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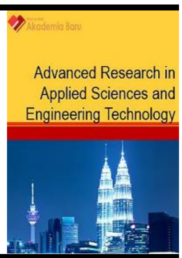

Investigation of Palm Oil Wastes Characteristics for Co-firing with Coal

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ABSTRACT

Nowadays, renewable energy is a reliable solution for addressing global warming and fossil fuel depletion issues. Malaysia has an abundance of biomass resources currently underutilized to generate electricity, such as palm oil waste. Wastes from a palm oil mill plant, such as empty fruit bunch (EFB), palm mesocarp fibre (PMF), and palm kernel shell (PKS), are worth to be investigated as a possible raw material for co-firing with coal. The co-firing technique is the low-cost risk approach for the utilization of biomass in electricity generation. This paper aims to review and perform a comparative study on the existing co-firing biomass processes worldwide in order to explore the potential of using palm oil wastes with coal. To achieve successful co-firing of biomass with coal, the feedstock characteristics need to be understood before undergoing several pre-treatment options. It is recommended to implement co-firing palm oil waste with coal in Malaysia because palm oil wastes can reduce greenhouse gas, NOX, and SOX. Co-firing of palm oil wastes in existing coal-fired power plants is one of the practical ways to be implemented as it helps to reduce the over-consumption of fossil fuels. Based on the findings, Malaysia seems to be on the right track to maximize the use of palm oil wastes either in a standalone biomass power plant or in a co-firing power plant. The improved utilization will further minimize the negative impact of the greenhouse gas emission from the untreated palm oil mill wastes.

Keywords:
Palm oil wastes, biomass co-firing, coal, empty fruit bunch (EFB), mesocarp fiber, palm kernel shell (PKS)

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1. Introduction

Climate change is currently one of the most pressing environmental issues facing humankind globally. According to The Fifth Assessment Report (AR5), carbon dioxide (CO_2) emissions from industrial processes and fossil fuel combustion contributed about 78% to the overall rise in greenhouse gas (GHG) emissions between 1970 and 2010, with a comparable percentage contribution over the period 2000 to 2010 [1]. Moreover, the depletion of fossil fuels encourages the development and use of renewable resources to reduce the dependence of power plants on fossil fuels.

Malaysia is blessed with abundant biomass resources, one of the most potential renewable energy candidates to overcome the issues mentioned above. Around 168 million tonnes of biomass

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are produced in Malaysia, including resources from palm oil waste, rice husks, sugar cane waste, coconut waste, forestry waste, and municipal waste [2]. As the world's second-largest producer of palm oil, Malaysia has immense potential resources from biomass. Table 1 clearly shows that Malaysia has produced around 19,900 million tons or 26% of the world's palm oil production in 2020, according to data from the United States Department of Agriculture [3]. On the other hand, Indonesia is still leading with 43,500 million tons of palm oil production, followed by Malaysia, Thailand, Colombia, and Nigeria.

Table 1
Palm oil production by country in 1000 MT (2020) [3]

Rankings	Country	Production (1000 MT)
1	Indonesia	43,500
2	Malaysia	19,900
3	Thailand	3,100
4	Colombia	1,600
5	Nigeria	1,280
6	Other	6,083

The residue from oil palm is a great source of biomass feedstock. With the rapid depletion of fossil fuel reserves, co-firing is a cost-effective option to maximize the utilization of the oil palm residues in general. More importantly, substitution of coal with biomass when co-firing will help to achieve the target in reducing CO_2 emissions.

Therefore, some co-firing consequences need to be identified and clearly understood in terms of the fuel characteristics for coal combustion with biomass, specifically the solid palm oil waste. The experience of utilities following the approach of various technology of co-firing in the utilization of biomass is useful to consider in this work.

2. Co-firing Experience in Other Countries

Co-firing biomass with coal is a promising economic and environmental choice for power generation since it is a low-risk option for renewable energy production, compared with other alternative uses of biomass in terms of the cost of raw material supply and major capital investments [6]. Co-firing can reduce biomass waste and environmental issues related to its disposal.

In addition, since biomass contain less nitrogen and sulfur than coal, co-firing coal with biomass has the capability to reduce nitrogen oxide (NO_X) and sulphur dioxide (SO_2) emissions [7]. The success of reducing fossil CO_2 emissions is largely due to the substitution of coal with renewable sources in cofiring [6-10]. Consequently, some major co-firing countries in the world, especially in European countries [6], have vigorously developed large-scale co-firing coal-biomass for power generation.

