PELLETIZATION AND DENSITY OPTIMIZATION OF OIL PALM EMPTY FRUIT BUNCH PELLET FOR BIOMASS ENERGY

NUR ADLIN BINTI AZIZ

FACULTY OF EARTH SCIENCE
UNIVERSITI MALAYSIA KELANTAN

2020

PELLETIZATION AND DENSITY OPTIMIZATION OF OIL PALM EMPTY FRUIT BUNCH PELLET FOR BIOMASS ENERGY

by

NUR ADLIN BINTI AZIZ

A report submitted in fulfillment of the requirement for the degree of Bachelor of Applied Science (Sustainable Science) with Honours

FACULTY OF EARTH SCIENCE
UNIVERSITI MALAYSIA KELANTAN

2020

DECLARATION

I declare that this thesis entitled “Palletization and Density Optimization of Oil Palm Empty Fruit Bunches for Biomass Energy” is the results of my own researched except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ___________________________

Name : NUR ADLIN BINTI AZIZ

Date : 5/12/2019

ACKNOWLEDGEMENT

I would like to express my deepest appreciation to everyone that has help me to complete this report. As special gratitude for my supervisor, Dr Mohd Faiz bin Mohd Amin and my research were leaded by Mr. Mohd Sukhairi Mat Rasat whose contribute in guiding and stimulating suggestion which encourage me to coordinate my project and completing this report.

Also I would like to acknowledge with much appreciation to Mr. Mohd Afifi Bin Shuhaimin that have helped and guide me on using the equipment used throughout the projects. Not to forget other supervisors that has given comments and advice on improving my final year project.

Lastly not to forget thanks to my parents, family and friends that that have been contributed by supporting my work and help myself during the final year project progress till it is fully completed. Thank you everyone for everything and May God Bless all of you.

Pelletization And Density Optimization Of Oil Palm Empty Fruit Bunch Pellet For Biomass Energy

ABSTRACT

Considering the global energy crisis affecting global consumers in terms of fossil fuel insufficiency and specific interest in inventing alternative sources of renewable energy. This study was conducted to identify the key factors affecting pelletization process of Oil Palm Empty Fruit Bunches based on particle size, pelletizing pressure and test speed. The size and mass of compressed pellet were measured to calculate the pellet density. The pelletization process have been carried out within the pelletizing pressure from 7 to 21 kN by using compression force of Universal Testing Machine (UTM) with a test speed at 2 to 8 mm/min. In brief, this study focusing on the optimization of the pellet density by using response surface method (RSM), Box-Behnken Model due by using particle size, pressure and test speed as the factor tested. The density pellet identified to be increase radically and then gradually with a higher pelletizing pressure. This study proven that for lowest optimum density value occurs at particle size of 500µm, pressure of 7kN and with a test speed 2mm/min. In conclusion, with a low density of pelletized OPEFB could aid towards the transportation and packaging of the pellet in order to meet the pellet market in future.

Pempeletan dan optimuman kepada ketumpatan pelet menggunakan tandan buah kelapa sawit kosong sebagai sumber tenaga biomas

ABSTRAK

Memandangkan krisis tenaga global yang menjejaskan pengguna di seluruh dunia dari segi kekurangan bahan bakar fosil dan kepentingan tertentu dalam mencipta sumber alternatif tenaga boleh diperbaharui. Kajian ini dijalankan untuk mengenal pasti faktor-faktor utama yang mempengaruhi proses pempeletan tandan buah kelapa sawit kosong (OPEFB) berdasarkan saiz partikel, tekanan proses pelet dan ujian kelajuan. Saiz dan jisim pelet dimampatkan dan diukur untuk mengira ketumpatan pelet. Proses pempeletan telah dilakukan dalam tekanan pelet dari 7 hingga 21 kN dengan menggunakan kekuatan mampatan Universal Testing Machine (UTM) dengan ujian kelajuan pada 2 hingga 8 mm / min. Ringkasnya, kajian ini memberi tumpuan kepada pengoptimuman ketumpatan pelet dengan menggunakan kaedah permukaan tindak balas (RSM), Model Box-Behnken dengan menggunakan saiz partikel, tekanan dan kelajuan ujian sebagai faktor yang diuji. Ketumpatan pelet dikenal pasti meningkat secara radikal dan kemudian secara beransur-ansur dengan tekanan pelet yang lebih tinggi. Kajian ini membuktikan bahawa nilai ketumpatan optimumal terendah berlaku pada saiz partikel 500μm, tekanan 7kN dan dengan kelajuan ujian 2mm / min. Sebagai kesimpulan, dengan kepadatan rendah pellet OPEFB dapat membantu proses pengangkutan dan pembungkusan pelet untuk memenuhi pasaran pelet di masa depan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATION

OPEFB	Oil Palm Empty Fruit Bunch
FFB	Fresh fruit bunches
OPT	Oil Palm Trunk
OPF	Oil Palm Frond
MF	Mesocarp Fiber
PKS	Palm Kernel Shell
PPF	Palm Pressed Fibers
POME	Palm Oil Mill Effluent
RSM	Response Surface Method
UTM	Universal Testing Machine
Mtoe	Million tonnes of oil equivalent
WEMO	World Energy Markets Observatory
GHG	Greenhouse gases
MIDA	Malaysian Investment Development Authority
FiT	Feed-in-Tariff
CPO	Crude palm oil
EFB	Empty Fruit Bunch
EU	European Union
RM	Ringgit Malaysia

LIST OF SYMBOLS

µm	Micrometer
kN	Kilonewton
mm/min	Micrometer per Minute
%	Percentage
MW	Megawatt
Mtoe	Million Tonnes of Oil Equivalent
mm	Millimeter
H_M	Meyer Hardness
N/mm^2	Newton per millimeter square
mm^2	Millimeter square
N	Newton
ρ	Density
m	Mass
V	Volume

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Consumptions of fossil fuels drastically shows an interconnection within the population size, industrialization of developing county and the quality of life. By depending fossil fuels as the energy sources has created the increase of environmental pollution and it sure effects the rate of diminishing fossil fuel sources. Developed countries mainly are focusing towards sustainable development, which defines as a development that does not compromise the needs of the future generations. Utilization of efficient energy and renewable energy are the possible solution towards the current environmental issues which will help in achieving an optimistic future energy with least possible of environmental problems. In Malaysia, the main energy use for production of energy were mainly comprised of coal, petroleum, oil and natural gas products (Chong et al., 2015). The production from combustion of fossil fuels produced various toxic gases, droplets of tar, soot and ashes and organic compound that released to the air and that leads to a huge consequences of climate change and pollution which will affects humans lives and the ecological balance of the planet (Shah Alam et al., 2013). Therefore, it is necessary to shift from non-renewable fossil fuels towards the usage of renewable energy sources such as biomass which be found from organic waste, crops, herbaceous and woody that gives a more convenient ways of energy production.

In Malaysia, the major contributor of waste for biomass energy is from wood product, rubber cultivation, cocoa cultivation, sugar cane cultivation and oil palm cultivation (Chuah et al., 2006). The example of waste that produced from oil palm industry are oil palm trunk (OPT), oil palm frond, mesocarp fiber, palm kernel shell (PKS), palm oil mill effluent (POME), and empty fruit bunches (EFB). Plantation of biomass is usually in a form of frond and trunks that will occur for replanting and as for the trunk is to be left on the ground for fertilizer purpose. While at the mill, abundance of empty fruit bunches, mesocarp fiber, palm kernel shell and palm oil mill effluent were produce (Abas et al., 2011).

