NUMERICAL AND STATISTICAL ANALYSIS OF ENERGY CONTENT OF SHELL-FIBRE-EFB MIXTURE 2

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ABSTRAK

Kilang kelapa sawit menghasilkan bahan buangan dalam kuantiti yang banyak dalam bentuk pepejal, cecair dan gas di mana ia mengandungi potensi bekalan tenaga yang tinggi. Serabut, tempurung dan dahan buah kosong merupakan sisa buangan utama di dalam proses pengekstrakan minyak kelapa sawit. Sisa buangan ini boleh digunakan sebagai bahan bakar pepejal di dalam dandang stim bagi menghasilkan kuasa eletrik. Sebagai pelan jangka masa panjang, proses pencegahan alam sekitar adalah diperlukan dalam proses pengekstrakan minyak kelapa sawit dari segi peningkatan teknologi produktiviti serta penggunaan semula sisa buangan kelapa sawit demi melindungi alam sekitar dari pencemaran di samping menjadi sumber yang berharga kepada negara kita. Terdapat 2 kaedah untuk menilai kandungan tenaga di dalam bahan tersebut; iaitu kaedah eksperimen dan kaedah pengganggaran dari 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. Kandungan tenaga bahan ini dapat ditunjukkan dalam LHV (nilai pemanasan rendah) dan HHV (nilai pemanasan tinggi). Matlamat penyelidikan ini adalah untuk menilai HHV bagi Serabut-Tempurung-Dahan Buah Kosong dalam nisbah peratusan yang berlainan dengan menggunakan pelbagai model matematik. Dalam penyelidikan ini, 12 matematik model-model berdasarkan analisis penghabisan telah dipilih untuk dianalisis; data komposisi unsur-unsur telah didapatkan dari 2 kilang minyak kelapa sawit. Komposisi unsur-unsur tersebut merupakan data input kepada 12 model-model untuk menilai HHV bagi campuran Serabut-Tempurung-Dahan Buah Kosong dalam nisbah peratusan yang berbeza. Seterusnya, analisis statistik ANOVA-1 dijalankan bagi membandingkan keputusan dalam lingkungan model-model dan analisis statistik T-test dijalankan bagi membandingkan keputusan model-model dengan HHV yang sebenar. Analisis statistik menunjukkan bahawa model yang terbaik ialah model Graboski and Bain kerana ia menunjukan perbezaan statistik yang tidak ternyata dengan HHV yang sebenar dalam kedua-dua kilang kelapa sawit. Modal Steuer dan model Mott & Spooner tidak sesuai bagi menilai HHV kerana mereka mempunyai perbezaan statistik yang sangat nyata dibandingkan dengan HHV yang sebenar dalam kedua-dua kilang kelapa sawit, manakala model-model yang lain adalah sesuai digunakan bagi menilai HHV bagi Kilang Pertama tetapi tidak sesuai untuk Kilang Kedua.

ABSTRACT

The palm oil mill generates a number of waste streams included solid residues, liquid effluent (POME) and gaseous emissions which are all have great potential energy resources. Fibre, shell and empty fruit bunches (EFB) is the main solid residues produced during the palm oil extraction process. This biomass can be used as solid fuel in steam boiler for electricity generation purpose. As a long term planning, process integrated pollution prevention and control strategy is needed for extraction of palm oil by improvement of production technology and utilization of palm oil residues in order to protect environment from pollution and generate revenue to our country. There are 2 methods to evaluate the energy content of solid wastes; experimental and prediction by semi-empirical models. The experiment is conducted by oxygen bomb calorimeter; whereas the semi-empirical models are based on the data from physical composition, proximate analysis and ultimate analysis which is the main part of this research. The energy content of wastes can be described in LHV, lower heating value and HHV, higher heating value. This research is carried out in order to evaluate the HHV of the Shell-Fibre-EFB at different percentages using different semi-empirical models. In this research, 12 semi-empirical models based on ultimate analysis were selected to be analysed; the elemental chemical compositions data were obtained from two oil palm mills. The elemental chemical compositions obtained are used as the data input to evaluate the HHV of Shell-Fibre-EFB at different percentages. Then ANOVA 1-way statistical analysis was applied to compare the results within the models and T-test analysis was applied to compare the result based on models with the actual HHV. The statistical analysis shows the best model is the Graboski and Bain because their difference with the actual HHV is statistically not significant for both mills. Steuer model and Mott & Spooner models are not suitable to be used for the HHV computation since they have statistically highly significant differences with the actual HHV for both mills; whereas the rest models are found suitable to be used for computation of HHV in Mill 1 but not suitable for Mill 2.

