NUMERICAL AND STATISTICAL ANALYSIS OF ENERGY CONTENT OF SHELL-FIBRE-EFB MIXTURE 1

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ABSTRAK

Serabut, tempurung dan dahan buah kosong merupakan sisa-sisa atau bahan buangan di dalam proses pengekstrakan minyak kelapa sawit. Sisa-sisa bahan buangan ini boleh membawa keuntungan apabila ia digunakan sebagai bahan bakar pejal di dalam pendidih stim bagi menghasilkan kuasa eletrik. Kandungan tenaga bahan dikenali sebagai LHV (nilai pemanasan rendah) dan HHV (nilai pemanasan tinggi). Terdapat 2 kaedah untuk menilai kandungan tenaga di dalam bahan tersebut; iaitu kaedah eksperimen atau kaedah pengganggaran daripada model-model matematik. Kaedah eksperimen dijalankan dengan menggunakan oksigen bom kalorimeter manakala kaedah model matematik adalah berdasarkan data komposisi fizikal, analisis penghampiran dan analisis penghabisan di mana ia adalah kandungan utama dalam penyelidikan ini. Matlamat penyelidikan ini adalah untuk mengira HHV bagi serabut, tempurung dan dahan buah kosong dengan menggunakan model matematik yang sesuai dan menganalisis data dengan kaedah analisis statistic dan numerik. Dalam penyelidikan ini, sebanyak 12 model matematik berdasarkan analisis penghabisan telah dipilih untuk dianalisis; data komposisi unsur-unsur telah didapatkan daripada 2 buah kilang minyak kelapa sawit. Komposisi unsur-unsur tersebut merupakan data input kepada 12 model-model untuk mengira HHV bagi campuran serabut, tempurung dan dahan buah kosong dalam nisbah peratusan yang berbeza-beza. Seterusnya, analisis statistik dijalankan bagi membandingkan keputusan dalam lingkungan model-model dan membandingkan keputusan model-model dengan HHV yang sebenar. Analisis statistik menunjukkan bahawa model original atau modified Dulong, model Scheurer-Kestner, model Boie, model Inst. for Gas Tech., model Demirbas dan model Jenkins boleh digunakan untuk mengira HHV bagi kilang kelapa sawit pertama sahaja kerana mereka mempunyai perbezaan statistik yang tidak nyata. Manakala, model Mott & Spooner dan model Channiwala & Parikh, adalah tidak sesuai digunakan untuk mengira HHV bagi kedua-dua kilang kelapa sawit yang dikaji kerana mereka mempunyai perbezaan statistik yang sangat nyata bagi kedua-dua kilang tersebut. Model yang terbaik yang boleh digunakan untuk menilai HHV bagi campuran serabut, tempurung dan dahan buah kosong dalam nisbah peratusan yang berbeza ialah model Steuer dan Graboski & Bain kerana mereka mempunyai perbezaan statistik yang tidak nyata bagi kedua-dua kilang kelapa sawit.

ABSTRACT

Empty fruit bunches (EFB), fibre and shell are the wastes produced during the extraction process of palm oil. The wastes are capable to generate revenue when used as solid fuel in steam boiler to generate electricity or energy for daily operation of palm oil mill. The energy content of wastes is described in lower heating value, LHV and higher heating value, HHV. The heating value is one of the most important properties of biomass fuels for design calculations or numerical simulations of thermal conversion systems for biomass. Generally, there are 2 methods to compute the energy content of solid wastes; prediction by semi-empirical models or experimental. The semi-empirical models are based on the data from physical composition, proximate analysis and ultimate analysis; the experiment is conducted using oxygen bomb calorimeter. The aim of this research is to compute the HHV for Shell-Fibre-EFB at different percentages using suitable semi-empirical models and analyse the data based on HHV, numerically and statistically. In this research, 12 semi-empirical models based on ultimate analysis were selected to be analysed; the elemental compositions data were obtained from 2 oil palm mills and used as the data input to the 12 models to compute the HHV of Shell-Fibre-EFB at different percentages. Then statistical analysis was applied to compare the results within the models and result based on models was compared with the actual HHV. The statistical analysis indicates that modified or original Dulong models, Scheurer-Kestner model, Boie model, Inst. for Gas Tech. model, Demirbas model and Jenkins model can be used for the computation of HHV in mill 1 only because they have statistically insignificant difference between actual HHV and computed HHV, whereas Mott & Spooner model and Channiwala & Parikh model can not be used for computation of HHV in both mills 1 and 2 because they have statistically highly significant difference. The best semi-empirical model which can be applied to compute the HHV of Shell-Fibre-EFB at different percentages are the Steuer model and Graboski & Bain model because they have statistically insignificant difference between actual HHV and computed HHV for both mill 1 and mill 2.