Formerly, biomass waste from oil palm industry were used as organic fertilizer for soil enhancement, as boiler fuel for steam and electricity in the mills, however most of the oil palm waste were simply dumped in open fields or were burnt away (Bevan Nyakuma, 2018). As an alternative sources of fossil fuel, transforming biomass waste to biofuel pellet shows higher energy density, lower storage and transportation cost that make biomass pellets as a preferable fuel than raw feedstock (Poddar et al., 2014). Biomass pellets were commonly produced in pellet mills using a ring die type, which mechanical pressure were given towards the biomass and the biomass were channeled to the channel walls therefore pellets were produced.

1.2 Problem Statement

Due to the global energy issues, Malaysia is depending on three major fossil fuel sources which are natural gas, coal and fuel oil. Depending on fossil fuels as the primary energy supply may contribute to the inadequacy of the sources and the causes of global warming. As the alternative ways to control the environmental issues, the government should consider to find an alternative way of getting electricity resources for a more sustainable development.

Malaysia are the second largest exporter of palm oil after Indonesia, which may have contributed to a large amount of agriculture waste was produced (Hussain, Bano, Yeoh, & Rozita, 2014). The after process of harvesting, extracting oil, biomass materials such as oil palm trunks (OPT), palm kernel shells (PKS), palm oil mill effluent (POME) and oil palm empty fruit bunches (OPEFB) were produced as the waste product and needed to be transported to specified location for further process. Large bulk of raw feedstock uses more cost for transportation needed to bring to fired power plant, thus biomass can be minimized through densification. Pelletization process is one of the method to produce a densified and solid fuel with uniform properties. In order to handle a convenient transportation process, pelletization of biomass are the most preferable fuels compared to raw feedstock. Thus, in this study is to examine the optimization density of OPEFB pellet based on different particle size of 250μm, 500μm and 750μm with pressure range of 7 kN to 21 kN and test speed at 2, 5 and 8 mm/min.

1.3 Objectives

i. To identify the key factors affecting pelletization process of OPEFB based on particle size, pelletizing pressure and test speed.

ii. To analyze the optimization density of the pelletized OPEFB by using Response Surface Method (RSM)

1.4 Scope of study

This study is to study the possibilities of OPEFB pellet as the energy resources by undergoing pelletization process according to the independent variable which are particle size, pelletizing pressure and test speed. The pelletization process will have three different particle sizes (250,500 and 750μm) of OPEFB and with a given pressure of 2 kN, 14 kN and 21 kN with test speed at 2, 5 and 8 mm/min. Moreover, this study analyzes the optimization for the density of OPEFB pellet based on the variable. Production of pellet were produced by given pressure and test speed using Universal Testing Machine (UTM) with a pellet mold. The limitation of this study is the pelletized OPEFB were only analyze the density due to lack in testing instrument for other response.

1.5 Significance of study

The Significance study of this research is to find some alternative ways that could be used as the energy resources in Malaysia. The energy demands are currently having a rapid demand globally due to the increase of the world's population. Therefore, biomass gives a good impression on production of energy and contributing to a healthy environment and economy. The utilization of biomass helps to reduce emission of greenhouse gases, reduce the forest or waste management cost and lastly provides a secured energy resources for future development. Pelletization process for biomass helps in reducing the bulkiness of the biomass for storage and transportation purpose and in order to fully utilize the waste as alternative renewable energy sources for power generation.

CHAPTER 2

LITERATURE REVIEW

2.1 Energy Overview

Countries from the Association of Southeast Asian Nations (ASEAN) are one of the highest influence for the global energy system and the energy demand has grown over 60% over the past years (Energy, 2017). The main common energy sources for generating electricity is by nuclear, natural gas, coal, oil and renewable energy (Hakeem et al., 2016). The reason of rising in energy consumption and the limitation of resources which contribute to the price of fossil oil to be more expensive than before. Due to the depletion of fossil fuels energy resources, rise for demand in electricity consumption and environmental concern that drives countries across the region to upgrade their policy framework, which reform fossil fuels consumption subsidies and to invest more in the region's renewable energy resources. Electrical demands mainly come from residential and services sector which are mainly from the rising of an urban development.

Many countries across the globe are aiming towards a more sustainable development which one of the matter are reducing the use of non-renewable energy as the source of energy. Renewable energy are the sources that can be replenish naturally for example hydro, solar, wind, geothermal and biomass. Sustainability is the key to conserves the resource for present and future generation which related to the social, economic and environmental factors. Since 2015, Malaysia has been moving towards renewable energy to reduce the usage of fossil fuels as energy sources (Renewable, 2018).

2.1.1 Energy Consumption

The primary energy demand in Southeast Asia has risen from 70% between 2000 and 2016, a total of 640 million tonnes of oil equivalent (Mtoe). Fossil fuels were chosen to be the main source of energy supply across the ASEAN countries, as shown in Figure 2.1 are the evolution of primary energy demand between 2000 and 2016. Almost 70% of the energy demand has increase since 2000, with coal as the largest share of the growth occurred.

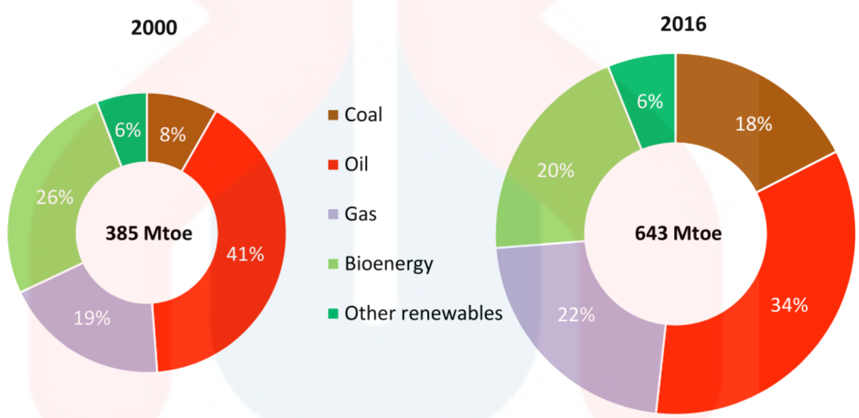


Figure 2.1: Evolution of primary energy demand between 2000 and 2016 (Source: Energy, 2017)

In Malaysia, the energy consumption is expected to grow at the rate of 4.8% from 2000 to 2023 that stated in the World Energy Markets Observatory (WEMO) 2017 report. Transportation sector are the major sector that needed a large amount of energy sources. As reported in Suruhanjaya Tenaga (2016), the primary energy supply was at 93,395 ktoe in 2016. The energy source for electricity generation consists of coal, natural gas, oil, hydro and renewables. With an input of energy in power stations is at 35,348 ktoe that shows an increased by 67% at 2016 compared to previous year. After the conversion process of the sources, the share among the sources are as for coal and coke is at 46%, hydropower at 13.3%, oil at 0.7% and the remaining are renewables at 0.4% Suruhanjaya Tenaga. (2016).

2.2 Renewable Energy

Primary energy sources for Malaysia mainly relies on non-renewable which are coming from fossil fuels to produce electricity. The burning of fossil fuels may lead to an increase in greenhouse gases (GHG) and climate change. Due to the environmental concern, Malaysia has started to takes initiative towards a low-carbon future. Renewable energy includes solar energy, hydro, waves, geothermal that were widely used to generate electrical energy. Malaysian Investment Development Authority (MIDA) has approved total of 111 renewable energy project in 2016 which includes hydro, solar power, biogas and biomass. Hydropower have shown to play a crucial role of renewable energy as the energy sources with a total installed capacity of 6094MW and photovoltaic solar were installed with the capacity of 294.85MW in 2016 stated in the World Energy Markets Observatory (WEMO) 2017 report. The government believes that there are areas that are suitable to produce wind power, the suggested area that can harness the wind energy is in Kudat and Kota Marudu in Sabah.

