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GASIFICATION OF NAPIER GRASS AND NAPIER GRASS-OIL PALM FROND BLENDING IN A FLUIDIZED BED GASIFIER

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By

TAN HONG BOON

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

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GASIFICATION OF NAPIER GRASS AND NAPIER GRASS-OIL PALM FROND BLENDING IN A FLUIDIZED BED GASIFIER

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Chairman : Associate Professor Wan Azlina Binti Wan Abdul Karim Ghani, PhD
Faculty : Faculty of Engineering

To date, oil palm is still the major biomass in Malaysia, thus this provides a strong reason why palm-based biomasses are one of the most promising renewable energy resources for electricity generation. In recent decade, palm-based biomasses have been greatly converted into various types of value-added products other than energy feedstock for power generation. Therefore, alternative fuel resources should be explored to replace palm-based biomasses to avoid over dependent on a single source.

In this study, napier grass (Pennisetum pupureum) (NG) is chosen as the feedstock due to its availability and high growth rates. In a year, NG is able to produce 40 tons/ hectare of dry biomass yield which is significantly higher than other short rotation grasses. In addition, the high volatility characteristic of NG makes it a suitable feedstock for thermo-chemical conversion. On the other hand, oil palm frond (OPF) is another suitable feedstock material for thermo-chemical conversion mainly because of its' availability and high volatility characteristic. Hence, it is blended with NG for performance enhancement. Gasification is chosen as the process to turn NG and NG-OPF blends into syngas due to its simplicity, performance efficiency and less pollutants emission. The physicochemical properties of NG and OPF were determined by Thermogravimetric Analysis (TGA) and Carbon-Hydrogen-Nitrogen-Sulphur (CHNS) characterization. The experimental tests have been carried out in a heat resistant stainless steel fluidized bed reactor (internal diameter 370 mm, length 54 mm) under temperature (650 – 850 °C) and equivalence ratio (0.2 – 0.4). The results revealed that the temperature and ER have significant effect on syngas quality and gasification performance. The higher heating value (HHV) based on the syngas composition obtained experimentally was 3.37 MJ/Nm3 and the higher Carbon Conversion Efficiency (CCE) was 82.12 % at temperature 850 °C with ER 0.25. For ER, the HHV was 3.37 MJ/Nm3 at ER 0.20 and the higher CCE was 89.08 % at ER 0.40. Moreover, the effect of NG-OPF blending ratio (25: 75, 50: 50, 75: 25) on the syngas composition and gas performance were also investigated under optimum condition (ER 0.20 and temperature 850°C). NG-OPF (50:

50) was found to obtained a higher H2 (13.04 mol.%) and higher HHV of gas product (3.42 MJ/kg). In order to generate reasonable prediction of the syngas composition and optimize the H2 production, a gasification model was developed based on the experimental data via LINGO software. In addition, syngas compositions obtained experimentally are validated with gasification modeling. Furthermore, the composition of syngas can be further optimized and determined based on the operating conditions (temperature, ER). The experimental result showed a very good agreement with the predicted result from the model at optimum condition and the RMS was calculated to be 0.0383. Therefore, it can be concluded that NG has the potential to be an alternative sustainable energy fuel for energy generation.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Master Sains

PENGEGASAN RUMPUT GAJAH DAN CAMPURAN RUMPUT GAJAH-PELEPAH KELAPA SAWIT MENGGUNAKAN REAKTOR TERBENDALIR FLUIDIZED

Oleh

TAN HONG BOON

Disember 2017

Pengerusi : Profesor Madya Wan Azlina Binti Wan Abdul Karim Ghani, PhD
Fakulti : Fakulti Kejuruteraan

Setakat ini, kelapa sawit merupakan biomas utama di Malaysia. Oleh kerana itu, biomas berasaskan kelapa sawit merupakan salah satu sumber tenaga boleh diperbaharui yang paling menjanjikan untuk penjanaan elektrik.

