PARAMETRIC AND KINETIC STUDIES OF MICROWAVE –ASSISTED PYROLIGNEOUS ACID FROM OIL PALM FIBER

FATIMATUL ZAHARAH ABAS

UNIVERSITI TEKNOLOGI MALAYSIA

PARAMETRIC AND KINETIC STUDIES OF MICROWAVE –ASSISTED PYROLIGNEOUS ACID FROM OIL PALM FIBER

FATIMATUL ZAHARAH ABAS

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy

School of Chemical and Energy Engineering
Faculty of Engineering
Universiti Teknologi Malaysia

OCTOBER 2018

ACKNOWLEDGEMENT

First and foremost, I would like to say Alhamdulillah and thank Allah for the strength and all His guidance for me to finish this research study. I am heartily thankful to my beloved husband, Wan Izzudin Sharudin, who has been the most influential in my life, his support, patience and an encouragement has inspired me to this point in my study. I would like to show my deepest gratitude to my late beloved father Hj. Abas bin Jusoh and my lovely mother Hajjah Hindun bt Muda for their endless love, support and blessing throughout my study.

To the infinite perseverance, enthusiasm and patient guidance of my supervisor Associate Prof. Dr. Zainul Akmar Zakaria, I would like to express my deepest appreciation and gratitude for your precious advice, guidance and unconditional support from the beginning until now which enabled me to develop an understanding of the project research study and writing this thesis. His motivation help me to endure all the hardness along the way. It is an honour for me to thank my co-supervisor, Prof. Ir. Dr. Farid Nasir Hj. Ani for her precious advice, guidance and assistant during my study.

My sincere thanks also to assistant engineer at FKM UTM, Mr. Rosli Ismail and postgraduate students under supervision of Prof. Dr. Farid Nasir, Mr. Abioye, Mr. Ho Guan Sem and Mrs. Siti Zulaiha for all their help and guidance, and lead me to the right path of my experiments. Without their help, my experiment will not finish successfully. Also, I would like to extend my gratitude to all my family for their endlessly caring and support, my beloved friends at IBD, UTM for their cooperation, motivation, and unparalleled help throughout my study.

Last but not least, thanks Ministry of Higher Education, Malaysia (MOHE) for the financial support of MYPHD scholarship throughout my study.

ABSTRACT

Malaysia is acknowledged as the world’s second largest producer and exporter of palm oil. This in turn has generated large amount of oil palm biomass which is normally left at the plantation to putrefy, burnt or turned into various low-value products. Hence, an alternative approach which is more robust, easier and environmental friendly to process this biomass is required. Microwave-assisted pyrolysis allows the conversion of biomass to various pyrolytic products for example pyroligneous acid (PA), biofuel, biogas, and biochar. However, to date, there are still limited reports available on the application of microwave-assisted pyrolysis for the production of PA in optimized condition, which is the novelty of this study. The objective of this study was to optimize the operating conditions during the microwave-assisted pyrolysis of oil palm fiber (OPF) in order to obtain the highest total phenolic content (TPC) as well as the highest liquid yield of microwave-assisted pyroligneous acid (MWPA). The optimization process was performed using central composite design technique via response surface methodology which focused on the following parameters; final temperature (400-600 °C), holding time (15-30 min) and activated carbon (AC) loading (50-100 g). MWPA was characterized for its chemical and antimicrobial properties. The thermal degradation profiles of OPF were evaluated using the Kissinger-Akahira Sunose (KAS), Ozawa-Flynn wall (OFW) and Coats-Redfern method (CRM) kinetic models based on the thermogravimetric analysis data. The optimum condition to produce the highest TPC and liquid yield of MWPA were as follows; 540 °C, holding time of 23 min and AC loading of 86.74 g. The following profiles were determined for concentrated MWPA extracted with ethyl acetate (C-MWPA); antioxidant properties of 18.52 ± 0.2% with IC_{50} of 285.66 µg/ml (2,2-diphenyl-1-picryhydrazyl radical scavenging), 0.836 ± 0.003 mM (ferric reducing antioxidant power), 12 ± 0.07% (metal chelating activity), 414.21 ± 4.74 µmol ascorbic acid/g (phosphomolybdenum), 85.42 ± 0.33% (hydrogen peroxide assay), and growth-inhibition of 28.67 ± 0.88 mm towards *Escherichia coli* American Type Culture Collection 25922 with minimum inhibition concentration value of 0.651 ± 0.13 mg/ml. The kinetics study evaluated for OPF found that the mean value of activation energy (E_a) were 97.01 kJ/mol (KAS) and 101.52 kJ/mol (OFW). The values of E_a calculated for C-MWPA were 28.59 kJ/mol and 33.87 kJ/mol for KAS and OFW, respectively. The validation of kinetic reaction model by using CRM model demonstrated that, OPF thermal degradation was well represented by the three dimension diffusion reaction model with mean value E_a of 84.71 kJ/mol while C-MWPA was well fitted with second order reaction type (E_a of 39.83 kJ/mol). To conclude, this study has successfully demonstrated the application of microwave-assisted pyrolysis to convert oil palm biomass into various useful pyrolytic products. This is considered as a significant finding as this technique can offer a substantial reduction in processing time, able to process large volumes at a given time, easy to operate as well as offering various valuable pyrolytic products.

ABSTRAK

Malaysia diiktiraf sebagai pengeluar dan pengeksport minyak kelapa sawit kedua terbesar dunia. Keadaan ini sebaliknya telah menghasilkan banyak sisa biojisim kelapa sawit yang selalunya dibiarkan di ladang untuk mereput, dibakar atau diubah menjadi pelbagai produk bernilai rendah. Oleh itu, ianya memerlukan pendekatan alternatif yang lebih mantap, mudah dan mesra alam sekitar. Pirolisis berbantukan gelombang mikro membolehkan penukaran biojisim kepada pelbagai produk pirolisis seperti asid piroligneus (PA), bio-bahanapi, bio-gas, dan bio-arang. Walaubagaimanapun, sehingga hari ini, kajian penggunaan pirolisis pemanasan berbantukan gelombang mikro bagi penghasilan PA dalam keadaan optimum masih terhad, yang merupakan pembaharuan dalam kajian ini. Objektif kajian ini adalah untuk mengoptimumkan keadaan operasi semasa pirolisis berbantukan gelombang mikro serat kelapa sawit (OPF) bagi tujuan memperoleh jumlah kandungan fenolik (TPC) dan juga hasil cecair asid piroligneus berbantukan gelombang mikro (MWPA) yang tertinggi. Proses pengoptimuman telah dilakukan menggunakan teknik rekabentuk komposit berpusat melalui kaedah tindakbalas permukaan dengan menumpukan kepada beberapa parameter seperti berikut; suhu akhir (400-600 °C), masa pegang (15-30 min) dan muatan karbon teraktif (AC) (50-100 g). Sifat-sifat kimia dan anti-bakteria MWPA telah dianalisa. Profil degradasi termal OPF telah dianalisa menggunakan model kinetik *Kissinger-Akahira Sunose* (KAS), *Ozawa-Flynn wall* (OFW) dan *Coats-Redfern method* (CRM) berdasarkan kepada data analisa termogravimetri. Keadaan optimum untuk menghasilkan TPC dan hasil cecair MWPA yang tertinggi adalah seperti berikut; 540 °C, 23 min masa pegang dan 86.74 g muatan AC. Berikut adalah profil yang telah dianalisa untuk kepekatan MWPA yang diekstrak dengan etil asetat (C-MWPA); sifat-sifat antioksidan iaitu 18.52 ± 0.2% dengan IC_{50} sebanyak 285.66 µg/ml (*2,2-diphenyl-1-picryhydrazyl radical scavenging*), 0.836 ± 0.003 mM (*ferric reducing antioxidant power*), 12 ± 0.07% (*metal chelating activity*), 414.21 ± 4.74 µmol asid askorbik/g (fosfomolibdenum), 85.42 ± 0.33% (*hydrogen peroxide assay*), dan rencatan pertumbuhan MWPA terhadap *Escherichia coli American Type Culture Collection* 25922 adalah 28.67 ± 0.88 mm dengan nilai kepekatan rencatan minimum sebanyak 0.651 ± 0.13 mg/ml. Kajian kinetik yang dikira untuk OPF mendapati bahawa nilai purata tenaga pengaktifan (E_a) adalah 97.01 kJ/mol (KAS) dan 101.52 kJ/mol (OFW). Nilai E_a bagi C-MWPA ialah 28.59 kJ/mol dan 33.87 kJ/mol bagi KAS dan OFW. Pengesahan dari analisa tindak balas kinetik menggunakan kaedah CRM menunjukkan degradasi termal OPF mempunyai model tindak balas penyebaran tiga dimensi dengan nilai purata E_a sebanyak 84.71 kJ/mol, manakala C-MWPA menunjukkan jenis tindak balas kedua (E_a sebanyak 39.83 kJ/mol). Kesimpulanya, kajian ini telah berjaya menunjukkan penggunaan pemanasan berbantukan gelombang mikro dapat menukarkan biojisim kelapa sawit kepada pelbagai produk pirolisis yang berguna. Penemuan hasil kajian ini penting kerana teknik ini menyebabkan pengurangan yang besar dalam masa pemprosesan, berkemampuan memproses dalam jumlah besar pada waktu tertentu, operasi yang mudah serta dapat menghasilkan pelbagai produk pirolisis berharga.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

.

LIST OF ABBREVIATIONS

AA	-	Ascorbic acid
ABTS	-	2,2'-azino-bis(3-ethylbenzothiazoline-6-sulphonic acid
AC	-	Activated Carbon
AH	-	Antioxidant
AIL	-	Acid Insoluble Lignin
A.M.U	-	Atom Mass Unit
ANOVA	-	Analysis of Variance
AP	-	Adequate Precision
APHA	-	American Public Health Association
ASL	-	Acid Soluble Lignin
ASTM	-	American Society for Testing and Material
ATCC	-	American Type Culture Collection
BBD	-	Box-Behnken Design
BHA	-	Butylated Hydroxyanisole
BHT	-	Butylated Hidroxytoluene
BPA	-	Baird-Parker Agar
C	-	Carbon
C-MWPA	-	Concentrated Ethyl Acetate Extract Microwave Pyroligneous Acid
C-MPOB-PA	-	Concentrated Ethyl Acetate Extract Malaysian Palm Oil Board Pyroligneous Acid
$C_{12}H_{22}O_{11}$	-	Cellobiose
C_2H_2	-	Acetylene
CH_4	-	Methane
CO	-	Carbon Monoxide
CO_2	-	Carbon Dioxide
CCD	-	Central Composite Design

CPA	-	Concentrated Pyroligneous Acid
CPAEA	-	Concentrated Pyroligneous Acid Ethyl Acetate
CRM	-	Coats-Redfern Method
CV	-	Coefficient Variation
db	-	dry basis
DIZ	-	Diameter Inhibition Zone
DCM	-	Dichloromethane
DF	-	Degree of Freedom
DNA	-	Deoxyribonucleic Acid
DP	-	Degree of Polymerization
DPPH	-	2,2-diphenyl-1-picryhydrazyl
DOE	-	Design of Experiment
DTG	-	Derivative Thermogravimetric
EA	-	Ethyl Acetate
EC_{50}	-	Half Maximal Effective Concentration
EDTA	-	Ethylenediaminetetraacetic acid
EFB	-	Empty Fruit Bunch
$FeCl_2$	-	Iron (II) Chloride / Ferrous Chloride
FESEM	-	Field Emission Scanning Electron Microscope
$FeSO_4.7H_20$	-	Iron (II) Sulfate Heptahydrate
FFB	-	Fresh Fruit Bunch
FRAP	-	Ferric Reducing Antioxidant Power
GA	-	Gallic Acid
GAE	-	Gallic Acid Equivalents
GC-MS	-	Gas Chromatograph-Mass Spectroscopy
H	-	Hydrogen
H_p	-	Enthalpy of Pyrolysis
H_2	-	Hydrogen Gas
H_2O_2	-	Hydrogen Peroxide
H_2SO_4	-	Sulfuric Acid
HBA	-	Hicrome™ Bacillus Agar
HPA	-	Hydrogen Peroxide Assay
HPLC	-	High Performance Liquid Chromatography
H_3PO_4	-	Phosphoric acid
IC_{50}	-	Half Maximal Inhibitory Concentration

ID	-	Inner Diameter
IKP	-	Isokinetic Point
KAS	-	Kissinger-Akahira-Sunose
KCE	-	Kinetic Correlation Effect
KFT	-	Karl Fischer Titration
LAP	-	Laboratory Analytical Procedure
LPM	-	Litre Per Minute
MBC	-	Minimum Bactericidal Concentration
MCA	-	Metal Chelating Activity
MIC	-	Minimum Inhibitory Concentration
MLC	-	Minimum Lethal Concentration
MPOB	-	Malaysian Palm Oil Board
MRSA	-	de Man, Ragosa, Sharpe Agar
MW	-	Microwave Heating
MWPA	-	Microwave-Assisted Pyroligneous Acid
N	-	Nitrogen
$NaHCO_3$	-	Sodium Bicarbonate
NIST	-	National Institute of Standards and Technology
NO	-	Nitric Oxide
O	-	Oxygen
$O-CH_3$	-	Alkoxy
OD	-	Outer Diameter
OFW	-	Ozawa-Flynn-Wall
OH	-	Hydroxyl
OPF	-	Oil Palm Fiber
OPT	-	Oil Palm Trunk
PA	-	Pyroligneous Acid
PAH	-	Polycyclic Aromatic Hydrocarbon
PBDEs	-	Polybrominated Diphenyl Ethers
PKS	-	Palm Kernel Shell
POME	-	Palm Oil Mill Effluent
R	-	Uiversal Gas constant
RPA	-	Raw Pyroligneous Acid
ROS	-	Reactive Oxygen Species
RSM	-	Response Surface Methodology

RPA	-	Raw Pyroligneous Acid
S	-	Sulphur
SCA	-	Simmon Citrate Agar
SO_2	-	Sulphur Dioxide
SRS	-	Sugar Recovery Standard
T	-	Absolute Temperature
TBHQ	-	Tertbutylhydroquinone
TCD	-	Thermal Conductivity Detector
TG	-	Thermogravimetric
TGA	-	Thermogravimetric Analysis
TPC	-	Total Phenolic Content
TPTZ	-	2,4,6-tripyridyl-striazine
UIRL	-	Universiti Industries Research Laboratory
UV-Vis	-	Ultra Violet Visible

LIST OF SYMBOLS

α	-	Conversion
A	-	Pre-exponential factor
β	-	Heating rate
cm	-	Centimeter
ΔG	-	Gibbs Free energy change
ΔH	-	Enthalpy change
ΔS	-	Entropy change
ºC	-	Degree celsius
°C/min	-	Degree Celsius per minute
cells/mL	-	Cells per mililiter
dm^3	-	Cubic decimeter
$dm^3\ dm^{-3}$	-	Cubic decimeter per cubic decimeter
E_a	-	Activation energy
eV	-	Electron volt
E/g	-	Equivalent per gram
ε’	-	Dielectric constant
ε”	-	Dielectric loss
g	-	Gram
GHz	-	Gigahertz
h	-	Planck’s constant
hr	-	Hour
J/mol	-	Joule per mol
k	-	Rate constant
K	-	Kelvin
Kg/dm^3	-	Kilogram per cubic decimeter
m	-	Meter

M	-	Molar
MJ kg^{-1}	-	Mega Joules per kilogram
M^{-1} S^{-1}	-	Per Molar per second
min	-	Minute
mg	-	Miligram
MHz	-	Megahertz
mL	-	Mililiter
mm	-	Milimeter
mM	-	Milimolar
mmol	-	Milimol
mg/ml	-	Miligram per mililiter
ml/min	-	Mililiter per minute
mg/L	-	Miligram per liter
mg/g	-	Miligram per gram
MJ/kg	-	Megajoules per kilogram
nm	-	Nanometer
%	-	Percent
ppm	-	Part per million
mt	-	Metric tonnes
>	-	More than
<	-	Less than
N	-	Avogadro’s Number
$R^{\bullet}$	-	Radical Species
R^2	-	Correlation Coefficient
rpm	-	Revolution per minutes
T	-	Temperature
tha^{-1}	-	Tonnes per hectare
t y^{-1}	-	tonnes per year
µg	-	Microgram
µL	-	Microliter
µL/mL	-	Microliter per mililiter
µm	-	Micrometer
Vol.%	-	Volume percent
v/v/v	-	Volume per volume per volume
W	-	Watt

wt.%	-	Weight percent
wt.%/min	-	Weight percent per minute
w/v	-	Weight per volume

LIST OF APPPENDICES

CHAPTER 1

INTRODUCTION

1.1 Research Background

In the last four decades, Malaysia has recorded unprecedented growth to emerge as the second largest producer as well as exporter of palm oil in the world where almost 5.4 million hectares of land were allocated for oil palm (*Elaeis guineensis*) plantation (Abas and Ani, 2014). It was estimated that every year Malaysia produces 22.1 million tonnes of palm oil from 37.2 × 10^6 tonnes of fresh fruit bunches compared to 15 million tonnes in 2005 (MPOB, 2015). This inevitably also produces huge amounts of biomass residues (yearly generation of around 100 million tonnes) and the trend is increasing annually by 5% (Abdullah and Sulaiman, 2013; Wafti *et al.*, 2017). This oil palm biomass residues includes empty fruit bunches (EFB), oil palm fiber (OPF), palm kernel shell (PKS), oil palm trunks (OPT) and palm oil mill effluent (POME) offers huge potential to be applied as raw materials to obtain valuable compounds based on its rich organic compositions (Wu *et al.*, 2007; Abas and Ani, 2014; Hosseini and Wahid, 2014).