Currently, the initiative of implementing renewable in Malaysia are hydro, solar, biogas and biomass through Feed-in-Tariff (FiT) structure has enhanced the use of renewable from biomass in the country. Combustion of biomass as fuels gives a positive economic and environmental impacts due to its cheap, clean and renewable source of energy. There are good financial gains and few advantages of using renewable energy power generation. Bioenergy or biomass energy are an important matter that have been employed in many developing and developed countries. (Rizman et al., 2018) Renewable energy may seems to be lack in many aspect, but the small usage of renewable energy may help in saving millions of ringgit and to reduce the greenhouse gases produced from non-renewable sources. Therefore, it is a good kick start for Malaysia to start considering as using biomass energy as an alternative energy source.

2.3 Biomass Source

Biomass are one of the largest provider for renewable fuel sources, it has a unique character that can produced a carbon-based fuels and chemicals. Since Malaysia is blessed with fertile agriculture land that leads to rich agro-biomass resources from the agriculture industry. The mass product of biomass that are available in Malaysia consists of from rice husk, timber, municipal waste, coconut fibers, sugar-cane waste and oil palm waste. As a result, Malaysia is one of the largest producer and exporter of palm oil which has created a mass production of agriculture waste. Oil palm waste was predicted to show arise due to the high demand from the production of oil palm throughout the coming years. From the plantation and milling activity in the oil palm industry, a huge amount of biomass was produced.

Type of oil palm waste that produced are oil palm trunks (OPT), oil palm fronds (OPF), palm pressed fibres (PPF), palm kernel shells (PKS), palm oil mill effluent palm (POME) and empty fruit bunches (EFB). Figure 2.3 illustrated the division of palm oil biomass that are produced in large quantity in the palm oil industry. Production of palm oil biomass is abundance at about 90% while only 10% are oils, and 43-45% of the mill residues is in a form of shell, fiber and EFB. Palm stems and fronds are still underutilized and the abundance of the waste has arisen the disposal issues (N. Abdullah and F. Sulaiman, 2013).

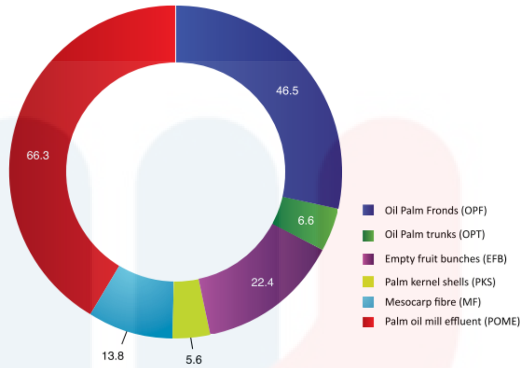


Figure 2.3: Potential Biomass of Palm Oil Industry in Malaysia
(Source from: MIGHT,2013)

From the major waste production from palm oil mill has enough energy to transform the waste as fuel to generate steam to produce electricity by turning the turbine (Suzuki et al., 2017). Furthermore, biomass energy proved as a climate free from its production and utilization (Aliyu, Abdullahi, & Sulaiman, 2017). With the good efficiency that can produced up to 8Mtoe of energy, it can save up to RM75 billion per year of crude oil (Nor, Ramli, & Aliyu, 2015). Through this matter, it has gain popularity due to its ample potential for biomass utilization, which is a jump-start for Malaysia to achieve a greener future.

2.3.1 Biomass from Oil Palm Plantation

In 2010, Malaysia has up to 4.85 million hectares of oil palm and this has contributed to the export revenues. The planting areas in Peninsular Malaysia is about 47% or 2.7 million hectares and due to the limited availability of land, 27% and 26% were expanded in Sabah and Sarawak. Total production up to 40 000 to 50 000 of crude palm oil were produced per day. The active development of crude palm oil (CPO) and fresh fruit bunches (FFB) for the utilization in fuels, food and chemical industries which has been the main assets in Malaysia that give a major impact on our national income. Oil palm yield is about 10 times higher compared to soybeans, 6.9 times higher than sunflower and 6.3 times higher compared to rapeseeds. Each oil palm tree has the height up to 6 meters and with the maximum age of 30 years, about 9 to 15 FFB per years were produce from a single oil palm tree. Each FFB weights 10 to 25 kg that contains 1,000 to 3,000 oil palm fruits (MGCC, 2017). As mention in section 2.3, a large amount of lignocellulose biomass waste was produced resulting to the presents of solid oil palm waste presents substantial disposal and challenges on the pollution management for the palm oil industry. Generally there are two ways to generate the waste in oil palm industry (Abas et al., 2011). Firstly, oil palm plantation produced harvested trunk and pruned fond. The trunk is available during the replanting season which in 25years and while the fond is from continuous pruning throughout the harvesting process. Another process is from the milling extraction of oil palm that produced PKS, POME and EFB.

There are various types of end products can be utilizing from every type of oil palm biomass that are available in Malaysia, as stated in Table 2.1. The starting opportunity of research that were into in mechanical shredding and fiberizing the palm EFB was since 1990s. The process of manufacturing fiber mats, pelletization of biomass, pulp and packaging materials as for feedstock for bio-conversion process. Previously the biomass was only enclosed as a low-value field mulching and composting, other than being used as combustion sources for electricity generation and steams for oil palm mills.

Table 2.1: Biomass Utilization and Commercialization Stage in Malaysia.
(Source from: Abdul Rahman et al., 2013)

	PELLETS	BIOFUELS	BIOGAS	GREEN CHEMICAL	BIOFERTILISERS	BIOCHAR	BIOCOMPOSITES	OTHERS
EFB	EFB Pellets	Bioalcohol	Syngas	Industrial Sugars/ Chemical	Organic Compost	Carbon Fibers	Fibreboard	Pulp Fibremat
PKS	Coal substitute					Activated Carbon		
OPT	OPT Pellets	Bioalcohols	Syngas	Industrial Sugars/ Chemical	Organic Compost	Biochar	Engineered lumber	
OPF	OPF Pellets	Bioalcohols	Syngas	Industrial Sugars/ Chemical	Organic Compost	Biochar		Phytochemicals
PKC	PKC Pellets			Biopolymers				Animal Feed
POME		Bioalcohols	Methane	Biopolymers	Organic Compost			

LEGEND: Commercialised; Development Stage; Potential

There are many Malaysian SMEs venturing into the production of briquettes and fuel pellets from wood biomass and palm oil biomass to be exported. Most of the solid fuels were used as small-scale home heating or large-scale power generation in industries. The major ventures of biomass in Malaysia either operational or under planning are focusing on the single sources of feedstock which either for biochemical production, eco products manufacturing or power generations. This can provide high chances of the demand of EFB that will contribute to the future price escalation of the biomass feedstock in Malaysia.

2.3.2 Empty Fruit Bunches

Palm trees consist of high yield for production of oil, which can fulfil the interest in vegetable-based lubricating oil from this moment of time. Empty fruit bunches (EFB) is one of the major agriculture waste that was produced in the oil palm industry specifically from the oil palm mill. The raw state of EFB is fibrous, woody and wet biomass while it has a high calorific value in its dry state (Hussain et al., 2014). Oil palm waste were commonly used as fuel for domestic consumption in palm oil mills, grid connected biomass power plant or industrial sectors. Nevertheless, the utilization of EFB in the palm oil industry is yet to be fully employed due to its high moisture content which make it unsuitable to be use as boiler fuel. EFB is obtained from the shredding process that with the presence in a form of fibers that are from the main stems and strand hand. EFB can be grade as a high lignin and low cellulose content compared to other high cellulose fibers such as hemp, flax and jute fibers (Cheng et al., 2018). Lately, the realization of upgrading biomass as fuel pellets as alternative energy resources are widely use across many developed countries.

