THE INFLUENCE OF MOISTURE AND ASH CONTENT OF PALM FIBRE AND SHELL TOWARDS PARTICULATE EMISSION IN PALM OIL MILLS

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I declare that this thesis entitled "*The Influence of Moisture and Ash Content of Palm Fibre and Shell Towards Particulate Emission in Palm Oil Mills*" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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To my beloved family and friends

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ABSTRACT

This study aims is to evaluate the influence of moisture and ash content of palm fibre and shell on particulate emission in palm oil mill boilers. The particulate mass emission concentration of size segregated particulate of PM2.5 (particulate with diameter less than 2.5μm) and PM10 (particulate with diameter less than 10μm) was estimated from the total particulate mass. The influence of the operational condition of the boiler on particulate emission was scrutinized based on fuel feeding rate, palm fibre and shell and air to fuel (A/F) ratio. The particulate morphology and the elemental composition of the fly ash were also investigated. A total of five biomass fired boilers found in palm oil mills, with steam capacity ranging from 17 to 35 ton/hr were selected in this study. Samples of palm fibre and shell, bottom ash, retained and stack fly ashes were collected from each of the boilers. The stack fly ash was sampled iso-kinetically following the USEPA Method 17, while the others were collected on the day of the sampling. The result showed that the proximate analysis of the palm fibre and shell had the highest moisture and ash content as compared to other biomass fuels. The study also showed that the average total particulate (TP) emission concentration emitted from the stacks was 2.2±0.9 g/Nm^3, ranging from 0.4 to 3.8 g/Nm^3 (corrected to 7% O_2). A high ash content of the biomass fuel contributed to higher particulate emission and similarly, high A/F ratio also promoted high particulate emission. The particulate size analysis showed that the under size 50% cumulative particulate distribution of the stack and retained fly ash ranged from 1.3 to 38 and 60 to 350μm, respectively. Meanwhile, the particulate emission of PM2.5 and PM10 were estimated to range from 0.03 to 0.30 and 0.37 to 0.73 g/Nm^3, respectively, which represented 0.8% to 71% and 13% to 95% of the total particulate emission concentration. The calculated Particulate Emission Factor (PEF) based on palm fibre and shell feeding rate for TP, PM10 and PM2.5 were found to be 12, 1.5 and 0.5 g/kg, respectively. A total of 13 elements were determined in the stack fly ash, with Zn was found to be extremely enriched. The maximum predicted ground level concentration (GLC) of PM10 and PM2.5 based on the air dispersion modelling was found in average of 25.9±8.7 and 12.5±11.8 μg/m^3, respectively occurring between 500 and 600m distance away from the stack. The predicted GLCs for both particulate pollutants were significantly lower than the Malaysia Ambient Air Quality Standards based on 24-hour averaging time and were compared with the AERMOD modelling. The health risk assessment impact of PM2.5, PM10 and selected elemental components such As, Cr and Ni found in the stack fly ash indicated that the emission from the boiler was unlikely to pose any significant impact towards human population in the vicinity.

