Empirical Model Development of Biomass Fuel Pellet Strength

by

Ibnu Sufi bin Hasan

15582

Dissertation submitted in partial fulfillment of

the requirement for the

Bachelor of Engineering (Hons)

(Chemical Engineering)

SEPTEMBER 2015

Universiti Teknologi PETRONAS

32610, Bandar Seri Iskandar

Perak Darul Ridzuan.

CERTIFICATION OF APPROVAL

Empirical Model Development of Biomass Fuel Pellet Strength

by

Ibnu Sufi bin Hasan

15582

A project dissertation submitted to the

Chemical Engineering Programme

UniversitiTeknologi PETRONAS

in partial fulfillment of the requirement for the

BACHELOR OF ENGINEERING (Hons)

(CHEMICAL ENGINEERING)

Approved by,

____

(NorfidzaYub Harun)

UNIVERSITI TEKNOLOGI PETRONAS

BANDAR SERI ISKANDAR, PERAK

September 2015

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

____

IBNU SUFI BIN HASAN

ABSTRACT

Biomass is an organic material that can be used as a fuel it is a promising alternative for clean fuel production. However, by simply taking the biomass as a fuel without any improvement will not give the best source of energy because it will cause instability combustion, less durability, costly in transportation and storage. So, the main aim of this study is to develop, test and verify the Respond Surface Methodology (RSM) model using the Box-Behken Respond type by focusing on the strength of mixed biomass fuel pellet. Each type of biomass resources was manipulated in term of the moisture content, blend ratio and the particle size. The moisture content was tested with three different percentages, which is 8%, 10% and 12%, then the blend ratio with 25%, 50% and 75% of the woody biomass and the particle sizes with 150µm, 300µm and 450µm. This study describes the several factors that affecting the strength of the mixed biomass pellet such as the size of particle, blending ratio, lignin content, moisture content and the porosity. The biomass strength model created based on Pine and Timothy Hay can be used for the similar species with the factor of moisture content in the range of 8 – 12%, blend ratio is in the range of 25 – 50%, and the particle size in the range of 150µm and below.

ACKNOWLEDGEMENT

First and foremost, the author would like to take this precious opportunity to firstly express my gratitude to all the people who played their role for the successful completion of this Final Year Project under the topic "Empirical Model Development of Biomass Fuel Pellet Strength". Firstly, I would like to dedicate my utmost gratitude to my both parents, Mr. Hasan bin Hamid and Mdm. Che' Wa binti Said. Their supports were always with me till I finished all the works. Then, my gratitude goes to my supervisor, Madam Noorfidza Yub Harun for the valuable guidance and advice. All the constructive comments and suggestions given has helped the author in improving the study and taught to focus on a lot of areas of research in completing this project, which is often overlooked. Her contribution is indeed precious and educational.

Besides, it is also an honor to thank to Universiti Teknologi PETRONAS (UTP) for all the resources available in the Information Resources Centre, and the information online services provided. These resources have provided the aids needed in order to effectively design the desired process and accomplish the work objective. In addition, I would like to express my special sense of gratitude to all the lecturers, technician in Chemical Engineering Department for their continuous support and guidance throughout this project. Without them, I am so sure this project will not completed successfully.

In the nutshell, an honorable mention goes to my friends, especially to Mohd Mu'izzuddin Pauzi, Anuar Abdullah, Raihan Fikri Roslan and Hudzaifah Yousof Humayun for their understandings and supports in completing this project. Without helps of the particular that mentioned above, the author would face many difficulties while doing this project.

TABLE OF CONTENT

LIST OF ABBREVATIONS

RCG	Reed Canary Grass
S	Spruce
P	Pine
T	Timothy Hay
SW	Switchgrass
GHG	Greenhouse Gas
RSM	Response Surface Methodology
UTM	Universal Testing Machine

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION

1.1 Background Study

Currently, the demand of energy is met by the conventional fossil fuels (i.e. coal petroleum and natural gas). However, the world fossil fuel production, beginning with petroleum and natural gas, will soon start to decline. Moreover, the continuous growth of the global population has called upon the need to have sustainable energy supply while limiting the emissions of greenhouse-gas (GHG). The biomass is the solution to keep the environment clean without any pollution. The last thirty years has catapulted the search for a clean and renewable energy in order to keep the environment clean and to reduce the use of depletable conventional energy sources. Renewable energy sources, such as biomass is being considered as possible sources of energy to meet these challenges.

