PHYSICOCHEMICAL PROPERTIES CHANGES ON MALAYSIA'S BIOMASS TORREFACTION AND DEVELOPMENT OF TORREFACTION CORRELATION MODEL

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I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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ABSTRAK

Pada ketika ini, *torrefaction* merupakan antara teknologi prarawatan yang penting untuk menambah baik ciri-ciri biojisim dalam usaha untuk mempromosi pemanfaatan biojisim bagi penghasilan tenaga lestari. *Torrefaction* adalah proses termal yang berlaku dalam persekitaran lengai bebas oksigen pada julat suhu 220 – 300°C. Sepanjang proses ini, biojisim akan terurai dan beberapa sifat biojisim akan berubah akibat kemusnahan strukturnya. Secara amnya, biojisim yang terurai mempunyai warna yang lebih gelap, ketumpatan tenaga yang tinggi, nilai pemanasan yang tinggi dan mempunyai ciri hidrofobik yang memudahkan pengisaran. Oleh itu, tujuan penyelidikan ini adalah untuk menjalankan eksperimen untuk mengenalpasti kesan *torrefaction* kepada sifat fizikal-kimia biojisism seterusnya membangunkan satu model matematik untuk penilaian penurunan berat kontang (AWL). Eksperimen untuk *torrefaction* telah dijalankan di dalam reaktor tiub pada empat suhu yang berbeza (240, 270, 300 and 300°C), di dalam keadaan lengai dengan kehadiran nitrogen pada tiga tempoh masa yang berbeza (15, 30 dan 60 minit). Kesan *torrefaction* pada tiga jenis sisa kelapa sawit (tandan kosong kelapa sawit, tempurung kelapa sawit dan pelepah kelapa sawit) dan tiga jenis sisa pembalakan (meranti, kulim, cengal) ditaksir dengan melakukan beberapa analisis bersandarkan kepada piawaian prosedur untuk bahan bakar. Analisis yang dilakukan adalah analisis hampiran dan muktamad, analisis nilai kalori (HHV) dan pandangan mikroskopi elektron pengimbasan (SEM). Tambahan itu, berdasarkan ciri– ciri sisa kelapa sawit dan pembalakan, hubungkait antara data ciri–ciri tersebut dengan kehilangan jisim dinilai untuk tujuan Model Regresi Linear. Pada masa yang sama, tiga model kinetik dianalisis dan dibangunkan untuk menunjukkan proses *torrefaction* sebenar untuk sampel sisa sawit dan pembalakan. Model yang digunakan adalah Model Mudah Global, dua tindak balas dalam siri iaitu Model Di Blasi-Lanzetta dan tiga tindak balas selari iaitu Model Rousset di mana semua parameter kinetik yang mewakili evolusi produk pepejal dan jirim meruap diramalkan dan disimulasikan menggunakan Matlab R2014a. Kemudian, parameter yang diperoleh daripada kerja simulasi diperbaiki untuk memadankan pengurangan jirim dan taburan jirim meruap yang diramalkan dengan data eksperimen. Kesimpulannya, terbukti bahawa *torrefaction* dapat meningkatkan ciri-ciri bahan bakar biojisim berdasarkan nilai HHV, dan analisis proksimat & muktamad. Dari hasil yang diperoleh, HHV untuk sisa kelapa sawit dan sisa pembalakan adalah di dalam julat 22 – 26 $MJkg^{-1}$. Nilai ini berada dalam lingkungan HHV untuk arang batu iaitu 24 – 35 $MJkg^{-1}$. Model korelasi linear telah dibangunkan untuk meramal analisis hampiran dan analisis muktamad dengan menggunakan pengurangan jirim sebagai input. Nilai regrasi yang bagus telah diperoleh menunjukkan bahawa satu model korelasi yang andal telah berjaya dibangunkan. Untuk pemodelan AWL, Model Di Blasi-Lanzetta dan Rousset telah berjaya mendemonstrasikan AWL secara tepat untuk biojisim yang berkenaan. Model-model ini dibuktikan dengan data eksperimen oleh itu, boleh digunakan untuk meramalkan AWL pelbagai biojisim. Sebagai kesimpulannya, hasil jisim selepas *torrefaction* untuk pelbagai jenis biojisim boleh diramalkan menggunakan model yang telah dibangunkan untuk mengoptimumkan proses *torrefaction* pada skala kecil dan industri.

