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Progress in biomass gasification technique – With focus on Malaysian palm biomass for syngas production

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ABSTRACT

Synthesis gas, also known as syngas, produced from biomass materials has been identified as a potential source of renewable energy. Syngas is mainly consists of CO and H_2, which can be used directly as fuel source for power generation and transport fuel, as well as feedstock for chemical production. Syngas is produced through biomass gasification process that converts solids to gas phase via thermochemical conversion reactions. This paper critically reviews the type of gasifiers that have been used for biomass gasification, including fixed bed, fluidized bed, entrained flow and transport reactor types. The advantages and limitations of these gasifiers are compared, followed by discussion on the key parameters that are critical for the optimum production of syngas. Depending on the biomass feedstock, the properties and characteristics of syngas produced can be varied. It is thus essential to thoroughly characterise the properties of biomass to understand the limitations in order to identify the suitable methods for gasification. This paper later focuses on a specific biomass – oil palm-based for syngas production in the context of Malaysia, where palm biomass is readily available in abundance. The properties and suitability for gasification of the major palm biomass, including empty fruit bunch, oil palm fronds and palm kernel shells are reviewed. Optimization of the gasification process can significantly improve the prospect of commercial syngas production.

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1. Introduction

The world's energy supply is dominated by the gradually depleting non-renewable fossil fuel. Production of oil, coal and gas is expected to decrease exponentially after reaching peak production in year 2015, 2052, 2035, respectively [1,2]. The huge consumption of fossil fuels is mainly driven by the ever increasing energy demand resulting from growth in global population and economical activities. Another major issue brought by fossil fuel burning is environmental pollution. The excessive emissions of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are detrimental to the environmental and human health [3]. These issues drive the development of renewable energy technologies.

Synthesis gas (or syngas) is regarded as one of the promising alternative energy due to its environmentally clean fuel characteristic. Syngas is produced through gasification process from carbonaceous materials by thermal cracking reactions [4–6]. It consists mainly of hydrogen (H_2), carbon monoxide (CO), carbon dioxide (CO_2), nitrogen (N_2), water vapor, methane (CH_4) and other hydrocarbons [5,7,8]. Syngas is well suited for various applications, including electricity generation and transport fuel production [9,10]. Primarily, syngas is used for power generation where it can be directly consumed as gaseous fuel to produce electricity and heat. Most of the harmful pollutants can be removed in the post-gasification process prior to combustion. In addition, syngas is widely used as key intermediary in the chemical industry to produce methanol, dimethyl ether, and methyl tert-butyl ether for liquid transportation fuel [11].

One of the key challenges of operating with syngas is the variation in chemical composition which can affect the combustion process [7]. Syngas composition varies depending on the feedstock and production methods. There are many types of feedstock that can be used to produce syngas such as biomass, coal, refinery residual, organic waste and municipal waste [12]. Biomass, being the fourth most abundant energy sources after coal, oil and natural gases, is regarded as a good candidate to produce renewable, sustainable and environmental-friendly energy source, which currently supplies 14% of the total global energy consumption [13,14]. In Malaysia, the agricultural sector contributes about 12% to the gross national income (GNI). A significant 8% of GNI comes from palm oil plantation with a gross value over $22.31 billion USD in 2014, making it the fourth largest source of national income [15,16]. Large quantity of biomass is produced from palm plantation, which could potentially be used as feedstock for syngas production. However, most of the palm biomass are either landfilled as waste or left on plantation ground for mulching as organic fertilizer [17]. There is a lack of initiative to process these biomass to become value added downstream products due to a lack of available efficient processing technology and poor management [17,18].

One potential use of palm biomass is as co-firing fuel in boiler system. However, most boiler system installations in Malaysia are still operating with low-pressure boilers with less than 40% overall cogeneration efficiency. Almost 77% of oil palm mills in Malaysia use combustion system with high CO_2 emissions [18]. Therefore, gasification system with combined heat and power (CHP) system is one potential technology that can replace conventional system to improve the biomass conversion efficiency, as well as to reduce carbon emission.

The objective of this paper is to critically review the state-of-the-art biomass gasification technologies, production methods, characteristics and governing parameters that affect the production of syngas. Understanding the biomass-to-syngas conversion processing route is important in order to assess the feasibility of gasifying palm biomass as alternative renewable energy source. This study also reviews the availability, current state, characteristic and potential of various palm biomass as solid feedstock to produce syngas via gasification method in the context of Malaysia.

2. Gasification of biomass to produce syngas

Gasification of biomass is a promising method to produce syngas. The raw product of the gasification process, usually called “product gas” or “producer gas” consists of stable chemical species. Producer gas contains CO, H_2, CH_4, aliphatic hydrocarbon, benzene, toluene and tars (besides CO_2 and H_2O) and is formed at low temperature (below 1000 °C) [19,20]. H_2 and CO typically contribute 50% of the energy in the product gas, while the remaining energy is contained in CH_4 and (aromatic) hydrocarbons. While the term “syngas” usually does not apply to the raw gas, it is widely used as an industrial shorthand to refer to the product gas from all types of gasification processes [21,22]. Fig. 1 shows the generic gasification process from which syngas is produced. Syngas is produced at high temperature (above 1200 °C) where feedstock is converted into H_2 and CO (besides CO_2 and H_2O) [19].

Generally, biomass conversion technology can be classified into three main categories, namely thermochemical, biological and physical conversion [20]. Gasification process is a thermochemical conversion technology where biomass feedstock is converted into higher heating value fuel [23,24]. The highlighted route in Fig. 2 indicates the production of syngas through gasification method. Gasification process can be utilized to produce syngas for combustion in boiler, turbine and internal combustion engines. Additionally, syngas is also produced for downstream application such as chemicals [21,25–27]. Before syngas can be used for downstream application, gas cleaning is necessary to eliminate unwanted by-product as shown in Fig. 1 [28,29]. Gasification reactors operation typically consist of four steps, namely drying, pyrolysis/devolatilization, reduction and combustion as detailed in Fig. 3 [21,22].

During gasification conversion process, unwanted by-products such as tars, impurities and ash will be produced. Tars consist of a complex mixture of hydrocarbon materials, which need to be removed or further processed to prevent it from condensing at

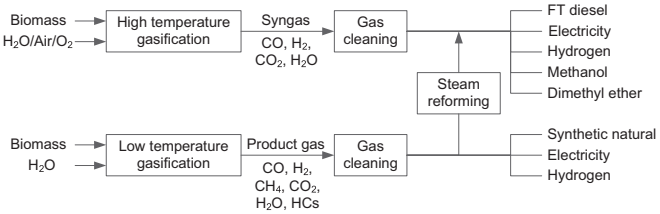

Fig. 1. Production of syngas and product gas and their typical application [19].