Biomass power uses an organic matter (wood, agricultural waste, food waste, etc) or an inorganic matter like municipal solid waste to create electricity or heat (energy). Wood pellets and chips are the most typical way to use as a fuel in biomass power plants. Usually the pellet are only the byproduct of the timber industry and can be created using residues from other processes, in the other way of thinking is the pellet production is made from the recycle waste product from the plant processes. Day to day the pellet industry is expanding by about 25% per year in production capacity and the wood pellet production and export have experienced rapid growth in recent years (Tooyserkani, 2012). Due to the environmental friendly factor, the utilization of biomass for the heat and power production become increasingly from year to year. The important thing for pellet fuel is quality standards that define and indicate about physical property and chemical property of the pellet fuel, the properties are, diameter, length, fine, ash, bulk density, durability, heating value, and the element component in fuel.

1.2 Problem Statement

Crisis of energy in the world can be seen through the economic expansion through the region. Economic growth is based largely on industrialization, combined with population growth and urbanization, has created an expanding demand for energy. So, the biomass can be a very promising alternative source of renewable energy for a country that has a significant amount of forestry biomass residue resources.

But, the biomass need to undergoes some process of modification if not it will not give the best source of energy. For example, the high moisture content in raw biomass causes instability of combustion. A problem also occurs when the raw biomass is moved from its source to the storage area. With the bulky size and heavy weight of raw biomass as well as its different shape, length, and size, the transportation takes a lot of time and cost, while each time of transportation, a small quantity of biomass can be moved. Fortunately, those problem mentioned has brought to this study on the effective optimization of biomass waste and its potential in the future by creating the pellet model with high strength and analyze it by using respond type called as Respond Surface Methodology (RSM) in Minitab 17 computer software.

1.3 Objectives

The main objective of this final year project is to produce the high durability of mixed biomass fuel pellet in term of the mechanical strength. To achieve this main objective, the following sub-objectives have to be achieved.

i. To model the strength of the international resources of biomass fuel pellet.
ii. To determine the factors that affecting the strength of the biomass fuel pellet.
iii. To verify the model by using other combination of biomass fuel pellet.

1.4 Scope of Study

Scope of study for this research project is to perform analysis on the effectiveness of mixed biomass and the comparison of the different pellet with the different chemical properties such as the effect of the moisture content, particle size and the blend ratio that has been highlighted to be the critical factors that affecting the strength of the biomass fuel pellet strength. Besides, the study is continued by doing the modeling and focusing on the strength of the mixed biomass pellet by using computer software, Respond Surface Methodology (RSM) to model the pellet and get the numerical parameters. So the verification of the model created by using the RSM will be investigated by comparing with the other combination data available from other species. In addition, based on the statistical result from the RSM, the critical factors affecting the strength of the biomass fuel pellet strength can be determined.

CHAPTER 2
LITERATURE REVIEW

2.1 Pelletization of Biomass Pellet Fuel

Biomass pelletization is a standard method to shape the biomass residue into a pellet size. The pelletization process will make the biomass more effectiveness as follows:

i. Increase the biomass density
ii. Standardize the size and shape of biomass residue
iii. Reduce in transportation and storage cost
iv. Easy in handling

The pellets produced are manufactured in several of types and grades depend on the type of businesses such as for electric power plants, homes, and other applications. Since nowadays biomass industry is expanding, the pelletization process requires several steps to produce a biomass pellet from the waste residue. Nowadays, the standard pelletization process requires several steps namely gathering the biomass from agricultural area and other sources, dehumidifying and biomass milling. In milling stage, the particle size of the biomass residue will be specified and to get good bind between the particles to form the pellet, the particle size needs to be below than 5000µm. after done specified the particle size, the biomass residue will continue the process with modifying, pelletizing, cooling, screening and pellet's packaging before being distributed to the market.