Malaysia amat bergantung kepada bahan api fosil untuk penjanaan elektrik. Sebaliknya, masih terdapat banyak kawasan luar bandar yang tidak dapat akses kepada bekalan elektrik secara berterusan, terutama Sabah dan Sarawak. Oleh itu, semua pihak termasuk kerajaan, masyarakat akademik dan masyarakat perlu bekerja bersama-sama untuk meneroka sumber bahan api alternatif yang baru. Walau bagaimanapun, dalam usaha untuk mempelbagaikan sumber tenaga boleh diperbaharui, rumput napier (Pennisetum Pupureum) (NG) dipilih sebagai sumber kerana kesediaan, kadar pertumbuhan yang tinggi, keneutralan karbon dan kemeruapan yang tinggi. Sebaliknya, dalam kerja-kerja ini, pelepah kelapa sawit (OPF) juga dipilih dan dicampur dengan NG kerana mudah didapati dan biasanya hanya ditinggalkan dalam tapak perladangan. Pengegasan dipilih kerana kesederhanaan, pencemar cekap yang fleksibel dan kurang pelepasan. Sifat-sifat fizik-kimia NG dan OPF ditentukan oleh analisis Termogravimetri (TGA) dan pencirian CHNS. Ujian eksperimen telah dijalankan dalam tahan haba keluli tahan karat fluidized reaktor katil (dalaman diameter 370 mm, panjang 54 mm). The syngas komposisi dan pengegasan prestasi NG telah dinilai di bawah suhu (650-850 ° C) dan nisbah kesetaraan (0,2-0,4). Selain itu, kesan NG-OPF nisbah campuran (25: 75, 50: 50, 75: 25) kepada komposisi syngas dan prestasi gas juga disiasat di bawah keadaan optimum (ER 0.20 dan suhu 850 ° C). Dalam usaha untuk menghasilkan ramalan yang munasabah komposisi syngas dan mengoptimumkan pengeluaran H2, model pengegasan telah dibangunkan berdasarkan data eksperimen melalui perisian LINGO. Hasil kajian menunjukkan bahawa suhu dan ER mempunyai kesan yang besar ke atas kualiti syngas dan prestasi pengegasan. Nilai pemanasan tinggi (HHV) berdasarkan komposisi gas bahan api yang diperolehi secara eksperimen adalah 3.37 MJ / Nm3 pada suhu 800 ° C, dan kecekapan

penukaran karbon yang lebih tinggi (CCE) adalah 82,12% pada suhu 850 ° C. Selain itu, kesan nisbah campuran antara NG dan OPF menunjukkan bahawa tidak ada tanda-tanda kesan sinergi antara NG dan OPF kecuali NG-OPF dengan 50: nisbah 50 adunan. Fenomena ini terutamanya mungkin disebabkan oleh oksida logam wujud dalam bio-arang dan tidak bercampur sempurna antara NG dan OPF. Di samping itu, model pengegasan berdasarkan keputusan eksperimen turut dibangunkan. Dalam usaha untuk memastikan ketepatan model, komposisi gas sintesis ramalan disahkan dengan keputusan eksperimen. Tambahan pula, komposisi gas sintesis boleh dilaksanakan secara optimum dan ditentukan berdasarkan keadaan operasi (suhu, ER). Semua dalam semua, NG mempunyai potensi untuk menjadi alternatif bahan api tenaga mampan untuk generasi tenaga.

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I certify that a thesis examination committee has met on 27th December 2017 to conduct the final examination of Tan Hong Boon on his thesis entitled "Evaluation of Napier Grass as Potential Renewable Energy Resource in Malaysia" in accordance with the universities and universities Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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Declaration by Graduate Student

I hereby confirm that:

- this thesis is my original work
- quotations, illustrations and citations have been duly referenced
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions
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Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in Rule 41 in Pules 2003 (Revision 2012-2013) were adhered to.

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Al	Aluminum
Al2O3	Aluminum oxide
ACstq	Stoichiometric air/fuel ratio
A/B	Absorbent to biomass ratio
BIPV	Building Integrated Photovoltaic
BFB	Bubbling fluidized bed
Br	Bromine
c	Number of component
C	Solid carbon
Ca	Calcium
CaO	Calcium oxide
CI	Chlorine
CuO	Copper (II) oxide
CO	Carbon monoxide
CnHm	Hydrocarbon
CFB	Continental flood basalt
CCE	Carbon conversion efficiency
CFB	Circulating fluidized bed
CHNS	Carbon-hydrogen-nitrogen-sulphur analyser
CFF	Crops for Future
CHP	Heat and power system
CH_4	Methane
daf	Dry ash free basis
dp	Mean bed particle size