ABSTRAK

Kajian ini bertujuan untuk menilai kesan kandungan lembapan dan abu bagi sabut dan tempurung kelapa sawit terhadap ciri-ciri emisi partikel dari kilang kelapa sawit. Jumlah kepekatan emisi jisim partikel dan partikel bersaiz PM2.5 (partikel berdiameter kurang daripada 2.5µm) dan PM10 (partikel berdiameter kurang daripada 10µm) telah dianggarkan daripada jumlah jisim emisi. Pengaruh daripada keadaan operasi dandang terhadap emisi partikel dinilai berdasarkan kadar suapan bahan bakar, nisbah sabut dan tempurung kelapa sawit, dan nisbah udara dan bahan bakar. Morfologi partikel dan komposisi asasi unsur dalam sampel abu turut dinilai. Sebanyak lima kilang kelapa sawit yang beroperasi dengan kapasiti stim daripada 17 hingga 35 ton/jam telah dipilih dalam kajian ini. Sampel sabut dan tempurung kelapa sawit, abu dandang, abu siklon dan abu serombong telah diambil dari setiap kilang. Abu serombong telah disampel secara iso-kinetik mengikut USEPA Metod 17, manakala sampel lain diambil pada hari yang sama. Dapatan kajian menunjukkan analisis proksimat sabut dan tempurung kelapa sawit mempunyai kelembapan dan kandungan abu tertinggi berbanding biojisim yang lain. Kajian ini juga menunjukkan purata kepekatan emisi keseluruhan partikel (TP) yang keluar daripada serombong adalah 2.2 ± 0.9 g/Nm^3, berjulat daripada 0.4 hingga 3.8 g/Nm^3 (berdasarkan kepada 7% O_2). Kandungan abu dalam biojisim menggalakkan penghasilan emisi partikel yang lebih tinggi dan perkara yang sama turut berlaku apabila nisbah udara terhadap bahan bakar yang tinggi digunakan. Analisis saiz partikel menunjukan bahawa pada 50% taburan kumulatif partikel di bawah saiz bagi abu serombong berjulat antara 1.3 hingga 38 µm dan bagi sampel abu siklon, adalah 60 hingga 350µm. Manakala, emisi partikel PM2.5 dan PM10 dianggarkan di antara 0.03 hingga 0.30 dan 0.37 hingga 0.73 g/Nm^3, masing-masing mewakili 0.8% hingga 71% dan 13% hingga 95% daripada jumlah kepekatan emisi partikel. Purata anggaran faktor emisi partikel (PEF) berdasarkan kadar suapan sabut dan tempurung kelapa sawit bagi TP, PM10, dan PM2.5 masing-masing adalah 12, 1.5 dan 0.5 g/kg. Sejumlah 13 unsur telah ditentukan dalam abu serombong, dengan kepekatan unsur Zn didapati sangat diperkaya. Kepekatan maksimum di permukaan tanah (GLC) bagi PM10 dan PM2.5 berdasarkan model penyebaran udara dianggarkan dengan purata sebanyak 25.9±8.7 and 12.5±11.8 µg/m^3, dengan jarak 500 hingga 600m dari serombong. GLC yang dijangka untuk kedua-dua partikel bahan cemar adalah rendah jika dibandingkan dengan Standard Kualiti Udara Ambien Malaysia berdasarkan jangka masa purata 24 jam dan nilai ini juga dibandingkan dengan model AERMOD. Penilaian risiko kesihatan bagi PM2.5, PM10 dan unsur As, Cr dan Ni di dalam abu serombong menunjukkan emisi dari dandang kelapa sawit tidak memberikan kesan signifikan terhadap penduduk sekitar.

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LIST OF ABBREVIATION

Al	-	Aluminium
Al_2O_3	-	Aluminium oxide
As	-	Arsenic
Ba	-	Barium
Br	-	Bromine
C	-	Carbon
Ca	-	Calcium
CaO	-	Calcium oxide
Ce	-	Cerium
CH4	-	Methane
Cl	-	Chlorine
CO	-	Carbon monoxide
CO_2	-	Carbon dioxide
Cr	-	Chromium
Cu	-	Copper
DOE	-	Department of Environment
PEF	-	Particulate Emission factor
Ef	-	Enrichment factor
EFB	-	Empty fruit bunches
Fe	-	Ferum
Fe_2O_3	-	Ferric oxide
FFB	-	Fresh fruit bunches
FT	-	Fire-tube
H	-	Hydrogen
HCl	-	Hydrochloric acid
HNO_3	-	Nitric acid

ICP-OES	-	Inductively coupled plasma optical emission spectrometry
K	-	Potassium
K_2CO_3	-	Potassium carbonate
K_2O	-	Potassium oxide
K_2SO_4	-	Potassium sulphate
KCl	-	Potassium chloride
Lu	-	Lutetium
MAAQS	-	Malaysia Ambient Air Quality Standards
Mg	-	Magnesium
Mg	-	Magnesium
MgO	-	Magnesium oxide
Mn	-	Manganese
MPOB	-	Malaysian Palm Oil Board
N	-	Nitrogen
Na	-	Sodium
Na_2O	-	Sodium oxide
NaHMP	-	Sodium hexametaphosphate
Ni	-	Nickel
NO	-	Nitrogen monoxide
NO_2	-	Nitrogen dioxide
NO_x	-	Nitrogen oxide
O	-	Oxygen
O_3	-	Ozone
P	-	Phosphate
P_2O_5	-	Phosphorus oxide
PAH	-	Polycyclic aromatic hydrocarbon
Pb	-	Lead
PM	-	Particulate matter
PM1.0	-	Particulate below 1.0 µm in aerodynamic diameter
PM10	-	Particulate below 10 µm in aerodynamic diameter
PM2.5	-	Particulate below 2.5 µm in aerodynamic diameter
POME	-	Palm oil mill effluent
Rb	-	Rubidium