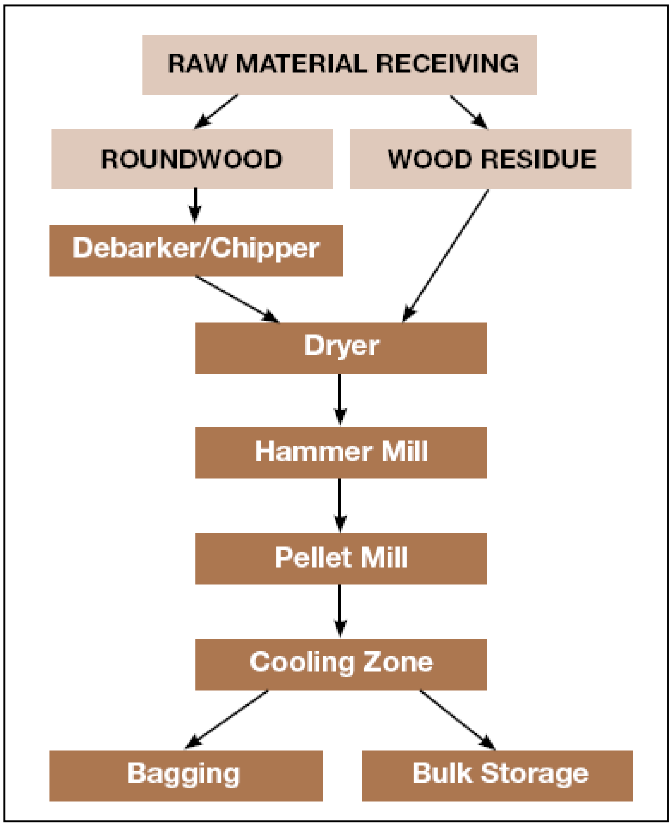

Figure 2.1 Schematic Pelletization of Woody Biomass

Firstly, all the needed feedstock is prepared which included selecting a feedstock suitable for this process, such as, the biomass from the foresting products, food waste and etc. The process is filtration, storage and protection. For example, the raw biomass from agricultural area and other sources is gathered together. Then the gathered biomass will be stored for a certain period before proceeding to the next process. Next is dehumidifying process. The meaning of dehumidifying is removal of water from the residue by controlling its moisture. Sometimes, the drying process needed about 24 hours to make the biomass completely dried in the oven at 80°C - 90°C.The drying process increases the efficiency of biomass and no smoke is produced during the combustion process. Over dried feedstock will cause the lignin content of the feedstock less efficiency. It's means that, it will weaken the binding the biomass particles.

Then, the process continues to the milling process and in the other word is cutting process of the biomass. In this process it reduces the feedstock size with the milling machine into a needed particles size that has been specified. Usually it is ¼ or 5/16 inches or about 3 mm. Pelletization is to form the milled biomass with pelletization machine. Before undergo the pelletization process, the water must be added into the feedstock and it is considered as the moisture content to the mixture. This will include the lignin effect to the feedstock as the binding agent. The cooling process will take their role to make sure that the temperature of the pellet reduces to the room temperature. The temperature will be reduced from 90℃ to 25℃. The, the process continues to the screening process which is to separate the pellet from the dust that will be returned to the producing process. Pellet's packaging (bagging) is done either in manual or automatically. This process is the last stage of pelletization before the fuel is distributed to the market (Warajanont, 2013).

Before deciding to produce a pellet from biomass, there are several key factors should be considered as important. Without knowing the exact parameters that affecting the quality of the biomass pellet, it will makes the pellet will not giving the optimum outcome as per requested. The factors such as, raw materials type, pellet parameters, temperature, pressure, moisture content, particle size, and etc.

2.2 Factors Affecting The Strength Of Biomass Fuel Pellet

2.2.1 Particle Size and Porosity

To form the pellet, the biomass feedstock ne to be compacted, the distance between the biomass particles will be reduced and the intermolecular attractive force between the particles size will play it function to bind the particle of the biomass. In fact, when the biomass is compacted, the particle size is decreased in resulted as the attractive force is. The effect of particle size on the pelletizing pressure was more defined, showing that the pelletizing pressure increases with a decreasing particle size (Wolfgang Stelte, 2012). To make a biomass pellet, the hypothesis has been stated and accepted that the smallest the particle size of the feedstock the strongest the biomass fuel pellet produced. The highest particle size to make a fuel pellet is 5000µm.

