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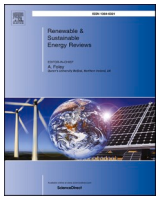

Pyrolysis of oil palm wastes for bioenergy in Malaysia: A review

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ABSTRACT

Oil palm wastes (OPWs) are important biomass resources, and approximately 127 million tons of OPWs are generated from the oil palm industry annually in Malaysia. The scientific and reasonable utilization of OPWs is essential to economic and environmental sustainability in the country. Pyrolysis is a mature and revolutionary technology that can convert OPWs into biofuel. The conversion of OPWs into biofuel is in accordance with the national conditions of Malaysia and can simultaneously address the problems of fossil fuel shortage and environmental deterioration. Therefore, Malaysia is the most active country in the research of OPWs pyrolysis and has achieved fruitful results. Bio-oil produced from the catalytic co-pyrolysis of OPWs with hydrogen-rich materials exhibits remarkable fuel properties. Biochar generated from OPWs pyrolysis presents huge application potential as an absorbent, catalyst, soil conditioner, and carbon sequestration agent. Consequently, the paper provides a comprehensive review of OPWs pyrolysis and lays the foundation for the exploitation of OPWs resources.

1. Introduction

Oil palm (*Elaeis guineensis*) was introduced to Malaysia from West Africa as an ornament plant in the early 1870s. Malaysia has a tropical rainforest climate with abundant rainfall and high temperature, which provides favorable climatic conditions for the large-scale planting of oil palm. Since the 1960s, the scale of oil palm planting has ushered in a tremendous expansion [1]. Approximately 5.9 million hectares of land have been utilized for the cultivation of oil palm. East Malaysia, including Sabah and Sarawak, is a major oil palm-producing region with over 3.12 million hectares of oil palm plantations, accounting for more than half of the plantation area in Malaysia. As the second-largest palm oil producer in the world, 19.14 million tons of palm oil were produced in 2020, which is an important cash crop in Malaysia [2].

Massive oil palm wastes (OPWs) are generated in the mass production of palm oil annually. Table 1 summarizes the annual yield and usage of various OPWs. Approximately 64.19, 26.08, 15.99, 14.87, and 6.49 million tons of palm frond (PF), empty fruit bunch (EFB), mesocarp fiber (MF), palm trunk (PT), and palm kernel shell (PKS) are produced every year. Traditionally, PF has been widely utilized as a roughage source or as a component in complete feed for ruminant animals. EFB is a potential land conditioner or fertilizer as it can ameliorate nutrient leaching, soil structure, and microbial communities in soil. Most palm oil mills harness the energy of PKS and MF through low-pressure boilers, and PT is discarded to decompose naturally [3]. OPWs are applied to the generation of electricity to ensure a clean and sustainable energy supply in Malaysia [4]. Moreover, OPWs have been applied to the construction, furniture, plastics, paper, and chemical industries. However, the small market demand, high production costs, and complex production processes inhibit the massive utilization of OPWs in the above fields.

Furthermore, Malaysia is highly dependent on fossil fuel, thus incurring two serious problems: The high consumption is constantly depleting fossil fuel reserves, threatening the energy security of Malaysia. Crude oil and natural gas in Malaysia are expected to be exhausted by 2029 according to the Economic Affairs Ministry [9]. Additionally, many environmental problems caused by the burning of fossil fuel, particularly the greenhouse effect, acid rain, air pollution,

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