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LIST OF SYMBOLS

A	Ash
BOD	Biochemical Oxygen Demand
C	Carbon
CIRP	Christmas Island Rock Phosphate
Cl	Chlorine
CPO	Crude Palm Oil
$C_{\alpha,k}$	Coefficient of elemental chemical composition *k* based on HHV semi-empirical model α
db	dry-basis
df	Degree of Freedom
DOE	Department of Environment
ETP	effluent treatment plant
EFB	Empty Fruit Bunches
ε_r	Error Generated in percentage (%)
F	Computed F-test based on ANOVA 1-way statistical analysis
$F_{0.05}$	F-test at α= 0.05 based on statistical Table, appendix A
$F_{0.01}$	F-test at α= 0.01 based on statistical Table, appendix A
FFB	Fresh Fruit Bunches
GHV	Gross Heating Value (MJ/kg)
HHV	Higher Heating Value (MJ/kg)
HHV_{α}	Higher Heating Value of Semi-Empirical Model (MJ/kg)
$HHV_{\alpha,j}$	Higher heating value of semi-empirical model α in set of mixture *j* (MJ/kg)
HHV_{exp}	Higher Heating Value of Experimental (MJ/kg)
$HHV_{exp,j}$	Higher heating value of experimental based on the percentages of Shell-Fibre-EFB in set mixture *j* (MJ/kg)

HHV_i	Higher heating value of experimental for the fuel *i* (MJ/kg)
H_2	Hydrogen
H_2O	Moisture
$H_2O_{wb,i}$	Mass of element H_2O for fuel *i* based on wet-basis percentages by weight (%)
HS	Highly Significant
i	Fuel contains in mixture, (i = 1 to 3)
j	Number set of mixture, (j = 1 to 11)
k	Elemental chemical compositions of fuel *i*, (k = 1 to 7)
LHV	Lower Heating Value (MJ/kg)
MF	mesocarp fiber
MOP	Muriate of Potash
$m_{k,i}$	Mass of element *k* for fuel *i* based on dry-basis percentage by weight (%)
$M_{k,j}$	Elemental chemical composition of fuel *i* based on the percentages of Shell-Fibre-EFB in set of mixture *j* (%)
MS	Mean Square
N_2	Nitrogen
NHV	Net Heating Value (MJ/kg)
NS	Not significant
O_2	Oxygen
$P_{i,j}$	Percentage of fuel *i* for the set of mixture *j* (%)
POME	Palm Oil Mill Effluent
$Q_{k,i}$	Mass of element chemical composition *k* for fuel *i* based on wet-basis percentage by weight (%)
S	Sulphur
S_1	Standard Deviation 1
S_2	Standard Deviation 2

SE	Standard Error
SESB	Sabah Electricity Sdn Bhd
SF	Significant
SS	Sum of Squares
T	Computed T-test
$T_{0.05}$	T-test at α= 0.05 based on statistical Table, appendix B
$T_{0.01}$	T-test at α= 0.01 based on statistical Table, appendix B
TSHRB	TSH Bio-Energy
wb	wet-basis
W	Moisture

CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

Palm oil is one of the most important revenue earners for Malaysia. In the year of 2006, Malaysian oil palm industry recorded an impressive performance, total export oil palm products 20.13 million tonnes with the earnings of RM 31.8 billion. Malaysia is the world's largest producer and exporter of palm oil (MPOB, 2007). Palm oil is derived from the fruit flesh of the oil palm. The main by-product and wastes produced from the processing of palm oil are the empty fruit bunches [EFB], palm oil mill effluent [POME], sterilizer condensate, palm fibre and palm kernel shell. The weight analysis of fresh fruit bunches [FFB] was found to be 51% palm oil, 6–7% palm kernel, 14–15% fiber, 6–7% shell and 23% EFB (Husain *et al.,* 2003). The shell, empty fruit bunches and pressed fibre from the mills can be used as solid fuel for the steam boiler to generate steam and electricity required for the operation of the mill or feed the substantial additional electricity to the national grid (Khoo & D Chandramohan, 2001).