The porosity is another factor that affecting the strength of the pellets. Smaller particle size (150 and 300μm) might exhibit lower porosity than larger size (425 and 600μm). The larger the particles size of the feedstock, the higher the porosity. Therefore, the fuel pellets made from the smaller particles size have higher strength than the pellets made from the coarse particles size due to their porosity characteristics of the feedstock.

2.2.2 Lignin Content

The lignin of the biomass will act as the binding agent in the biomass fuel pellet. The lignin content is varying from each species to the other species. Within a plant, the lignin content in a wood plant can vary from 15-40%. The lignin content is very low in young shoots species and high in wood. The lignin content have it own function to be as an adhesive and maintain the structural integrity of pellets. Before the pelletization starts, the water must be added to stimulate lignin in the biomass to absorb the water and bind the particle (Warajanont, 2013).

2.2.3 Moisture Content

The optimum moisture content may help to increase the bonding within the pellets by spreading the natural lignin inside the biomass particle (Inesa Barmina, 2013). Therefore, the moisture content must be controlled properly to get the optimum moisture content because too much moisture may lower the bonding strength and even block the pellet die holes. Final pellet moisture is also certainly dependent on cooling and drying, and while these factors were not examined in these experiments, it is prudent at this point to examine what relationships might exist between the final moisture level and determined pellet durability (Charles, 2012).

2.2.4 Blend Ratio

Malaysia having a plenty amount of agriculture biomass and it can be used as a fuel pellet to utilize the country residues. However, the pellets made from the agricultural biomass are having poor quality as compared to forestry biomass (N. Y. Harun, 2015). So the blend ratio is to blend the agricultural and woody cellulose and getting the new durability properties. It seems that the chemical content of the woody sample plays a more dominant role, as compared to the agricultural sample, in blended biomass (N. Y. Harun, 2015). The durability of the blend pellets was higher than that of the individual agricultural biomass pellets and comparable to the woody biomass pellets.

2.3 Response Surface Method and Design

Response Surface Methods are designs and models for working with continuous treatments when finding the optima or describing the response is the goal. The first goal for Response Surface Method is to find the optimum response. When there is more than one response then it is important to find the compromise optimum that does not optimize only one response (Bradley, 2007). When there are constraints on the design data, then the experimental design has to meet requirements of the constraints. The second goal is to understand how the response changes in a given direction by adjusting the design variables. In general, the response surface can be visualized graphically. The graph is helpful to see the shape of a response surface; hills, valleys, and ridge lines. Hence, the function f (x_1, x_2) can be plotted versus the levels of x_1 and x_2 as shown as figure below.