dp*	Dimensionless measure of particle size
ER	Equivalence ratio
EFB	Empty fruit bunch
EJ	Exajoule
F	Degree of freedom
Fe	Iron
Fe_2O_3	Iron (III) oxide
FB	Feeding rate
FR	Biomass feeding rate
GDP	Gross domestic product
GC	Gas Chromatography
GCMS	Gas chromatography-mass spectrometry
GW	Gigawatt
He	Helium
H_2	Hydrogen
HHV	Higher heating value
H_2O	Steam
i.d	Internal diameter
IC	Internal combustion
K	Potassium
K_2O	Potassium oxide
Kj	Kilojoule
KMD	Equilibrium constant for methane decomposition reaction
KWGS	Equilibrium constant for water-gas shift reaction
KHWGS	Equilibrium constant for heterogeneous water-gas shift reaction

LHV	Lower heating value
LFG	Landfill gas
MOSTI	Ministry of Science, Technology and Innovation
MSW	Municipal solid waste
Mg	Magnesium
MnO	Manganese (II) oxide
MgO	Magnesium oxide
Mc	Molecule weight for carbon
M_{H_2}	Molecule weight for hydrogen
M_{O_2}	Molecule weight for oxygen
M_{N_2}	Molecule weight for nitrogen
Ms	Molecule weight for sulphur
MC	Molecule weight of carbon
M_{H_2}	Molecule weight of hydrogen
M_{O_2}	Molecule weight of oxygen
Mton	Million tonnes
MW	Megawatt
NG	Napier grass
NGS	Napier grass stem
NGL	Napier grass leaf
NGT	Napier grass leaf and stem
Na	Sodium
Na_2O	Sodium oxide
NiO	Nickel (II) oxide
O_2	Oxygen
OPF	Oil palm frond

OPA	Oil palm ash
OPS	Oil palm shell
P	Phosphorus
P_2O_5	Phosphorus pentoxide
PKS	Palm kernel shell
p	Phrase rule
PV	Photovoltaic
POME	Palm oil mill effluent
R&D	Research and development
Rb_2O	Rubidium oxide
Re_{mf}	Reynolds number at minimum fluidization state
rpm	Revolutions per minutes
S	Sulfur
Si	Silica
SiO_2	Silicon dioxide
SO_3	Sulphur trioxide
SrO	Strontium oxide
S/B	Steam to biomass ratio
scf/h	Standard cubic feet per hour
SR	Gas to hydrocarbon residues ratio
Ti	Titanium
TiO_2	Titanium dioxide
TGA	Thermogravimetric analyser
TCD	Thermal conductive detector
TWh	Terawatt hour
T	Temperature

T_i	Initial temperature
U_{tr}	Terminal velocity
U_{mb}	Minimum bubbling
U_{mf}	Minimum fluidization velocity
U_{ms}	Minimum slugging
U_c	Transition velocity to turbulent fluidization
U_k	Transition velocity to turbulent fluidization
U	Fluidization velocity
U*	Dimensionless velocity
U_{t*}	Dimensionless measure of terminal velocity for spherical particles
wt%	Weight percent
WGS	Water gas shift reaction
XRF	X-ray Fluorescence Spectrometer
ZnO	Zinc oxide
a	Number of carbon atoms
A	Surface area of reactor
Ar	Archimedes number
A_i	Peak area (Standard)
A_s	Peak area (Sample)
b	Number of hydrogen atoms
c	Number of oxygen atoms
d	Number of nitrogen atom
E	Equivalence ratio for modelling
f_i	Molar flow rate of the feedstock
g	Acceleration due to gravity

H_{mf}	Height of the fluidized bed at minimum fluidization
h	Stoichiometric coefficient of oxygen
K_i	Response/ Calibration factor
k_{H_2O}	Thermodynamic equilibrium constant of H2O formation
k_{CH_4}	Thermodynamic equilibrium constant of CH4 formation
k_{CO}	Thermodynamic equilibrium constant of CO formation
k_{CO_2}	Thermodynamic equilibrium constant of CO2 formation
M_a	Total mass of biomass after experiment
M_b	Total mass of biomass before the experiment
μ_2	Viscosity of fluid media
n_c	Carbon conversion efficiency
n_1	Number of moles of hydrogen
n_2	Number of moles of carbon monoxide
n_3	Number of moles of carbon dioxide
n_4	Number of moles of water
n_5	Number of moles of methane
n_6	Number of moles of nitrogen
p	Correction factor for methane decomposition reaction with ER
P	Pressure
V	Volumetric flow rate
w	Stoichiometric coefficient of biomass moisture
x_i	Molar composition of calibration gas
x_s	Mole percent of gases