Malaysia's major energy demand is fulfilled by the conventional energy resources like coal, petroleum, hydropower and natural gas. Recently, Malaysia government has stated that the renewable energy as the fifth energy source. Biomass and solar have been identified as major renewable energy sources, with priorities on conversion of palm oil waste to energy (CSMR, 2005).

1.2 BACKGROUND OF STUDY

Based on the research done by Friedl (2005), the heating value of biomass is an important parameter for the planning and the control of power plants. The 'higher heating value' (HHV), also called gross calorific value, is the enthalpy of complete combustion of a fuel with, for instance, all carbon converted to CO_2, and all hydrogen converted to H_2O. The higher heating value is given for standard conditions (101.3 kPa, 25 °C) of all products and has included the condensation enthalpy of water. The 'lower heating value' (LHV), also called net heating value, is obtained when the condensation enthalpy of water is not included (Friedl *et al.*, 2005).

The most common methods currently being practiced to evaluate the heating value of Municipal Solid Waste (MSW) are by using the equation derived by Dulong or experimentally by using the bomb calorimeter. There have been various other semi-empirical equations, which were created based on data from the physical composition, proximate or elemental analysis (ultimate analysis) of the MSW (Sivaplan *et al.*, 2003).

Biomass fuels are characterized using the Proximate and Ultimate analysis. The proximate analysis gives the moisture content, volatile content (when heated to 950 °C), free carbon remaining at that point, ash (mineral) in the sample and HHV based on the complete combustion of the sample to carbon dioxide and liquid water. Whereas, the ultimate analysis gives the composition of the biomass in fraction weight (% wt) of carbon, hydrogen and oxygen (the major components) as well as sulphur and nitrogen (Tom, 1997).

Lim (1991) have conducted a research to find alternative ways to beneficially utilize EFB, e.g. combustion and composting. In areas where there are energy intensive subsidiary industries near a palm oil mill, EFB can be considered as an energy source similar to the pressed fibre and shell. A pretreatment process is required to prepare the EFB for efficient combustion (Lim, 1991).

1.3 STATEMENT OF PROBLEM

The process of burning the Shell-Fibre-EFB will produces gases which have a harmful effect on the environment in terms of global warming. Regarding to the matter above, it's vital to choose the most optimum HHV in a sense of less harmful to our environment. In additional, the energy content of the Shell-Fibre-EFB at different percentages has not been computed in any palm oil mills. Therefore, this research is to evaluate the energy content (HHV) of the Shell-Fibre-EFB at different percentages. The elemental compositions of Shell-Fibre-EFB in every palm oil mills may not be the same, thus the HHV computed for each palm oil mill may varies from each other.

1.4 OBJECTIVES

The main objectives of this project are:

a) To compute energy content (HHV) for Shell-Fibre-EFB at different percentages.

b) To analyse the energy content (HHV) numerically and statistically.

1.5 IMPORTANT AND BENEFITS OF THE RESEARCH

The energy content of solid fuel Shell-Fibre-EFB plays a good role in designing boiler which will provide steam for steam turbine to generate electricity to feed to a local or national grid. At the same time, the used of fossil fuel is reduced and greenhouse gas emissions mitigated. The HHV is used in the computation of the optimum net energy or power, heat losses and thermal efficiency of the Shell-Fibre-EFB at different percentages.

1.6 RESEARCH SCOPE

The energy content of the Shell-Fibre-EFB at different percentages will be studied; mainly the HHV. This research requires elemental chemical composition of Shell-Fibre-EFB from different palm oil mills. Different existing semi-empirical models will be studied and chosen to compute the HHV of Shell-Fibre-EFB at different percentages. The results from the models will be grouped for analysis, discussion and comparison to experimental results.