Current management practice for oil palm residue, includes landfill and open burning, necessitates an improve approach as with time these biomass will contribute to uncontrolled released of greenhouse gases and global warming to the environment (Hassan *et al.*, 2011). In addition, the open burning of biomass will lead to haze hazard, smoke as well as emission of toxic chemicals (Abdullah and Sulaiman, 2013). Due to this situation, proper disposal and management of oil palm biomass is necessary to minimize the environmental impact as well as maximizing utilization of these biomass into various value-added products such as biofuel, bio-oil, biochar, pyroligneous acid and activated carbon that can be utilized in a wide range of applications. In general, biomass conversion technologies can be classified into three major processes namely thermochemical, physical and biochemical conversion (Figure 1.1).

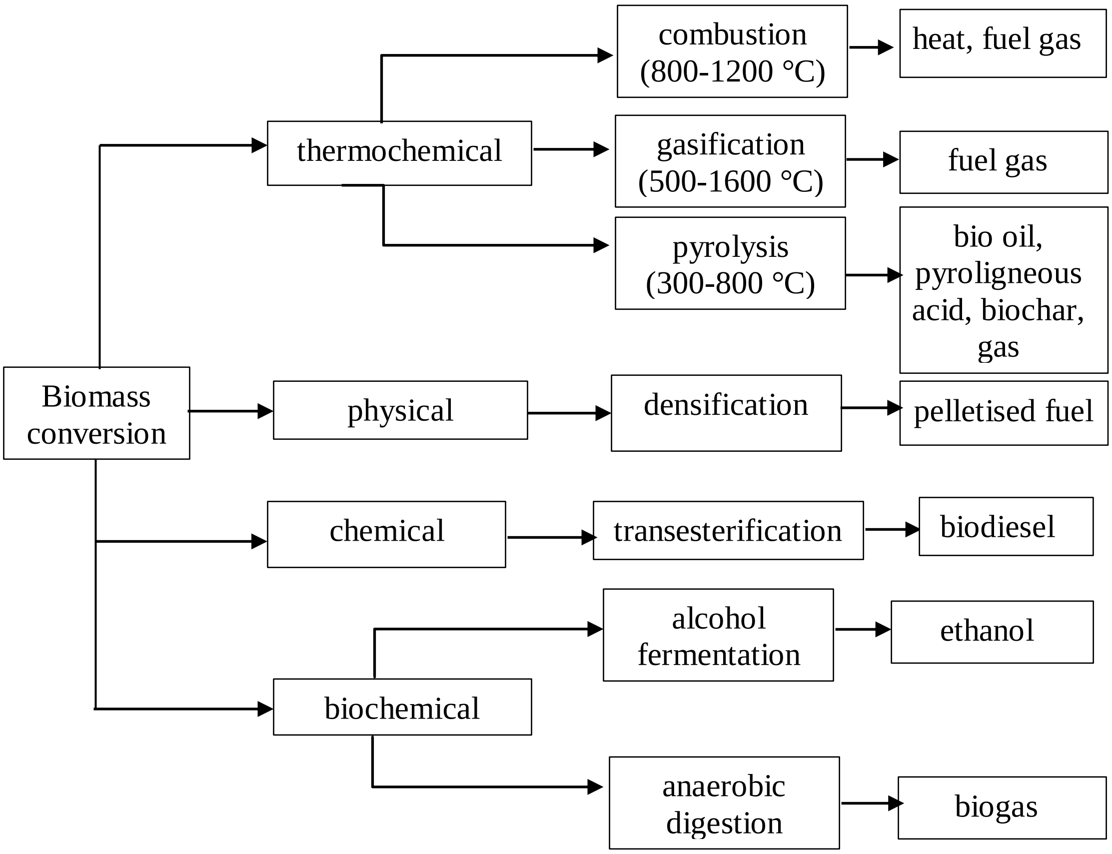

Figure 1.1 The main process of biomass conversion (Ani, 2012; Asomaning *et al*., 2018)

Biochemical conversion involves the use of microorganisms whether as whole cells or extracted enzymes for the production of biogas and ethanol via anaerobic digestion and alcohol fermentation respectively. Thermochemical conversion has been acknowledged as the efficient process in handling various kind of biomass and solid waste with a higher conversion rate in a rapid process time compared to others (Shakorfow, 2015) and it consist of combustion, gasification and pyrolysis. Thermochemical conversion is a proven technique both to dispose various types of biomass wastes as well as the production of valuable products such as bio-oil, pyroligneous acid, biochar and fuel-gas (Ani, 2012; Goyal *et al.,* 2008; Lam and Chase, 2012). Amongst the available thermochemical conversion techniques, pyrolysis offers the advantage of being an environmental friendly method as well as an independent process to convert biomass into valuable chemical products (Ingole *et al.,* 2016; Czajczyńska *et al*., 2017). Pyrolysis also offers simple operation, reasonable operating cost with lower range of the temperature required (350 to 800 °C) and produce less hazardous gas (CO_2, CO) relative to combustion (Shakorfow, 2015, Czajczyńska *et al*., 2017). Apart from this, pyrolysis also acts as the initial step for all thermochemical processes that emits less air pollutants such as polybrominated diphenyl ethers (PBDEs) due to lower process temperature requirement. In contrast, gasification involved high energy consumption to maintain high process temperature required (Czajczyńska *et al*., 2017; Yuan *et al.*, 2017). Table 1.1 highlights some of the characteristics of each processes:

Table 1.1: Characteristic comparison between gasification, combustion and pyrolysis (Shakorfow, 2015)

Characteristic	Gasification	Combustion	Pyrolysis
Process requirement	occurred in insufficient or partial air or oxygen or steam	occurred in sufficient oxygen or excess air	occurred in the absence of oxygen
Temperature	550-1600 °C	800 to 1200 °C	350 to 800 °C
Heat supply	allo or auto-thermal (internal heating)	exothermal	allo-thermal (external heating)
Carbon conversion	80-95 %	>99 %	≈ 75 %
Phase	gas	gas	solid, liquid, gas
Final product	fuel gases (CO_2, H_2O, N_2) heat, tar and combustible gases (CO, H_2 and CH_4)	heat, fuel gas and gases as: CO_2, H_2O, N_2.	bio-oil, char, tar (liquid/vapour), CO_2, H_2O, and combustible gases
Reactivity of main product	stable, combustible	non-reactive	reactive, combustible

Pyrolysis can be defined as thermal decomposition of organic material in the absence of oxygen which is operating at medium temperature range normally from 350-550°C. Generally, it can be categorized into three types namely flash pyrolysis (favoring gas production), fast pyrolysis (principal product is liquid) and slow pyrolysis (applied for the production of char). The difference in pyrolysis types is determined mainly by two process parameters i.e. heating rate and residence time (Abubakar and Ani, 2013). Initial decomposition of waste material is around 120°C-200°C. During pyrolysis, decomposition of large molecule of biomass causing the breakdown of long chains of carbon, hydrogen and oxygen compounds into smaller molecules in the forms of condensable vapours (tars and oils), solid charcoal and non-condensable gaseous product (Abas and Ani, 2014; Yaman, 2004). Generally, pyrolysis of biomass consists of three main stages which includes; (i) initial evaporation of free moisture, (ii) primary decomposition and (iii) secondary reactions (oil cracking and repolymerisation). These stages are intermingled, with a possibility to observe their transitional behavior through thermal analysis (Kan *et. al.*, 2016). In addition, the temperature of pyrolysis process can be adjusted in order to favor charcoal, pyrolysis liquid or gas production (Goyal *et. al.*, 2008).

Pyroligneous acid (PA) is the aqueous liquid fraction that can be produced by condensing the vapor produced during pyrolysis of plant biomass in the absence of oxygen. It is also known as liquid smoke that has a distinctive smoky odor, reddish brown in color and acidic in nature (pH 2-3). Most of the studies carried out on PA production were using conventional heating methods that include charcoal kiln, jacket electric heater and furnace (rotating cone reactors, melting vessels, tabular reactor, blast furnaces). Amongst the disadvantages of conventional heating pyrolysis are slow reaction time, heat transfer resistance, inefficient heating due to heat losses to surrounding, lack of rapid heating, non-selective heating and damage to the reactor walls due to continuous electrical heating (Salema and Ani, 2011). Thus, microwave heating has promptly become an interesting alternative in the various industrial process in recent years. Microwave heating is widely used not only in analytical, organic and environmental chemistry but also in the pyrolysis of various kind of materials such as biomass, coal, oil shales and organic wastes (Domínguez *et al.*, 2006). Microwave heating offers many advantages over conventional heating including rapid internal heating, shorter processing time, lower relative energy consumption, environmental friendliness, quick start-up, automated and volumetric heating. The application of microwave-assisted technology applied to the pyrolysis process not only contribute to the ability to enhance the reaction rates and rapid heating during pyrolysis, but also can improve the quality and properties of the product required and has been regarded as a way of cost-effective and operationally feasible processes (Menéndez *et al.*, 2010; Nomanbhay *et al.*, 2017).

Oil palm fiber (OPF) is one of the most abundant biomass produced during palm oil milling process. It is obtained after the pressing process of palm fruits for palm oil extraction. OPF can be converted into useful products for various applications such as in biofuel, bioethanol, biochemical, biocompost as well as biosugar. OPF is clean, non- carcinogenic, free from pesticides and soft parenchyma cell. Cellulose content has been observed as the principle component in chemical analysis of OPF since it plays an important role in the fiber's performance (Sreekala *et. al*., 1997; Abdullah and Sulaiman, 2013). Thus, the analysis of the pyroligneous acid produced from OPF via microwave heating is required to get better understanding about the characteristic of the product, energy consumption, antioxidant and antimicrobial properties as well as kinetic analysis during the pyrolysis process.

1.2 Problem Statement

Numerous studies have investigated on the production of pyroligneous acid (PA) from various biomass feedstock by using conventional system such as the pyrolysis reactor and charcoal kiln. The quality of PA is based on the phenolic content. Production of PA by using conventional heating system is generally time consuming, requires high energy consumption, uneven heat distribution as well as generation of highly carcinogenic compounds such as polycyclic aromatic hydrocarbon (PAH). This situation leads to the production of low quality PA (low phenolic contents). Microwave heating can be used to improve the quality of pyroligneous acid from its lower energy consumption, short pyrolysis time and better heat distribution with the expectation of high fraction of phenolic compounds produced with the absence of PAH. Amongst the available oil palm biomass in Malaysia, OPF offers an attractive alternative as feedstock for the production of PA based on its high lignin content. Nevertheless, to date, investigation on the production of PA from OPF via microwave-assisted heating in optimized condition is still very limited, hence is the focus of this study. The optimization process is important to determine optimum pyrolysis condition to obtain highest total phenolic content (TPC) as well as highest yield of PA. High phenolic content in PA would directly indicate high antioxidant and antimicrobial properties. Optimization would also lead to better understanding of the relationship between parameters verified (i.e holding time, final temperature and activated carbon loading) with the responses (TPC and yield of PA). Kinetic analysis is important for detail understanding on the pyrolysis temperature range and the behavior of lignocellulosic material degradation (cellulose, hemicellulose and lignin) during pyrolysis. Kinetic parameters such as activation energy (E_a), pre-exponential factors, (A) and reaction model are valuable information for any scaling up attempts notably for design of equipment and process optimization condition for yield maximization.

1.3 Research Objectives

The objective of this study were as follows:

i) To optimize the production of total phenolic content (TPC) and liquid yield of microwave-assisted pyroligneous acid from OPF.

ii) To evaluate the efficiency of optimized microwave-assisted pyroligneous acid as antioxidant and antimicrobial agents.

iii) To elucidate the kinetic study analysis of OPF biomass and optimized microwave-assisted pyroligneous acid for details understanding on the energy requirement and mechanism behavior of the material degradation during pyrolysis process.

1.4 Scope of Study

i) The pyroligneous acid was synthesized from OPF via microwave-assisted pyrolysis heating.

ii) The activated carbon was used as microwave absorber to produce pyroligneous acid from OPF via microwave-assisted pyrolysis heating.

iii) Three parameters were used during the optimization study namely holding time (15-30 minutes), final temperature (400-600 °C) and amount of activated carbon loading (50-100 g).

iv) The Central Composite Design (CCD) approach via response surface methodology (RSM) was used for the optimization process on the TPC as well as liquid yield of microwave-assisted pyroligneous acid (MWPA).

v) The efficiency of optimized concentrated microwave-assisted pyroligneous acid extracted with ethyl acetate (C-MWPA) was evaluated for antioxidant and antimicrobial properties. Ethyl acetate (99.5%, AnalaR grade) was used due to its less toxicity and higher capacity to extract phenolic compound in MWPA.

vi) Kinetic study analysis were based on thermogravimetric analysis (TGA) data using three kinetics models approach namely Ozawa-Flynn Wall (OFW) Kissinger-Akahira-Sunose (KAS) and Coats-Redfern method (CRM).

vii) The kinetic model validation of OPF biomass and optimized C-MWPA were analyzed using 13 types of reaction models from CRM.

1.5 Significance of Study

The establishment on the production of pyroligneous acid containing highest amount of total phenolic content and highest yield in optimized microwave-assisted pyrolysis process can lead to larger application such as at pilot scale level. Process optimization would allow significant energy and time saving. The kinetic study analysis assist in the understanding of pyrolysis temperature range and the behavior of biomass degradation during pyrolysis. The combination of model free method (KAS and OFW) with the model fitting method (CRM) significantly contribute to the ability to reveal the complexity of the process and to find the best fitted kinetic reaction model of the material involved during pyrolysis process. Moreover, it also contribute to the minimization in the volumes of oil palm biomass waste that needs to be transported to the plantation area from the mills. This directly contributes to the reduction in transportation cost as well as reduction in environmental pollution from degradation of these biomass.

REFERENCES

Aamer, A. A., Abdul-Hafeez, M. M. and Sayed, S. M. (2014). Minimum Inhibitory and Bactericidal Concentrations (MIC And MBC) of Honey and Bee Propolis Against Multi-Drug Resistant (MDR) *Staphylococcus Sp.* Isolated from Bovine Clinical Mastitis. *Alternative and Integrative Medicine,* 15(2), 1-9.

Abas, F. Z. and Ani, F. N. (2014). Comparing Characteristics of Oil Palm Biochar Using Conventional and Microwave Heating. *Jurnal Teknologi*, 68(3), 33-37.

Abdelaziz, O.Y., Brink, D.P., Prothmann, J., Ravi, K., Sun, M., García-Hidalgo, J., Sandahl, M., Hulteberg, C.P., Turner, C., Lidén, G. and Gorwa-Grauslund, M.F. (2016). Biological Valorization of Low Molecular Weight Lignin. *Biotechnology Advances*, 34(8), 1318-1346.