There are three main methods of utilizing biomass wastes for co-firing coal-biomass power generation [7,9,16]: (1) Direct co-firing, the best approach of co-firing, where biomass is fed directly into the furnace alongside with coal, (2) In-direct co-firing, involves advance gasification of biomass in a separate gasifier, and then inject the biomass gas generated by gasification into a pulverized coal furnace for combustion, (3) Parallel co-firing is the lowest risk method which requires the installation of a separate 100% biomass co-fired furnace to generate steam. The types of boilers used in co-firing technologies are typically determined by the current coal-fired or gas-fired combustion technologies.

This paper will review the existing cofiring biomass in some of the major European, North America, South America and Asia countries.

2.1 European

The European Union (E.U.) has pledged to reduce its greenhouse gas emissions from year 1990 to 2020 by 20% reduction and aims to reach a further reduction of 80-95% by 2050 [6]. A brief discussion of co-firing biomass technologies of European countries such as United Kingdom (U.K.), Netherlands, Denmark, and Germany will be explained in this section. A summary of the current type of cofiring activities and primary feedstocks used in Europe are shown in the Table 2 below.

Table 2
Type of combustion and primary feedstocks in European countries [6]

Country	Type of Combustion	Primary Feedstock
U.K.	Direct co-firing	Agricultural residues, energy crops, forestry residues.
Netherlands	Direct and indirect co-firing	Imported wood pellet, palm kernel shells, wastes wood, cocoa shells
Germany	Direct (Fluidize bed: dry or wet bottom)	Sewage sludge, straw, waste wood, organic residue
Denmark	Direct and indirect co-firing	Straw, wood chips, wood pellets

Biomass co-firing has been embraced by all of the U.K.'s main co-fired power plants. Coal power plants in the U.K. have used a variety of raw materials, including agricultural residues, energy crops and forestry residues. On the other hand, the most common co-firing method in the Netherlands is direct co-firing, primarily for wood pellets and coal. However, Netherlands imported majority of their wood pellet resources because of the limited domestic resources available. Besides, in Netherlands, other resources used for co-firing include waste and demolition wood, cocoa shells, paper sludge, Malaysian palm kernel shells, olive kernel pulp, bio-oil, meat and bone meal, hydrocarbon gases and municipal waste [6].

In comparison, although other European countries, such as the Netherlands, Denmark, U.K., and Belgium, make the best use of wood pellets for co-fired purposes, the trend in Germany has not yet caught up, primarily due to its feed-in tariff policy for wood pellets. Germany mainly uses pulverized boilers, when co-firing biomass with coal, depending on whether the ash is removed in a solid or molten state. Sewage sludge, straw, waste wood and organic residues are some of Germany's significant sources of biomass.

Denmark is one of the very few countries in Europe with experience of co-firing operations. The main sources of biomass used in common co-firing power plants in Denmark are straw, wood chips and wood pellets.

2.2 North America

North America solutions to GHG emissions are by reducing the coal combustion, increasing the utilization of renewable energy, implementing green manufacturing practices, and taking action on eliminating deforestation [6]. The United States (U.S.) and Canada are the two most powerful North American countries. GHG emissions from the U.S. energy industry are projected to decrease by about 28% from their 2007 value by 2030. Canada also expects to reduce its GHG emissions by 30% from its 2005 level. Table 3 summaries the types of combustion and primary feedstocks for both of the country.

Table 3
Type of combustion and primary feedstocks for North America countries [6]

Country	Type of Combustion	Primary Feedstock
USA	Direct (pulverized coal fired boiler)	Wood pallets, wood chips, wood wastes, railroad ties
Canada	Direct co-firing	Agricultural products, forest residues, domestic and municipal waste, and energy crops

All biomass co-firing power plants in the U.S. use direct co-firing, which mostly uses a pulverized coal fired boiler [6]. Almost 50% of mills in the U.S. use wood products such as wood pellets, wood chips, and wood wastes as the primary source of feedstock for co-firing biomass with coal. While in Canada, the majority of biomass co-firing power plants are also direct co-firing and the primary feedstocks for co-firing include agricultural products, forest residues, domestic and municipal waste, and energy crops.

2.3 South America

Biomass co-firing is not common in South America compared to Europe, considering the abundance of biomass resources. However, the possibilities for biomass co-firing in this region is very promising. Brazil, for example, is one of the richest producers of agricultural waste in the world (such as soy, corn, rice, manioc, wheat, cotton, beans, and sugarcane), yet still uses coal to generate electricity.