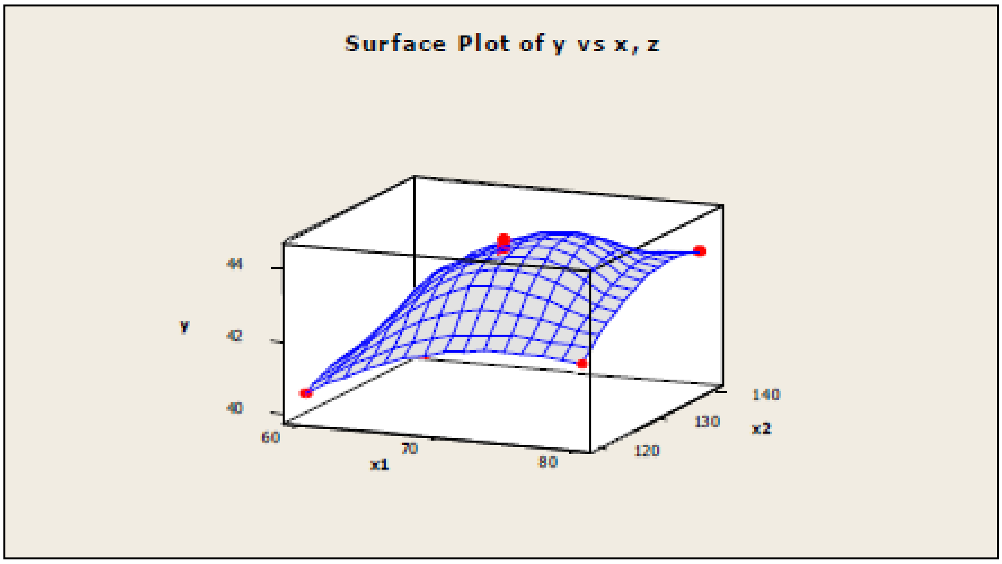

Figure 2.3 Response Surface Plot

In this graph, each value of x1 and x2 generates a y-value. This three-dimensional graph shows the response surface from the side and it is called a response surface plot. Sometimes, it is less complicated to view the response surface in two-dimensional graphs. The contour plots can show contour lines of x1 and x2 pairs that have the same response value y. An example of contour plot is as shown in figure below.

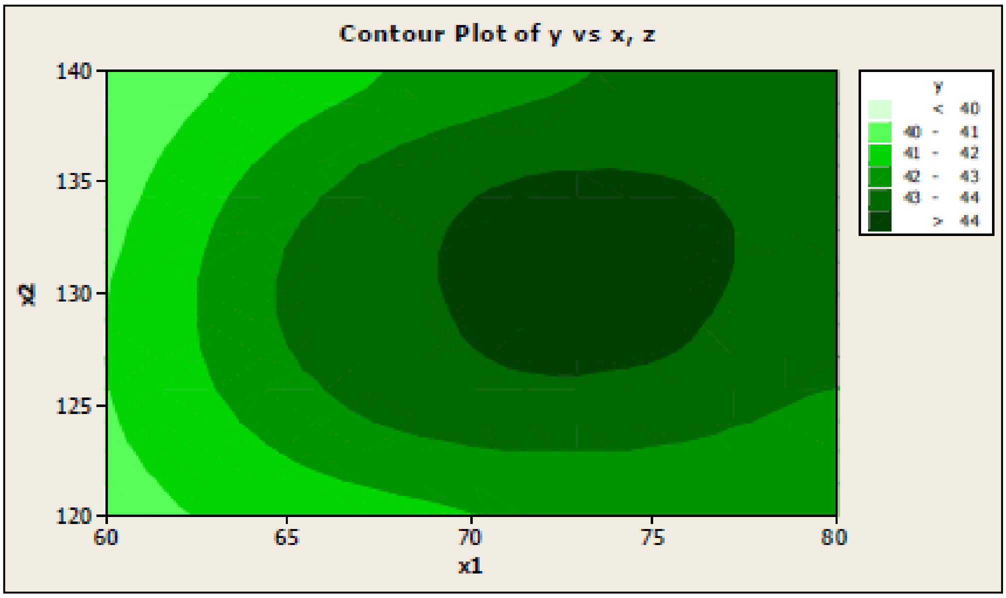

Figure 2.4 The Contour Plot

In order to understand the surface of a response, graphs are helpful tools. But, when there are more than two independent variables, graphs are difficult or almost impossible to use to illustrate the response surface, since it is beyond 3-dimension. For this reason, response surface models are essential for analyzing the unknown function f.

CHAPTER 3
METHODOLOGY

3.1 Response Surface Methodology (RSM)

This paper will give details of described methods for the modeling the biomass pellet using. This method is based on previous data experiments collected through the literature Chemical and Mechanical Properties of Pellets Made from Agricultural Woody Biomass Blends (N. Y. Harun, 2015). The simulation use in this paper is called Respond Surface Methodology (RSM) inside Minitab® 17 software. Therefore, the objective of studying RSM can be accomplished by:

i. Understanding the topography of the response surface.
ii. Finding the region where the optimal response occurs.

The Response Surface Methodology (RSM) is a collection of mathematical and statistical techniques useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize this response (Montgomery, 2005). Such as in this paper the strength of the pellet is dependent on both type of biomass which is from the woody and agriculture biomass. Each biomass give affects to the strength of the biomass itself. So the strength of the biomass affected by the amount by mass of the woody, x_1 and the agriculture biomass, x_2. The strength of the pellet can be controlled under any combination of treatment x_1 and x_2. Therefore, amount of woody and agriculture biomass can vary continuously. When treatments are from a continuous range of values, then a Response Surface Methodology (RSM) is useful for developing, improving, and optimizing the response variable. In this case, the strength of the pellet, y is the response variable, and it is a function of water and sunshine.

