomass Pretreatment:

Biomass is primarily composed of cellulose, hemicelluloses and lignin. The cellulose and hemicelluloses are polysaccharides of hexose and pentose. Any process that uses biomass needs to be pretreated so that the cellulose and hemicellulose in the biomass are broken down to their monomeric form. Pretreatment processes produce a solid pretreated biomass residue that is more amenable to enzymatic hydrolysis by cellulases and related enzymes than native biomass. Pretreatment process involves physical pretreatment like comminution, biological pretreatment, chemical pretreatment and physicochemical pretreatment [4]. Comminution in which coarse size reduction, chipping, shredding, grinding, milling are amongst the different mechanical size reduction methods that have been used to enhance the digestibility of lignocellulosic biomass. Biological pretreatments have been mostly been associated with the action of fungi capable of producing enzymes that can degrade lignin, hemicellulose, and cellulose. In chemical pretreatment some chemicals such as acids, alkali, organic solvents, and ionic liquids have been reported to have significant effect on the native structure of lignocellulosic biomass [5]. Where physicochemical pretreatment like steam pretreatment, liquid hot water pretreatment, dilute acid pretreatment, ammonia fiber explosion, lime pretreatment, organosolv pretreatment, carbon dioxide explosion pretreatment, ionic liquid pretreatment have been reported [4, 6].

Fermentation:

The pretreatment of biomass is followed by the fermentation process where pretreated biomass containing 5-carbon and 6-carbon sugars is catalyzed with biocatalysts to produce desired products. Fermentation refers to enzyme-catalyzed, energy-yielding chemical reactions that occur during the breakdown of complex organic substrates in presence of microorganisms. The microorganisms used for fermentation can be yeast or bacteria. The microorganisms feed on the sucrose or glucose released after pretreatment and converts them to alcohol and carbon dioxide [7, 8]. Ethanol is blended with gasoline called as gasohol; when added to gasoline, ethanol promotes complete combustion and reduces the emissions of pollutants such as carbon monoxide. Ethanol is also an effective octane enhancer. Although other additives can promote combustion and increase the octane number, ethanol is attractive because of its low toxicity and biodegradability. Ethanol, however, has lower energy content than gasoline, resulting in higher fuel consumption, especially when it is used pure.

Anaerobic digestion:

Anaerobic digestion of biomass is the treatment of biomass with a mixed culture of bacteria to produce methane (biogas) as a primary product. The four stages of anaerobic digestion are hydrolysis, acidogenesis, acetogenesis and methanogenesis. The standard process for anaerobic digestion of cellulose waste to biogas (65% methane- 35% carbon dioxide) uses a mixed culture of mesophilic and thermophilic bacteria [9].Biogas has been used for cooking, lightening and quality manure is produced.

Transesterification:

Transesterification is the reaction of an alcohol with vegetable oil containing triglycerides to produce monoalkyl esters and glycerol. Monoalkyl esters have been used as biodiesel so biodiesel is produced by transesterification reaction. A wide variety of vegetable oils can be used for transesterification. Generally transesterification reactions are catalysed by homogeneous acid catalyst like hydrochloric acid, sulphuric acid or base catalyst like sodium hydroxide, potassium hydroxide or enzymes calayst like lipase. Transesterification have been catalyzed by heterogeneous acid catalyst like sulphated zirconia [10], base catalyst like calcium oxide, magnesium oxide, hydrotalcite, cement [11, 12]. The use of biodiesel reduces the emissions of most pollutants, with the important exception of nitrogen oxides. First, biodiesel eliminates the fugitive emissions of such toxic compounds as benzene and formaldehyde that are associated with the production, storage and distribution of regular diesel fuel.

Gasification:

Biomass gasification is the conversion of biomass to synthesis gas, a mixture of carbon monoxide and hydrogen [3]. In biomass gasification, steam and oxygen are used to produce synthesis gas where the amount of steam and oxygen are controlled to produce carbon monoxide and hydrogen with a minimum amount of carbon dioxide and other products. Gasification of biomass may performed by two routes namely catalytic and noncatalytic. Noncatalytic process requires a very high temperature of operation, as high as 1300 ºC, whereas catalytic process can be operated at substantially lower temperature. With more advances in the catalysis, the temperature requirement is expected to go downward further from the current value of about 900 ºC [8]. Catalysts used in biomass gasification are olivine, iron ore (limonite), zeolite (HZSM-5), FCC catalysts, alumina, transition metal catalysts (Fe/Cr), Al-MCM-41, Ni-cordierite [13, 14, 15]. Recently hydrothermal biomass gasification and microbial catalystytic processes have been reported [16, 17].

Pyrolysis:

Pyrolysis is the direct thermal decomposition of the organic components of biomass in the absence of oxygen to yield an array of useful products like liquid and solid derivatives and fuel gases [3]. Depending on the operating conditions, the pyrolysis process can be divided into three subclasses: (a) Conventional pyrolysis, (b) Fast pyrolysis, and (c) Flash pyrolysis. Conventional pyrolysis occurs in between 550 and 950 K under a slow heating rate (0.1–1 K/s) and residence time is 45–550s and massive pieces of wood. Fast pyrolysis occurs at temperature range of 850–1250 K with fast heating rate (10–200 K/s), short solid residence time (0.5–10 s) and fine particle (<1 mm). While flash pyrolysis occurs in the temperature range of 1050–1300 K, fast heating rate (>1000 K/s), short residence time (<0.5 s) and very fine particle (<0.2 mm) [8,18].

The products of pyrolysis under high pressure and temperature include mainly liquids with some gases and solids (water, carbon oxides, hydrogen, charcoal, organic compounds, tars and polymers). The pyroligneous oil is the liquid product formed and mainly composed of water, settled tar, soluble tar, volatile acids, alcohols, aldehydes, esters and ketones [19]. Catalyst used in pyrolysis includes zeolites and metal substituted zeolite, alumina [20].

Conclusion:

This review has shown that, many processes that can convert biomass into fuels and chemicals, but needs emphasis on use of second generation biofuels which is depending on lignocellulosic biomass. However first generation biofuels are depend on food grade biomass which may have impact on food prices. The best solution is likely a biorefinery that combines various processes to maximize economic and environmental benefits while minimizing pollution. Although significant progress continues to be made to overcome the technical and economic challenges, second generation biofuels production will continue to face major constraints to full commercial deployment.

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