S	-	Sulphur
Sc	-	Scandium
SEM	-	Scanning electron microscope
SiO_2	-	Silica oxide
SO_2	-	Sulphur dioxide
SO_3	-	Sulphur oxide
SO_x	-	Sulphur oxide
Sr	-	Srontium
Th	-	Thorium
Ti	-	Titanium
US EPA	-	United States Environmental Protection Agency
V	-	Vanadium
VOC	-	Volatile organic compounds
WHO	-	World Health Organizations
WT	-	Water-tube
Yb	-	Ytterbium
Zn	-	Zinc

LIST OF SYMBOL

ΔH	-	Pressure drop across orifice meter
ΔP	-	Velocity pressure
A_n	-	Area of nozzle
A_s	-	Area of stack
B_{ws}	-	Fraction of moisture content
C_s	-	Particulate mass concentration
C_{sN}	-	Particulate mass concentration at normal condition
I	-	Isokinetic
K	-	Constant
M_s	-	Molecular of weight of gas on wet basis
P_{bar}	-	Barometric pressure
P_s	-	Stack gas pressure
Q_a	-	Volumetric flow rate
Q_m	-	Particulate mass emission rate
t	-	Sampling time
T_m	-	Metered temperature
T_s	-	Stack gas temperature
V_m	-	Dry gas volume sampled
V_{mN}	-	Dry gas volume sampled at normal condition
V_s	-	Stack gas velocity
V_{wc}	-	Volume of water collected
V_{wcN}	-	Volume of water collected at normal condition
W_t	-	Weight of particulate collected

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CHAPTER 1

INTRODUCTION

1.1 Background

Biomass has been widely used as an alternative replacing fossil fuel such as oil, coal and natural gas. Currently, the carbonaceous material has covered up about 10-15% of the worldwide energy demand. This percentage are expected to rise in the future as the world energy council projected that the renewable source energy would present 30% of the direct fuel usage and 60% of the global electricity supply by 2025 (Koh and Hoi, 2003). Numbers of literatures have discussed on the advantages of utilising biomass as fuel. Vassilev *et al.* (2010) reported that the renewable fuel have low content of ash, C, S, N and also trace element, which are related to SO_2 and NO_x gaseous emission. As a comparison with fossil fuel, Fernández *et al.* (2012) listed a few point on the biomass advantages such as lower ash content and cheaper fuel. In addition, biomass is also known as CO_2 neutral as it consumes CO_2 during the growth period for photosynthesis process and release it during the combustion (Werther *et al*., 2000).

Biomass can be grouped into several general categories such as woody, herbaceous and agricultural, aquatic, animal and human waste, industrial and mixture biomass (Vassilev *et al.*, 2010). One of the biomass category that have high potential and being used in Malaysia is the agricultural residue such as palm fiber and shell (F&S), rice husk, sawdust and also municipal solid waste. The abundant amount of agricultural residue are not wasted and transformed into source of energy. The palm

fibre and shell for example, were burned in boilers for steam generation and also electricity. In 2003, palm oil mills in Malaysia were estimated to release 300MW electricity from palm fibre and shell combustion and this amount is enough to be supplied through the whole mill (Najmi and Abdullah, 2011).

Although the biomass fuel have already been used for a long time, study on the emission generation from biomass combustion and its impact towards health and environment are still limited. Several issues have been raised up regarding to the characteristics of the fuel and the combustion strategies that closely related to the emission profile. High amount of the biomass that comprise of wide diversity of composition and variables makes it hard to generalize the characteristic of the fuel. A study on particulate emission from biomass combustion concluded that the characteristics of biomass fuel, combustion operating system and appliances have significant impact towards the release of the particulate emission (Obaidullah *et al.*, 2012). In addition, the presence of potassium, chlorine, sulphur, sodium and zinc in biomass fuel might create operational problems.

In Malaysia, the palm oil mills are generating an average of 51.7±5.4 g/s dust load from the burning of palm fibre and shell in the boiler. It is estimated that the particulate control system need to achieve at least 91% efficiency in order to comply with the previous Environment Quality (Clean Air) Regulations limits of 0.4g/Nm^3 (Kun and Abdullah, 2013). Most of the mills are equipped with the multi-cyclone to filter the particulate emission but somehow the system only manage to capture most of the coarser size particulate while fine particulate emitted to the atmosphere. Syahirah *et al.* (2014) discovered that 13.7% of the total particulate that are emitted from the stack of a palm oil mill were represent by particulate of less than 10 microns or also known as PM10.