Abdelhady, M. I., Motaal, A. A. and Beerhues, L. (2011). Total Phenolic Content and Antioxidant Activity of Standardized Extracts from Leaves and Cell Cultures of Three Callistemon Species. *American Journal of Plant Sciences*, 2(6), 847-850.

Abdullah, S. S., Yusup, S., Ahmad, M. M., Ramli, A. and Ismail, L. (2010). Thermogravimetry Study on Pyrolysis of Various Lignocellulosic Biomass for Potential Hydrogen Production. *International Journal of Chemical, Molecular, Nuclear, Materials and Metallurgical Engineering*, 4(12), 42-20.

Abdullah, N. and Sulaiman, F. (2013). *Chapter 3*: *The Oil Palm Wastes in Malaysia*. In Matovic, M.D. (Ed). *Biomass Now - Sustainable Growth and Use*. (pp.75-100). Canada: InTech.

Abnisa, F., Daud, W. W. and Sahu, J. N. (2011). Optimization and Characterization Studies on Bio-Oil Production from Palm Shell by Pyrolysis Using Response Surface Methodology. *Biomass and Bioenergy,* 35(8), 3604-3616.

Abnisa, F., Arami-Niya, A., Daud, W. W. and Sahu, J. N. (2013). Characterization of Bio-Oil and Bio-Char from Pyrolysis of Palm Oil Wastes. *BioEnergy Research*, 6(2), 830-840.

Aboulkas, A. and El Harfi, K. (2008). Study of the Kinetics and Mechanisms of Thermal Decomposition of Moroccan Tarfaya Oil Shale and Its Kerogen. *Oil Shale*, 25,426–443.

Aboyade, A. O., Hugo, T. J., Carrier, M., Meyer, E. L., Stahl, R., Knoetze, J. H. and Görgens, J. F. (2011). Non-Isothermal Kinetic Analysis of the Devolatilization of Corn Cobs and Sugar Cane Bagasse in an Inert Atmosphere. *Thermochimica Acta*, 517(1), 81-89.

Abubakar, Z. and Ani, F. N. (2013). Microwave-Assisted Pyrolysis of Oil Palm Shell Biomass. *Jurnal Mekanikal*, 36, 19-30.

Achmadi, S. S., Mubarik, N. R., Nursyamsi, R. and Septiaji, P. (2013). Characterization of Redistilled Liquid Smoke of Oil-Palm Shells and Its Application as Fish Preservatives. *Journal of Applied Sciences*, 13(3), 401-408.

Adam, Mohamed AB. (2017). *Understanding Microwave Pyrolysis of Biomass Materials*. Doctor of Philosophy Thesis. University of Nottingham.

Adjimani, J. P. and Asare, P. (2015). Antioxidant and Free Radical Scavenging Activity of Iron Chelators. *Toxicology Reports*, 2, 721-728.

Afzal, I., Ahmad, M.S., Malik, S., Ibrahim, M., Al-Ayed, O.S., Qadir, G., Al, H.D. and Gull, M. (2018). Bioenergy potential of *Eichhornia crassipes* assessed via thermodynamics and kinetics analyses. *Protein and Peptide Letters*, 25, 1-8.

Ahmad, A. L., Yasin, N. M., Derek, C. J. C. and Lim, J. K. (2014). Kinetic Studies and Thermodynamics of Oil Extraction and Transesterification of *Chlorella Sp*. for Biodiesel Production. *Environmental Technology*, 35(7), 891-897.

Ahmad, M. I., Rasat, M. S., Soid, S. N., Mohamed, M., Rizman, Z. I. and Amini, M. H. (2016). Preliminary Study of Microwave Irradiation towards Oil Palm Empty Fruit Bunches Biomass. *Journal of Tropical Resources and Sustainable Science*, 4, 133-137.

Akhtar, J. and Amin, N. A. S. (2011). A Review on Process Conditions for Optimum Bio-Oil Yield in Hydrothermal Liquefaction of Biomass. *Renewable and Sustainable Energy Reviews*, 15(3), 1615-1624.

Al-Ayed, O. S., Amer, M. W. and Matouq, M. (2017). Variable Activation Energy Principle to Model Oil Shale Pyrolysis Kinetics. *Oil Shale*, 34(2), 181-194.

Aljohi, A., Matou-Nasri, S. and Ahmed, N. (2016). Antiglycation and Antioxidant Properties of Momordica Charantia. *PloS one*, 11(8), 1-14.

Alkhatib, M. F., Mamun, A. A. and Akbar, I. (2015). Application of Response Surface Methodology (RSM) For Optimization of Color Removal from POME by Granular Activated Carbon. *International Journal of Environmental Science and Technology*, 12(4), 1295-1302.

Ani, F. N. (2012). *Sustainability and Recycling Through Thermal Conversion of Bioresources*. In *Professorial Inaugural Lecture Series*. (pp 1-42). UTM Press.

Andrews, J. M. (2001). Determination of Minimum Inhibitory Concentrations. *Journal of Antimicrobial Chemotherapy*, 48 (suppl 1), 5-16.

Ariffin, S. J., Yahayu, M., El-Enshasy, H., Malek, R. A., Aziz, A. A., Hashim, N. M. and Zakaria, Z. A. (2017). Optimization of Pyroligneous Acid Production from Palm Kernel Shell and Its Potential Antibacterial and Antibiofilm Activities. *Indian Journal of Experimental Biology*, 55, 427-435.

Araújo, E., Pimenta, A. S., Feijó, F. M., Castro, R. V. O., Fasciotti, M., Monteiro, T. V. C., and Lima, K. M. G. (2018). Antibacterial and Antifungal Activities of Pyroligneous Acid from Wood of *Eucalyptus Urograndis* and *Mimosa Tenuiflora*. *Journal of Applied Microbiology*, 124(1), 85-96.

Ashengroph, M., Nahvi, I. and Amini, J. (2013). Application of Taguchi Design and Response Surface Methodology for Improving Conversion of Isoeugenol Into Vanillin by Resting Cells of *Psychrobacter Sp. CSW4*. *Iranian Journal of Pharmaceutical Research: IJPR*, 12(3), 411-421.

Asomaning, J., Haupt, S., Chae, M. and Bressler, D. C. (2018). Recent Developments in Microwave-Assisted Thermal Conversion of Biomass for Fuels and Chemicals. *Renewable and Sustainable Energy Reviews*, 92, 642-657.

Awalludin, M. F., Sulaiman, O., Hashim, R. and Nadhari, W. N. A. W. (2015). An Overview of the Oil Palm Industry in Malaysia and its Waste Utilization through Thermochemical Conversion, Specifically Via Liquefaction. *Renewable and Sustainable Energy Reviews*, 50, 1469-1484.

Aziz, M. A., Uemura, Y. and Sabil, K. M. (2011). Characterization of Oil Palm Biomass as Feed for Torrefaction Process. *National Postgraduate Conference (NPC).* 19-20 September. Perak, Malaysia: IEEE, 1-6.

Azura, N. W., Zularisam, A. W., Norsita, S., Nasrullah, M. and Wahida, N. (2017). Effect of Fast Pyrolysis Operating Conditions on Product Yield of Red

Meranti Sawdust. *International Research Journal of Engineering and Technology*, 4(9), 607-611.

Bacanli, M., Başaran, A.A. and Başaran, N. (2015). The Antioxidant and Antigenotoxic Properties of Citrus Phenolics Limonene and Naringin. *Food and Chemical Toxicology*, 81, 160-170.

Balat, M., Balat, M., Kırtay, E. and Balat, H. (2009). Main Routes for the Thermo-Conversion of Biomass into Fuels and Chemicals. Part 1: Pyrolysis Systems. *Energy Conversion and Management*, 50(12), 3147-3157.

Balouiri, M., Sadiki, M. and Ibnsouda, S. K. (2016). Methods for in Vitro Evaluating Antimicrobial Activity: A Review. *Journal of Pharmaceutical Analysis*, 6(2), 71-79.

Bandet, T., Whitehead, S., Blondel-Hill, E., Wagner, K., and Cheeptham, N. (2014) Susceptibility of Clinical *Moraxella Catarrhalis* Isolates in British Columbia To Six Empirically Prescribed Antibiotic Agents. *Canadian Journal of Infectious Diseases and Medical Microbiology* 25(3), 155-158.

Barcelos, E., de Almeida Rios, S., Cunha, R.N., Lopes, R., Motoike, S.Y., Babiychuk, E., Skirycz, A. and Kushnir, S., (2015). Oil Palm Natural Diversity and the Potential for Yield Improvement. *Frontiers in Plant Science*, 6(190), 1-16.

Barrie, P. J. (2012). The Mathematical Origins of the Kinetic Compensation Effect: 1. the Effect of Random Experimental Errors. *Physical Chemistry Chemical Physics*, 14(1), 318-326.

Bhattacharjee, N. and Biswas, A. B. (2018). Pyrolysis of Alternanthera Philoxeroides (Alligator Weed): Effect of Pyrolysis Parameter on Product Yield and Characterizationo of Liquid Product and Bio Char. *Journal of the Energy Institute*, 91(4), 605-618.

Bilehal, D., Li, L. and Kim, Y. H. (2012). Gas Chromatography–Mass Spectrometry Analysis and Chemical Composition of the Bamboo-Carbonized Liquid. *Food Analytical Methods*, 5(1), 109-112.

Borges, F.C., Du, Z., Xie, Q., Trierweiler, J.O., Cheng, Y., Wan, Y., Liu, Y., Zhu, R., Lin, X., Chen, P. and Ruan, R. (2014). Fast Microwave Assisted Pyrolysis of Biomass Using Microwave Absorbent. *Bioresource Technology*, 156, 267-274.

Bosch, M. and Hazen, S. P. (2013). Lignocellulosic Feedstocks: Research Progress and Challenges in Optimizing Biomass Quality and Yield. *Frontiers in Plant Science*, 4*(474), 1-3.*

Boytsova, A., Kondrasheva, N.and Ancheyta, J. (2017). Thermogravimetric Determination and Pyrolysis Thermodynamic Parameters of Heavy Oils and Asphaltenes. *Energy and Fuels*, 31(10), 10566-10575.

Brebu, M. and Vasile, C. (2010). Thermal Degradation of Lignin–A Review. *Cellulose Chemistry and Technology*, 44 (9), 353-363.

Bridgwater, A.V. (2012). Review of Fast Pyrolysis of Biomass and Product Upgrading. *Biomass and Bioenergy*, 38, 68-94.

Bu, Q., Lei, H., Ren, S., Wang, L., Zhang, Q., Tang, J. and Ruan, R. (2012). Production of Phenols and Biofuels by Catalytic Microwave Pyrolysis of Lignocellulosic Biomass. *Bioresource Technology*, 108, 274-279.

Bu, Q., Lei, H., Qian, M. and Yadavalli, G. (2016). A Thermal Behavior and Kinetics Study of the Catalytic Pyrolysis of Lignin. *The Royal Society of Chemistry Advances*, 6(103), 100700-100707.

Budarin, V.L., Clark, J.H., Lanigan, B.A., Shuttleworth, P., Breeden, S.W., Wilson, A.J., Macquarrie, D.J., Milkowski, K., Jones, J., Bridgeman, T., and Ross, A. (2009). The Preparation of High-Grade Bio-Oils through the Controlled, Low Temperature Microwave Activation of Wheat Straw. *Bioresource Technology*, 100(23), 6064-6068.

Byarugaba, D. K. (2010). *Mechanisms of Antimicrobial Resistance*. In Sosa *et al*. (Eds.) *Antimicrobial Resistance in Developing Countries* (pp.15-26). New York: Springer.

Cai, K. Z. and He, Y. J. (2011). Antioxidant Activities of the Pyroligneous Acid in Living *Caenorhabditis elegans*. In *Advanced Materials Research*, 236-238, 2564-2569. Trans Tech Publications.

Cai, J., He, Y., Yu, X., Banks, S. W., Yang, Y., Zhang, X., Yu, Y., Liu, R. and Bridgwater, A. V. (2017). Review of Physicochemical Properties and Analytical Characterization of Lignocellulosic Biomass. *Renewable and Sustainable Energy Reviews*, *76*, 309-322.

Çepelioğullar, Ö. and Pütün, A. E. (2013). Thermal and Kinetic Behaviors of Biomass and Plastic Wastes in Co-Pyrolysis. *Energy Conversion and Management*, 75, 263-270.

Ceylan, S. and Topçu, Y. (2014). Pyrolysis Kinetics of Hazelnut Husk Using Thermogravimetric Analysis. *Bioresource technology*, 156, 182-188.

Chaiyaomporn, K. and Chavalparit, O. (2010). Fuel Pellets Production from Biodiesel Waste. *Environmental Asia*, 3(1), 103-110.

Chaudhary, R. G., Ali, P., Gandhare, N. V., Tanna, J. A. and Juneja, H. D. (2016). Thermal Decomposition Kinetics of Some Transition Metal Coordination Polymers of Fumaroyl *bis* (paramethoxyphenylcarbamide) Using DTG/DTA Techniques. *Arabian Journal of Chemistry*, 1-13.

Chávez-González, M. L., Rodrıguez-Herrera, R. and Aguilar, C. N. (2016). Chapter 11: *Essential Oils: A Natural Alternative to Combat Antibiotics Resistance*. In Kon, K. and Rai, M. (Ed). *Antibiotic Resistance: Mechanisms and New Antimicrobial Approaches* (pp. 227-237). United Kingdom: Elsevier

Chen, K., Wang, Z., Liu, H., Ruan, Y. and Guo, A. (2013). Thermodynamic and Thermokinetic Study on Pyrolysis Process of Heavy Oils. *Journal of Thermal Analysis and Calorimetry*, 112(3), 1423-1431.

Chen, H. (2014). *Biotechnology of Lignocellulose: Theory and Practice*. (1st ed.) London: Springer.

Chen, Z., Zhu, Q., Wang, X., Xiao, B. and Liu, S. (2015). Pyrolysis Behaviors and Kinetic Studies on Eucalyptus Residues Using Thermogravimetric Analysis. *Energy Conversion and Management*, 105, 251-259

Chen, Y. R. (2016). Microwave Pyrolysis of Oily Sludge with Activated Carbon. *Environmental technology*, 37(24), 3139-3145.

Chen, W. H. and Lin, B. J. (2016). Characteristics of Products from the Pyrolysis of Oil Palm Fiber and Its Pellets in Nitrogen and Carbon Dioxide Atmospheres. *Energy*, 94, 569-578.

Collard, F. X. and Blin, J. (2014). A Review on Pyrolysis of Biomass Constituents: Mechanisms and Composition of the Products Obtained from the Conversion of Cellulose, Hemicelluloses and Lignin. *Renewable and Sustainable Energy Reviews*, 38, 594-608.

Cortés, A. M. and Bridgwater, A. V. (2015). Kinetic Study of the Pyrolysis of Miscanthus and Its Acid Hydrolysis Residue by Thermogravimetric Analysis. *Fuel Processing Technology*, 138, 184-193.

Cunha, L.C., de Morais, S.A., de Aquino, F.J., Chang, R., de Oliveira, A., Martins, M.M., Martins, C.H., Sousa, L.C., Barros, T.T., da Silva, C.V. and do

Nascimento, E.A., (2017). Bioassay-Guided Fractionation and Antimicrobial and Cytotoxic Activities of *Cassia Bakeriana* Extracts. *Revista Brasileira de Farmacognosia*, 27(1), 91-98.

Czajczyńska, D., Nannou, T., Anguilano, L., Krzyzynska, R., Ghazal, H., Spencer, N. and Jouhara, H. (2017). Potentials of Pyrolysis Processes in the Waste Management Sector. *Energy Procedia*, 123, 387-394.

Czarnocka, J. (2015). The Use of Microwave Pyrolysis for Biomass Processing. *Archiwum Motoryzacji*, 67(1), 11-21.

Darmawan, S., Wistara, N. J., Pari, G., Maddu, A., and Syafii, W. (2016). Characterization of Lignocellulosic Biomass as Raw Material for the Production of Porous Carbon-based Materials. *BioResources*, 11(2), 3561-3574.

Das, I., Kumar, G. and Shah, N. G. (2013). Microwave Heating as an Alternative Quarantine Method for Disinfestation of Stored Food Grains. *International Journal of Food Science*, 2013, 1-13.