1.7 RESEARCH METHODOLOGY

In this research, semi-empirical modelling of twelve models elemental composition of Shell-Fibre-EFB will be conducted. The HHV will be computed and compared using statistical analysis, mainly t-test analysis and ANOVA 1-way analysis. Three widely used equations in design calculation are Dulong's equations, Scheurer and Kestner's equations, and Steuer's equations. All models are based on ultimate or elemental composition analysis. An example calculation is shown on the following page:

Dulong's equation, $HHV = 8080 C + 34,460 H_2 - 4,308 O_2 + 2250 S$ [1.1]

Assume if a coal has $C= 0.76$, $H_2= 0.003$, $O_2= 0.005$, $S= 0.004$ (fraction weight)

$HHV= 8080 \times 0.76 + 34,460 \times 0.003 – 4308 \times 0.005 + 2250 \times 0.004$

HHV= 6231.64 Btu/ℓb

$HHV= (6231.64/0.000948) / 10^6 \times 2.205$ (conversion)

HHV= 14.49 MJ/kg

(Source: Ganapathy, 1993 and Sivapalan *et al.*, 2003)

The percentages of Shell-Fibre-EFB that will be used are shows in Table1.1.

Table 1.1: Percentages of Shell-Fibre-EFB in Mixture 1

Shell (%)	80	60	50	40	20	0	80	60	50	40	20
Fibre (%)	20	40	50	60	80	100	0	20	30	40	60
EFB (%)	0	0	0	0	0	0	20	20	20	20	20
Total (%)	100	100	100	100	100	100	100	100	100	100	100

The following are the brief steps for this research.

Step 1: Collect the elemental compositions of the Shell-Fibre-EFB from different palm oil mills.

Step 2: Collect and classify the 12 semi-empirical models with order.

Step 3: Convert the units of the models to MJ/kg and converting the elemental composition expressed in dry-basis percentage by weight to wet-basis percentage by weight.

Step 4: Compute the higher heating value, HHV of Shell-Fibre-EFB at different percentages.

Step 5: Combine the HHV according to the percentages of Shell-Fibre-EFB from step 3 and 4 then plot the graphs for each of model.

Step 6: Using statistical analysis to compare the computed HHV among the models with the actual experimental HHV.

Step 7: Find out the best models.

Step 8: Discuss the results obtained and make conclusion.

1.8 THESIS ORGANIZATION

This project has been organized into five chapters. The first chapter is the general introduction of this research which contains the background of study, statement of problem, the objectives and etc.

In chapter 2, it gives the literature review regarding to this research, all information that is related to this research will be combined in this chapter. It briefly explains the background of oil palm, the palm oil mill processes, the characteristic of solid waste, the relevant semi-empirical models for computing the HHV and etc.

In chapter 3, the methodology used in this research is shown in detail such as the computation of HHV at different percentages of Shell-Fibre-EFB and decides which suitable semi-empirical models can be used.

In chapter 4, the results of the HHV are shown in graphs, tables or figures, computation of error generated for each models, statistical analysis of computed HHV and discussion after comparing the computed results with real results.

In chapter 5, it will be the conclusion of this research study and also recommendations of this research for further studies.

CHAPTER 2

LITERATURE REVIEW

2.1 BACKGROUND OF OIL PALM

It is generally agreed that the Oil Palm *(Elaeis guineensis)* originated in the tropical rain forest region of West Africa. The Oil Palm was first introduced into the Malaya in 1870 when it was the regarded as an ornamental plant. It was almost fifty years later that its commercial viability as an estate crop was recognized and the first commercial oil palm plantation was started at Tennamaran Estate, Batang Berjuntai in Selangor (MPOC, 2007).

In the sixties, with the increasing demand for edible oils in the world market, coupled with the mounting threat of synthetic rubber, Malaysia embarked on a vast planned agricultural diversification programme. New lands were opened up and old rubber lands were replanted with oil palm. The area under oil palm cultivation was 54, 000 hectares in 1960. Today, forty years later, the area under cultivation has reached 4,000,000 hectares. Sixty years after the first commercial planting on an estate basis, Malaysia has become the world's largest producer and exporter of palm oil. This position is still being maintained today. The production has dramatically increased from 92,000 tonnes in 1960 to an estimated 18,000,000 tonnes for the year 2007. Palm oil is the most productive of all oil plants and in commercial terms, is the one which offers major prospects of development (Michael, 2007).