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LIST OF SYMBOLS

BOD	Biochemical Oxygen Demand
C	Carbon
Cl	Chlorine
COD	Chemical Oxygen Demand
CPKO	Crude Palm Kernel Oil
CPO	Crude Palm Oil
$C_{\alpha,k}$	Coefficient of elemental chemical composition *k* based on HHV semi-empirical model α
df	Degree of Freedom
db	Dry-basis
DOE	Department of Environment
DP	Dry percentage
ε_r	Percentage Relative Error (%)
EFB	Empty Fruit Brunches
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 B
$F_{0.01}$	F-test at α= 0.01 based on statistical Table, appendix B
FFB	Fresh Fruit Brunches
GHV	Gross Heating Value (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 (%)

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)
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)
N_2	Nitrogen
NHV	Net Heating Value (MJ/kg)
NS	Not Significant
$m_{k,i}$	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
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 (%)

RE	Renewable energy
S	Sulphur
SF	Significant
S_1	Standard Deviation 1
S_2	Standard Deviation 2
SE	Standard Error
SS	Sum of Squares
T	Computed T-test
$T_{0.05}$	T- test at $\alpha = 0.05$ based on statistical Table, appendix D
$T_{0.01}$	T- test at $\alpha = 0.01$ based on statistical Table, appendix D
wb	Wet-basis

CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

The fast diminishing energy reserves coupled with increasing energy consumption as a nation develops and greater environmental awareness have led to an intensified search for viable alternate sources of energy. In the 8th Malaysia Plan (2001-2005), Renewable Energy was announced as the fifth fuel in the new Five Fuel Strategy (biomass, biogas and solar) in the energy supply mix after oil, coal, natural gas and hydropower. It is targeted that RE will contribute 5% of the country's total electricity demand over the year. Ministry of Energy, Water and Communication has identified palm oil wastes as the biggest resource that can be easily developed which able to produce 6,379 energy values in RM Million per annual (KTKM, 2002).

Malaysia is now the largest producer and exporter of palm oil in the world, accounting for 52% or 26.3 million tonnes of the total world oils and fats exports in year 2006 (Sumathi *et al.*,2007). Malaysia has already begun preparations to change from diesel to bio-fuels by the year 2008, including drafting legislation that will make the switch mandatory. From 2007, all diesel sold in Malaysia must contain 5% palm oil. Being the world's largest producer of crude palm oil, Malaysia intends to take advantage of the rush to find cleaner fuels (MPOB, 2007). Empty fruit bunches (EFB), fibre and shell are the main solid residues produced during extraction of oil from oil palm. The empty fruit bunches; shell, fibre and liquid effluent can be used much more efficiently to fuel biomass power plants which provide the mills' steam and power requirements and substantial surplus electricity to feed to a local or national grid. Press fibre and shell generated by the palm oil mills are traditionally used as solid fuels for steam boilers. EFB is mostly used as mulch in the field or, in some cases, after incineration and occasionally after composting. In fact, fresh EFB returns mineral nutrients and organic matter to the soil and helps to maintain soil fertility. The palm oil mill effluent (POME) is presently used as fertilizer.