Daugaard, D. E. and Brown, R. C. (2003). Enthalpy for Pyrolysis for Several Types of Biomass. *Energy and Fuels*, *17*(4), 934-939.

Davis, K. M., Rover, M., Brown, R. C., Bai, X., Wen, Z. and Jarboe, L. R. (2016). Recovery and Utilization of Lignin Monomers as Part of the Biorefinery Approach. *Energies*, 9(10), 808,1-28.

de Cortes Sánchez-Mata, M. and Tardío, J. (Eds.). (2016). *Mediterranean Wild Edible Plants: Ethnobotany and Food Composition Tables*. Springer.

Demirbas, A. (2000). Mechanisms of Liquefaction and Pyrolysis Reactions of Biomass. *Energy Conversion and Management*, 41(6), 633-646.

Demirbas, A. (2007). The Influence of Temperature on the Yields of Compounds Existing in Bio-Oils Obtained from Biomass Samples Via Pyrolysis. *Fuel Processing Technology*, 88(6), 591-597.

Deng, H., Li, G., Yang, H., Tang, J. and Tang, J. (2010). Preparation of Activated Carbons from Cotton Stalk by Microwave Assisted KOH and K_2CO_3 Activation. *Chemical Engineering Journal*, 163(3), 373-381.

Dhaundiyal, A., Singh, S. B., Hanon, M. M. and Rawat, R. (2018). Determination of Kinetic Parameters for the Thermal Decomposition of Parthenium hysterophorus. *Environmental and Climate Technologies*, 22(1), 5-21.

Domínguez, A., Menéndez, J. A., Inguanzo, M. and Pis, J. J. (2006). Production of Bio-Fuels by High Temperature Pyrolysis of Sewage Sludge Using

Conventional and Microwave Heating. *Bioresource technology*, 97(10): 1185-1193.

Domínguez, A., Menéndez, J. A., Fernandez, Y., Pis, J. J., Nabais, J. V., Carrott, P. J. M. and Carrott, M. R. (2007). Conventional and Microwave Induced Pyrolysis of Coffee Hulls for the Production of A Hydrogen Rich Fuel Gas. *Journal of Analytical and Applied Pyrolysis*, 79(1), 128-135.

Dong, Q. and Xiong, Y. (2014). Kinetics Study on Conventional and Microwave Pyrolysis of Moso Bamboo. *Bioresource Technology*, 171, 127-131.

Dongala, V. and Tigulla, P. (2013). The Novel Antioxidant Activity Method for Phenolic Compounds. *Der Pharma Chemica*, 5(4), 308-320.

Dorez, G., Ferry, L., Sonnier, R., Taguet, A. and Lopez-Cuesta, J. M. (2014). Effect of Cellulose, Hemicellulose and Lignin Contents on Pyrolysis and Combustion of Natural Fibers. *Journal of Analytical and Applied Pyrolysis*, 107, 323-331.

Driscoll, A. J., Bhat, N., Karron, R. A., O'Brien, K. L. and Murdoch, D. R. (2012). Disk Diffusion Bioassays for the Detection of Antibiotic Activity in Body Fluids: Applications for the Pneumonia Etiology Research for Child Health Project. *Clinical Infectious Diseases*, 54(suppl 2), S159-S164.

Du, Z., Li, Y., Wang, X., Wan, Y., Chen, Q., Wang, C., Lin, X., Liu, Y., Chen, P. and Ruan, R. (2011). Microwave-Assisted Pyrolysis of Microalgae for Biofuel Production. *Bioresource Technology*, 102(7), 4890-4896.

Dungani, R., Karina, M., Sulaeman, A., Hermawan, D. and Hadiyane, A. (2016). Agricultural Waste Fibers towards Sustainability and Advanced Utilization: A Review. *Asian Journal of Plant Sciences*, 15(1/2), 42-55.

Duku, M.H. (2015). *Bio-Oil Production from Lignocellulosic Biomass Using Fast Pyrolysis in a Fluidized-Bed Reactor*. Doctor of Philosophy Thesis. Kwame-Nkrumah University of Science and Technology.

Dutka, M., Ditaranto, M., and Løvås, T. (2015). Application of a Central Composite Design for the Study of NO_x Emission Performance of a Low NOx Burner. *Energies*, 8(5), 3606-3627.

El-Gendy, N. S., Deriase, S. F. and Hamdy, A. (2014). The Optimization of Biodiesel Production from Waste Frying Corn Oil Using Snails Shells as a Catalyst. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 36(6), 623-637.

Elshikh, M., Ahmed, S., Funston, S., Dunlop, P., McGaw, M., Marchant, R. and Banat, I. M. (2016). Resazurin-Based 96-Well Plate Microdilution Method for the Determination of Minimum Inhibitory Concentration of Biosurfactants. *Biotechnology Letters*, 38(6), 1015-1019.

European Committee for Antimicrobial Susceptibility Testing of the European Society of Clinical, M. and Infectious, D. (2003). *Determination of Minimum Inhibitory Concentrations (Mics) of Antibacterial Agents by Broth Dilution*. *Clinical Microbiology and Infection, 9*(8) (pp.1-7). John Wiley: Germany.

Fagbemi, L., Khezami, L. and Capart, R. (2001). Pyrolysis Products from Different Biomasses: Application to the Thermal Cracking of Tar. *Applied Energy,* 69(4), 293-306.

Fan, L., Zhang, Y., Liu, S., Zhou, N., Chen, P., Cheng, Y., Addy, M., Lu, Q., Omar, M.M., Liu, Y. and Wang, Y. (2017). Bio-Oil from Fast Pyrolysis of Lignin: Effects of Process and Upgrading Parameters. *Bioresource Technology*, 241, 1118-1126.

Federation, W. E., and APH Association. (2005). Standard Methods for the Examination of Water and Wastewater. *American Public Health Association (APHA): Washington, DC, USA*.

Fernández, Y., Arenillas, A. and Menéndez, J. Á. (2011). *Microwave Heating Applied to Pyrolysis*. In Stanisław, G. (Ed.) *Advances in Induction and Microwave Heating of Mineral and Organic Materials* (pp. 723-752). Europe: InTech.

Fernando, C. D. and Soysa, P. (2015). Optimized Enzymatic Colorimetric Assay for Determination of Hydrogen Peroxide (H_2O_2) Scavenging Activity of Plant Extracts. *MethodsX*, 2, 283-291.

Ferreira, S.L.C., Bruns, R.E., da Silva, E.G.P., dos Santos, W.N.L., Quintella, C.M., David, J.M., de Andrade, J.B., Breitkreitz, M.C., Jardim, I.C.S.F. and Neto, B.B. (2007). Statistical Designs and Response Surface Techniques for the Optimization of Chromatographic Systems. *Journal of Chromatography A*, 1158(1), 2-14.

Frei, M. (2013). Lignin: Characterization of A Multifaceted Crop Component: Review Article. *The Scientific World Journal*, (2013), 1-25.

Fu, C. W. F., Ho, C. W., Yong, W. T. L., Abas, F. and Tan, C. P. (2015). Effects of Phenolic Antioxidants Extraction from Four Selected Seaweeds Obtained from Sabah. *PeerJ PrePrints*, 3, (e1529), 1-15.

Fullerton, M., Khatiwada, J., Johnson, J. U., Davis, S. and Williams, L. L. (2011). Determination of Antimicrobial Activity of Sorrel (Hibiscus Sabdariffa) on *Esherichia Coli* O157: H7 Isolated from Food, Veterinary, and Clinical Samples. *Journal of Medicinal Food*, 14(9), 950-956.

Gai, C., Dong, Y. and Zhang, T. (2013). The Kinetic Analysis of the Pyrolysis of Agricultural Residue under Non-Isothermal Conditions. *Bioresource Technology*, 127, 298-305.

Gajdhane, S. B., Bhagwat, P. K. and Dandge, P. B. (2016). Response Surface Methodology-Based Optimization of Production Media and Purification of A-Galactosidase in Solid-State Fermentation by Fusarium Moniliforme NCIM 1099. *3 Biotech*, 6(260), 1-14.

Galooyak, S. S. and Dabir, B. (2015). Three-Factor Response Surface Optimization of Nano-Emulsion Formation Using A Microfluidizer. *Journal of Food Science and Technology*, *5*2(5), 2558-2571.

Gao, X. K., Low, T. S., Liu, Z. J. and Chen, S. X. (2002). Robust Design for Torque Optimization Using Response Surface Methodology. *IEEE Transactions on Magnetics*, 38(2), 1141-1144.

Gao, Y., Yang, Y., Qin, Z. and Sun, Y. (2016). Factors Affecting the Yield of Bio-Oil from the Pyrolysis of Coconut Shell. *Springer Plus*, 5(1), 1-8.

Geetha, R. V. and Roy, A. (2013). In Vitro Antioxidant and Free Radical Scavenging Activity of The Ethanolic Extract of *Aesculus Hippocastanum*. *International Journal of Drug Development and Research*, 5(3), 403-407.

Genieva, S. D., Vlaev, L. T. and Atanassov, A. N. (2010). Study of the Thermooxidative Degradation Kinetics of Poly (Tetrafluoroethene) Using Iso-Conversional Calculation Procedure. *Journal of Thermal Analysis and Calorimetry*, 99(2), 551-561.

Georgieva, V., Vlaev, L. and Gyurova, K. (2012). Non-Isothermal Degradation Kinetics of $CaCo_3$ from Different Origin. *Journal of Chemistry*, 2013, 1-12.

Goh, C. S., Tan, K. T., Lee, K. T. and Bhatia, S. (2010). Bio-Ethanol from Lignocellulose: Status, Perspectives and Challenges in Malaysia. *Bioresource Technology*, 101(13), 4834-4841.

Goyal, H. B., Seal, D. and Saxena, R. C. (2008). Bio-Fuels from Thermochemical Conversion of Renewable Resources: A Review. *Renewable and Sustainable Energy Reviews*, 12(2), 504-517.

Grima-Olmedo, C., Ramírez-Gómez, Á., Gómez-Limón, D. and Clemente-Jul, C. (2016). Activated Carbon from Flash Pyrolysis of Eucalyptus Residue. *Heliyon*, 2(9), e00155, 1-18.

Gülçin, İ., Huyut, Z., Elmastaş, M. and Aboul-Enein, H. Y. (2010). Radical scavenging and antioxidant activity of tannic acid. *Arabian Journal of Chemistry*, 3(1), 43-53.

Guo, J. and Lua, A. C. (2000). Kinetic Study on Pyrolysis of Extracted Oil Palm Fiber. Isothermal and Non-Isothermal Conditions. *Journal of Thermal Analysis and Calorimetry*, 59(3), 763-774.

Gupta, D. (2015). Methods for Determination of Antioxidant Capacity: A Review. *International Journal of Pharmaceutical Sciences and Research*, 6(2), 546-566.

Hames, B., Posey-Eddy, F., Roth, C., Ruiz, R., Sluiter, A. and Templeton, D. (2002). Laboratory Analytical Procedure LAP-004CS, 2002, 1-8.

Hanif, M. U., Capareda, S. C., Iqbal, H., Arazo, R. O. and Baig, M. A. (2016). Effects of Pyrolysis Temperature on Product Yields and Energy Recovery from Co-Feeding of Cotton Gin Trash, Cow Manure, and Microalgae: A Simulation Study. *PloS one*, 11(4), 1-11.

Harada, K., Iguchi, A., Yamada, M., Hasegawa, K., Nakata, T. and Hikasa, Y. (2013). Determination of Maximum Inhibitory Dilutions of Bamboo Pyroligneous Acid against Pathogenic Bacteria from Companion Animals: An in Vitro Study. *Journal of Veterinary Advance*, 3(11), 300-305.

Harmsen, P., Huijgen, W., Bermudez, L. and Bakker, R. (2010). Literature Review of Physical and Chemical Pretreatment Processes for Lignocellulosic. *Biomass*, 1-49.

Hassan, M. N. A., Jaramillo, P. and Griffin, W. M. (2011). Life cycle GHG Emissions from Malaysian Oil Palm Bioenergy Development: The Impact on Transportation Sector's Energy Security. *Energy Policy*, 39(5), 2615-2625.

Hassan, E., Elsayed, I. and Eseyin, A. (2016). Production High Yields of Aromatic Hydrocarbons through Catalytic Fast Pyrolysis of Torrefied Wood and Polystyrene. *Fuel*, 174, 317-324.

He, B. J., Zhang, Y., Yin, Y., Funk, T. L. and Riskowski, G. L. (2000). Operating Temperature and Retention Time Effects on the Thermochemical Conversion Process of Swine Manure. *Transactions of the ASAE*, 43(6), 1821.

Heydari, M., Rahman, M. and Gupta, R. (2015). Kinetic Study and Thermal Decomposition Behavior of Lignite Coal. *International Journal of Chemical Engineering*, 2015, 1-10.

Ho, C.L., Lin, C.Y., Ka, S.M., Chen, A., Tasi, Y.L., Liu, M.L., Chiu, Y.C. and Hua, K.F. (2013). Bamboo Vinegar Decreases Inflammatory Mediator Expression and NLRP3 Inflammasome Activation by Inhibiting Reactive Oxygen Species Generation and Protein Kinase C-α/δ Activation. PloS one, 8(10), 1-11.

Hooi, K. K., Alimuddin, Z. and Ong, L. K. (2009). Laboratory-Scale Pyrolysis of Oil Palm Pressed Fruit Fibres. *Journal of Oil Palm Research*, 21(June), 577-587.

Hosoya, T., Kawamoto, H. and Saka, S. (2008). Pyrolysis Gasification Reactivities of Primary Tar and Char Fractions from Cellulose and Lignin as Studied With a Closed Ampoule Reactor. *Journal of Analytical and Applied Pyrolysis*, 83(1), 71-77.

Hossain, M. A., Ganesan, P., Jewaratnam, J. and Chinna, K. (2017). Optimization of Process Parameters for Microwave Pyrolysis of Oil Palm Fiber (OPF) for Hydrogen and Biochar Production. *Energy Conversion and Management*, 133, 349-362.

Hosseini, S. E. and Wahid, M. A. (2014). Utilization of Palm Solid Residue as a Source of Renewable and Sustainable Energy in Malaysia. *Renewable and Sustainable Energy Reviews*, 40, 621-632.

Hu, L., Pan, H., Zhou, Y. and Zhang, M. (2011). Methods to Improve Lignin's Reactivity as a Phenol Substitute and as Replacement for Other Phenolic Compounds: A Brief Review. *BioResources*, 6(3), 3515-3525.

Huang, D., Ou, B. and Prior, R. L. (2005). The Chemistry behind Antioxidant Capacity Assays. *Journal of Agricultural and Food Chemistry*, 53(6), 1841-1856.

Huang, Y. F., Kuan, W. H., Lo, S. L. and Lin, C. F. (2008). Total Recovery of Resources and Energy from Rice Straw Using Microwave-Induced Pyrolysis. *Bioresource Technology*, 99(17), 8252-8258.

Huang, Y.F., Chiueh, P.T., Kuan, W.H. and Lo, S.L. (2013). Microwave Pyrolysis of Rice Straw: Products, Mechanism, and Kinetics. *Bioresource Technology*, 142, 620-624.

Huang, X., Cao, J. P., Zhao, X. Y., Wang, J. X., Fan, X., Zhao, Y. P. and Wei, X. Y. (2016). Pyrolysis Kinetics of Soybean Straw Using Thermogravimetric Analysis. *Fuel*, 169, 93-98.

Husain, Z., Zainac, Z. and Abdullah, Z. (2002). Briquetting of Palm Fibre and Shell from the Processing of Palm Nuts to Palm Oil. *Biomass and Bioenergy*, 22(6), 505-509.

Hwang, Y. H., Matsushita, Y. I., Sugamoto, K. and Matsui, T. (2005). Antimicrobial Effect of the Wood Vinegar from *Cryptomeria Japonica* Sapwood on Plant Pathogenic Microorganisms. *Journal of Microbiology and Biotechnology*, 15(5), 1106-1109.

Hyldgaard, M., Mygind, T. and Meyer, R. L. (2012). Essential Oils in Food Preservation: Mode of Action, Synergies, and Interactions with Food Matrix Components. *Frontiers in Microbiology*, 3 (12), 1-24.