Oil palm is normally monoic. It produces thousands of fruits, in compact bunches whose weight varies between 10 and 40 kilograms. Each fruit is almost spherical, ovoid or elongated in shape. Generally the fruit is dark purple, almost black before it ripens and orange red when ripe (MPOC, 2007).

The fruit has a single seed – the palm kernel – protected by a wooden endocarp or shell, surrounded by a fleshy mesocarp or pulp. This fruit produces two types of oil: one extracted from the pulp (palm oil) and the other from the kernel (palm kernel oil). Figure 2.1 shows the FFB and the palm fruit.

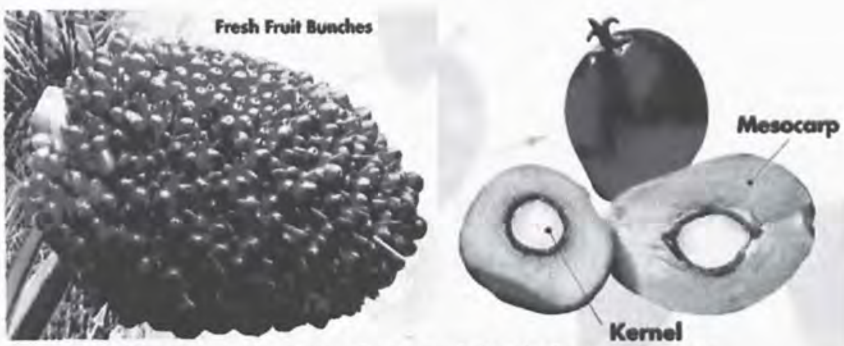

Figure 2.1: Palm fruit and fresh fruit bunches
(Source: MPOB, 2007)

A normal oil palm tree will start bearing fruits after 30 months of planting and will continue to be productive for the next 20 to 30 years. Each ripe bunch is commonly known as Fresh Fruit Bunch (FFB) (MPOC, 2007). In Malaysia, the trees planted are mainly the *tenera* variety. The *tenera* variety yields about 4 to 5 tonnes of crude palm oil (CPO) per hectare per year and about 1 tonne of palm kernels.

2.1.1 The Statistic of Oil Palm In Malaysia

The Table 2.1 shows the total of oil mills, crushing factories and refineries and area planted of oil palm.

Table 2.1: Number and capacities of oil mills, crushing factories, refineries and area planted of oil palm in Malaysia in the year 2007

Region	Oil mills		Crushing factories		Refineries		Area planted
	No.	Capacity[a]	No.	Capacity[b]	No.	Capacity[c]	Hectares
P.Malaysia	247	52,339,800	26	3,369,600	34	11,004,400	2,335,380
Sabah	114	27,772,200	10	1,522,500	13	6,469,000	1,240,000
Sarawak	39	8,336,400	3	495,000	4	1,648,000	589,835
Total	400	88,448,400	39	5,387,100	51	19,122,200	4,165,215

[a]Tonnes of FFB/year , [b]Tonnes of Palm Kernel/year, [c]Tonnes of CPO/year

(Source: MPOB, 2007)

2.1.2 Forecasting

Malaysian palm oil production stood at 15.8 million tonnes last year and was expected to rise to 16.5 million tonnes this year. More than 90% of this was exported, accounting for 57% of world's trade-in palm oil. In 2006, export earnings amounted to RM31.8 billion compared to RM5.4 billion in 1990. Because of effective market development strategies, it is likely that prices will hover close to the international crude petroleum price, which should remain high. This close correlation implies that, for 2007 and from 2008 onwards, palm oil producers can expect higher revenues (Yusof, 2007).

2.2 PALM OIL EXTRACTION PROCESSES

There are 3 types of palm oil extraction processes; they are frying process, dry process and wet process. In the frying process, the FFB is fried in oil under vacuum and the fruits and bunches are pressed to extract the kernel oil. In the dry process, liquid wastes are not produced. This can be done by heating directly the fruits

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