ABSTRACT

Nowadays, torrefaction has become one of the important pretreatment technologies to upgrade the properties of biomass in order to promote utilization of biomass for sustainable energy production. Torrefaction is a thermal process that occurs in an inert oxygen-free environment at temperature range of 200 – 300°C. Throughout the process, biomass is decomposed and some properties of biomass changed as a result of structure destruction. In general, torrefied biomass has darker color, high energy density, high heating value and exhibits hydrophobic characteristic that makes it easier for grinding. Therefore, the objectives of this research are to conduct an experimental work in order to identify the effect of torrefaction on the physicochemical properties of biomass and to development of linear correlation model and mathematical model for anhydrous weight loss (AWL) evaluation. Torrefaction experiments were conducted in a tubular reactor at four different temperatures (240, 270, 300 and 330°C), in an inert nitrogen condition at three different residence times (15, 30 and 60 minutes). The effect of torrefaction on three types of oil palm waste (empty fruit bunch, palm kernel shell, oil palm frond) and three types of forestry residue (meranti, kulim, cengal) samples were assessed by conducting several analyses following the standard procedure for fuel. Analyses performed were proximate analysis and ultimate analysis, calorific value analysis (HHV) and scanning electron miscroscopy (SEM). Based on the properties of torrefied oil palm waste and forestry residue, the correlation of the properties data were evaluated with respect to mass loss data for Linear Regression Model purpose. Concurrently, three kinetic models were analysed and developed to briefly demonstrate the real torrefaction process using oil palm waste and forestry residue samples. AWL model used were Simple Global Model, a two reaction in series model namely Di Blasi-Lanzetta model and three parallel reaction namely Rousset Model in which all kinetic parameters that represents the evolution of solid and volatile products are predicted and simulated using Matlab R2014a. Later, parameters obtained from the simulation work were fine-tuned in order to fit the predicted mass loss and volatiles distribution with the experimental data. From the results obtained, mass yield for oil palm waste and forestry residues were reduced about 20 to 40%. Energy yield for oil palm waste decreased for about 20% whereas energy yield for forestry residues increased for about the same. HHV for torrefied oil palm waste and forestry residue are in the range of 22 – 26 $MJkg^{-1}$. These values are in the range of HHV for coal which is 24 – 35 $MJkg^{-1}$. In conclusion, it is proven that torrefaction can improve the fuel characteristics of biomass based on the HHV value, proximate analysis and ultimate analysis. Among oil palm waste, palm kernel shell is the most suitable feedstock for torrefaction as recorded HHV is 25.83 $MJkg^{-1}$@330°C whereas cengal is the most suitable feedstock for forestry residue (25.45 $MJkg^{-1}$@330°C). Good regression value has been obtained indicating a reliable correlation model has been developed for predicting the proximate and ultimate analysis using mass loss as an input. For AWL modelling, Di Blasi-Lanzetta and Rousset Model have accurately demonstrated the AWL of the respective biomass. The models were validated with the experimental data therefore, can be implemented to predict the AWL of various biomass.

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LIST OF SYMBOLS

m_i	Initial mass
m_{torr}	Torrefied mass
Y_{energy}	Energy yield
Y_{mass}	Mass yield
HHV_i	Initial HHV
HHV_{torr}	Torrefied HHV
[A]	Solid A
$[A_0]$	Initial solid A
[B]	Solid B
$[B_0]$	Initial Solid B
[C]	Solid C
$[C_0]$	Initial solid C
k_B	Kinetic constant for intermediate compound (B)
k_C	Kinetic constant for char
k_{V1}	Kinetic constant for volatile 1
k_{V2}	Kinetic constant for volatile 2
k_L	Kinetic constant for lignin
k_T	Kinetic constant for tar
k_{CL}	Kinetic constant for cellulose
k_{V3}	Kinetic constant for volatile 3
k_{HB}	Kinetic constant for hemicellulose
k_{CI}	Kinetic constant for char 1
k_{V4}	Kinetic constant for volatile 4
k_{C2}	Kinetic constant for char 2

LIST OF ABBREVIATIONS

ASTM	American Standard for Testing Method
AWL	Anhydrous Weight Loss
CPO	Crude Palm Oil
CPKO	Crude Palm Kernel Oil
CS	Cengal Sawdust
DTG	Differential Thermogravimetry
EFB	Empty Fruit Bunch
EY	Energy Yield
FC	Fixed Carbon
FELDA	Federal Land Development Authority
FFB	Fresh Fruit Bunch
GCV	Gross Calorific Value
GHG	Green House Gas
HDPE	High Density Polyethylene
HHV	High Heating Value
KS	Kulim Sawdust
KTOE	Kilotonne of Oil Equivalent
MC	Moisture Content
MF	Mesocarp Fibre
ML	Mass Loss
MS	Meranti Sawdust
MY	Mass Yield
PKS	Palm Kernel Shell
POME	Palm Oil Mild Effluent
OPF	Oil Palm Frond
OPT	Oil Palm Trunk
SCORE	Sarawak Corridor of Renewable Energy
SEDA	Sustainable Energy Development Authority
SEM	Scanning Electron Microscopy
SREP	Small Renewable Energy Power
SSR	Sum of Square Residuals
TDT	Thermal Degradation Temperature
TGA	Thermogravimetric Analysis
VM	Volatile Matter

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