2.4 Pelletization of Oil Palm Empty Fruit Bunch

Production of biomass fuel pellets for export is a part of global commitment to address climate change issues that involves many developed countries like United States, United Kingdom, Canada, Sweden, Finland, Italy and Japan to use fuel pellet for furnace and boilers to generate heat and power for residential and industrials fulfillment. By the turn of the millennium, the concerns about energy security and the impact of climate change associated by the use of non-renewable energy has led to the realization of using biomass fuel pellets for alternatives renewable sources. Although currently there are constraints for exporting EFB pellet to European Union (EU) countries due to their negative perception of our oil palm industry that involves high shipment cost. China, Japan and South Korea are neighboring countries that has a lower entry barrier for Malaysian EFB pellets. By the year of 2020, the demand of biomass fuel pellet within the three countries is projected to be in range of 16 million tonnes. The potential total market annually is RM 4.8 billion based on the current price of pellet fuels at about RM300/tonnes (Abdul Rahman et al., 2013). Along these lines, there are many beneficial that could gain from exportation of fuel pellet from the pelletization process of biomass.

Pelletization process are a type of biomass densification to formed a cylindrical pellet that can enhance the management of biomass by reducing the bulk density of the raw feedstock for storage and transportation purpose. Production of pelletized biomass with higher density and bulk are able to lower the transportation cost with higher energy conversion, while it also reduces the moisture content and maximize the storage period. The uniform shape and sizes of the pelletized biomass ease the ways of handling and storage equipment which are economically valuable for long distance transport of the biomass that are used outside from the production areas. The process is the most popular densified by-product for alternative fuel resources for power and heat production for industrial feeding boilers (Poddar et al., 2014). Formation of pellet from biomass commonly depending on the physical properties of the ground sample and the variables during the pelletization process such as temperature and pressure. Different type of biomass has different compaction properties, thus it is important to understand the suitable properties that needed to achieves optimized condition of the pelletized OPEFB.

2.5 Properties and density optimization of pelletized OPEFB

OPEFB pellets is formed by using a ring die mold 8 mm die diameter, the pellet was relatively in uniform size of their diameter (D) and length (L) within the acceptable range required by the EN 14961-2 and proposed ISO 17225-6 (D: 8.0 ± 1.0 mm. L:31.5< L < 40.00 mm). Pelletizing properties of OPEFB that were verify using single pellet press by compression testing were evaluated through the density of the pellet. The characteristic of the pellets will affect towards the handling and storage of the pellet. Thus the dimensions of the pellet should be standardize for a further determination on the responses.

2.5.1 Pellet density

The specific density of the pellet is determined by mass over volume of individual pellet from the single pellet press. The strength of pellets is measured 48h after production using Equation (2.1), through calculating the dimensions (length and diameter) and the mass of each pellet in order to obtain the volume of pellet. Liu et al., (2012) reported that to control the density of pellet is to increase the compaction pressure or increase the die temperature for the pelletization process. Aside from that, there are other several parameters such as particle size that affects the physical properties of the pellet which significantly effects the mechanical strength of the pellet.

$$\rho = \frac{m}{V} \tag{2.1}$$

Where;

ρ = density,

m = mass,

V = volume

2.6 Response Surface Methodology

Response surface methodology (RSM) is a set of mathematical and statistic technique, which to determine the optimization of the output variable that influences by the independent variables. (Qiu et al., 2014) RSM is a multivariate technique to use in analytical optimization which based on the fit of a polynomial equation of the experimental data which explains the characteristic of a data set with the objectives of making statistical previsions. (Almeida et al .,2008) It is also depending on the type of model being used. In this study, a multi-response experiment was used that measures the analysis obtained from the properties of controlled variable. In this study, RSM Box-Behnken experimental design model is used to identify the optimum condition of pelletized OPEFB based on the pellet density.

CHAPTER 3

MATERIALS AND METHODS

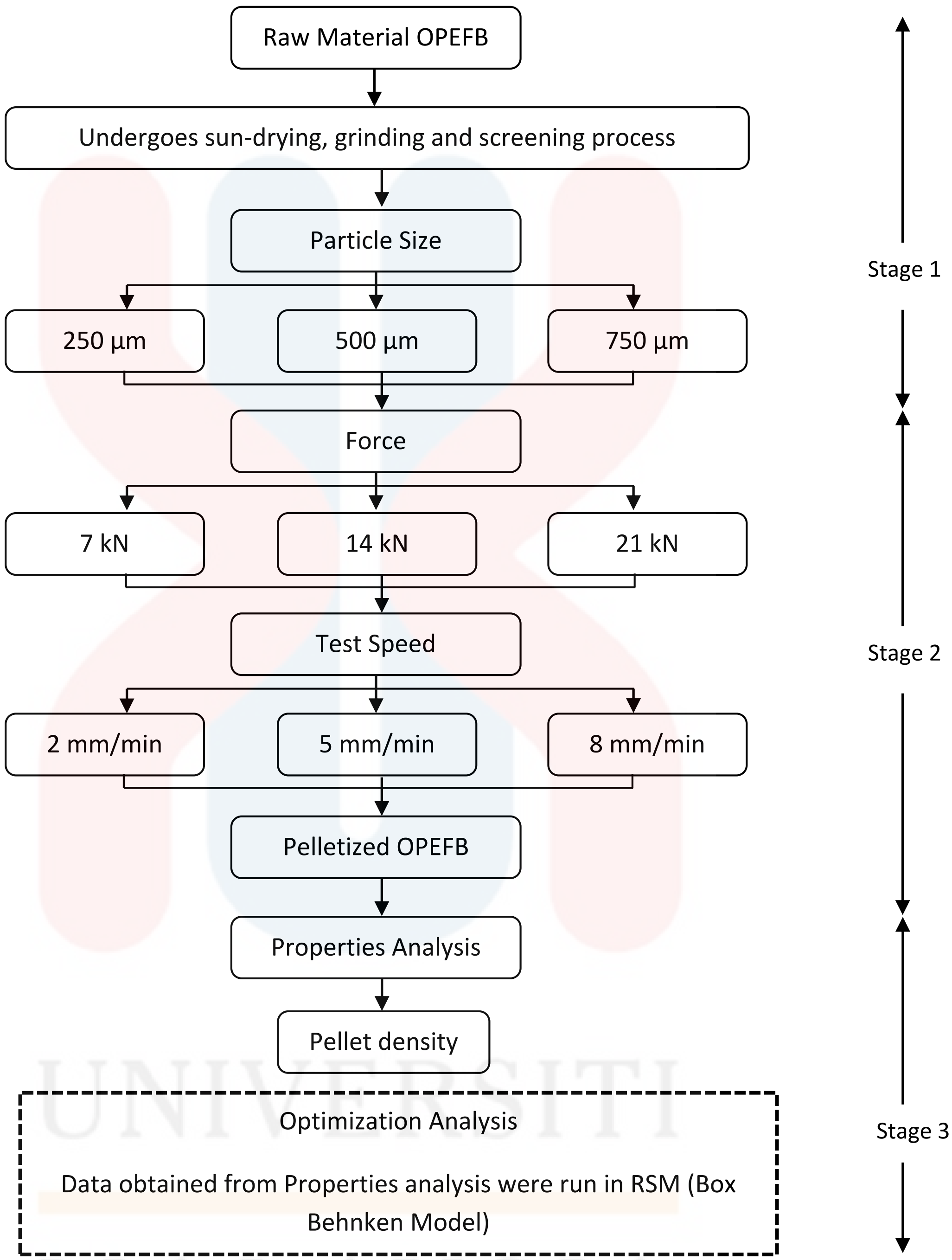
3.1 Materials

The raw material that being used in this study is OPEFB fiber that was derived from an oil palm plantation in Jeli. OPEFB was chosen due to its possible sources for renewable biomass since it is abundance in Malaysia. As shown in Figure 3.1 is the raw material of extracted fiber Figure 3.1 that were used to further the pelletization process. The pelletized OPEFB was undergoes physical properties analysis and analysis of data were run to investigate the optimum density condition of the pelletized OPEFB based on the properties.