Ibrahim, D., Kassim, J., Sheh-Hong, L. and Rusli, W. (2013a). Efficacy of Pyroligneous Acid from *Rhizophora Apiculata* on Pathogenic *Candida Albicans*. *Journal of Applied Pharmaceutical Science*, 3(7), 7-13.

Ibrahim, D., Hong, L. S. and Kuppan, N. (2013b). Antimicrobial Activity of Crude Methanolic Extract from *Phyllanthus niruri*. *Natural Product Communications*, 8(4), 493-496.

Ibrahim, D., Kassim, J., Lim, S. H. and Rusli, W. (2014). Evaluation of Antibacterial Effects of *Rhizophora Apiculata* Pyroligneous Acid on Pathogenic Bacteria. *Malaysian Journal of Microbiology*, 10(3), 197–204.

Ibrahim, D. and Lim, S. H. (2015). In Vitro Antimicrobial Activities of Methanolic Extract from Marine Alga *Enteromorpha intestinalis*. *Asian Pacific Journal of Tropical Biomedicine,* 5(9), 785-788.

Ibrahim, M. N. M, Zakaria, N., Sipaut, C. S., Sulaiman, O. and Hashim, R. (2011). Chemical and Thermal Properties of Lignins from Oil Palm Biomass as a Substitute for Phenol in a Phenol Formaldehyde Resin Production. *Carbohydrate Polymers*, 86(1), 112-119.

Ibrahim, N., Jensen, P. A., Dam-Johansen, K., Ali, R. R. and Kasmani, R. M. (2012). Influence of Reaction Temperature and Water Content on Wheat Straw Pyrolysis. *World Academy of Science, Engineering and Technology, International Journal of Chemical, Molecular, Nuclear, Materials and Metallurgical Engineering*, 6(10), 919-925.

Idris, S. S, Rahman, N. A, Ismail, K, Alias, A. B, Rashid, Z. A, and Aris M. J (2010). Investigation on Thermochemical Behaviour of Low Rank Malaysian Coal, Oil Palm Biomass and Their Blends during Pyrolysis via Thermogravimetric Analysis (TGA). *Bioresource Technology*, 101:4584–4592.

Ingole, P. M., Ranveer, A. C., Deshmukh, S. M. and Deshmukh, S. K. (2016). Microwave Assisted Pyrolysis of Biomass: A Review. *International Journal of Advance Technology in Engineering and Science*, 4(6), 78-84.

Imran, A., Bramer, E. A., Seshan, K. and Brem, G. (2016). Catalytic Flash Pyrolysis of Biomass Using Different Types of Zeolite and Online Vapor Fractionation. *Energies*, 9(187), 1-17.

Islam, A.F.M.M., Uddin, N., Hossain, M.S., Hossain, M.M., Hasan, M.R., Kader, M.A., Akter, M.I. and Aziz, M.A. (2016). Qualitative Phytochemical Screening and Evaluation of Antioxidant, Toxicity, Antibacterial and Alpha-Amylase Inhibitory Activities of Citrus Macroptera. *Pharmacology Online*, 2,116-122.

Jahirul, M. I., Rasul, M. G., Chowdhury, A. A. abd Ashwath, N. (2012). Biofuels Production through Biomass Pyrolysis-A Technological Review. *Energies*, 5(12), 4952-5001.

Jakab, E. (2015). Analytical Techniques as a Tool to Understand the Reaction Mechanism. *In Recent Advances in Thermochemical Conversion of Biomass*, 5-108. Elsevier Inc.

Januri, Z., Idris, S. S., Akhawan, H. A., Rahman, N. A., Matali, S. and Manaf, S. F. A. (2017). Effect of Mass Loading and Microwave Absorber Application Method on the Product from Microwave Assisted Pyrolysis of Palm Oil Mill Effluent. *Malaysian Journal of Analytical Sciences*, 21(2), 470-483.

Jenkins, S. G. and Schuetz, A. N. (2012). Current Concepts in Laboratory Testing To Guide Antimicrobial Therapy. In *Mayo Clinic Proceedings*, 87(3), 290-308.

Jin, W., Singh, K. and Zondlo, J. (2013). Pyrolysis Kinetics of Physical Components of Wood and Wood-Polymers Using Isoconversion Method. *Agriculture*, 3(1), 12-32.

Jorgensen, J. H. and Ferraro, M. J. (2009). Antimicrobial Susceptibility Testing: A Review of General Principles and Contemporary Practices. *Clinical*

Infectious Diseases: An Official Publication of the Infectious Diseases Society of America, 49(11), 1749-1755.

Jung, K. H. (2007). Growth Inhibition Effect of Pyroligneous Acid on Pathogenic Fungus, *Alternaria Mali,* the Agent of Alternaria Blotch of Apple. *Biotechnology and Bioprocess Engineering,* 12(3), 318-322.

Kamaludin, N. H. I., Yun, T. C., Abdullah, N. A. H. and Sa'adi, R. A. (2015). Evaluation of Antioxidant Activity and Total Phenolic Content from the Selected Malaysian Traditional Herbs Extract. *Advances in Environmental Biology,* 9(19), 57-63.

Kan, T., Strezov, V. and Evans, T. J. (2016). Lignocellulosic Biomass Pyrolysis: A Review of Product Properties and Effects of Pyrolysis Parameters. *Renewable and Sustainable Energy Reviews*, 57, 1126-1140.

Kang, C. G., Hah, D. S., Kim, C. H., Kim, Y. H., Kim, E. and Kim, J. S. (2011). Evaluation of Antimicrobial Activity of the Methanol Extracts from 8 Traditional Medicinal Plants. *Toxicological Research*, 27(1), 31-36.

Karou, D., Dicko, M. H., Simpore, J. and Traore, A. S. (2005). Antioxidant and Antibacterial Activities of Polyphenols from Ethnomedicinal Plants of Burkina Faso. *African Journal of Biotechnology*, 4(8), 823-828.

Kaseleht, K., Leitner, E. and Paalme, T. (2011). Determining Aroma-Active Compounds in Kama Flour Using SPME-GC/MS and GC–Olfactometry. *Flavour and Fragrance Journal*, 26(2), 122-128.

Kaur, R., Gera, P., Jha, M. K. and Bhaskar, T. (2018). Pyrolysis Kinetics and Thermodynamic Parameters of Castor (*Ricinus communis*) Residue using Thermogravimetric Analysis. *Bioresource Technology*, 250, 422-428.

Kawamoto, H. (2017). Lignin Pyrolysis Reactions. *Journal of Wood Science*, *63*(2), 117-132.

Keser, S., Celik, S., Turkoglu, S., Yilmaz, O. and Turkoglu, I. (2012). Hydrogen Peroxide Radical Scavenging and Total Antioxidant Activity of Hawthorn. *Chemistry Journal,* 2(1), 9-12.

Khalid, K. A., Ahmad, A. A. and Yong, T. L. K. (2017). Lignin Extraction from Lignocellulosic Biomass Using Sub-and Supercritical Fluid Technology as Precursor for Carbon Fiber Production. *Journal of the Japan Institute of Energy*, *96*(8), 255-260.

Khiari, B. and Jeguirim, M. (2018). Pyrolysis of Grape Marc from Tunisian Wine Industry: Feedstock Characterization, Thermal Degradation and Kinetic Analysis. *Energies*, 11(4), 730, 1-14.

Kim, S. S., Ly, H. V., Kim, J., Choi, J. H. and Woo, H. C. (2013). Thermogravimetric Characteristics and Pyrolysis Kinetics of Alga *Sagarssum* sp. Biomass. *Bioresource Technology*, 139, 242-248.

Koba, Y. and Ishizaki, A. (1990). Chemical Composition of Palm Fiber and Its Feasibility as Cellulosic Raw Material for Sugar Production. *Agricultural and Biological Chemistry*, 54(5), 1183-1187.

Kong, S. H., Loh, S. K., Bachmann, R.T., Rahim, S. A. and Salimon, J. (2014). Biochar from Oil Palm Biomass: A Review of Its Potential and Challenges. *Renewable and Sustainable Energy Reviews*, 39, 729-739.

Kongkaew, N., Pruksakit, W. and Patumsawad, S. (2015). Thermogravimetric Kinetic Analysis of the Pyrolysis of Rice Straw. *Energy Procedia*, 79, 663-670.

Krishnan, R., Arumugam, V. and Vasaviah, S. K. (2015). The MIC and MBC of Silver Nanoparticles against *Enterococcus faecalis*-A Facultative Anaerobe. *Journal of Nanomedicine and Nanotechnology*, 6(3), 1-4.

Kurnia, J. C., Jangam, S. V., Akhtar, S., Sasmito, A. P. and Mujumdar, A. S. (2016). Advances in Biofuel Production from Oil Palm and Palm Oil Processing Wastes: A Review. *Biofuel Research Journal*, 3(1), 332-346.

Kusuma, H. S. and Mahfud, M. (2017). Comparison of Kinetic Models of Oil Extraction from Sandalwood by Microwave-Assisted Hydrodistillation. *International Food Research Journal*, 24(4), 1697-1702.

Lam, S. S. and Chase, H. A. (2012). A Review on Waste to Energy Processes Using Microwave Pyrolysis. *Energies*, 5(10): 4209-4232.

Lange, H., Decina, S. and Crestini, C. (2013). Oxidative Upgrade of Lignin- Recent Routes Reviewed. *European Polymer Journal*, 49(6), 1151-1173.

Laurichesse, S. and Avérous, L. (2014). Chemical Modification of Lignins: Towards Biobased Polymers. *Progress in Polymer Science*, 39(7), 1266-1290.

Lee, S. H., H'ng, P. S., Lee, A. N., Sajap, A. S., Tey, B. T. and Salmiah, U. (2010). Production of Pyroligneous Acid from Lignocellulosic Biomass and Their Effectiveness against Biological Attacks. *Journal of Applied Sciences (Faisalabad)*, 10(20), 2440-2446.

Lee, H. V., Hamid, S. B. A. and Zain, S. K. (2014). Conversion of Lignocellulosic Biomass to Nanocellulose: Structure and Chemical Process. *The Scientific World Journal*, 2014, 1-20.

Leonelli, C. and Mason, T. J. (2010). Microwave and Ultrasonic Processing: Now a Realistic Option for Industry. *Chemical Engineering and Processing: Process Intensification*, 49(9), 885-900.

Leroy, V., Cancellieri, D., Leoni, E. and Rossi, J. L. (2010). Kinetic Study of Forest Fuels by TGA: Model-Free Kinetic Approach for the Prediction of Phenomena. *Thermochimica Acta*, 497(1-2), 1-6.

Li, L., Yin, X., Wu, C., Ma, L. and Zhou, Z. (2008). Kinetic Studies on the Pyrolysis and Combustion of Bio-Oil. *Proceedings of ISES World Congress 2007*. 18th-21st September, Beijing: Springer Berlin Heidelberg, 2393-2396.

Li, L., Rowbotham, J.S., Greenwell, C.H., and Dyer, P.W. (2013). *An Introduction to Pyrolysis and Catalytic Pyrolysis*. In Suib, S. L. (Ed.) *New and Future Development in Catalysis-Catalytic Biomass Conversion* (*pp.* 174-202). Netherland: Elsevier.

Li, H., Niu, S. and Lu, C. (2017). Thermal Characteristics and Kinetic Calculation of Castor Oil Pyrolysis. *Procedia Engineering*, 205, 3711-3716.

Lim, A. C. R., Chin, B. L. F., Jawad, Z. A., and Hii, K. L. (2016). Kinetic Analysis of Rice Husk Pyrolysis Using Kissinger-Akahira-Sunose (KAS) Method. *Procedia Engineering*, 148, 1247-1251.

Limayem, A. and Ricke, S. C. (2012). Lignocellulosic Biomass for Bioethanol Production: Current Perspectives, Potential Issues and Future Prospects. *Progress in Energy and Combustion Science*, 38(4), 449-467.

Lin, T., Goos, E. and Riedel, U. (2013). A Sectional Approach for Biomass: Modelling the Pyrolysis of Cellulose. *Fuel Processing Technology*, 115, 246-253.

Liu, N. A., Fan, W., Dobashi, R. and Huang, L. (2002). Kinetic Modeling of Thermal Decomposition of Natural Cellulosic Materials in Air Atmosphere. *Journal of Analytical and Applied Pyrolysis*, 63(2), 303-325.

Liu, N., Wang, B. and Fan, W. C. (2003). Kinetic Compensation Effect in the Thermal Decomposition of Biomass in Air Atmosphere. *Fire Safety Science*, 7, 581-592.

Liu, Q., Wang, S., Zheng, Y., Luo, Z., and Cen, K. (2008). Mechanism Study of Wood Lignin Pyrolysis by Using TG–FTIR Analysis. *Journal of Analytical and Applied Pyrolysis, 82*(1), 170-177.

Liu, C., Wang, H., Karim, A. M., Sun, J., and Wang, Y. (2014). Catalytic Fast Pyrolysis of Lignocellulosic Biomass. *Chemical Society Reviews,* 43(22), 7594-7623.

Liu, H., Cao, J. and Jiang, W. (2015). Evaluation and Comparison of Vitamin C, Phenolic Compounds, Antioxidant Properties and Metal Chelating Activity of Pulp and Peel from Selected Peach Cultivars. *LWT-Food Science and Technology*, 63(2), 1042-1048.

Liu, Y., Duan, Z.H., Shang, F.F, Hu B.Y and Liu, B. (2016). Composition Analysis and Antioxidant Activity Evaluation of Oyster Enzymatic Hydrolysates. *EC Nutrition* 3.6: 737-747.

Liu, P. and Xu, J. (2017). Nonisothermal Degradation Kinetics and Life Prediction of the Pendent Phenyl-Containing Polyarylate. *Journal of Macromolecular Science*, *Part B*, 56(1), 1-11.

Liyana-Pathirana, C. and Shahidi, F. (2005). Optimization of Extraction of Phenolic Compounds from Wheat Using Response Surface Methodology. *Food chemistry*, 93(1), 47-56.

Loo, A. Y., Jain, K. and Darah, I. (2007). Antioxidant and Radical Scavenging Activities of the Pyroligneous Acid from a Mangrove Plant, *Rhizophora Apiculata*. *Food Chemistry*, 104(1), 300-307.

Loo. A.Y. (2008). *Isolation and Characterization of Antioxidants Compound from Pyroligneous Acid of Rhizophora Apiculata*. Doctor of Philosophy Thesis. Universiti Sains Malaysia.

López, F. A., Rodríguez, O., Urien, A., Lobato, B., Centeno, T. Á. and Alguacil, F. J. (2013). Physico-Chemical Characteristics of the Products Derived from the Thermolysis of Waste *Abies Alba* Mill. Wood. *Journal of Environmental Protection*, 4(01), 26-30.

Lopez-Velazquez, M. A., Santes, V., Balmaseda, J. and Torres-Garcia, E. (2013). Pyrolysis of Orange Waste: A Thermo-Kinetic Study. *Journal of Analytical and Applied Pyrolysis,* 99, 170-177.

Lu, K. M., Lee, W. J., Chen, W. H., Liu, S. H. and Lin, T.-C. (2012). Torrefaction and Low Temperature Carbonization of Oil Palm Fiber and Eucalyptus in Nitrogen and Air Atmospheres. *Bioresource Technology,* 123, 98-105.

Luber, P., Bartelt, E., Genschow, E., Wagner, J. and Hahn, H. (2003). Comparison of Broth Microdilution, E Test, and Agar Dilution Methods for Antibiotic Susceptibility Testing of *Campylobacter jejuni* and *Campylobacter coli*. *Journal of Clinical Microbiology*, 41(3), 1062-1068.

Luque, R., Menéndez, J. A., Arenillas, A. and Cot, J. (2012). Microwave-Assisted Pyrolysis of Biomass Feedstocks: The Way Forward? *Energy and Environmental Science*, 5(2), 5481-5488.

Ly, H. V., Kim, J. and Kim, S. S. (2013). Pyrolysis Characteristics and Kinetics of Palm Fiber in a Closed Reactor. *Renewable Energy*, 54, 91-95.

Lyu, G., Wu, S., and Zhang, H. (2015). Estimation and Comparison of Bio-Oil Components from Different Pyrolysis Conditions. *Frontiers in Energy Research*, 3, 28.

