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Utilization of palm solid residue as a source of renewable and sustainable energy in Malaysia

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ABSTRACT

Today, global energy consumers are addicted to fossil fuels such as natural gas, oil and coal. Although it has been anticipated that fossil fuels will be depleted soon, these fuels are still dominant as the primary source of energy in the world. Recently, many efforts have been done to substitute renewable alternative fuels to reduce dependency on fossil fuels. Biomass as one of the earliest energy sources appears to be the most promising renewable energy source due to its numerous resources and its environmentally sound characteristics. Since Malaysia is agriculture based tropical country, many crops such as palm, paddy rice and sugarcane are cultivated in this region. Malaysian palm oil industry generate huge amounts of palm solid residue (PSR) biomass such as empty fruit bunches (EFB), palm fiber, shell, trunks and fronds as byproducts which are capable to be taken into account in the energy mix of the country. In this paper, an overview of the PSR generation from Malaysian palm oil industries and its social and economic effects has been given. Indeed, performance of the direct combustion of PSR in terms of PSR composition, properties, heating value, emissions and its effects on the equipment or the components of the boilers have been reviewed. It has been found that the very high moisture content of PSR of palm industry makes their collection and transportation expensive, therefore energy conversion process could be inefficient and utilization of these materials inside the palm oil mills seems more beneficial.

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Abbreviations: CRR, crop-to-residual-ratio; EARS, early agglomeration recognition system; EFB, empty fruit bunches; FFB, fresh fruit bunches; FELDA, Federal Land Development Agency; FELCRA, Federal Land Consolidation Rehabilitation Agency; GW, global warming; GHGs, greenhouse gases; MPOB, Malaysian Palm Oil Board; NO_x, oxides of nitrogen; PAH, polycyclic aromatic hydrocarbons; PM, particulate matter; PSR, palm solid residue; RSE, renewable and sustainable energy; RISDA, Rubber Industry Smallholders Development Authority; SAF, surplus-availability-factor; SO_x, oxides of sulfur; VOC, volatile organic compounds

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1. Introduction

Today, around 80% of total world energy consumption has been supplied by fossil fuels such as coal, natural gas and oil. However, it has been anticipated that these non-renewable fuels will be exhausted within 50 years. Indeed, global warming (GW) has emerged as a major problem due to increasing rate of greenhouse gases (GHGs) generated from fossil fuel combustion [1–4]. It is expected that the temperature of the world will increase around 5.8 °C by the year 2100 compared to the year 1990 [5]. Carbon dioxide (CO_2) as the main GHGs generated by an upward trend during the last decade and total CO_2 emission from consumption of energy was reported to be 32,578.645 million tons in 2011. Therefore, development of renewable and sustainable energy (RSE) resources play a crucial role in the future of human life due to their renewability and environmentally friendly characteristics. Biomass as one of the earliest source of energy is a kind of RSE with very especial properties [6–15]. Currently, around 10–15% of world energy demand has been supplied by biomass which in developed countries supplies more than 10% of the total energy demand and in developing countries biomass contribution to total energy consumption has been estimated around 3% [16]. Any organic matter derived from animal materials or plants such as animal and human waste, organic industrial, forest wood, agricultural left overs, crops, forestry processes and seaweed are known as biomass. Solid, liquid and gaseous biomass fuels have been applied in energy generation industry using a variety of feedstock such as cattle and coal biomass [17], solid sludge and solid waste [18], cellulosic ethanol [19] and food and garden wastes [20]. Solar energy derived from plants converted into chemical energy by photosynthesis process and stored in the form of vegetation biomass. Palm solid residue (PSR) biomass is the organic matter derived from palm trees in tropical countries like Malaysia, Indonesia and Thailand as a result of photosynthesis. Photosynthesis is the process by which solar energy is converted into chemical energy by plants with the help of a pigment known as chlorophyll as given in Eq. (1).

$$6CO_2 + 6H_2O + \text{sunlight} + \text{chlorophyll} \rightarrow C_6H_{12}O_6 + 6O_2 + \text{chlorophyll} \quad (1)$$