Figure 3.1: OPEFB fibre used for pelletization process

3.1.1 Sample Preparation

The OPEFB fiber were undergone sun-dried for 24 hours to let it dry. In order to minimize the moisture content of the OPEFB, the sample were undergoes oven-dried at 103±2℃ for 24 hours. After preheated process, the sample were cut into small pieces to make it easier to grind and sieved. The sample were grinded using blender until it produced fine particles and the screening of the OPEFB was done by using sieve of 250, 500 and 700 µm. The process of grinding and screening was to obtain the desired sample scales without having other contaminants mixed up with the samples such as dust which may affect when the sample need to be analyzed. Figure 3.2 shows the research flowchart of this study.



Stage 1: Sample preparation based on particle size
Stage 2: Pelletization process of OPEFB based on force and test speed
Stage 3: Analysis of properties and optimization of pelletized OPEFB

Figure 3.2: Flowchart of the overall process

3.2 Methods

In this study, there three stages involve which started with sample preparation based on the particles sizes, pelletization process of OPEFB were done based on the compression force and test speed given towards the OPEFB that were loaded in the pellet mold. Based on previous study, the structure of the pellet mold used in the process is based on Figure 3.3 that are in 2D drawing schematic diagram flow.

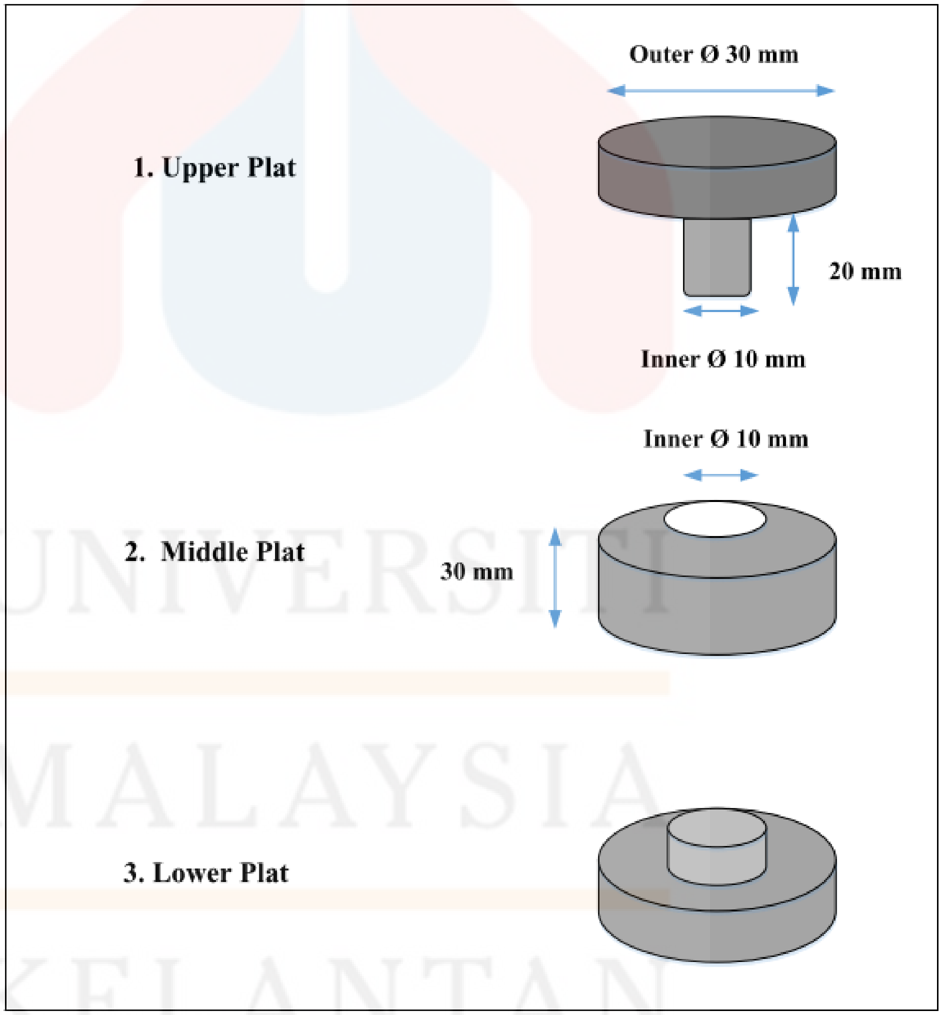


Figure 3.3: Schematic diagram of pellet mold
(**Source**: Ahmad et al., 2018)

3.2.1 Pelletization process of OPEFB

In this study, the pelletization process of OPEFB were involved 3 stages as shown on Figure 3.1. After sample preparation according to sample sizes, the sample were loaded approximately of 0.25g into the pellet mold and compressed with the desired pressure by using an universal testing machine (UTM). The cylindrical die comprised an opening of 10 mm in diameter which are made of carbon steel. Pressure were given to the pellet mold with a specify test speed, at length of 129mm of the compression length was released after 10s and the piston were removed. The samples were test using pressure of 7 kN.14 kN and 21 kN with a test speed of 2 mm/min, 5 mm/min and 8 mm/min for respective forces and particle sizes. By using RSM (Box Behnken Model) in order to perform Design of Experimental (DOE) for the processing parameters which are particle size, pressure and test speed. Design of experiment (DOE) were suggested to reduce the number of experiment need to be done and to achieve the optimized experimental conditions for maximum pellet density, it may help in reducing the usage of raw material and time to complete the pelletizing process. DOE offers comparative testes, combined design, mixture designs and optimization conditions. The implication of the parameters is to determine the analysis of variance (ANOVA), which can identify the relation of each parameter for desired result (Arafat Hossain et al., 2017).

3.2.2 Properties and Density Optimization Analysis of pelletized OPEFB

As in to get the optimization, RSM (Box-Behnken Model) a mathematical and statistical technique was used to help in the process. The independent variables used are particle sizes, pelletizing pressure and test speed that were used to be analyzed using RSM Box-Behnken model. 15 runs of experiments were suggested by the experimental design for the production of OPEFB pellet. The complete design matrix produced for the experiments and responses (density) is shown in Table A.1 of (Appendix A).

a. Density analysis

In order to measures the density of the pelletized OPEFB, the weight and dimension (length and diameter) were determined by using Vernier calipers and analytical balance. Every single density of the pellet was calculated by using the ratio of weight to volume of pellet by using Equation (2.1) after 48h after production.