Ma, X., Wei, Q., Zhang, S., Shi, L. and Zhao, Z. (2011). Isolation and Bioactivities of Organic Acids and Phenols from Walnut Shell Pyroligneous Acid. *Journal of Analytical and Applied Pyrolysis*, 91(2), 338-343.

Ma, C., Song, K., Yu, J., Yang, L., Zhao, C., Wang, W., Zu, G. and Zu, Y. (2013). Pyrolysis Process and Antioxidant Activity of Pyroligneous Acid from *Rosmarinus Officinalis* Leaves. *Journal of Analytical and Applied Pyrolysis*, 104, 38-47.

Ma, C., Li, W., Zu, Y., Yang, L. and Li, J. (2014). Antioxidant Properties of Pyroligneous Acid Obtained by Thermochemical Conversion of *Schisandra chinensis* Baill. *Molecules*, 19(12), 20821-20838.

Ma, J., Meng, X., Guo, X., Lan, Y. and Zhang, S. (2017). Thermal Analysis during Partial Carbonizing Process of Rhubarb, Moutan and Burnet. *PloS one*, 12(3), 1-17.

Malaysian Palm Oil Board 2018, *Statistic Area*. Available from: <http://bepi.mpob.gov.my/index.php/en/statistics/area.html> [20 January 2018].

Mamaeva, A., Tahmasebi, A., Tian, L. and Yu, J. (2016). Microwave-Assisted Catalytic Pyrolysis of Lignocellulosic Biomass for Production of Phenolic-Rich Bio-Oil. *Bioresource Technology*, 211, 382-389.

Manivannan, K., Anantharaman, P. and Balasubramanian, T. (2011). Antimicrobial Potential of Selected Brown Seaweeds from Vedalai Coastal waters, Gulf of Mannar. *Asian Pacific Journal of Tropical Biomedicine*, 1(2), 114-120.

Maquiné, T. M., Cysne, A. Q., de Lima, W. A. A., Abreu, S. C., Green, M. and de Almeida Rios, S. (2014). Germination of Seeds of Interspecific Hybrid Caiaué× Oil Palm Submitted to the Mechanical Depulping. *American Journal of Plant Sciences*, 5(20), 2965-2977.

Marumoto, S., Yamamoto, S. P., Nishimura, H., Onomoto, K., Yatagai, M., Yazaki, K. and Watanabe, T. (2012). Identification of a Germicidal Compound against Picornavirus in Bamboo Pyroligneous Acid. *Journal of Agricultural and Food Chemistry*, 60(36), 9106-9111.

Mathew, S. and Zakaria, Z. A. (2015). Pyroligneous Acid-The Smoky Acidic Liquid from Plant Biomass. *Applied Microbial Technology*, 99: 611-622.

Mathew, S., Zakaria, Z. A. and Musa, N. F. (2015). Antioxidant Property and Chemical Profile of Pyroligneous Acid from Pineapple Plant Waste Biomass. *Process Biochemistry*, 50(11), 1985-1992.

Mathiarasi, R. and Partha, N. (2016). Optimization, Kinetics and Thermodynamic Studies on Oil Extraction from *Daturametel Linn* Oil Seed for Biodiesel Production. *Renewable Energy*, 96, 583-590.

Matsuoka, S., Kawamoto, H., and Saka, S. (2014). What Is Active Cellulose in Pyrolysis? An Approach Based On Reactivity of Cellulose Reducing End. *Journal of Analytical and Applied Pyrolysis*, 106, 138-146.

Mehmood, N., Zubair, M., Rızwan, K., Rasool, N., Shahid, M. and Ahmad, V. (2012). Antioxidant, Antimicrobial and Phytochemical Analysis of Cichorium Intybus Seeds Extract and Various Organic Fractions. *Iranian Journal of Pharmaceutical Research*, 11(4), 1145-1151.

Mehmood, M. A., Ye, G., Luo, H., Liu, C., Malik, S., Afzal, I., Xu, J. and Ahmad, M. S. (2017). Pyrolysis and Kinetic Analyses of Camel Grass (*Cymbopogon schoenanthus*) for Bioenergy. *Bioresource Technology*, 228, 18-24.

Mehrabian, R., Scharler, R. and Obernberger, I. (2012). Effects of Pyrolysis Conditions on the Heating Rate in Biomass Particles and Applicability of TGA Kinetic Parameters in Particle Thermal Conversion Modelling. *Fuel*, 93, 567-575.

Mela, E., Arkeman, Y., Noor, E. and Achsani, N. A. (2013). Potential Products of Coconut Shell Wood Vinegar. *Research Journal of Pharmaceutical, Biological and Chemical Sciences*, 4(4), 1480-1493.

Menéndez, J. A., Arenillas, A., Fidalgo, B., Fernández, Y., Zubizarreta, L., Calvo, E. G. and Bermúdez, J. M. (2010). Microwave Heating Processes Involving Carbon Materials. *Fuel Processing Technology,* 91(1), 1-8.

Min, W., Shuangfang, L., Haitao, X. and Zhanqing, Y. (2013). Effect of Uncertainty of the Pre-Exponential Factor on Kinetic Parameters of Hydrocarbon Generation from Organic Matter and its Geological Applications. *Acta Geologica Sinica (English Edition)*, 87(1), 211-218.

Minić, D. M., Šumar-Ristović, M. T., Miodragović, Đ. U., Anđelković, K. K. and Poleti, D. (2011). Kinetics and Mechanism of Degradation of Co (II)–N-benzyloxycarbonylglycinato Complex. *Journal of Thermal Analysis and Calorimetry*, 107(3), 1167-1176.

Mirkarimi, M., Amin-Marashi, S. M., Bargrizan, M., Abtahi, A., Fooladi, I. and Ali, A. (2013). The Antimicrobial Activity of Grape Seed Extract against Two Important Oral Pathogens. *Zahedan Journal of Research in Medical Sciences*, 15(1), 43-46.

Mishra, R. K. and Mohanty, K. (2018). Pyrolysis Kinetics and Thermal Behavior of Waste Sawdust Biomass Using Thermogravimetric Analysis. *Bioresource Technology*, 251, 63-74.

Mo, Y., Zhao, L., Chen, C.-L., Tan, G. Y. A. and Wang, J.Y. (2013). Comparative Pyrolysis Upcycling of Polystyrene Waste: Thermodynamics, Kinetics, and Product Evolution Profile. *Journal of Thermal Analysis and Calorimetry,* 111(1), 781-788.

Mohamed, B. A., Kim, C. S., Ellis, N. and Bi, X. (2016). Microwave-Assisted Catalytic Pyrolysis of Switchgrass for Improving Bio-Oil and Biochar Properties. *Bioresource Technology,* 201, 121-132.

Mohan, D., Pittman, C. U. and Steele, P. H. (2006). Pyrolysis of Wood/Biomass for Bio-Oil: A Critical Review. *Energy and fuels,* 20(3), 848-889.

Mohan, S. K., Viruthagiri, T.and Arunkumar, C. (2013). Statistical Optimization of Process Parameters for the Production of Tannase by *Aspergillus Flavus* under Submerged Fermentation. *3 Biotech,* 4(2), 159-166.

Mohapatra, D. P., Thakur, V. and Brar, S. K. (2011). Antibacterial Efficacy of Raw and Processed Honey. *Biotechnology Research International*, *2011,* 1-6.

Molyneux, P. (2004). The Use of the Stable Free Radical Diphenylpicrylhydrazyl (DPPH) For Estimating Antioxidant Activity. *Songklanakarin Journal of Science and Technology,* 26(2), 211-219.

Montazeri, N., Oliveira, A., Himelbloom, B. H., Leigh, M. B. and Crapo, C. A. (2013). Chemical Characterization of Commercial Liquid Smoke Products. *Food Science and Nutrition*, 1(1), 102-115.

Moodley, K., Singh, R., Musapatika, E. T., Onyango, M. S. and Ochieng, A. (2011). Removal of Nickel from Wastewater Using an Agricultural Adsorbent. *Water South Africa*, 37(1), 41-46.

Moran-Mirabal, J. M. (2013). *Advanced-Microscopy Techniques for the Characterization of Cellulose Structure and Cellulose-Cellulase Interactions*. In Van de ven, T. and Godbout, L. (Ed.) *Cellulose–Fundamental Aspects* (pp. 1-44). Canada: InTech

Motasemi, F. and Afzal, M. T. (2013). A Review on the Microwave-Assisted Pyrolysis Technique. *Renewable and Sustainable Energy Reviews*, 28, 317-330.

Mothé, C. G. and de Miranda, I. C. (2018). Decomposition through Pyrolysis Process of Coconut Fiber and Rice Husk and Determination of Kinetic Parameters According Isoconversional Methods. *Journal of Thermal Analysis and Calorimetry*, 131(1), 601-609.

Mu, J., Uehara, T. and Furuno, T. (2004). Effect of Bamboo Vinegar on Regulation of Germination and Radicle Growth of Seed Plants II: Composition of Moso Bamboo Vinegar at Different Collection Temperature and Its Effects. *Journal of Wood Science*, 50(5), 470-476.

Muktham, R., Ball, A. S., Bhargava, S. K. and Bankupalli, S. (2016). Study of Thermal Behavior of Deoiled Karanja Seed Cake Biomass: Thermogravimetric Analysis and Pyrolysis Kinetics. *Energy Science and Engineering*, 4(1), 86-95.

Mullen, C. A. and Boateng, A. A. (2008). Chemical Composition of Bio-Oils Produced by Fast Pyrolysis of Two Energy Crops. *Energy and fuels*, 22(3), 2104-2109.

Mungkunkamchao, T., Kesmala, T., Pimratch, S., Toomsan, B. and Jothityangkoon, D. (2013). Wood Vinegar and Fermented Bioextracts: Natural Products to Enhance Growth and Yield of Tomato (*Solanum Lycopersicum L.*). *Scientia Horticulturae*, 154, 66-72.

Mushtaq, F., Abdullah, T. A. T., Mat, R. and Ani, F. N. (2015). Optimization and Characterization of Bio-Oil Produced by Microwave Assisted Pyrolysis of

Oil Palm Shell Waste Biomass With Microwave Absorber. *Bioresource Technology*, 190, 442-450.

Musule, R., Alarcón-Gutiérrez, E., Houbron, E. P., Bárcenas-Pazos, G. M., del Rosario Pineda-López, M., Domínguez, Z. and Sánchez-Velásquez, L. R. (2016). Chemical Composition of Lignocellulosic Biomass in the Wood of *Abies Religiosa* across an Altitudinal Gradient. *Journal of Wood Science*, 62(6), 537-547.

Naz, R. and Bano, A. (2012). Antimicrobial Potential of *Ricinus Communis* Leaf Extracts in Different Solvents against Pathogenic Bacterial and Fungal Strains. *Asian Pacific Journal of Tropical Biomedicine*, 2(12), 944-947.

Ng, W. P. Q., Lam, H. L., Ng, F. Y., Kamal, M. and Lim, J. H. E. (2012). Waste-To-Wealth: Green Potential from Palm Biomass in Malaysia. *Journal of Cleaner Production*, 34, 57-65.

Nguyen Cong, T. (2018). *A Thermogravimetric and Kinetic Study on Devolatilization of Biomass.* Master of Thesis. Norwegian Universityof Science and Technology.

Nicolai, R. P., Dekker, R., Piersma, N. and van Oortmarssen, G. J. (2004). Automated Response Surface Methodology for Stochastic Optimization Models With Unknown Variance. *Proceedings of the 2004 Conference on Winter Simulation*. 5-8 December. Rotterdam, Netherlands: IEEE, 491-499.

Nithiyanantham, S., Siddhuraju, P. and Francis, G. (2013). A Promising Approach to Enhance the Total Phenolic Content and Antioxidant Activity of Raw and Processed *Jatropha Curcas* L. Kernel Meal Extracts. *Industrial Crops and Products*, 43, 261-269.

Nomanbhay, S., Salman, B., Hussain, R. and Ong, M. Y. (2017). Microwave pyrolysis of lignocellulosic biomass−a contribution to power Africa. *Energy, Sustainability and Society*, *7*(1), 1- 24.

Noor, M. M. (2003). Zero Burning Techniques in Oil Palm Cultivation: An Economic Perspective. *Oil Palm Industry Economic Journal*, 3, 16-24.

Noordin, M. Y., Venkatesh, V. C., Sharif, S., Elting, S. and Abdullah, A. (2004). Application of Response Surface Methodology in Describing the Performance of Coated Carbide Tools When Turning AISI 1045 Steel. *Journal of Materials Processing Technology*, 145(1), 46-58.

Nordin, N. I. A. A., Ariffin, H., Andou, Y., Hassan, M. A., Shirai, Y., Nishida, H., Yunus, W. M. Z. W., Karuppuchamy, S. and Ibrahim, N. A. (2013). Modification of Oil Palm Mesocarp Fiber Characteristics Using Superheated Steam Treatment. *Molecules*, 18(8), 9132-9146.

Nyakuma, B. B., Johari, A., Ahmad, A. and Abdullah, T. A. (2014). Thermogravimetric Analysis of the Fuel Properties of Empty Fruit Bunch Briquettes. *Carbon*, *43*(43.52), 46-62.

Nyakuma, B. B., Ahmad, A., Johari, A., Tuan, T. A., Oladokun, O. and Aminu, D. Y. (2015). Non-Isothermal Kinetic Analysis of Oil Palm Empty Fruit Bunch Pellets by Thermogravimetric Analysis. *Chemical Engineering Transaction*, 45, 1327-1332.

Oasmaa, A. and Peacocke, C. (2001). *A Guide to Physical Property Characterisation of Biomass-Derived Fast Pyrolysis Liquids*. (No.450). Technical Research Centre of Finland Espoo: Valtion Teknillinen Tutkimuskeskus.

Oladeji, J. T., Itabiyi, E. A. and Okekunle, P. O. (2015). A Comprehensive Review of Biomass Pyrolysis as a Process of Renewable Energy Generation. *Journal of Natural Sciences Research*, 5(5), 99-105.

Omoriyekomwan, J. E., Tahmasebi, A., and Yu, J. (2016). Production of Phenol-Rich Bio-Oil during Catalytic Fixed-Bed and Microwave Pyrolysis of Palm Kernel Shell. *Bioresource Technology*, 207, 188-196.

Oroian, M. and Escriche, I. (2015). Antioxidants: Characterization, Natural Sources, Extraction and Analysis. *Food Research International,* 74, 10-36.

Pandey, A. K. and Kumar, S. (2013). Perspective on Plant Products as Antimicrobial Agents: A Review. *Pharmacologia*, *4*(7), 469-480.

Papuc, C., Goran, G. V., Predescu, C. N., Nicorescu, V. and Stefan, G. (2017). Plant Polyphenols as Antioxidant and Antibacterial Agents for Shelf-Life Extension of Meat and Meat Products: Classification, Structures, Sources, and Action Mechanisms. *Comprehensive Reviews in Food Science and Food Safety*, 16(6), 1243-1268.

Parthasarathy, P., Choi, H. S., Park, H. C., Hwang, J. G., Yoo, H. S., Lee, B. K. and Upadhyay, M. (2016). Influence of Process Conditions on Product Yield of Waste Tyre Pyrolysis-A Review. *Korean Journal of Chemical Engineering*, 33(8), 2268-2286.

Peng, F., Guan, Y., Zhang, B., Bian, J., Ren, J.-L., Yao, C.-L. and Sun, R.-C. (2014). Synthesis and Properties of Hemicelluloses-Based Semi-IPN Hydrogels. *International Journal of Biological Macromolecules*, 65, 564-572.

Pimenta, A. S., Fasciotti, M., Monteiro, T. V. and Lima, K. M. (2018). Chemical Composition of Pyroligneous Acid Obtained from Eucalyptus GG100 Clone. *Molecules*, 23(2), 426, 1-12.

Poletto, M. (2016). Thermogravimetric Analysis and Kinetic Study of Pine Wood Pyrolysis. *Revista Ciência da Madeira (Brazilian Journal of Wood Science)*, 7(2), 111-118.

Prior, R. L., Wu, X. and Schaich, K. (2005). Standardized Methods for the Determination of Antioxidant Capacity and Phenolics in Foods and Dietary Supplements. *Journal of Agricultural and Food Chemistry*, 53(10), 4290-4302.