This process applies carbon dioxide and water in the presence of sunlight to produce glucose. PSR is a renewable fuel with reasonable price which can be stored for use. Moreover, minimum capital is required for energy extraction from this fuel [21,22]. Generally, PSR can be developed with present manpower and material sources in Malaysia, therefore electrical energy can be generated on a large scale at very low cost. Indeed, low gestation period of biomass has improved rural life in Malaysia and has generated many jobs. From an environmental aspect, during burning of PSR, the oxygen from the atmosphere combines with the carbon in the plants to produce CO_2 and water. This CO_2 and water are again available for palm tree growth and hence the cyclic process continues making PSR a renewable source of energy which does not contribute to global warming. Furthermore, low levels of sulfur and ash in PSR combustion products prevent acid rain formation. In general, air pollution can cause health problems and it can also damage the environment and property. It has been reported that coal is responsible for 30–40% of worldwide CO_2 emission [23]. Unlike fossil fuel PSR does not lead to substantial GHGs production and GW phenomena [24]. The environmental benefits include reduction in air and water pollution and reduced SO_2 and CO_2 emission have highlighted the environmentally sound characteristics of PSR utilization in Malaysia [25–27]. Although it has been claimed that dioxins as toxic and bio-accumulative chemicals can be emitted from biomass combustion, the dioxin emissions found in PSR boilers are controllable and can be reduced in an effective manner [28]. It is necessary to avoid high temperature biomass combustion due to negative effects such as volatilization of mercury, leaving solid ash and slag residuals which emerge in biomass combustion when the temperature of the process increases up to 575 °C [29].

1.1. Palm tree plantations in Malaysia

Oil palm plantations in Malaysia have been discussed in detail by Corley and Tinker et al. [30]. Generally, palm trees are planted in Malaysia for food applications like frying oil and cooking oil. However, palm oil industries generate huge amounts of biomass residue which can be utilized in different industries [31–34]. Fig. 1 illustrates the summary of biomass byproduct generation in palm oil industries in Malaysia. Indeed, Fig. 2 demonstrates the types of different byproducts generated annually from palm oil industry as palm biomass in Malaysia [35].

In recent decades, Malaysian government has introduced biomass as the fifth fuel resource after petroleum, gas, coal, and hydro. Wood chips, agricultural waste, effluent sludge and domestic wastes have been mentioned as the most important biomass resources in Malaysia [36,37]. Moreover, due to specific weather circumstances, palm biomass has been developed in huge quantities in Malaysia [38]. In the harvesting process of palm crops and also in the palm oil mills, some solid residues and leftovers like EFB, palm fiber and palm shell from palm oil fruit remain. PSR can be applied as a substitute alternative fuel for energy generation in industrial boilers and consequently, can help solve the problem of very high fossil fuel prices as well as environmental issues and global warming. The amount of PSR from agricultural products can be projected by their productivities, surplus-availability-factor (SAF) and crop-to-residual-ratio (CRR). SAF is the rate of unused PSR or residue left-overs which are not applied regularly and the CRR is the amount of PSR generated per one unit mass of the produced palm. The extracted energy from solid by-products of palm industry is calculated from the quantity of PSR and the lower heating value of PSR [39]. Elaeis guineensis from western Africa and Elaeis oleifera from tropical Central America and South America are mentioned as the two origins of oil palm and of the two, Elaeis guineensis has been cultivated on a wide scale in South East Asia [40]. Today, the palm trees plantation in Malaysia are continuously increasing due to Malaysian government strategies for palm oil-based biodiesel production [41]. Malaysian Palm Oil Board (MPOB) reported that the land area committed to oil palm plantation in 2012 accounted for around 5076929 ha. Federal Land Development Agency (FELDA), Rubber Industry Smallholders Development Authority (RISDA), Federal Land Consolidation Rehabilitation Agency (FELCRA), private estates, state agencies and independent smallholders are the main palm trees ownership forms in Malaysia.Table 1 depicts oil palm planted areas in different states of Malaysia at the end of 2012 and Table 2