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Small Scale Biomass Gasification Challenges for Power Generation in Rural Area: A Review

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Abstract: *Nowadays, the world highly depends on the fossil fuels like coal, oil and natural gas for its energy source. Yet within the next decades, fossil fuels will be depleted. Furthermore, environmental issues such as greenhouse emission enforced the government to switch to renewable energy. Biomass is one of the promising renewable energy due to its unique characteristics and availability. The fact, however, utilization of biomass as a source of energy, particularly in small scale for a rural area, is very limited. Some challenges in converting biomass for power generation will be stressed in this review. As one of the most challenging steps, gasification of biomass will be highlighted for investigation. In accordance with the latest reports, an excellent gasification method could produce a specific gas composition suitable for power generation in the rural area.*

Keywords: *biomass, challenges, gasification, rural area, small scale.*

1. Introduction

Energy has become one of the most fundamental needs for the human. Everyday energy is used for the industrial sector such as agriculture, mining, manufacturing, construction, transportation, housing like heating, cooling, lighting, and many other appliances. Based on IEA [1], the world still relies on fossil fuel as its main energy source. Oil, coal, and natural gas remain on the top of energy source, followed by renewable energy like biomass, geothermal energy, hydropower, solar energy, tidal and wave power, and also wind power.

Fossil fuels need more than a million years to be formed. Once being used, it could not be filled anymore. It is estimated that the world will run out of fossil fuels within the next 50-120 years. Environmental issues caused by the use of fossil fuel such as carbon dioxide (CO_2) emission that will form the layer in our atmosphere and prevent heat emitted by the earth. As a result, the temperature will be increased and climate will be changed. Climate change could lead to flood, drought, famine, or spread of disease through the world. The need of renewable and sustainable energy is critical.

According to Basu [2], human is very familiar with energy conversion from biomass, since it is as old as the history of civilization. Even some of its process already began from the early days of vegetation on the earth. Forest burnt because of the lightning is an illustration of flaming pyrolysis. Decomposition of biomass with methane gas formation and combustion could be seen in the blue fame in the swamp. While increasing soil fertility by burning trees is a model of biochar production.

Biomass is a natural energy source, coming mostly from agricultural crops and waste, forest waste, and animal waste. Biomass could also come from municipal waste produced by human. As one of the renewable energy, only biomass could be produced into solid, liquid or gas fuel. As a renewable energy source, biomass is environment-friendly carbon neutral attribute as stated in McKendry [3]. It is a condition wherein net zero carbon emissions achieved due to balance amount of carbon released as a result of combustion, with an equivalent amount of carbon absorbed by the source of biomass, explained by Anderson [4]. According to Asadullah, M., [5] biomass gasification based power system made up of several steps including pretreatment of biomass, gasification of biomass, gas cleaning, and feeding the product gas into gas turbine or gas engine to produce electricity, or as a fuel for boiler to generate steam able to run the turbine.

2. Biomass Pretreatment

Moisture content in biomass gasification plays a critical role from technical point of view. During gasification process, heat added will generate steam derived from the moisture content and acts as gasifying agents, reacting with volatile matters and char to convert them to product gas, also enhance the hydrogen content in the reaction as explained by Yuan, Z., et al. [6] and Yan, F., et al. [7]. For compost with moisture content less than 40%, self-combustion will be taken place investigated by Torii, S., and Watanabe, S., [8]. Higher moisture content above 40% however, reduces the thermal efficiency of the gasification system as investigated by Hosseini, M., et al. [9].

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The drying of biomass as a pretreatment has a crucial impact on the overall efficiency of the biomass-based power generation, as described by Asadullah, M. [5]. Raw biomass, like palm empty fruit bunch in Malaysia and Indonesia usually content more than 50% of moisture, even though its plentifully available in these countries as reported by Ma, A. N., and Basiron, Y. [10]. Biomass drying is one of the most challenging factors for maintaining the constant supply of biomass. There are several ways to lower the moisture content of biomass. Biomass could be dried by the sun at the source of origin where the biomass is produced. Sun drying is less expensive, but longer time is required, and also highly depends on the weather. The longer the drying process, the more chance the biomass get mold and reduce its quality. While another way of drying is by using heat produced by the processing plant. This method, however, is more expensive due to additional equipment and constant heat needed. Acharjee, T.C., et al. [11] had already explored these methods. Physical size of biomass often caused operational issue in the gasification process. Especially feeding the biomass into the gasifier. Biomass such as rice straw, wheat straw, grass, and empty fruit bunch are bulky and fibrous, hence usually get stuck in the feeding line. While some biomass like palm kernel shell and wood chips are easily fed into the gasification unit, though. The characteristics low bulk density of biomass could have a negative impact on the gasification process as mentioned by Chevanan, N., et al. [12].