Rabeta, M. S., and Faraniza, R. N. (2013). Total Phenolic Content and Ferric Reducing Antioxidant Power of the Leaves and Fruits of *Garcinia atrovirdis* and *Cynometra cauliflora*. *International Food Research Journal*, 20(4), 1691-1696.

Rakmai, J. (2009). *Chemical Determination, Antimicrobial and Antioxidant Activities of Thai Wood Vinegars*. Master of Science Thesis. Prince of Songkla University.

Ramukutty, S., and Ramachandran, E. (2014). Reaction Rate Models for the Thermal Decomposition of Ibuprofen Crystals. *Journal of Crystallization Process and Technology*, 4, 71-78.

Ranade, S. S., and Thiagarajan, P. (2017). Selection of a design for response surface. In *IOP Conference Series: Materials Science and Engineering*, 263 (2), 1-14. IOP Publishing.

Rapp, B. E. (2016). *Chapter 6: Thermodynamic*. In William A. (Ed). *Microfluidics: Modeling, Mechanics and Mathematics*. (pp. 93-135). United State: Elsevier.

Rasmussen, H., Tanner, D., Sørensen, H. R. and Meyer, A. S. (2017). New Degradation Compounds from Lignocellulosic Biomass Pretreatment: Routes for Formation of Potent Oligophenolic Enzyme Inhibitors. *Green Chemistry*, 19(2), 464-473.

Ratanapisit, J., Apiraksakul, S., Rerngnarong, A., Chungsiriporn, J. and Bunyakarn, C. (2009). Preliminary Evaluation of Production and Characterization of

Wood Vinegar from Rubberwood. *Songklanakarin Journal of Science and Technology*, 31(3), 343-349.

Re, R., Pellegrini, N., Proteggente, A., Pannala, A., Yang, M. and Rice-Evans, C. (1999). Antioxidant Activity Applying an Improved ABTS Radical Cation Decolorization Assay. *Free Radical Biology and Medicine*, *26*(9), 1231-1237.

Reber, E. A. (2014). *Gas Chromatography-Mass Spectrometry (GC-MS): Applications in Archaeology*. In: Smith C. (Ed). *Encyclopedia of Global Archaeology*. (pp. 2953-2959). Springer, New York.

Ren, S., Lei, H., Wang, L., Bu, Q., Chen, S., Wu, J., Julson, J and Ruan, R. (2012). Biofuel Production and Kinetics Analysis for Microwave Pyrolysis of Douglas Fir Sawdust Pellet. *Journal of Analytical and Applied Pyrolysis*, 94, 163-169.

Revathi, D., Baskaran, K. and Subashini, R. (2015). Antioxidant and Free Radical Scavenging Capacity of Red Seaweed *Hypnea Valentiae* from Rameshwaram Coast Tamil Nadu, India. *International Journal of Pharmacy and Pharmaceutical Science*, 7 (8), 232-237.

Rocha, E. P. A., Gomes, F. J. B., Sermyagina, E., Cardoso, M. and Colodette, J. L. (2015). Analysis of Brazilian Biomass Focusing on Thermochemical Conversion for Energy Production. *Energy and fuels*, 29(12), 7975-7984.

Rodloff, A., Bauer, T., Ewig, S., Kujath, P. and Müller, E. (2008). Susceptible, intermediate, and resistant–the intensity of antibiotic action. *Deutsches Ärzteblatt International*, 105(39), 657-662.

Roslee, A. N. and Munajat, N. F. (2017). Comparative Study on the Pyrolysis Behaviour and Kinetics of Two Macroalgae Biomass (*Gracilaria changii* and *Gelidium pusillum*) by Thermogravimetric Analysis. *Materials Science and Engineering*, 257(1), 1-12.

Rowlands, H. and Antony, J. (2003). Application of Design of Experiments to a Spot Welding Process. *Assembly Automation*, 23(3), 273-279.

Rungruang, P. and Junyapoon, S. (2010). Antioxidative Activity of Phenolic Compounds in Pyroligneous Acid Produced from Eucalyptus Wood. Proceeding of *the 8th International Symposium on Biocontrol and Biotechnology*. 4-6 October. Pattaya, Thailand: 102-106.

Saberi, M., Sarpeleh, A., Askary, H. and Rafiei, F. (2013). The Effectiveness of Wood Vinegar in Controlling *Rhizoctonia Solani* and *Sclerotinia*

Sclerotiorum in Green House-Cucumber. *International Journal of Agricultural Sciences*, 5(5), 849-853.

Sadeghi, Z., Valizadeh, J., Shermeh, O. A. and Akaberi, M. (2015). Antioxidant Activity and Total Phenolic Content of *Boerhavia Elegans* (Choisy) Grown In Baluchestan, Iran. *Avicenna journal of phytomedicine*, 5(1), 1.

Saffe, A., Fernandez, A., Echegaray, M., Mazza, G. and Rodriguez, R. (2017). Pyrolysis Kinetics of Regional Agro-Industrial Wastes Using Isoconversional Methods. *Biofuels*, 1-13.

Said, M. S. M., Ghani, J. A., Kassim, M. S., Tomadi, S. H. and Haron, C. H. C. (2013). Comparison between Taguchi Method and Response Surface Methodology (RSM) In Optimizing Machining Condition. In *International Conference on Robust Engineering*, 60-64).

Saldarriaga, J. F., Pablos, A., Aguado, R., Amutio, M. and Olazar, M. (2012). Characterization of Lignocellulosic Biofuels by TGA. *International Review of Chemical Engineering*, 4(6), 585-588.

Salehi, E., Abedi, J. and Harding, T. (2009). Bio-Oil from Sawdust: Pyrolysis of Sawdust in a Fixed-Bed System. *Energy and Fuels,* 23(7), 3767-3772.

Salema, A. A. and Ani, F. N. (2010). Microwave Pyrolysis of Oil Palm Fibres. *Jurnal Mekanikal*, (30), 77-86.

Salema, A. A. and Ani, F. N. (2011). Microwave Induced Pyrolysis of Oil Palm Biomass. *Bioresource Technology*, 102(3), 3388-3395.

Salema, A. A. and Ani, F. N. (2012). Pyrolysis of Oil Palm Empty Fruit Bunch Biomass Pellets Using Multimode Microwave Irradiation. *Bioresource Technology*, 125, 102-107.

Santos, S. B. D., Martins, M. A., Caneschi, A. L., Aguilar, P. R. M. and Coimbra, J. S. D. R. (2015). Kinetics and Thermodynamics of Oil Extraction from Jatropha Curcas L. Using Ethanol as a Solvent. *International Journal of Chemical Engineering*, 1-9.

Sarla, S., Prakash, M. A., Apeksha, R. and Subhash, C. (2011). Free Radical Scavenging (DPPH) and Ferric Reducing Ability (FRAP) of *Aphanamixis polystachya (Wall) Parker*. *International Journal of Drug Development and Research*, 3(4), 271-274.

Saumya, S. M. and Basha, P. M. (2011). In Vitro Evaluation of Free Radical Scavenging Activities of Panax Ginseng and Lagerstroemia Speciosa: A

Comparative Analysis. *International Journal of Pharmacy and Pharmaceutical Science,* 3(1), 165-169.

Selvakumar, K., Madhan, R., Srinivasan, G. and Baskar, V. (2011). Antioxidant Assays in Pharmacological Research. *Asian Journal of Pharmacy and Technology*, 1(4), 99-103.

Sellin, N., de Oliveiraa, B. G., Marangonia, C., Souzaa, O., de Oliveirab, A. P. N. and de Oliveiraa, T. M. N. (2013). Use of Banana Culture Waste to Produce Briquettes. *Chemical Engineering*, 32, 349-354.

Semeniuc, C. A., Pop, C. R. and Rotar, A. M. (2017). Antibacterial Activity and Interactions o Plant Essential Oil Combinations against Gram-Positive and Gram-Negative Bacteria. *Journal of Food and Drug Analysis*, 25(2), 403-408.

Shafiei, Z., Shuhairi, N. N., Md Fazly Shah Yap, N., Harry Sibungkil, C. A. and Latip, J. (2012). Antibacterial Activity of *Myristica fragrans* Against Oral Pathogens. *Evidence-Based Complementary and Alternative Medicine*, 2012, 1-7.

Shakorfow, A. M. (2016). Biomass. Incineration, Pyrolysis, Combustion and Gasification. *International Journal of Science and Research*, 5(7), 13–25.

Shang, H., Lu, R. R., Shang, L. and Zhang, W. H. (2015). Effect of Additives on the Microwave-Assisted Pyrolysis of Sawdust. *Fuel Processing Technology*, 131, 167-174.

Shariff, A., Aziz, N. S. M., Ismail, N. I. and Abdullah, N. (2016). Corn Cob as a Potential Feedstock for Slow Pyrolysis of Biomass. *Journal of Physical Science*, 27(2), 123-137.

Sharma, P.and Singh, R. P. (2013). Evaluation of Antioxidant Activity in Foods with Special Reference to TEAC Method. *American Journal of Food Technology*, 8(2), 83-101.

Sharma, A., Pareek, V. and Zhang, D. (2015). Biomass Pyrolysis-A Review of Modelling, Process Parameters and Catalytic Studies. *Renewable and Sustainable Energy Reviews*, 50, 1081-1096.

Sharuddin, S. D. A., Abnisa, F., Daud, W. M. A. W. and Aroua, M. K. (2016). A Review on Pyrolysis of Plastic Wastes. *Energy Conversion and Management*, 115, 308-326.

Shen, D., Xiao, R., Gu, S. and Zhang, H. (2013). *The Overview of Thermal Decomposition of Cellulose in Lignocellulosic Biomass*. In Van de ven, T.

and Kadla, J. (Ed.) *Cellulose–Biomass Conversion* (pp.193-226). Canada: InTech

Shi, K. Q., Wu, T., Zhao, H. T., Lester, E., Hall, P. and Wang, Y. D. (2013). Microwave Induced Pyrolysis of Biomass. *Applied Mechanics and Materials*, 319, 127-133. Trans Tech Publications.

Shi, K., Wu, T., Yan, J., Zhao, H. and Lester, E. (2014). Microwave Enhanced Pyrolysis of Gumwood. In *Materials for Renewable Energy and Environment (ICMREE*), *2013 International Conference*. 19-21 August. Chengdu, China: IEEE, 223-227.

Shin, S., Im, S. I., Kwon, E. H., Na, J. G., Nho, N. S. and Lee, K. B. (2017). Kinetic Study on the Nonisothermal Pyrolysis of Oil Sand Bitumen and Its Maltene and Asphaltene Fractions. *Journal of Analytical and Applied Pyrolysis*, 124, 658-665.

Shinoj, S., Visvanathan, R., Panigrahi, S. and Kochubabu, M. (2011). Oil Palm Fiber (OPF) and Its Composites: A Review. *Industrial Crops and Products,* 33(1), 7-22.

Shuit, S. H., Tan, K. T., Lee, K. T. and Kamaruddin, A. H. (2009). Oil Palm Biomass as a Sustainable Energy Source: A Malaysian Case Study. *Energy*, 34(9), 1225-1235.

Singh, G., Pai, R. S. and Devi, V. K. (2012). Response Surface Methodology and Process Optimization of Sustained Release Pellets Using Taguchi Orthogonal Array Design and Central Composite Design. *Journal of Advanced Pharmaceutical Technology and Research*, 3(1), 30.

Sivakumar, P., Parthiban, K. S., Sivakumar, P., Vinoba, M. and Renganathan, S. (2012). Optimization of Extraction Process and Kinetics of *Sterculia Foetida* Seed Oil and Its Process Augmentation for Biodiesel Production. *Industrial and Engineering Chemistry Research*, 51(26), 8992-8998.

Sivarao, S. and Anand, T. J. S. Ammar (2010). DOE Based Statistical Approaches in Modeling of Laser Processing-Review and Suggestion. *International Journal of Engineering Technology*, 10(4), 1-7.

Slopiecka, K., Bartocci, P. and Fantozzi, F. (2012). Thermogravimetric Analysis and Kinetic Study of Poplar Wood Pyrolysis. *Applied Energy*, 97, 491-497.

Sluiter, A., Hames, B., Ruiz, R., Scarlat, C., Sluiter, J., Templeton, D. and Crocker, D. (2008). Biomass Analysis Technology Team Laboratory Analytical Procedure: Determination of Structural Carbohydrates and Lignin in

Biomass. *Golden, CO: National Renewable Energy Laboratory (NREL)*, 1-18.

Sluiter, J. B., Ruiz, R. O., Scarlata, C. J., Sluiter, A. D. and Templeton, D. W. (2010). Compositional Analysis of Lignocellulosic Feedstocks. 1. Review and Description of Methods. *Journal of Agricultural and Food Chemistry*, 58(16), 9043-9053.

Soetardji, J. P., Widjaja, C., Djojorahardjo, Y., Soetaredjo, F. E. and Ismadji, S. (2014). Bio-Oil from Jackfruit Peel Waste. *Procedia Chemistry*, 9, 158-164.

Sohaib, Q., Habib, M., Fawad Ali Shah, S., Habib, U. and Ullah, S. (2017). Fast Pyrolysis of Locally Available Green Waste at Different Residence Time and Temperatures. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 39(15), 1639-1646.

Sokoto, A. M. and Bhaskar, T. (2018). Pyrolysis of Waste Castor Seed Cake: A Thermo-Kinetics Study. *European Journal of Sustainable Development Research*, 2(2), 1-12.

Soler-Rivas, C., Espín, J. C. and Wichers, H. J. (2000). An Easy and Fast Test to Compare Total Free Radical Scavenger Capacity of Foodstuffs. *Phytochemical Analysis*, 11(5), 330-338.

Soon, V. S. Y., Chin, B. L. F. and Lim, A. C. R. (2016). Kinetic Study on Pyrolysis of Oil Palm Frond. In *IOP Conference Series: Materials Science and Engineering*, 121(1), 1-8.

Souza, A., Santos, J. C., Conceição, M. M., Silva, M. C. and Prasad, S. (2004). A Thermoanalytic and Kinetic Study of Sunflower Oil. *Brazilian Journal of Chemical Engineering*, 21(2), 265-273.

Souza, F. H. and Marcos-Filho, J. Ú. L. I. O. (2001). The Seed Coat as a Modulator of Seed-Environment Relationships in Fabaceae. *Brazilian Journal of Botany*, 24(4), 365-375.

Souza, J. B. G., Ré-Poppi, N. and Raposo Jr, J. L. (2012). Characterization of Pyroligneous Acid Used in Agriculture by Gas Chromatography-Mass Spectrometry. *Journal of the Brazilian Chemical Society*, 23(4), 610-617.

Sreekala, M. S., Kumaran, M. G. and Thomas, S. (1997). Oil Palm Fibers: Morphology, Chemical Composition, Surface Modification, and Mechanical Properties. *Journal of Applied Polymer Science*, 66(5), 821-835.

Sroka, Z. and Cisowski, W. (2003). Hydrogen Peroxide Scavenging, Antioxidant and Anti-Radical Activity of Some Phenolic Acids. *Food and Chemical Toxicology*, 41(6), 753-758.

Sudan, R., Bhagat, M., Gupta, S., Singh, J. and Koul, A. (2014). Iron (FeII) Chelation, Ferric Reducing Antioxidant Power, and Immune Modulating Potential of *Arisaema jacquemontii* (Himalayan Cobra Lily). *Biomed Research International*, 2014, 1-7.

Sulaiman, F., Abdullah, N., Gerhauser, H. and Shariff, A. (2011). An Outlook of Malaysian Energy, Oil Palm Industry and Its Utilization of Wastes as Useful Resources. *Biomass and Bioenergy*, 35(9), 3775-3786.

Supramono, D. and Lusiani, S. (2016, November). Improvement of Bio-Oil Yield and Quality in Co-Pyrolysis of Corncobs and High Density Polyethylene in a Fixed Bed Reactor at Low Heating Rate. In *IOP Conference Series: Materials Science and Engineering* (Vol. 162, No. 1, p. 012011). IOP Publishing.

Stefanidis, S. D., Kalogiannis, K. G., Iliopoulou, E. F., Michailof, C. M., Pilavachi, P. A. and Lappas, A. A. (2014). A Study of Lignocellulosic Biomass Pyrolysis via the Pyrolysis of Cellulose, Hemicellulose and Lignin. *Journal of Analytical and Applied Pyrolysis*, 105, 143-150.