Palm oil fruits are considered as the source to obtain the oil in the palm oil mill. Generally, the normal fresh fruits bunches can be a combination of 51% of palm oil fruits, 6–7% palm kernel, 14–15% of fibre, 6–7% of shell, and 21% of empty fruit bunch (EFB) by weight (Harimi *et al.*, 2004). For a ton of fresh fruit bunch (FFB) of oil palm the following residues are generated at the mill; 0.87 m^3 of waste water (biogas 434.3 MJ per m^3 of wastewater), 0.28 ton of empty fruit bunch (4.6 MJ/kg), 0.12 ton of pressed fibre (9.6 MJ/kg) and 0.08 ton of kernel shell (17.4 MJ/kg). In brief, each ton of FFB gives residue equivalent to 4.2 MJ of heat. The milling process for a ton of FFB requires 20–25 kWh electricity and steam of 0.73 ton (2.5 bar), which requires total primary energy of 2.2 MJ. Thus, surplus energy from the mill is 2 MJ for each ton of FFB being processed (Prasertsan *et al.*, 2005).

1.2 BACKGROUND OF STUDY

The scarcity of conventional fossil fuels, growing emissions of combustion generated pollutants and their increasing costs will make biomass sources more attractive (Sensoz *et al.*, 2000). The most feasible way to overcome these problems is by utilizing alternative fuels. One such fuel that exhibits great potential is utilizing palm oil waste since Malaysian palm oil industry has grown to become a very important agriculture-based industry particularly the large commodity, palm oil.

There are two main products produced by the oil palm fruit namely crude palm oil (CPO) and crude palm kernel oil (CPKO). CPO is obtained from the mesocarp and CPKO is obtained from the endosperm (kernel) (Sumiani, 2004). At present the palm oil industry generates the most biomass from the oil extraction process such as the mesocarp fibre, palm kernel shell, empty fruit bunch (EFB) and palm oil mill effluent (POME) (Shahrakbah *et al.*, 2005). Each of the palm oil waste can be fully utilized in different ways. However, not every waste is suitable as solid fuel combustion purpose. Press fibre and shell are traditionally used as solid fuels for steam boilers to generated steam run turbines for electricity production. The empty fruit bunches (EFB) are traditionally incinerated for its ash which is a very good fertilizer/soil conditioner. However, due to the "white smoke" problem, the Department of Environment (DOE) discourages incineration of EFB. The "white smoke" is mainly contributed by the high moisture (>60%) in the EFB. A pretreatment process is required to prepare the EFB for efficient combustion to decrease the moisture content below 50%, thus generally the EFB is being used as fertilizer or soil mulching in the oil palm plantation.

Combustion is the most common and developed way of converting palm oil waste to energy among the various conversion technologies. The design and operation of biomass combustion systems significantly relies on biomass characteristics such as the density, heating value, moisture content, elemental composition, ash properties, etc (Werther *et al.*, 2000). The heating value (calorific value) or heat of combustion is used to define the energy content of a biomass fuel during the combustion. It is the enthalpy of complete combustion of a fuel including the condensation enthalpy of formed water (Friedl *et al.*, 2005). Based on research done by Sheng (2005), the heating value of a fuel may be described in the higher heating value (HHV) or gross calorific value and the lower heating value (LHV) or net calorific value. The HHV refers to the heat released from the fuel combustion with the original and generated water in a condensed state, while the LHV is based on gaseous water as the product. It can be determined experimentally by employing an adiabatic bomb calorimeter or can be calculated from the data based on the physical composition, proximate or ultimate analysis (elemental analysis). The experimental determination of heating values requires special instrumentation, complicated measurement and is a time-consuming process whereas the conventional analysis, i.e. proximate and ultimate analyses, data can be obtained relatively easily, quickly, and cheaply by using common laboratory equipments (Ayhan, 1996). Proximate analysis presents the weight percent of the moisture, volatile matter, fixed carbon and ash. Ultimate analysis gives the weight percent content of the elemental constituents such as elements Carbon, Hydrogen, Oxygen, Nitrogen, Sulphur and others; where the former three are the major, representing up to 97–99% of the biomass organic mass.

In this research, Dulong's equation will be used as semi-empirical models reference which is based on the ultimate analysis. The formulae based on the ultimate analysis are generally more accurate than those based on proximate analysis, because it quantifies the elemental contents providing more detailed chemical composition information on biomass. The accuracy of the correlations based on the proximate analysis data is very low because the analysis provides only the empirical composition of biomass (Sheng, 2005).