x	Number of atom of carbon in hydrocarbon
y	Number of atom of hydrogen in hydrocarbon
z	Number of atom of oxygen in hydrocarbon
α_1	Correction factor for methane decomposition reaction with ER
α_2	Correction factor for water gas shift reaction with ER
α_3	Correction factor for heterogeneous water gas shift reaction with ER
β_1	Correction factor for methane decomposition reaction with temperature
β_2	Correction factor for water gas shift reaction with temperature
β_3	Correction factor for heterogeneous water gas shift reaction with temperature
ρ_p	Bed particle density
ρ_g	Density of fluidizing gas
ρ_{air}	Density of air
Φ	Sphericity
ε_{mf}	Bed voidage

CHAPTER 1

INTRODUCTION

1.1 Energy Demand and Poverty in Malaysia

To date, Malaysia is still relying heavily on fossil fuels for electricity generation. Energy would be one of the themes that challenge the Malaysia in the near future due to high demand of electricity. Therefore, in order to reduce dependency on the fossil fuels, more renewable sources should be introduced and utilized to generate electricity.

Most of the cities are equipped with electricity supply, but, there are still many rural areas especially in East Malaysia (Sabah and Sarawak) where they are not able to access to electricity continuously. As stated by Sreeraj et al. [1], energy poverty in rural areas could mitigate by the sustainable technology development such as transmission and distribution of energy generated from fossil fuel. However, it may not be possible in the remote areas as they are surrounded by difficult terrains and thick jungles. Besides, most of the schools that located in Sabah and Sarawak are not supplied electricity continuously [2].

Thus, it is inevitable that all parties such as government, academic society and communities have to explore new alternative fuel resource urgently to promote sustainable, affordable and accessible energy to the entire nation of Malaysia.

1.2 Current Electrification Status of Rural Areas in Malaysia

The local remote communities usually use small diesel-powered generators and solar panels as temporary measures to sustain their daily electricity usage. However, the diesel generator is found to be expensive to operate and maintain especially for those who are from low-income remote communities [3]. Furthermore, the fuel must be transported long distances by rivers or terrain roads from the urban town which are often washed out.

On the other hand, remote communities who live in rural areas which situated in close proximity to rivers fully relied on rivers as source of water supply, food and transport paths. It also could provide electricity by using water turbine. Water turbine harness kinetic energy from the natural flow of rivers, and generate electricity but the floating debris (tree branches, leaves, rubbish) and weeds [4, 5] are the main cause of damage the turbine. In addition, the flash floods and drastic changes in water level after rains are also seen to be major threats.

Moreover, solar panels and their electronic components also found to be easily broken and prone to corrosion in hot and wet countries. It is found out not efficient due to contaminants (dirt, dust, tree debris, bird dropping, etc) and the changeable weather in Malaysia. In spite of effort in remote electrification by the government, progress and success rates remain low due to the difficult conditions such as poor planning, limited resources and lack of research in problems and technology used [3].

1.3 Biomass as Alternative Energy Source

Due to strategic location and climate condition of Malaysia, plenty of the natural resources (agricultural and tropical forest) are available all year around. The biomass resources availability is covered nearly 76 % of land [6], thus, biomass has huge potential as a promising alternative renewable energy source for energy production via the different type of conversion technologies (e.g., biological and thermo-chemical conversion).

Table 1.1 shows that the biomass resources and their energy potential in Malaysia. It can be seen that oil palm industry has generated numerous raw material production and byproduct such as empty fruit bunches, frond, trunk, fibers, shell and palm kernel as compared to other industry. In this context, biomass residues from various industries can be one of the best alternative renewable resources for electricity generation. In addition, all these residues have no economic value and underutilized, they would bring benefit to the industry as well as mitigate the environmental problem if fully utilized and convert them to more valuable and usable forms of energy. Ali et al. [7] mentioned that biomass fuel contributes to 16 % of the energy consumption in the country where 51 % comes from palm oil biomass waste, 27 % from wood waste and 2 % from paddy residues. In addition, the production fodder crop (NG) generated approximately 43.7-65.9 t/ha/year. Although the production quantity is not comparable to other biomass but because of its fast growth rate and high volatile matter characteristics, it can be one of the promising energy feedstock in Malaysia.