Even though additional process, energy consumption and cost needed, balling, briquetting and palletizing are the common techniques to overcome the low bulk density of biomass as investigated by Chen, L., et al. [13] and Mani, S., et al. [14]. These techniques could make biomass more compact, thus avoid issue in regard to biomass feeding. Balling due to its size sometimes not applicable for constant feeding. Pallets are suitable for constant feeding instead, because of its size and shape, however, is difficult to break. Not to mention additional cost and energy to convert to pallets. Briquette comes as another option with balanced density, transported, stored and feed easily.

3. Biomass Gasification

As reported by Dahlquist [15], there are many methods to convert biomass to energy. Main biomass energy conversions are through combustion, gasification, pyrolysis, and torrefaction. Combustion is 100% oxidation of all organic contents of the fuel using air or oxygen. Gasification indicates partial combustion, where only 15-30% of the oxygen is being added in relation to what would be needed for 100% oxidation. Pyrolysis uses heat but without air, as a result, gaseous components of the organic material are evaporated and later condensed as a liquid. And torrefaction is partial pyrolysis aim to remove some of the gaseous components, so that instead of liquid hydrocarbons produced, but a compact residue that could replace coal for coal power plants.

Compared to direct combustion, gasification technique produces lower NOx, CO and particulate emissions, and have more potential for efficient conversion process when generation power. On the other hand, gasification technology is currently still in the development phase and during the process need fuel with rather low size distribution and low moisture content. According to Knoef, H.A.M., [16] health, safety and environmental issues are found to be an important barrier for biomass gasification market. Hence risk assessment in biomass gasification is becoming increasingly important.

Biomass gasification is a promising, energy efficient technology for renewable energy generation and considered as a key technology for the use of biomass as described by Heidenreich and Foscolo [17]. Biomass gasification is a thermal conversion of biomass into useful combustible gas called producer gas or syn gas. Product gas produced by the gasification of biomass occurred at temperature ranging from 700 to 1000 ^{0}C could be burned in a boiler for heat production or in an internal gas combustion engine for combined heat and power generation.

Saidur, R., et al. [18] within his exergy analysis research conclude that compared to other methods, gasification found to be the main thermochemical process and was the most effective method of converting biomass. Gasification also determined as one of the main sources of exergy losses. This means that exergy in gasification was the most transformed into energy during its process.

Fluidized bed combustion, fixed bed combustion, and pulverized bed combustion are some of the available biomass combustion techniques as a fuel for boilers. According to Saidur, R., et al. [19], fluidized bed combustion was considered as the most excellent technology compared to other methods due to its ability to deal with low quality biomass, high ash content and low calorific value that often abundantly available in the rural area.

Due to the endothermic behavior of the process, gasification require a significant amount of energy, hence the energy consumption is one of the most dominant restriction on the thermal efficiency and the design of the gasifier. In order to achieve optimal gasification process parameters, several modeling and simulation were needed in order to anticipate the actual process. Ahmad, A. A., et al. [20] conclude that reaction temperature, ER value and the presence of catalyst are the most important parameter in gasification that will determine the process performance and the quality of gas produced. While the biomass particle size was found to be the least significant parameter for process. Among the tools that could be used for modeling are Aspen Plus and Aspen Hysys, that able to apply the kinetic and equilibrium model.

4. Biomass Gas Cleaning

Product gas from gasification process could be used directly without further treatment for boiler application. In boiler application, product gas being used to generate steam, that will rotate the turbine to produce electricity.This method still, will reduce the overall efficiency of power generation through steam turbine to below 20% level, compared to about 50% in gas turbine and engine. One of the most challenging part is the cleaning of product gas in order to meet the gas turbine requirement and engine operation, especially for tar contaminant less than 100 mg N/m^3 as reported by Asadullah, M. [5].

Raw syn gas produce by gasification of biomass contains essential gas like CO, CO_2, H_2 and CH_4, however raw syn gas also consist of small but significant amount of unwanted contaminants like tars, nitrogen compounds, sulfur compounds, hydrogen halides and other metals such as Sodium and Potassium. It is important to clean up the raw gas produced by gasification by employing cold, warm, and hot gas clean up techniques. Abdoulmoumine, N., et al. [21] found that cold gas cleanup was the most effective way to remove the contaminants at desirable lower concentration limit. This method posses some disadvantages because will reduce the overall efficiency caused by cooling, and increase cost as a result of complexity and additional steps needed for raw syn gas treatment.

Gas cleaning method could be done by physical gas cleaning. This method employs filter or wet scrubbing of the product gas so that tar and other particulate matter could be removed. This method may use gas/solid or gas/liquid interaction in high or ambient temperature. High temperature filter must utilize high tolerance material like ceramics, fiber glass, or sand. While ambient temperature may use other materials such as cotton fibers, charcoal and so on. Obstacle of these procedure are the fouling of particulate matter and sticky tar occurred in the passages. For greater application, filter may cause significant pressure drop. Water scrubbing could be one of the option to collect the particulate and tar, however in is difficult to handle a large amount of contaminated water and could be dangerous to the environment.