1.3 STATEMENT OF PROBLEM

The world energy demand continues to increase. Presently, the demand of energy is met by fossil fuels (i.e. coal, petroleum and natural gas). However, at the current rate of production the world production of liquid fossil fuel (petroleum and natural gas) will decline by the year 2012 (Sumiani, 2004). Thus, the most feasible way to meet this growing demand is by utilizing alternative fuels. One such fuel that exhibits great potential is biofuel, in particular, biodiesel (Fernando *et al.*, 2006). In addition, protecting the environment has been the priority of many sectors in our endeavor to ensure sustainable development. Differences percentage combination of the fibre, shell and EFB would produce different energy content [calorific value]. Since the energy content of the palm mill wastes has not been proper evaluated in any palm oil mills yet. Thus, this research is to evaluate the HHV of the Shell-Fibre-EFB at different percentage by utilization the palm oil waste. In this research, the evaluation of the HHV is based on the locality of the oil palm cultivation, since different palm oil mills have different elemental compositions of palm oil waste. Therefore, different mills will have its own HHV of the Shell-Fibre-EFB.

1.4 OBJECTIVES

The main objectives of this research are:

a) Evaluate the higher heating value of palm oil waste, mainly fibre, shell and EFB at different percentage, using different semi-empirical models.
b) Deduce the most suitable semi-empirical model to obtain the relation between HHV of the palm oil waste at different percentage of Shell-Fibre-EFB based on different mills.

1.5 IMPORTANCE AND BENEFITS OF THE RESEARCH

In this research, the HHV of the palm oil waste is evaluated which plays a good role in designing boiler that provides the mill's steam and generate the sufficient steam to flow through steam turbine to generate electricity for the whole palm mill power usage purpose. It helps to reduce a mill's reliance on fossil fuels and it reduces greenhouse gas emissions such as carbon dioxide, carbon monoxide, PAHs, nitrated PAHs emissions (Ayhan, 2007). The HHV is used in the computation of the heat losses, the optimum net energy produced from the palm oil waste at different percentage and also evaluate the sufficient thermal efficiency. Different percentage of Shell-Fibre-EFB combination will produce different power during combustion. Thus, it is important to obtain the best combination percentages in this research to benefit palm oil mills for their renewal energy application in real world.

1.6 RESEARCH SCOPE

This research needs data elemental composition of Shell-Fibre-EFB to evaluate the HHV computation at different percentages. These data will be obtained from varies palm oil mills. This research will concern with the energy content of the palm oil waste. The HHV or LHV value of this biomass will be collected for the computation reference. Different semi-empirical models are used to conduct and evaluate the HHV. Subsequently, the most suitable model for computing the HHV of Shell-Fibre-EFB will be decided. Comparison will be made with the results from the models. Analysis and discussion will be conducted for the result obtained.

1.7 RESEARCH METHODOLOGY

The method that will be used to evaluate the element chemical composition of Shell-Fibre-EFB is through semi-empirical models. Numerous empirical equations have been established to estimate the heating value from the elemental composition of fuels as obtained by elemental analysis. Most of these equations are the modifications of the famous Dulong's equation. The following example is given as a sample to clear the idea:

HHV equation = 14500C + 62000(H − O/8) + 4000S

Assume if a coal has C = 0.85, H = 0.002, O = 0.005, S = 0.006 (fraction weight)

$$HHV = 14500(0.85) + 62000(0.002 - 0.005/8) + 4000(0.006)$$

$$HHV = 12434.25 \text{ Btu/lb}$$

$$HHV = (12434.25 / 0.000948) / 10^6 \times 2.205$$

$$HHV = 28.92 \text{ MJ/kg}$$

(Source: Ganapathy, 1994 and Sivapalan *et al.*, 2003)

The higher heating value, HHV, is in MJ/kg; C, H, N, O are mass percentages of carbon, hydrogen and nitrogen, oxygen respectively, in dry biomass. If the unit of the result is not MJ/kg, conversion factor is used to covert the unit. The HHV of the Shell-Fibre-EFB will be calculated for the following percentages:

Table 1.1: Percentages of Shell-Fibre-EFB in Mixture 2

Shell (%)	60	50	40	20	0	50	40	30	20	10	0
Fibre (%)	0	10	20	40	60	0	10	20	30	40	50
EFB (%)	40	40	40	40	40	50	50	50	50	50	50
Total (%)	100	100	100	100	100	100	100	100	100	100	100

The following steps briefly describe the method carries out on this research:

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

Step 2: Doing literature survey about the previous study which relevant and related to the research's topic.