3.3 Data Analysis

Lastly, the optimization was done by using RSM (Box-Behnken model) based data obtained from the analysis of pelletized OPEFB. Three independent variables were used for the statiscal analysis which are particle size, pressure and test speed in response to density. Data produced from the experimental were analyzed using ANOVA.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Physical Dimension and density of OPEFB pellets

Density of the pellet is an important parameter by determined through the mass per volume of the pelletized OPEFB. In this study, the density of single pellet pelletized process was calculated based on the mass of pellet and volume of the pellet based of the factors were shown in Table 4.1. Major role that affects the density of the pellet is the particle sizes, this is because the smaller the particles fills in between of the gap in the die first. Average length of pellet from the process are 5.54 to 6.77mm while average diameter is about 10mm. The weight of the pellet is constant for every pellet which are in range of 0.25g ± 0.1, the weight will only be affected when temperature is given through the process. The character of the pellet is important in order to reduce the volume thus increase the energy density of the OPEFB pellet. Next, the pellet must have remained solid until it serves its purpose such as handling and transporting conditions.

Table 4.1: Physical Dimension of 250µm OPEFB pellet

Sample Size (µm)		**250**		
Pressure (kN)	7kN		14kN	21kN
Test Speed (mm/min)	5	2	8	5
Mass (g)	0.24	0.25	0.25	0.25
Length (mm)	6.02	5.76	5.78	5.87
Diameter (mm)	10.13	9.99	10.16	10.08

Table 4.2: Physical Dimension of 500µm OPEFB pellet

Sample Size (µm)				**500**			
Pressure (kN)	7kN			14kN		21kN	
Test Speed (mm/min)	2	8	5 (1)	5 (2)	5 (3)	2	8
Mass (g)	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Length (mm)	6.48	5.76	6.06	5.61	5.96	6.12	5.87
Diameter (mm)	10.20	9.93	10.16	10.19	10.04	9.92	10.12

Table 4.3: Physical Dimension of 750µm OPEFB pellet

Sample Size (µm)		**750**		
Pressure (kN)	7kN		14kN	21kN
Test Speed (mm/min)	5	2	8	5
Mass (g)	0.24	0.25	0.25	0.25
Length (mm)	6.54	5.73	6.00	6.11
Diameter (mm)	9.96	10.21	10.05	10.08

4.2 Density optimization of Pelletized OPEFB

The optimization of pelletized OPEFB was studied by using Box-Behnken design where 15 experimental runs in random order as shown in Table A.1 in (Appendix A). Three independent variables were selected to investigate the most significant factors that affects the density of the OPEFB pellet. According to Table 4.2, from the analysis of ANOVA that shows the P-value are in a significant state of value at 0.014 which are less than or equal to 0.05. In this case, particle size and pressure showed the significant levels at 0.042 and 0.038 respectively. However, values that are greater than 0.05 indicates the model terms are not significant. This the insignificant model terms identify from the analysis are test speed. The F-value (3.687) shown a higher value than P-value (0.014), this higher F-value proven to produce a reproducible and reliable regression model (Arafat Hossain et al., 2017).

Table 4.4: Analysis of ANOVA for density

Source	Sum of squares	Mean square	F	P-value
Constant (β_0)	376.856	102.224	3.687	0.014
A – Particle Size (β_1)	0.042	0.227	0.183	0.042
B – Pressure (β_2)	17.909	8.101	2.211	0.038
C – Test Speed β_3)	2.04	17.268	0.119	0.910

4.2.1 Normal plot of residuals

Normal plot of residuals is to ensure the construction of normal probability plot of the experimental residuals,thus the normal probability of experiment residuals for density is as shown in Figure 4.1. The ordinariness supposition will be fulfilled when the typical likelihood of trial residuals are lined up with the straight line. Figure 4.1 clearly shows that the density residuals are approximately nearing the straight line. The presence of few points away from the straight line implies a distribution with outliers which may influence by any other conditions such as measurement errors which may affect the experiment.

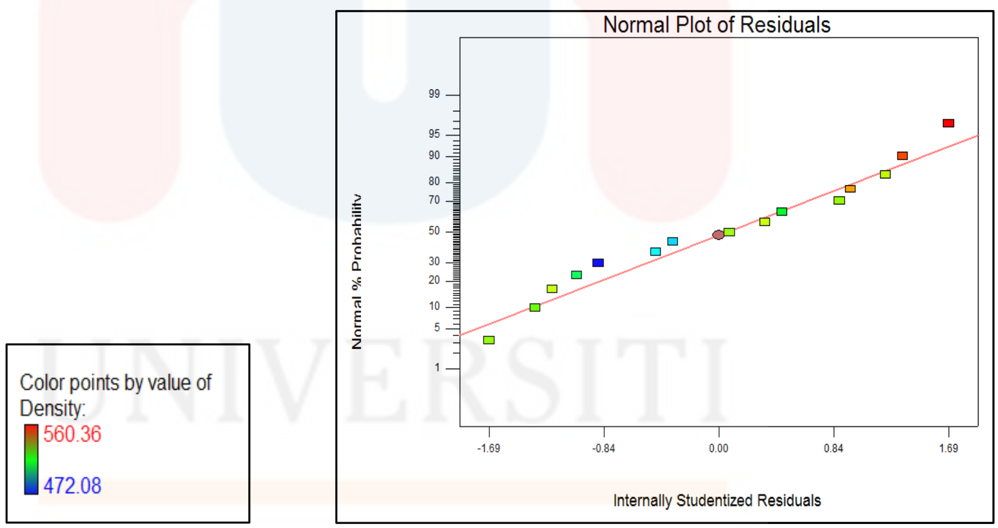


Figure 4.1: Normal Plot of Residuals for the density of OPEFB pellet

4.2.2 Contour plot of density vs Pressure and Particle Size

Contour plot is to determine the relation of a response variable and the two predictor variable, thus in this study the countour plot of density with the relation of pressure and particle sizes is shown in Figure 4.2. The contour plot provides a two-dimensional view within pressure and particle size of the pellet that interconnects with the density. The contour plots is a helpful ways for invistigating the response values with the desirable conditions of the response. Based on Figure 4.2, particle size shows less significance impact towards the density of the pellet. Meanwhile, compression pressure at about from 14 – 20 kN provides a robust affects towards the density of the OPEFB pellet. Test speed of the experimental act as the hold values, it is because it does not give any significant impact towards the OPEFB pellet.

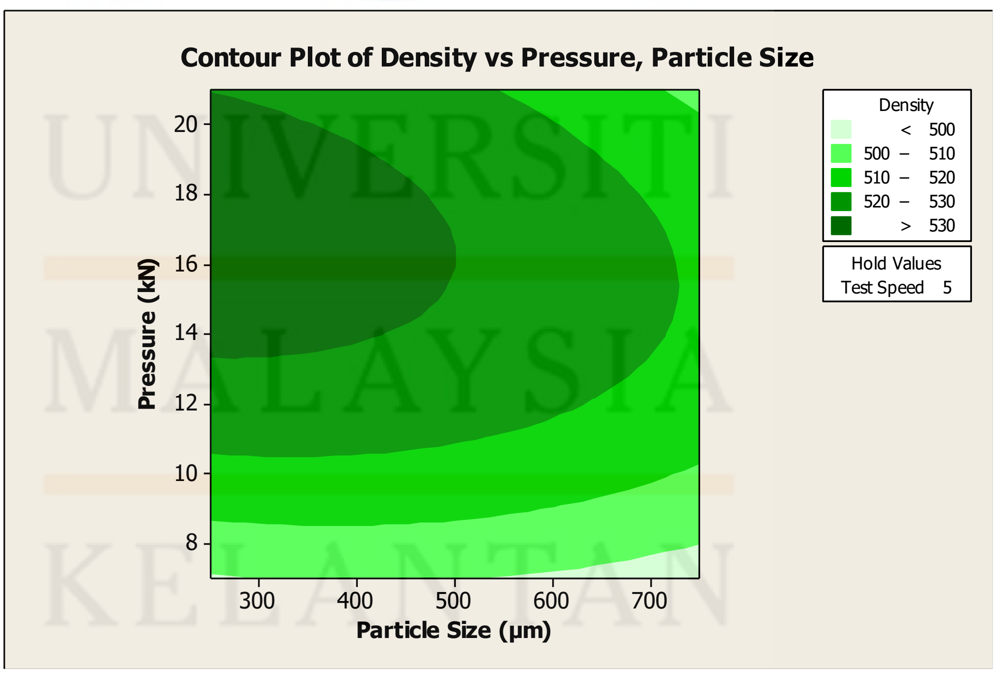


Figure 4.2: Contour plot of density versus pressure and particle size.

