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Review of solar energy for biofuel extraction

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ABSTRACT

One of the most complex challenges of today is managing greenhouse gas emissions produced by excessive use of fossil fuels as energy source. With fossil fuels dominating the energy production, the sustainable and environmental problems will continue unless alternative sources of energy are put in place. Biomass is considered as a promising sustainable energy source which can be introduced to the energy mix. One way of converting raw biomass to higher value biofuels is following the thermochemical conversion processes, which include pyrolysis, gasification, torrefaction, combustion and distillation. However, these processes typically require heat energy to treat the biomass, which is often supplied from non-renewable energy sources. This greatly reduces the conversion efficiency and causes environmental problems. Utilization of solar energy for assisting the biomass conversion through thermochemical conversion process significantly improves the overall sustainability and process performance. This work reviews the solar based technologies and their application to solar assisted biomass utilization and conversion technologies. The review then discusses outcomes of different solar assisted biomass pyrolysis and gasification processes performed to date. It also presents the status of solar assisted distillation for improving ethanol concentration.

1. Introduction

Due to the rapid global population growth and rising living standards, there has been a significant increase in energy demand and consumption over the last several decades [1]. By 2040, the total energy use is expected to grow by about 40% of the current use. Even though the share of fossil fuels in the entire energy mix is expected to fall, it will still remain the dominant source of energy with oil, coal and gas each expected to account to over 25% of the global energy needs [2]. It is also estimated that the world population will reach 9.3 billion by 2050 [3]. This rapid population growth will increase the energy demand while fossil fuels, being dominant energy sources, are estimated to significantly deplete after 70 years [4]. It is inevitable that sustainability and environmental challenges will continue, unless an alternative source of energy is put in place ahead of time. The existing pattern of energy supply cannot be sustained in the near future because of the depletion of fossil fuel reserves and also environmental impacts from their use [5]. According to Morales et al. [3] one of the most complex challenges faced today is managing and halting climate changes produced by the over-exploitation of natural resources.

Biomass is seen as the most promising energy source to mitigate greenhouse gas emissions. Substantial adoption of this ubiquitous energy source could alleviate the environmental, social and economic problems faced by the modern society [6]. Until 2012, global biomass use was 8–14% of the world final energy consumption. The annual availability of biomass is estimated to reach as high as 108 Gtoe, which is almost ten times the world's current energy requirement [7–10].

There should be efficient utilization of biomass through the adoption of improved energy technologies. There are many existing processes that convert raw biomass to usable forms of energy and chemicals. These include combustion, pyrolysis, gasification, torrefaction, liquefaction, esterification and fermentation [11,12]. These processes are considered as critical biomass utilization alternatives, offering economic benefits through the production of high value fuel gasses and liquids, char and chemicals [13–16]. These processes are highly endothermic requiring large heat input generally supplied from non-renewable sources of energy [3]. Solar energy can be captured and stored in chemicals or fuels, also known as solar fuels, for later use and easy transportation. Utilization of solar energy for assisting the biomass conversion through distillation or thermochemical processing is expected to significantly improve the overall biofuel life cycle performance. Recently, biofuel extraction technologies using concentrated solar energy have been tested in solar reactors with real sun [17]. Current technologies consist of concentrating part with polished aluminium or glass mirror as reflecting surface, while the biomass reactors are mostly made of quartz or borosilicate glasses and metals, such as

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steel, including controllers for temperatures, heating rates, pressure and tracking units [18].

The objective of this work is to review solar based technologies and their applications for solar assisted biomass utilization and conversion technologies. The first part of the paper describes the fundamental conversion mechanisms of biomass to biofuels, with emphasis on the thermochemical conversion mechanisms. Different types of solar concentrating technologies with potential to capture the solar heat to drive the thermochemical conversion process are further discussed. Integration of the prospective solar collectors with biomass reactors are additionally elaborated. Finally, review of the solar assisted pyrolysis, gasification and status of solar assisted distillation process, together with characterization of the different product fractions obtained from the processes, are presented.

2. Overview of biomass to biofuel conversion mechanisms

Biofuel is a type of energy derived from biomass such as plants, agricultural, animal, domestic and industrial wastes. Biomass can be converted into higher value biofuels either through biochemical, thermochemical or physico-chemical processes.

Biochemical conversion process involves fermentation of the sugars into alcohols, such as ethanol. This includes biomass pre-treatment followed by fermentation of the sugars to ethanol then separation and purification to produce pure ethanol [19]. Fig. 1 shows the recent trends for the second generation of biofuel production through biochemical process from lignocellulosic biomass. The efficiency of the biochemical conversion process is between 35% and 50%wt [20]. This process can also be used to transform biomass into any type of petrochemical product compounds, such as olefins and aromatics which are made from petroleum or fossil fuels.