Step 3: Searching the available semi-empirical models and selecting the suitable semi-empirical models.

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

Step 5: Combining the HHV of Shell-Fibre-EFB computed from step 4 to plot the graphs for each model at different percentages of Shell-Fibre-EFB.

Step 6: Comparing the computed HHV value with the actual experimental HHV value by using the statistical analysis.

Step 7: Find out the best models.

Step 8: Discussing the results obtained and making a conclusion.

1.8 THESIS ORGANIZATION

In this thesis, it consists five chapters to describe detail about their own relevant contents.

In Chapter 1, the general introduction of this research which include the overview, background of study, the objective and the scope of this research. Besides, it also consist of statement of problem and beneficial of the research in order to ensure the analysis is not out from the scope and determined the beneficial of this research to palm oil mills on their application in real world.

In Chapter 2, the literature review is regarding the research topic. In this chapter, it describes the background of oil palm, the palm oil waste residues, the palm mill process and the characteristic of solid waste. Furthemore, the existing semi-empirical models for evaluated the higher heating value (HHV) computation that related to this research is studied.

In Chapter 3, the methodology of the research is stated clearly and in detail regarding the most suitable semi-empirical models should be used in evaluation of the HHV at different percentages of Shell-Fibre-EFB. Besides, it involves the statistically analysis of the HHV at different percentage of palm oil waste.

In Chapter 4, the results of the HHV evaluation are illustrated with graft, figure and table. The discussion based on the comparison for results between the experiment value and actual value is discussed here in detail. It is followed by statistically analysis.

In Chapter 5, the conclusion of this research study and recommendations of this research for further studies in order to improve future studies on this title are included. As well, there is necessity in determining whether the results are fulfilling the initial objectives of this research.

REFERENCES

Abdul Latif Ahmad, Suzylawati Ismail, Subhash Bhatia. 2003. *Water recycling from palm oil mill effluent (POME) using membrane technology*. **157**: 87-95.

Ayhan Demirba. 1996. *Calculation of higher heating values of biomass fuels*. 431-434.

Calvin R.Brunner.1993.*Hazardous Waste Incineration Second Edition*,McGraw-Hill, Inc.

Archie W. Culp, Jr., Ph.D. 1991. *Principle of Energy Conversion Second Edition*. New York: McGraw-Hill, Inc.

Changdong Sheng, J.L.T. Azevedo. 2005. *Estimating the higher heating value of biomass fuels from basic analysis data*. **28**: 499–507.

Chow, M.C. and Ho, C.C. 2000. *Surface Active Properties of Palm Oil With Respect To The Processing of Palm Oil*. Journal of oil Palm Research. **12**(1), 107-116.

David A.Tillman.1991.*The Combustion of Solid Fuels and Wastes*. Academic Press,Inc.

Fernando S., Hall C., Jha S. 2006. *NOx reduction from biodiesel fuels*. **20**: 376–382.

Friedl A., Padouvas E., Rotter H., Varmuza K. 2005. *Prediction of heating values of biomass fuel from elemental composition*. **544** : 191–198.

Ganapathy V. 1994. *Steam Plant Calculation Manual Second Edition*. Revised and Expanded, Marcel Dekker, Inc.

Graham Stowell, Bronzeoak Group. 1999. *Maximising Energy Recovery from Palm Oil Wastes*, World Palm Oil Congress, and Kuala Lumpur. Available online at http://www.bronzeoak.com/paper2.html. (accessed September 2007).