Tabatabaei-Yazdi, F., Alizadeh-Behbahani, B. and Zanganeh, H. (2015). The Comparison among Antibacterial Activity of Mespilus germanica Extracts and Number of Common Therapeutic Antibiotics “In Vitro”. *Zahedan Journal of Research in Medical Sciences*, 17(12), 29-34.

Tan, P. W., Tan, C. P. and Ho, C. W. (2011). Antioxidant Properties: Effects Of Solid-To-Solvent Ratio on Antioxidant Compounds and Capacities of Pegaga (*Centella asiatica*). *International Food Research Journal*, 18(2), 557-562.

Theapparat, Y., Chandumpai, A., Leelasuphakul, W., Laemsak, N. and Ponglimanont, C. (2014). Physicochemical Characteristics of Wood Vinegars from Carbonization of *Leucaena leucocephala*, *Azadirachta indica*, *Eucalyptus camaldulensis, Hevea brasiliensis* and *Dendrocalamus asper*. *Social Sciences*, 48, 916-928.

Theapparat, Y., Chandumpai, A., Leelasuphakul, W. and Laemsak, N. (2015). Pyroligneous Acids from Carbonisation of Wood and Bamboo: Their Components and Antifungal Activity. *Journal of Tropical Forest Science*, 517-526.

Tiilikkala, K., Fagernäs, L. and Tiilikkala, J. (2010). History and Use of Wood Pyrolysis Liquids as Biocide and Plant Protection Product. *The Open Agriculture Journal,* 4(Special Issue 002), 111-118.

Tsai, S. F., Liao, C. T. and Chai, F. S. (2012). D-Optimal Partially Replicated Two-Level Factorial Designs. *Statistica Sinica*, 419-432.

Uttamaprakrom, W., Reubroycharoen, P., Vitidsant, T. and Charusiri, W. (2017). Catalytic Degradation of Rapeseed (*Brassica Napus*) Oil to a Biofuel Using MgO: An Optimization and Kinetic Study. *Journal of the Japan Institute of Energy,* 96(6), 190-198.

Van Boekel, M. A. (2008). Kinetic Modeling of Food Quality: A Critical Review. Comprehensive Reviews in Food Science and Food Safety, 7(1), 144-158.

Varma, A. K. and Mondal, P. (2016). Physicochemical Characterization and Kinetic Study of Pine Needle for Pyrolysis Process. *Journal of Thermal Analysis and Calorimetry*, 124(1), 487-497.

Veggi, P. C., Martinez, J., and Meireles, M. A. a. (2013). *Microwave-assisted Extraction for Bioactive Compounds. Microwave-assisted Extraction for Bioactive Compounds: Theory and Practice*. In Farid Chemat (Ed.) *Food Engineering Series 4*(pp.15-52). New York: Springer.

Vijaya, S., Ma, A. N. and Choo, Y. M. (2009). Crude Palm Kernel Oil Using Life Cycle Assessment Approach. *American Journal of Environmental Sciences*, 5(3), 267-272.

Vlaev, L. T., Georgieva, V. G. and Tavlieva, M. P. (2015). On the Kinetic Mechanism of Non-Isothermal Degradation of Solids. *Reactions and Mechanisms in Thermal Analysis of Advanced Materials*, 547-578.

Volpe, R., Zabaniotou, A. A. and Skoulou, V. (2018). Synergistic Effects between Lignin and Cellulose during Pyrolysis of Agricultural Waste. *Energy and Fuels*, 32(8), 8420-8430.

Vyazovkin, S. (2006). Model-Free Kinetics. *Journal of Thermal Analysis and Calorimetry*, 83(1), 45-51.

Wafti, N. S. A., Lau, H. L. N., Loh, S. K., Aziz, A. A., Ab Rahman, Z. and May, C. Y. (2017). Activated Carbon from oil Palm Biomass as Potential Adsorbent for Palm Oil Mill Effluent Treatment. *Journal of Oil Palm Research*, 29(2), 278-290.

Wanderley, C. d. S., Faria, R. T. d. and Ventura, M. U. (2012). Chemical Fertilization, Organic Fertilization and Pyroligneous Extract in the

Development of Seedlings of Areca Bamboo Palm (*Dypsis lutescens*). *Acta Scientiarum. Agronomy,* 34, 163-167.

Wang, X. H., Chen, H. P., Ding, X. J., Yang, H. P., Zhang, S. H. and Shen, Y. Q. (2009). Properties of Gas and Char from Microwave Pyrolysis of Pine Sawdust. *BioResources*, 4(3), 946-959.

Wang, M. F., Jiang, E. C., Xiong, L. M., Xu, X. W., Zhao, C., Wang, G., and Ma, Q. (2013). Components Characteristics of Wood Vinegar from Rice Husk Continuous Pyrolysis and Catalytic Cracking. Applied Mechanics and Materials, 291-294, 368-374.

Wang, N., Tahmasebi, A., Yu, J., Xu, J., Huang, F. and Mamaeva, A. (2015). A Comparative Study of Microwave-Induced Pyrolysis of Lignocellulosic and Algal Biomass. *Bioresource Technology*, 190, 89-96.

Weerachanchai, P., Tangsathitkulchai, C, and Tangsathitkulchai, M. (2010). Comparison of Pyrolysis Kinetic Models for Thermogravimetric Analysis of Biomass. *Suranaree Journal of Science and Technology*, 17(4), 387-400.

Wei, Q., Ma, X., Zhao, Z., Zhang, S. and Liu, S. (2010a). Antioxidant Activities and Chemical Profiles of Pyroligneous Acids from Walnut Shell. *Journal of Analytical and Applied Pyrolysis,* 88(2), 149-154.

Wei, Q., Ma, X. and Dong, J. (2010b). Preparation, Chemical Constituents and Antimicrobial Activity of Pyroligneous Acids from Walnut Tree Branches. *Journal of Analytical and Applied Pyrolysis*, 87(1), 24-28.

Wells, M. J. (2003). Principles of Extraction and the Extraction of Semivolatile Organics from Liquids. *Sample Preparation Techniques in Analytical Chemistry*, 162, 37-225.

Wiegand, I., Hilpert, K. and Hancock, R. E. (2008). Agar and Broth Dilution Methods to Determine the Minimal Inhibitory Concentration (MIC) of Antimicrobial Substances. *Nature Protocols,* 3(2), 163-175.

Wititsiri, S. (2011). Production of Wood Vinegars from Coconut Shells and Additional Materials for Control of Termite Workers, *Odontotermes Sp*. and Striped Mealy Bugs, *Ferrisia Virgata*. *Journal of Science and Technology,* 33(3), 349-354.

Woittiez, L. S., van Wijk, M. T., Slingerland, M., van Noordwijk, M. and Giller, K. E. (2017). Yield Gaps in Oil Palm: A Quantitative Review of Contributing Factors. *European Journal of Agronomy*, 83, 57-77.

Wong, B. Y., Tan, C. P. and Ho, C. W. (2013). Effect of Solid-To-Solvent Ratio on Phenolic Content and Antioxidant Capacities of “Dukung Anak” (Phyllanthus niruri). *International Food Research Journal*, 20(1), 325-330.

Wu, T. Y., Mohammad, A. W., Jahim, J. M. and Anuar, N. (2007). Palm Oil Mill Effluent (POME) Treatment and Bioresources Recovery Using Ultrafiltration Membrane: Effect of Pressure on Membrane Fouling. *Biochemical Engineering Journal*, 35(3): 309-317.

Wu, Q., Zhang, S., Hou, B., Zheng, H., Deng, W., Liu, D. and Tang, W. (2015). Study on the Preparation of Wood Vinegar from Biomass Residues by Carbonization Process. *Bioresource Technology*, 179, 98-103.

Xiang, Z., Liang, J., Morgan Jr, H. M., Liu, Y., Mao, H. and Bu, Q. (2018). Thermal Behavior and Kinetic Study for Co-Pyrolysis of Lignocellulosic Biomass with Polyethylene over Cobalt Modified ZSM-5 Catalyst by Thermogravimetric Analysis. *Bioresource Technology*, 247, 804-811.

Xu, X., Jiang, E., Li, B., Wang, M., Wang, G., Ma, Q., Shi, D. and Guo, X. (2013). Hydrogen Production from Wood Vinegar of Camellia Oleifera Shell by Ni/M/Γ-Al_2O_3 Catalyst. *Catalysis Communications*, 39,106-114.

Xu, Y. and Chen, B. (2013). Investigation of Thermodynamic Parameters in the Pyrolysis Conversion of Biomass and Manure to Biochars Using Thermogravimetric Analysis. *Bioresource Technology*, 146, 485-493.

Yagmur, E., Ozmak, M. and Aktas, Z. (2008). A Novel Method for Production of Activated Carbon from Waste Tea by Chemical Activation with Microwave Energy. *Fuel*, 87(15–16), 3278-3285.

Yahya, M., Lee, H. V., Zain, S. K. and Hamid, S. A. (2015). Chemical Conversion of Palm-based Lignocellulosic Biomass to Nano-Cellulose: Review. *Polymers Research Journal*, 9(4), 385-402.

Yamaguchi, A., Mimura, N., Shirai, M. and Sato, O. (2017). Bond Cleavage of Lignin Model Compounds into Aromatic Monomers Using Supported Metal Catalysts In Supercritical Water. *Scientific Reports*, *7*, 46172.

Yaman, S. (2004). Pyrolysis of Biomass to Produce Fuels and Chemical Feedstocks. *Energy Conversion and Management*, 45(5): 651–671.

Yang, H., Yan, R., Chen, H., Lee, D. H. and Zheng, C. (2007). Characteristics of Hemicellulose, Cellulose and Lignin Pyrolysis. *Fuel*, 86(12), 1781-1788.

Yang, K., Peng, J., Srinivasakannan, C., Zhang, L., Xia, H. and Duan, X. (2010). Preparation of High Surface Area Activated Carbon from Coconut Shells Using Microwave Heating. *Bioresource Technology*, 101(15), 6163-6169.

Yang, J., Chen, C., Zhao, S., Ge, F. and Liu, D. (2014). Effect of Solvents on the Antioxidant Activity of Walnut (*Juglans Regia L.)* Shell Extracts. *Journal of Food and Nutrition Research*, 2(9), 621-626.

Yang, J. F., Yang, C. H., Liang, M. T., Gao, Z. J., Wu, Y. W. and Chuang, L. Y. (2016). Chemical Composition, Antioxidant, and Antibacterial Activity of Wood Vinegar from Litchi chinensis. *Molecules*, 21(9), 1150, 1-10

Yao, F., Wu, Q., Lei, Y., Guo, W. and Xu, Y. (2008). Thermal Decomposition Kinetics of Natural Fibers: Activation Energy with Dynamic Thermogravimetric Analysis. *Polymer Degradation and Stability*, 93(1), 90-98.

Yao, X., Xu, K. and Liang, Y. (2017). Assessing the Effects of Different Process Parameters on the Pyrolysis Behaviors and Thermal Dynamics of Corncob Fractions. *BioResources*, 12(2), 2748-2767.

Ye, G., Luo, H., Ren, Z., Ahmad, M.S., Liu, C.G., Tawab, A., Al-Ghafari, A.B., Omar, U., Gull, M. and Mehmood, M.A. (2018). Evaluating the Bioenergy Potential of Chinese Liquor-Industry Waste Through Pyrolysis, Thermogravimetric, Kinetics and Evolved Gas Analyses. *Energy Convers Manage*, 163, 13-21.

Yeo, J. Y., Chin, B. L. F., Tan, J. K. and Loh, Y. S. (2017). Comparative Studies on the Pyrolysis of Cellulose, Hemicellulose, and Lignin Based on Combined Kinetics. *Journal of the Energy Institute*, 1-11.

Yin, J., Heo, S. I. and Wang, M. H. (2008). Antioxidant and Antidiabetic Activities of Extracts from *Cirsium Japonicum* Roots. *Nutrition Research and Practice*, 2(4), 247-251.

Yin, C. (2012). Microwave-Assisted Pyrolysis of Biomass for Liquid Biofuels Production. *Bioresource Technology*, 120, 273-284.

Yu, F., Ruan, R. and Steele, P. (2009). Microwave Pyrolysis of Corn Stover. *Transactions of the ASABE*, 52(5), 1595-1601.

Yuan, X., He, T., Cao, H. and Yuan, Q. (2017). Cattle Manure Pyrolysis Process: Kinetic and Thermodynamic Analysis with Isoconversional Methods. *Renewable Energy*, 107, 489-496.

Yuen, F. K. and Hameed, B. H. (2009). Recent Developments in the Preparation and Regeneration of Activated Carbons by Microwaves. *Advances in Colloid and Interface Science*, 149(1), 19-27.

Yunos, N. S. H. M., Baharuddin, A. S., Yunos, K. F. M., Naim, M. N. and Nishida, H. (2012). Physicochemical Property Changes of Oil Palm Mesocarp Fibers Treated With High-Pressure Steam. *BioResources*, 7(4), 5983-5994.

Yusoff, S. (2006). Renewable Energy from Palm Oil–Innovation on Effective Utilization of Waste. *Journal of Cleaner Production*, 14(1), 87-93.

Zatar, N. A., Abu-Eid, M. A. and Eid, A. F. (1999). Spectrophotometric Determination of Nitrite and Nitrate Using Phosphomolybdenum Blue Complex. *Talanta*, 50(4), 819-826.

Zengin, G., Uysal, S., Ceylan, R. and Aktumsek, A. (2015). Phenolic Constituent, Antioxidative and Tyrosinase Inhibitory Activity of *Ornithogalum Narbonense* L. From Turkey: A Phytochemical Study. *Industrial Crops and Products*, 70, 1-6.

Zhai, M., Shi, G., Wang, Y., Mao, G., Wang, D. and Wang, Z. (2015). Chemical Compositions and Biological Activities of Pyroligneous Acids from Walnut Shell. *BioResources*, 10(1), 1715-1729.

Zhai, M., Guo, L., Zhang, Y., Dong, P., Qi, G. and Huang, Y. (2016). Kinetic Parameters of Biomass Pyrolysis by TGA. *BioResources*, 11(4), 8548-8557.

Zhang, X., Xu, M., Sun, R. and Sun, L. (2006). Study on Biomass Pyrolysis Kinetics. *Journal of Engineering for Gas Turbines and Power*, 128(3), 493-496.

Zhang, R., Zhong, Z. and Huang, Y. (2009). Combustion Characteristics and Kinetics of Bio-Oil. *Frontiers of Chemical Engineering in China*, 3(2), 119-124.

Zhang, X., Rajagopalan, K., Lei, H., Ruan, R. and Sharma, B. K. (2017). An Overview of a Novel Concept in Biomass Pyrolysis: Microwave Irradiation. *Sustainable Energy and Fuels*, 1(8), 1664-1699.

Zhao, X., Wang, W., Liu, H., Ma, C. and Song, Z. (2014). Microwave Pyrolysis of Wheat Straw: Product Distribution and Generation Mechanism. *Bioresource Technology*, 158, 278-285.

Zhao, C., Jiang, E., and Chen, A. (2016) Volatile Production from Pyrolysis of Cellulose, Hemicellulose and Lignin. *Journal of the Energy Institute*, 1-12.

Zhou, R., Lei, H., and Julson, J. (2013). The Effects of Pyrolytic Conditions on Microwave Pyrolysis of Prairie Cordgrass and Kinetics. *Journal of Analytical and Applied Pyrolysis*, 101, 172-176.

Zhu, Y. J. and Chen, F. (2014). Microwave-Assisted Preparation of Inorganic Nanostructures in Liquid Phase. *Chemical Reviews,* 114(12), 6462-6555.

Zhu, F., Feng, Q., Xu, Y., Liu, R. and Li, K. (2015). Kinetics of Pyrolysis of Ramie Fabric Wastes from Thermogravimetric Data. *Journal of Thermal Analysis and Calorimetry*, 119(1), 651-657.

Zulkarami, B., Ashrafuzzaman, M., Husni, M. O. and Ismail, M. R. (2011). Effect of Pyroligneous Acid on Growth, Yield and Quality Improvement of Rockmelon in Soilless Culture. *Australian Journal of Crop Science*, 5(12), 150.