Table 1.1: Biomass resources and their estimated energy potential in Malaysia [8, 9]

Type of industry	Production (Mton)	Type of biomass	Residue generated (Mton)	Calorific value of biomass (kJ/kg)	Potential energy generated (Mton)
Oil palm	59.8	Empty fruit bunches (EFB)	12.30	18,838	5.53
		Fronds and trunk	21.10	-	-
		Fiber	8.75	19,068	3.99
		Shell	3.94	20,108	1.89
		Palm kernel	2.11	18.900	95
Paddy	2.14	Rice husk	0.47	15,324	0.17
		Rice straw	0.86	13,620	0.28
Sugar	1.11	Bagasse	0.36	8021	0.069
Wood	1.67	Sawdust	0.96	19,008-19,188	0.44
	0.3	Plywood residues	0.069	10,000-19,000	0.024
Municipal solid waste (MSW)	11,940 t/day	MSW	-	9500	-
Fodder crop	43.7-65.9t/ha/year	Napier grass	-	-	-

*****Potential energy generated (ton) = residue generated (ton) * 1000 kg * calorific value (kJ/kg)/41,86,8000 k

1.4 Problem Statement

Due to the difficult terrain and thick jungle, transmission and distribution of energy generated from fossil fuel are nearly not able to reach out to remote communities for their daily activities. Thus, diesel generator and solar panel have become the temporary alternative, however, diesel for the generator is found to be expensive and solar panel is less efficiency due to unpredictable weather. Furthermore, remote communities are also heavily reliance on fuel wood and charcoal for cooking and heating purpose but this creates indoor smoke pollution and leading to serious health damage, such as respiratory diseases and blindness.

Oil palm is the major biomass in Malaysia, thus this provides a strong reason palm oil residues as an alternative renewable energy resource for electricity generation. However, there is a growing interest to turn palm biomass into various types of value-added products other than energy feedstock for power generation. Therefore, some alternative non-valuable crops should be utilized to replace oil palm to have more effective biomass sources and to avoid the over dependent on a single source.

Napier grass (NG) was selected as the energy feedstock and blending with oil palm frond for energy generation via gasification conversion due to its availability and higher growth rate than most of the other crops. Besides, NG and OPF have higher energy value and high volatility characteristics which is suitable for combustion purpose.

1.5 Objectives

The objectives of the project are summarized as followed:

a. To determine the physicochemical properties of selected biomass (napier grass (NG) and oil palm frond (OPF)).
b. To perform and evaluate the NG air gasification performance at varying operating conditions of temperature, equivalence ratio and blending ratio with OPF.
c. To improve gasification model which is able to generate a reasonable prediction of the producer gases based on experimental data and further optimize the H_2 production via LINGO 14.0 software.

1.6 Scope of Study

- This study was conducted to determine the chemical composition of NG and OPF feedstock via TGA, CHNS, oxygen bomb calorimeter and lignocellulosic analysis. It is important to know the composition of biomass as they have greatly influence the gasification performance.

- This study was performed to evaluate the NG gasification performance at temperature (650 – 850 °C), ER (0.2 – 0.4) and blending ratio (25: 75; 50: 50; 75: 25) with OPF to find out the optimum condition that could maximize the syngas production.

- This gasification modeling study was conducted using the experimental data via LINGO 14.0 optimization tool software. The experiment was duplicated based on the optimum conditions (Temperature at 1123 K and ER 0.2092) provided by modelling to verify with the prediction data from modelling.

1.7 Significance of Study

This study is important to improve the research gap on NG and NG-OPF gasification. In present, there is limited or nil research on the abovementioned gasification and hence more research attention should be attracted in order to determine the suitability of NG and NG-OPF as energy feedstock. In addition, this study explores the opportunity of syngas production from NG and NG-OPF blends via gasification for sustainable electricity generation. Gasification of this high growth rate energy crop has the potential to assist local communities, especially those in rural areas by providing sufficient feedstock. Hence, cultivation of NG is believed to be highly beneficial to serve this purpose.

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