Despite its huge potential, Brazil's main agricultural residue producing areas are still far from existing coal-fired power plants [6]. Therefore, it is not economically feasible to introduce co-firing in coal-fired power plants. Building a biomass power plant in a region rich in agricultural residues is one potential solution to address this problem. In this case, the government needs to establish a strong strategy to resolve the seasonality and volatility of raw materials.

2.4 Asia

Some Asian countries such as Japan, China, and South Korea have already adopted co-firing technologies. Biomass production and trade have also increased in countries where new investors are increasingly investing in co-firing biomass. In these regions, wood pellets co-fired with coal are considered the main source of electricity production.

In Japan, 12 coal-fired thermal power units are currently listed as having begun co-firing test trials or having begun commercially co-fired power generation. These plants mainly use forest residues with a 2-3% biomass or coal mixing rate. Most plants in Japan co-fired biomass in their existing coal mills, although some smaller plants use gasifiers.

3. Characteristics of Suitable Biomass for Co-Firing Based on Pervious Examples/Other Countries

Biomass co-firing in coal-fired boilers introduces different types of fuels into the boiler. Several variables need to be considered when coal biomass is co-fired, as the physical and chemical properties of biomass may cause some challenges when feeding higher biomass percentages in the boiler [10]. Furthermore, it is necessary to understand the biomass characteristics as to prevent potential problems such as slagging, fouling and early combustion than coal. In this section, the most important biomass characteristics, including palm oil waste, will be explained in detail.

3.1 Heat value

One of the most important characteristics of a fuel is the heat value or the amount of heat contained in a fuel (kJ/kg). This is because heat value shows the total amount of energy available in the fuel. The heat value can be representing in two ways, by the higher heating value (HHV) or by the lower heating value (LHV) [11].

The HHV also known as the gross calorific value, can be measured experimentally with an adiabatic calorimeter in the laboratory, and it is always use in practical and scientific. This also involves the latent heat of the moisture, which not related to the LHV or the net calorific value. The net calorific value removed latent heat by evaporating the moisture content [12].

3.2 Moisture and Volatiles Content

The characteristics of biomass (such as high moisture and volatile content) influence the grinding, feeding and combustion behavior during combustion. The higher moisture content can limit the capacity if grinders when biomass is co-milled with coal for co-firing. In addition, higher moisture content will reduce the maximum temperature of combustion and increase the time taken for the feedstock to remain in the combustion chamber. This leads to incomplete combustion and increases emissions [10].

For the efficiency of the thermochemical process, it is important to keep the moisture content of the biomass as low as possible, because the high moisture content of the biomass will result in drying costs [13]. In addition, it is also essential to have a low concentration of volatile matter and high activation energy of biomass waste in to prevent early combustion and volatile oxidation.

3.3 Chemical Composition

The difference in characteristics of coal and biomass make it challenging to produce solid fuel for co-firing. Another issues when co-firing biomass with coal is the presence of ash composition in the biomass, which can result in the formation of slags and fouling in the boiler [13]. Generally, woody biomass contains less ash than coal. Its ash composition is produced by chemical components needed for plant growth, while coal ash reflects mineral composition [10].

Harmful substances such as heavy metals can also be found in the biomass ash. In addition, operational problems in the boiler like slagging and fouling can cause when the alkali or alkaline matter namely potassium (K), sodium (Na), magnesium (Mg), and calcium (Ca) when react with silica (Si) [13]. At the same time, biomass ash is characterized by a significant diversification of properties depending on the type of biomass burned and its sources [14].

3.4 Fuel Size and Density

According to previous studies [10], the quantity of biomass that can be co-fired with coal depends on physical properties such as bulk density, distribution of particle size, moisture content, and unrestricted yield strength. Biomass particles are naturally large, with uneven size, shape and density. For co-firing purposes, the biomass must be densified. Low bulk density and uneven distribution of particle size include the physical property limitations of biomass for co-firing with coal. Biomass densification can be done using pellets mills, screw extruders, or briquette presses [10]. This densified biomass can be adapted to the existing boiler design with little or no modification.

One of the most critical keys to an effective co-firing process is to size the biomass appropriately and consistently according to the parameters of the type of boiler used. Biomass that does not meet these specifications may cause flow problems in fuel processing equipment or incomplete burnout in the boiler. The general biomass size requirements for each type of boiler mentioned here are presented in Table 4.