Distillation is typically used to produce, separate and distil ethanol into usable fuels. The energy is supplied through either an external heat source, such as gas or electricity from grid. In both cases, this practice reduces the environmental benefits of the biomass conversion processes on a full life cycle basis.

Thermochemical processes of converting biomass into biofuels involve application of heat energy to treat the biomass in the conversion process with conversion efficiencies in the range between 41% and 77% wt [20]. The treatment processes include combustion, gasification and pyrolysis.

Combustion is the direct burning of biomass in the air for the purpose of heating and power generation, initially practiced for long time since mankind has started using fire. Gasification is a process that converts organic or fossil fuel based carbonaceous materials into carbon monoxide, carbon dioxide and hydrogen known as syngas. The syngas can be processed to produce different types of gaseous biofuels and liquids. Gasification is achieved by reacting the material at high temperatures (> 700 °C), without combustion, but with a controlled amount of oxygen and/or steam. Fisher-Tropsch process with chemical catalytic conversion are advanced engineering processes developed to optimize the production of syngas. Gasification is highly endothermic process. The heat required to maintain this process is supplied from non-renewable sources of energy by burning significant portion (at least 35%) of the feedstock or using the electric grid which lowers the final efficiency of the process [21–23].

Pyrolysis is another thermochemical process that uses heat in the near absence of oxygen to destruct biomass to produce biofuels, bio-oils (bio-crude), biogas and char. Pyrolysis has high flexibility in that it can be used to produce heavy fuel oil for heat and power applications, upgraded for conventional refinery operations, or it can be gasified for syngas which can be converted to hydrogen. Pyrolysis can convert over 60 wt% of the biomass into liquid bio-oil [24]. Pyrolysis requires moderate temperature in the range of 400–600 °C to depolymerize biomass to a mixture of oxygenates (or 'bio-oil') that are liquid at room temperature [25]. This external heat energy generally comes from burning part of the biomass or fossil fuels or using grid electricity [3].

3. Energy from the sun

About 885 million terawatt hours reach the earth's surface in a year which is 4200 times the energy that mankind would consume in 2035 according to the IEA's Current Policies Scenario [26]. In just three hours the Earth collects enough solar radiation to meet world's energy needs for one year. If one-tenth of one percent of the solar energy is captured and distributed, then the energy supply problem disappears [26].

Biomass captures and converts solar radiation into energy ($C_xH_{2x}O_x$) through photosynthesis. Agrawal and Singh [27] provided a review on the fraction of solar energy which can be recovered as biofuels, mainly liquid fuels for transportation purpose, via the cultivation and then conversion of the biomass using different methods (pyrolysis, gasification, fermentation, H_2bioil B and H_2CAR processes). The highest sunlight conversion efficiency for a full season growing biomass can be achieved up to 3.7% [28]. Fast pyrolysis of biomass can generate 524–627 liters of liquid fuel per year which corresponds to recovery of 65–77% of the absorbed solar energy by the biomass. Estimates of the solar energy recovery as liquid fuels from fermentation, gasification, H_2bioil-B and H_2CAR processing of biomass were found to be 41–50, 35–50, 59–69% and 58% respectively [27]. Using supplementary energy such as H_2 or electricity that is recovered from solar energy at higher efficiencies than the biomass can increase the fuel yield by a factor of 1.5–3 [27].

These estimates can be considerably improved if the heat energy for biomass conversion can be supplied from the sun using solar concentrating technologies. The following section describes the solar concentrating technologies available to integrate with biomass conversion for production of biofuels from biomass.

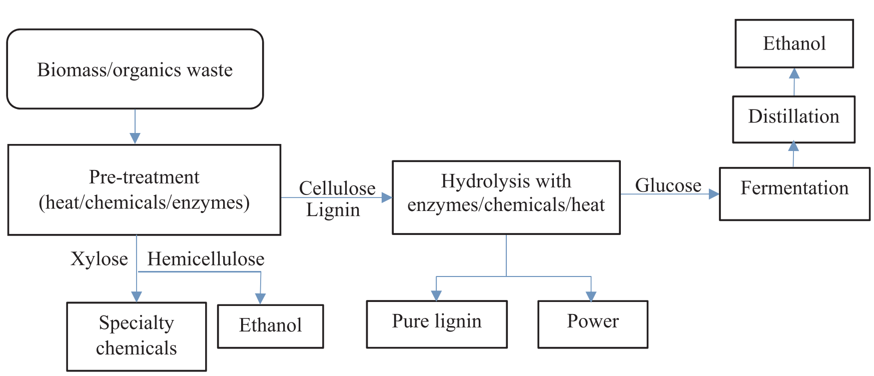

Fig. 1. Biochemical process of biofuel production.