Limited work have been done in understanding the behaviour of the palm fibre and shell combustion in the boiler that contributes to the particulate generation. Thus, this study is aim to find the association between the palm fibre and shell fuel characteristics and boiler operating parameters towards the mass concentration, size and elemental content of particulate emission. Suggestion and recommendation to

overcome the air pollution issues in the palm oil mills based on the findings in this study and literatures were also presented in the last chapter.

1.2 Problem Statement

The utilization of biomass as a source of renewable energy has brought substantial benefits as far as the environment is concern. In Malaysia, biomass residue such as palm fibre and shell is used as fuel in the mill boiler to generate electricity. This process helps to dispose off the abundance of these waste materials. However, the combustion process releases tremendous amount of particulates which can be harmful to the environment. Numbers of epidemiological studies have shown that the particulate emission in ambient air can cause adverse health impact (Pope *et al.,* 1995).

There are three main reason behind the initiation of this research. Firstly, numbers of literatures and analysis on particulate emission from palm oil mill boiler in Malaysia is still limited. There are only a few studies on particulate emission from palm oil mill boiler were done based on-site stack measuring. Meanwhile, most of the available documentation, are based on stimulation and assumption. Sune *et al.* (2015) showed that the numbers of publication in emission and impacts from palm oil sustainability area under ISI journal from year 2004 to 2013, was very low although publication on palm oil production increases every year. In this particular study, the data where obtained from on-site measuring at the stack gas, which can give more accurate and beneficial data. Moreover, there are lack of studies on investigating the influences of certain operating conditions of the boiler, such as, the amount of excess air and fuel to air ratio towards the generation of particulate.

Secondly, the new regulation for air quality set by the Department of Environment of Malaysia (DOE), become a motivation for the researches to provide a deep and substantial knowledge on particulate emission from palm oil mill boiler. The new standard for total particulate matter from fuel burning equipment based on

Clean Air Regulations 2014 is currently 0.15g/Nm^3, 62.5% more lenient from the previous limit at 0.40g/Nm^3. Yusoff (2004) had highlight the importance of having an efficient air pollution control system in the palm oil mill, claiming that the current multi-cyclone is adequate but still insufficient to comply with the regulations. Study on the particulate emission characteristics would definitely help to estimate the control strategies that are needed in the mill.

Finally, data on size-segregated particulate emission, especially on particulate matter with diameter size less than 10µm (PM10) and particulate matter with diameter size less than 2.5µm (PM2.5) from palm oil mill boiler are still non-existence. The Department Of Environment Of Malaysia have promulgated the air quality standard for PM10 and PM2.5 in the Malaysia Ambient Air Quality Standards 2013, due to the impact of the fine particulate towards human health and environment. By having this research, the particulate emission of PM10 and PM2.5 can be analyse and mitigation step to control the particulate matter from being disperse to the environment can be suggested.

The findings from this research will be beneficial in understanding the factors that affect the generations of particulate from the combustion of palm fibre and shell in terms of their mass concentration, size distribution, morphology and chemical characteristics. Hence, required action can be suggested to promotes efficient combustion characteristics and control strategies.

1.3 Research Hypothesis

The moisture and ash content of the palm fibre and shell have a direct impact on the generation of particulate emission in palm oil mill boilers. It is expected that by having a high moisture and ash content of the fuel will result in higher particulate concentration and size compared with drier fuel and lower ash content. Furthermore, the oxygen supplied and air to fuel ratio of a palm oil mill boiler would influence the particulate formation. In this regard, too high or too low amount of oxygen and air to fuel ratio will result in poor combustion state, and produce high concentration of particulate emission. As the palm oil mill boiler is combusting palm fibre and shell as their fuel, it is expected that it is unlikely the particulate emission to impose any significant impact towards human population in the vicinity.

1.4 Research Objectives

Generally, the main objective of this study is to investigate the characteristics of particulate emission from biomass combustion. The specific objectives of the study are:

i. To evaluate the influence of moisture and ash content of palm fibre and shell on particulate emission from the palm oil mill boilers.
ii. To investigate the influence of boiler operating conditions on particulate emission from the palm oil mill boilers.
iii. To analyze and evaluate the physical and elemental characteristic of palm fibre and shell ash content of bottom ash, retained fly ash and stack fly ash.
iv. To perform and evaluate the health risk assessment of size segregated particulate and selected metals emission from the boiler using air dispersion modelling.