Table 4
Biomass sizing requirements [15]

Existing Type of Boiler	Size Required (mm)
Pulverized coal	≤ 6.35
Stoker	≤ 76.2
Cyclone	≤ 12.7
Fluidized bed	≤ 76.2

4. Required Process for Co-Firing Palm Oil Wastes

The difference in biomass and coal properties makes it challenging to produce solid fuels for co-firing with coal. As biomass has high moisture contents, which will result in incomplete combustion, and the presence of alkali and alkaline elements like potassium (K), chlorine (Cl), and sodium (Na) concentrations may cause problems associated with ash deposition, corrosion, slagging, and fouling inside the combustor [13].

Therefore, few pretreatments of biomass have been developed prior to co-firing with coal and address different biomass characteristics [10] such as leaching or washing, torrefaction, and hydrothermal treatment (HTT). The biomass pretreatment includes converting it into a shape that can be incorporated into the generation plant's fuel chain without much modification to the plant itself. However, palm oil wastes like PKS and PMF are widely used as fuels to generate electricity in the oil palm mills without pretreatment in the boilers due to the high CV and low moisture content of PKS and PMF.

Nevertheless, thermal pretreatment of EFB is required to be regarded as a good fuel. A commercial scale study of EFB, which was conducted using HTT, has increased the CV and reduced the Cl content. HTT of EFB also reduces the moisture content to approximately 3%, improving the drying performance [17] as raw EFB is known for its high moisture content, around 65-67%. [4].

5. Potential of Energy Generation and GHG Reduction

Biomass can provide a great solution for deforestation and greenhouse gas (GHG) emissions [6]. Many advanced countries are working on reducing the emissions of GHGs associated with fossil fuel combustion. Governments in different countries are attempting to implement various policies and to include subsidies in order to promote the use of biomass in the energy sector [6]. Over the years, a number of oil palm biomass power plants have begun operations in Malaysia and their target is to reduce the GHG emissions.

The palm oil industry in Malaysia leaves behind an enormous amount of biomass from its plantation and milling operations, as shown in Table 5, which is much higher relative to other biomass types [20]. Palm oil waste, such as EFB, PMF, and PKS, can be used to produce steam for processing and generating electricity. The basic pretreatment process required for the effective use of palm oil waste due to their properties [19], e.g. a drying process to reduce the moisture content and shredding machine to reduce the size of EFB.

Table 5
Biomass potential for power generation in Malaysia [20]

Biomass Type	Quantity, Ktonne/year	Annual Generation Potential, GWh	Maximum Energy Potential, MW
EFB	16,700		
PMF	12,200	28,000	3,150
PKS	4,900		
POME	38,900	2,800	320
Wood Chips	2,200	600	70
Rice Husks	400	300	30
Bagasse	300	200	25
TOTAL	58,500	31,900	3,595

Other than that, the oil palm tree known as a carbon neutral element [5,10], because when it's going through a combustion process or decomposition, the amount of carbons emitted into the atmosphere is equivalent to what they have absorbed. Therefore, it is noteworthy that, this biomass is a sustainable source of raw materials and energy. Palm oil has also been in the spotlight as an alternative bioenergy sources to solve fossil fuel problems. It has been proven to be a potential alternative to reduce the negative environmental impact of global warming due to its environmentally friendly nature [21].

6. Conclusions

Co-firing biomass with coal is a promising alternative to reduce greenhouse gas (GHG) emission and can minimize biomass wastes that related to its disposal. Most of the existing co-firing biomass in other countries are using wood pellets in their boiler. However, due to the lack of biomass resources in some of the countries such as Denmark, its result in the increased demand of biomass that can bring negative impact on the economy.

The utilization of palm oil waste in Malaysia is a key factor in providing a long-term approach to Malaysia's energy needs as well as in supporting sustainable development. Palm mesocarp fiber (PMF) and palm kernel shells (PKS) are commonly used in oil palm mills as fuel without pre-treatment due to its high heating value and low moisture content. However, for EFB, it is required to do some pre-treatment followed by densification to modify the physical and chemical properties. This results in significant changes in reducing the moisture content, and increasing the calorific value of EFB.

Subsequently, Malaysia has the potential to be one of the world's major contributors to renewable energy by usage of palm oil waste. In addition, reducing the amount of greenhouse gas (GHS) emission as well as the cost of imported fossil fuel by substituting fossil fuels with EFB, PKS and PMF definitely will benefits Malaysia in terms of economic and environmental. Therefore, further research and development must be carried out to fully utilize it in the power generation industry.

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