Harimi Mohamed, M.M.H. Megat Ahmad, S.M. Sapuan, Azni Idris. 2004. *Numerical Analysis of Emission Component from Incineration of Palm Oil Wastes.* **28**:339–345.

H-Kittikun A., Praertsan P., Srisuwan G., Krause A. 2000. *Environmental Management from Palm Oil Mill.* Proceedings of the Internet Conference on Material Flow Analysis of Integrated Bio-system. http://wwwias.unu.edu/proceedings/icibs/ic-mfa/index.html

Joseph P.Reynolds, John S.Jeris, Louis Theodore. 2002. *Handbook of Chemical and Environment Engineering Calculation*. New York: John Wiley & Sons, Inc.

KTKM, Ministry of Energy, Communications and Multimedia. 2002. "*Energy Division*". Available online at http://www.ktak.gov.my/images/EnergyKTKM.pdf (accessed November 2007).

Mahlia T.M.I., Abdulmuin M.Z., Alamsyah T.M.I., D.Mukhlishien. 2001. *An Alternative Energy Source from Palm Wastes Industry for Malaysia and Indonesia, Energy Conversion and Management*; **42**:2109-2118.

Ministry of Plantation Industries and Commodities and Ministry of Finance Malaysia. 2007. Oil *Palm Area and Palm Oil Production 2006-2007*. Available online at www.treasury.gov.my/view. (accessed November 2007).

MPOB, Malaysian Palm Oil Board, 2007. Available online at http://www.mpob.gov.my/ (accessed October 2007).

MPOC, Malaysian Palm Oil Council, 2007. Available online at http://www.mpoc.org.my/ (accessed September 2007).

Prasertsan S., Sajjakulnukit B. 2005. *Biomass and Biogas Energy in Thailand: Potential, Opportunity and Barriers.* **31**:599–610.

Ravi Menon N., Nasrin Abu Bakar, Endang Jati. 2003. *Points to Consider in Biomass-Based Grid Connected RE Power plant Design.* Palm Oil Engineering Buletin Issue No. 69.

Rosnah Mat Soom, Wan Hasamudin Wan Hassan, Ab Gapor Md Top, Kamarudin Hassan. 2006. *Thermal Properties of Oil Palm Fibre, Cellulose and Its Derivatives.* Journal of Oil Palm Research Vol. 18, 272-277.

Sensoz, Angin S., Yorgun D. 2000. *Influence of Particle Size on the Pyrolysis of Rapeseed.* **19**: 271–279.

Shahrakbah Yacob, Mohd Ali Hassan, Yoshihito Shirai, Minato Wakisaka, Sunderaj Subash. 2005. *Baseline Study of Methane Emission from Anaerobic Ponds of Palm Oil Mill Effluent Treatment.* **366** : 187– 196.

SIRIM, 1999. Report: *Feasibility Study on Grid Power Generation Using Biomass Cogeneration Technology.*

SIRIM, 2005. Country report: *Biomass- Potentials, Research and Development and Application in Malaysia.*

Sivapalan Kathiravalea, Muhd Noor Muhd Yunusa, Sopian K., Samsuddin A.H., Rahman R.A. 2003. *Modeling the heating value of Municipal Solid Waste.* **82**: 1119–1125.

Sumathi S., Chai S.P., Mohamed A.R. 2007. *Utilization of Oil Palm As A Source of Renewable Energy in Malaysia.*

Sumiani Yusoff. 2004. *Renewable Energy from Palm Oil- Innovation on Effective Utilization of Waste.* **14**: 87-93.

Teoh Cheng Hai. 2002. *The Palm Oil Industry In Malaysia from Seed to Frying Pan.* Prepared for WWF Switzerland, 20-21.

Werther J., Saenger M., Hartge EU., Ogada T., Siagi Z. 2000. *Combustion of agricultural residues. Progress in Energy and Combustion Science.* **26**:1–27.

Yusof Basiron, Chan Kook Weng. 2004. *The Oil Palm and Its Sustainability*, Journal of Oil Palm Research; **16**(1), 1-10.