1.5 Scope of Study

The palm fibre and shell fuel characteristics and particulate emission characteristics from five different palm oil mill boilers were investigated in this study. These mills were selected based on their availability to do sampling and difference on the boiler capacity of each mill. The boiler capacity ranging from 25,000 to 45,000 kg of steam per hour and all of the boilers are equipped with multi-cyclone particulate arrestor. Questionnaire were given out to the mills representative in order to get the detail operation of the boiler and multi-cyclone configuration. Information obtained from the questionnaire were further analysed to find the relation between boiler operating condition and particulate emission. Samples of palm fibre and shell, bottom ash, retained fly ash and stack fly ash were collected in this study. The stack fly ash samples were collected according to the USEPA Method 17: 'Determination of in-stack particulate emissions from stationary sources'. As the sampling were done based on real operating condition, the average number of stack sampling were limit at maximum of three sampling.

The first part of the study is to find the correlation between the characteristics of the palm fibre and shell and the boiler operating condition towards the generation of particulate emission in the palm oil mill boilers. Palm fibre and shell were analysed for their moisture content, ash content, volatile matter and fixed carbon by proximate analysis. The analysis were done in a laboratory and it is following the ASTM standard method. Furthermore, information of the oxygen and carbon dioxide level at the stack gas were analysed. Information from this analysis were examined in order to find their role in contributing towards particulate emission generation. In addition, the size segregated of PM2.5 and PM10 particulate in the stack fly ash were also examined to find their contribution towards the total particulate emission and emission factor. The performance of the multi-cyclone were also evaluated to find the efficiency of the particulate arrestor to capture fine particulate matter.

The morphology of the bottom ash, retained fly ash and also stack fly ash were presented accordingly. In addition, the elemental constituent based on qualitative and quantitative measurement for selected particulate samples were also

examined and compared with the particulate emission elemental from coal combustion. Analysis such as elemental enrichment factor and total elemental burden were also performed.

Finally, the air dispersion modelling were performed using Gaussian equations and analyse the downwind distance of selected particulate emission concentration. The results were then compared with more sophisticated air dispersion modelling software, AERMOD. In addition, risk assessment of PM2.5, PM10 and selected metal content on particulate were analysed for their Health Quotient (HQ) level.

1.6 Significant of the Study

Combustion of palm fibre and shell in the palm oil mills are releasing tremendous amount of particulate emission. In this study, information on the particulate mass emission concentration from five palm oil mill boilers reveal the state of compliances of the examined source towards its emission standards. In addition, the promulgation of the Clean Air Regulations 2014 by the Department of Environment is more stringent is imposed on the industry. Furthermore, the effectiveness of the air pollution control system which is the multi-cyclone can be calculated and analysed for further improvement.

Further understanding on the influence with regard to selected palm fibre and shell characteristics and boiler operational parameters towards particulate emission in palm oil mill boilers could recommend a range value of these parameters that can improves the combustion efficiency and helps to control the formation of the particulate emission. To the best knowledge of the author, these information are still lack and more to explore. In this regard, the particulate emission problems in the palm oil mills can be overcome by handling the source that creates the problems.

This study also evaluate the characteristics of particulate emission in terms of its size segregation and elemental constituents which are potential in causing health and environment deterioration. Estimation of PM10 and PM2.5 dispersion towards the ambient using Gaussian equations and AERMOD can contribute towards ambient air quality and its probable impact can also be assessed with the information. In addition, the development of Particulate Emission Factor (PEF) in this study is beneficial to the authority as a tool to study the impact of a newly proposed mil. This information can also be used as a part of environmental impact assessment.

In addition, information on particulate emission according to its size segregation and its morphology could give a better understanding on the performance of the air pollution control system installed in the mills. This information are also essential for designing a new particulate control device in order to get a higher performance device.

1.7 Outline of the thesis

Chapter 1 presents an overview of this study. It generally describe the basis and background of doing this research. The problem statement describe the importance of the research. Moreover, the objectives and scope of the study were also included in this chapter to give a better view for the reader.

Chapter 2 presents literature review that are related with this study. The literature review generally describe the world demand on alternative energy such as biomass fuel. This chapter also discuss the important characteristics of biomass fuel from proximate analysis and ultimate analysis. Several type of biomass were also included in the discussion. Next, the mechanism and combustor apparatus of biomass fuel combustion were presented. Review on particulate emission generation from biomass fuel combustion and factors that affecting the generation process were also featured in this chapter. Finally, study on palm oil boiler particulate emission were compiled and discussed.

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