Tar could be cracked down into less dangerous molecules like methane, carbon dioxide and hydrogen by thermal process. As reported by Abuadala, A., and Dincer, L. [22], tar thermal process could be done with very high temperature, it may reach 1000 ^{0}C. This will initial another issue like construction of high temperature and expensive alloys that need highly controllable and complex heating system. In addition, the ash melts in this temperature, and after the process, the product gas still need to be cooled with an intensive system.

Since physical filtration and thermal process found to be inefficient for gas cleaning process, utilization of effective catalyst may draw our attention because not only could reduce the concentration of tar and ammonia effectively, but also occurred in lesser temperature (600-800 ^{0}C). Another benefit for this techniques are due to same operation temperature, it does not need to be heat up or cool down. In addition, catalyst could convert tar into CO and H_2, so will increase the burnable gas composition described by Asadullah, M. [5].

Absorption and adsorption process combination proven to be a feasible option for purification, because carbon grabbing, desulfurization, and moisture control occurred in the same period of time. As reported by Al Mamun, M. R. and Torii, S. [23], nanotechnology were applied for removal of H_2S and H_2O, while CO_2 could also removed by aqueous solution.

5. Small Scale Biomass Gasification Power Generation

Spark ignition or compression ignition engines are the choice of technologies in gasification based power generation from biomass for the size range under 5 MW , as described by Larson [24]. While Williams [25] said that fuel cell and micro gas turbines couples with biomass gasifier will offer considerably high efficiency at small scale compared to typical internal combustion engines, however this advanced technologies are still being developed. Product gas or syn gas from gasification process could be used for small scale Combined Heat and Power (CHP) units. Dong, L., et al. [26] classifies small scale CHP when produce less than 100 kW, and micro scale CHP for less than 15 kW. CHP or cogeneration has been considered as an alternative for energy saving as stated by Denntice [27], and according to Bernotat [28] heat will be produced along with power for environmental conservation.

Small scale gasification biomass power generation bring a better way to adapt biomass characteristic in rural area that very diverse and scattered. Bubbling fluidized bed gasification with steam, indirect heat supply and primary conditioning method with catalysts will improve product gas earning and quality. This system is more reliable, because of the better annual operation hours, more different types of biomass being used, greater load variation and other benefit. However due to the early development stages, global capital cost will be higher. As reported by Bocci, E., et al. [29] for high energy efficient heat and power generator like gas turbines or fuel cells, syngas quality still need to be refined, especially for syngas cleaning materials using catalyst.

Small scale CHP system is satisfactory for commercial building appliance, like hospitals, schools, industrial area, office building, and domestic houses. This system could supply adequate amount of energy required while keeping the positive social impacts. Environmental issues such as greenhouse emission effect, improved energy security, and also economical savings as a result of excessive electricity transmission omission distribution network and will lower the energy cost to the consumer. This already explained by Hawkes, A. D., and Leach, M. A. [30]. A small CHP also possess higher standard of dependability since this system operate independently, hence will not be affected by blackout from the grid.

Rural area has decentralized characteristic source of energy, hence biomass is consider as the fittest substitute of fossil fuel due to its intrinsic properties as mentioned by Fischer, I.J. [31]. Transportation cost reduction will be a very good asset for small scale biomass plants, while it will be more tough to find an end user for the heat produced in larger power generation user, according to Eriksson, O., et al. [32].

Larson [24] stated that in rural areas, small scale gasification based biomass power generation is a promising strategy for maintain the sustainable electricity supply. Small scale gasification biomass power generation could contribute to rural development area in several manners. Biomass collection, delivery, power plant operation could employ people around the power plant. Economically competitive electricity produce by the power plant could attract even more employment, and benefit for income generative activities within the area, especially energy intensive industries. Surplus electricity power could be sent out to urban area that will lead to other advantages.

6. Conclusions

As an alternative source of energy, biomass has interesting characteristics suitable for rural area where limited electricity is to be expected. Plentiful point of supplies and historical background make biomass is familiar as a replacement of fossil fuels. Wood biomass remains the main energy source for widespread biomass powered CHP systems at small scale. Gasification of biomass using a gas engine (or gas turbine) presents interest possibility for small co-generation. Yet biomass gasification possess several aspects to be considered for the permanent replacement of fossil fuels. Pretreatment of biomass, syn gas contaminant are some of the barriers need to be solved. Researchers have done meaningful progress to overcome these obstructions. Briquetting techniques for pretreatment, modeling and simulation tools for biomass process flow prediction, the use of fluidized bed combustion, and syn gas cleaning process using catalyst or material selection are some of them. Integrating these most advanced techniques seems to be feasible and will promote the use of biomass and reduce fossil fuel in the near future.

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