4.2.3 Surface plot of Optimized Density

Surface plot is a three-dimensional data that shows the character information of the individual data points, it shows a functional relationship between dependent variable at the Y-axis and two independent variables at the X and Z-axis. Surface plot shows on how fitted the response values relating with the two continuous variables based on the model equation. As illustrated at Figure 4.3, is the surface plot of optimized conditions of the OPEFB pellet. The resulting of the surface plot to be in curved shape is due to the model that contains quadratic terms which are statistically significant. According to Figure 4.3, red dots indicate the optimal value of the density of the pellet. The estimated optimum density from the surface plot is to be at 518.5 kg/m^3 based on particle size of 500μm at pressure of 14kN based on the suggested from the analysis process.

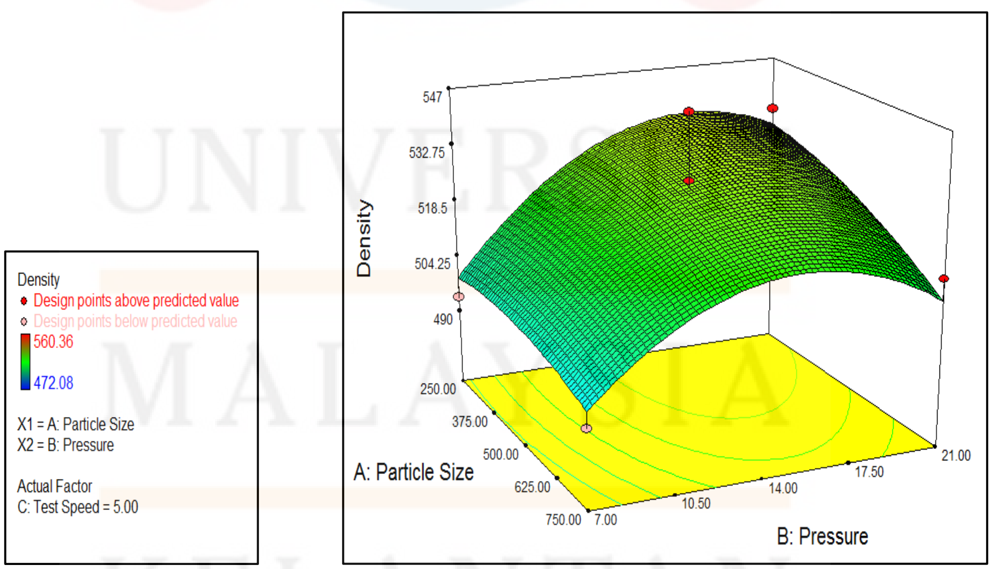


Figure 4.3: Surface plot of optimized density

4.2.4 Optimization plot of density

Prediction profiler from optimization plot is to check the maximize desirability function by setting the maximum meters dyed (loom yielf), it is to help in establishing the optimum setting for all the contributory variables. From the predicton profiler aditionally allow us to know on how the prediction model changes as the individual setting of the factor will change too. Figure 4.3 shows the optimization plot of density for the OPEFB pellet. Numbers at the top of the columns that shows the present variable setting that is in red with the high and low variable settings of the data.

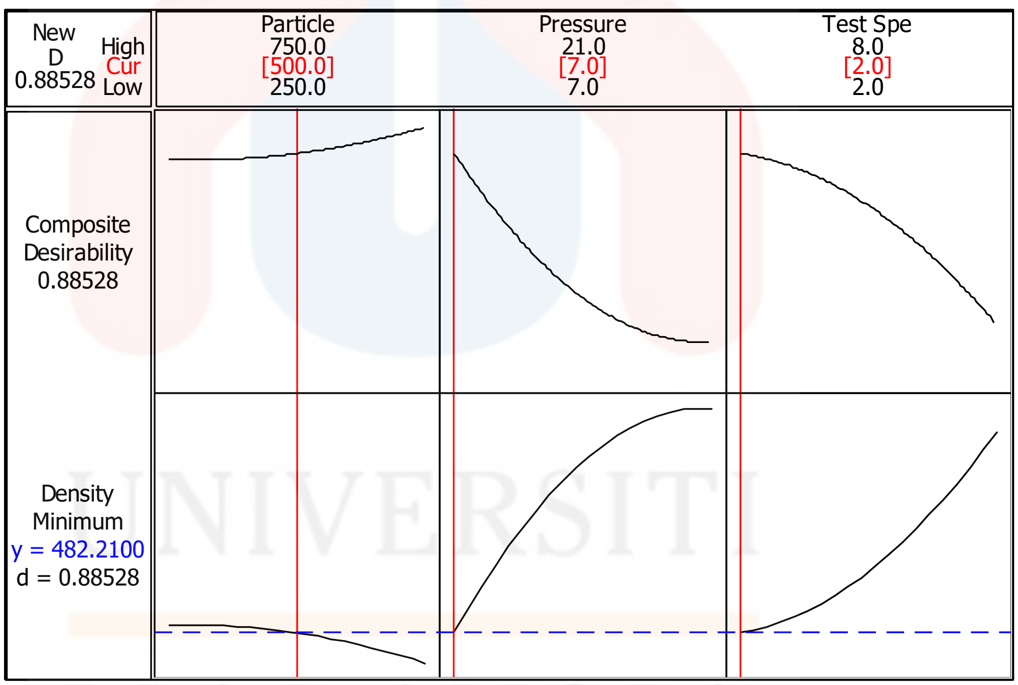


Figure4.4: Optimization Plot of density.

Red vertical lines on the graph indicates the current settings while the blue horizontal lines represents the current response values for optimized density of the OPEFB pellet. The desired minimum density was adjusted within the wanted range by moving the red lines in the graph, the movement of the lines will show the direct affects towards other factors. Based on the Figure 4.3, the composite desirability is 0.88528. The variable settings for the optimum density are at particle size of 500µm ,7kN pressure with the test speed of 2mm/min. As for an optimal minimum density values based on the present variable setting, the predicted value are 482.21 kg/m^3 with individual desirability of 0.88528. As the individual desirability are close to 1, it implies the settings seems to reach ideal results for all response that involves. Meanwhile, the individual desirability of the density is still within the acceptable range. The differences value suggested at 3D surface plot and optimization plot shows different value in order to achieve the minimal density value.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The production of OPEFB pellet by using Universal Testing Machine (UTM) by single pellet press according to the responses which are particle size, pressure and test speed and the compression testing was used to determined the physical properties of the pelletized OPEFB. The average length of pellet from the process are 5.54 to 6.77 mm while average diameter is about 10 mm. The determination of optimal condition for the density was analyze and produced at particle size of 500 µm, pressure of 7 kN with a test speed 2 mm/min. From this research, the relation between the physical properties of the pellet may affects the optimal condition of the pellet. In order to reduce the cost of pellet production and energy efficient for the pelleting process in palm oil industry, it is preferable to pelletized the raw biomass to form a lower density of the pellet.

5.2 Recommendation

For the future study, there are several suggestions that need to be addresed and streghthened. Firstly, the pelletization process could add die temperature as the additional factors in the experimental. Next, this study only focuses on density as the response for pelletization of OPEFB. In the future, the pelletization process could add various responds such as bulk density, hardness test and characterization of the pellet to further analysis on the optimal state of the OPEFB pellet. Lastly, other than EFB there are abundance of oil palm biomass such as OPT, OPF, MF and PKS to be pelletized as biomass energy. Future study can compare on the effectiveness of the pelletized OPEFB and other oil palm biomass.

REFERENCES

Abas, R., Kamarudin, M. F., Nordin, A., & Simeh, M. A. (2011). A Study on the Malaysian Oil Palm Biomass Sector – Supply and Perception of Palm Oil Millers. *Oil Palm Industry Economic Journal*, *11*(1), 28–41. https://doi.org/10.1016/j.jclepro.2012.04.004

Abdul Rahman, N., Kin Mun, D. L., Kathiravale, S., Tang, K. M., S Puvaneswari, & Abd Aziz, N. (2013). MALAYSIAN BIOMASS INDUSTRY ACTION PLAN 2020: Driving SMEs Towards Sustainable Future iii. *Journal of Chemical Information and Modeling*, *53*, 160. https://doi.org/10.1017/CBO9781107415324.004

Ahmad, M. I., Jusoh, W. N. K. W., Rizman, Z. I., Rasat, M. S. M., Alauddin, Z. A. Z., Soid, S. N. M., Amin, M. F. M. (2018). Effect of torrefaction on oil palm empty fruit bunch pelletization. *Journal of Fundamental and Applied Sciences*, *9*(3S), 955. https://doi.org/10.4314/jfas.v9i3s.66

Aliyu, A. S., Abdullahi, N., & Sulaiman, F. (2017). Pyrolysis of torrefied oil palm wastes for better biochar. *Malaysian Journal of Fundamental and Applied Sciences*, *13*(2), 124–128. https://doi.org/10.11113/mjfas.v13n2.636

Almeida, M., Erthal, R., Padua, E., Silveira, L., & Am, L. (2008). Talanta Response surface methodology (RSM) as a tool for optimization in analytical chemistry, *76*, 965–977. https://doi.org/10.1016/j.talanta.2008.05.019

Arafat Hossain, M., Ganesan, P., Jewaratnam, J., & 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. https://doi.org/10.1016/j.enconman.2016.10.046

Suruhanjaya Tenaga. (2016). National Energy Balance 2016. ISSN NO:0128-6323.

Bevan Nyakuma, B. (2018). Biomass Energy Outlook in Malaysia using Functions of Innovation Systems, (February). https://doi.org/10.1093/cvr/cvr291

Energy, A. (2017). Southeast Asia Energy Outlook 2017.

Hussain, S. A., Bano, S., Yeoh, H. S., & Rozita, O. (2014). Simulation on temperature distribution of oil palm empty fruit bunches during the microwave pyrolysis process. *Asia-Pacific Journal of Chemical Engineering*. https://doi.org/10.1002/apj.1744

Nor, A., Ramli, A. T., & Aliyu, A. S. (2015). Malaysia energy strategy towards sustainability : A panoramic overview of the bene fi ts and challenges, *42*, 1094–1105. https://doi.org/10.1016/j.rser.2014.10.056

Poddar, S., Kamruzzaman, M., Sujan, S. M. A., Hossain, M., Jamal, M. S., Gafur, M. A., & Khanam, M. (2014). Effect of compression pressure on lignocellulosic biomass pellet to improve fuel properties: Higher heating value. *Fuel*, *131*, 43–48. https://doi.org/10.1016/j.fuel.2014.04.061

Qiu, P., Cui, M., Kang, K., Park, B., Son, Y., Khim, E., Khim, J. (2014). Application of Box-Behnken design with response surface methodology for modeling and optimizing ultrasonic oxidation of arsenite with H2O2. *Central European Journal of Chemistry*, *12*(2), 164–172. https://doi.org/10.2478/s11532-013-0360-y

Renewable, A. (2018). Exciting and Electrifying, *17*.

Rizman, Z. I., Mohamed, M., Rasat, M. S. M., Ahmad, M. I., Aziz, M. S. A., Alauddin, Z. A. Z., Amin, M. F. M. (2018). The effect of torrefaction on oil palm empty fruit bunch properties using microwave irradiation. *Journal of Fundamental and Applied Sciences*. https://doi.org/10.4314/jfas.v9i3s.67

Shah Alam, S., Omar, N. A., Bin Ahmad, M. S., Siddiquei, H. R., & Mohd. Nor, S. (2013). Renewable Energy in Malaysia: Strategies and Development. *Environmental Management and Sustainable Development*, *2*(1), 51–66. https://doi.org/10.5296/emsd.v2i1.3197

Suzuki, K., Tsuji, N., Shirai, Y., Hassan, M. A., & Osaki, M. (2017). Evaluation of biomass energy potential towards achieving sustainability in biomass energy utilization in Sabah, Malaysia. *Biomass and Bioenergy*, *97*, 149–154. https://doi.org/10.1016/j.biombioe.2016.12.023

APPENDIX A

Table A.1: Experimental design matrix and the corresponding respond results

Std Order	Run Order	Particle Size (x_1)	Pressure (x_2)	Test Speed (x_3)	Density (kg/m^3)
13	1	500	14	5	508.78
1	2	250	7	5	493.62
11	3	500	7	8	560.36
6	4	750	14	2	532.83
3	5	250	21	5	533.62
15	6	500	14	5	546.36
5	7	250	14	2	554.28
2	8	750	7	5	490.56
12	9	500	21	8	529.41
10	10	500	21	2	528.46
7	11	250	14	8	533.44
9	12	500	7	2	472.08
4	13	750	21	5	512.66
14	14	500	14	5	529.76
8	15	750	14	8	525.19

Table A.2: Density for particle size of 250 μm

Sample Size (μm)	**250**			
Pressure (kN)	7kN	14kN		21kN
Test Speed (mm/min)	5	2	8	5
Mass (g)	0.24	0.25	0.25	0.25
Volume (cm^3)	0.486204	0.451037	0.46866	0.4685
Density (kg/m^3)	493.62	554.28	533.44	533.62

Table A.3: Density for particle size of 500 μm

Sample Size (μm)			**500**				
Pressure (kN)	7kN			14kN		21kN	
Test Speed (mm/min)	2	8	5 (1)	5 (2)	5 (3)	2	8
Mass (g)	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Volume (mm^3)	529.57	446.14	491.37	457.57	471.91	473.07	472.22
Volume (cm^3)	0.52957	0.44614	0.49137	0.45757	0.47191	0.47307	0.47222
Density (kg/m^3)	472.08	560.36	508.78	546.36	529.76	528.46	529.41

Table A.4: Density for particle size of 750 μm

Sample Size (μm)		**750**		
Pressure (kN)	7kN	14kN		21kN
Test Speed (mm/min)	5	2	8	5
Mass (g)	0.25	0.25	0.25	0.25
Volume (mm^3)	509.62	469.19	476.02	487.65
Volume (cm^3)	0.50962	0.46919	0.47602	0.48765
Density (kg/m^3)	490.56	532.83	525.19	512.66