$$y = f(x_{1,}x_2) + \varepsilon \tag{1}$$

While the variables x_1 and x_2 are independent variables where the response y depends on them as the y is the strength of the pellet. The dependent variable y is a function of x_1, x_2, and the experimental error term, denoted as a sigma,ε. The error term, ε represents any measurement error on the response, as well as other type of variations not counted in f. It is a statistical error that is assumed to distribute normally with zero mean and variance, s^2.In order to develop a right approximation for f, the experimenter usually starts with a low-order polynomial in some small region. A first-order model with 2 independent variables can be expressed as:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \varepsilon \tag{2}$$

If the curvature is exist in the response surface, the higher degree polynomial need to be used. The approximating function with 2 variables is called a second-order model:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{11} x_{11}^2 + \beta_{22} x_{22}^2 + \beta_{12} x_1 x_2 + \varepsilon \tag{3}$$

In general of all RSM problems use either one or the mixture of the both of these models. In each model, the levels of each factor are independent of the levels of other factors. In order to get the most efficient result in the approximation of polynomials the proper experimental design must be used to collect data. Once the data are collected, the Method of Least Square is used to estimate the parameters in the polynomials. The response surface analysis is performed by using the fitted surface. The response surface designs are types of designs for fitting response surface (Warajanont, 2013).

3.2 Model Verification via DOE Analysis Data

After the model created, the model need to be analyze whether the model is reliable or not. The steps for fitting a response surface (second-order or quadratic) model are as follows:

1. Fit the full model to the first response.
2. Use stepwise regression, forward selection, or backward elimination to identify important variables.
3. When selecting variables for inclusion in the model, follow the hierarchy principle and keep all main effects that are part of significant higher-order terms or interactions, even if the main effect p-value is larger than you would like (note that not all analysts agree with this principle).
4. Generate diagnostic residual plots (histograms, box plots, normal plots, etc.) for the model selected.
5. Examine the fitted model plot, interaction plots, and ANOVA statistics (R2, adjusted R2, lack-of-fit test, etc.). Use all these plots and statistics to determine whether the model fit is satisfactory.
6. Use contour plots of the response surface to explore the effect of changing factor levels on the response.
7. Repeat all the above steps for the second response variable.
8. After satisfactory models have been fit to both responses, you can overlay the surface contours for both responses.
9. Find optimal factor settings.

3.3 Project Gantt Chart and Key Milestones

Table 3.3(a) Gantt Chart and Key Milestone for FYP 1

ACTIVITIES	FINAL YEAR PROJECT (FYP) 1													
	WEEKS													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Introduction to the Course														
Project title Selection														
First Meeting with Supervisor														
Literature Review Selection and Study														
Data Gathering														
Methodology Selection (RSM)														
Extended Proposal Submission							●							
Proposal Defense Preparation														
Proposal Defense Viva									●					
Simulation Works in RSM														
Drafting the Interim Report														
Review and Submission Interim Draft Report														
Completion & Submission Interim Report													●	

Table 3.3(b) Gantt Chart and Key Milestone for FYP 2

ACTIVITIES	FINAL YEAR PROJECT (FYP) 1													
	WEEKS													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Run and Gathering Simulation Result														
Progress Report Preparation and Submission							●							
Analyzing the Simulation Data														
Pre-SEDEX										●				
Final Report Drafting														
Submission Draft of Final Report														
Completion and Submission of Project Dissertation in Soft Bound Copy												●		
Technical Paper Submission												●		
FYP Viva													●	
Completion and Submission of Project Dissertation in Hard Bound Copy														●

CHAPTER 4
RESULT AND DISCUSSION

4.1 Model Development using Respond Surface Methodology

For the Response Surface Methodology (RSM) contour result of fuel pellet strength, the complete contours associating all the critical factors were created to explain the variation in the factors that influencing the strength of the mixed biomass. The RSM executed the result from (N. Y. Harun, 2015) study and created the contour for each of the biomass combination. The model and contours created by using the RSM is a combination species from Pine and Timothy Hay. Pine represents the forestry biomass while Timothy Hay represents the agricultural biomass. Below is the contour result of this combination species.

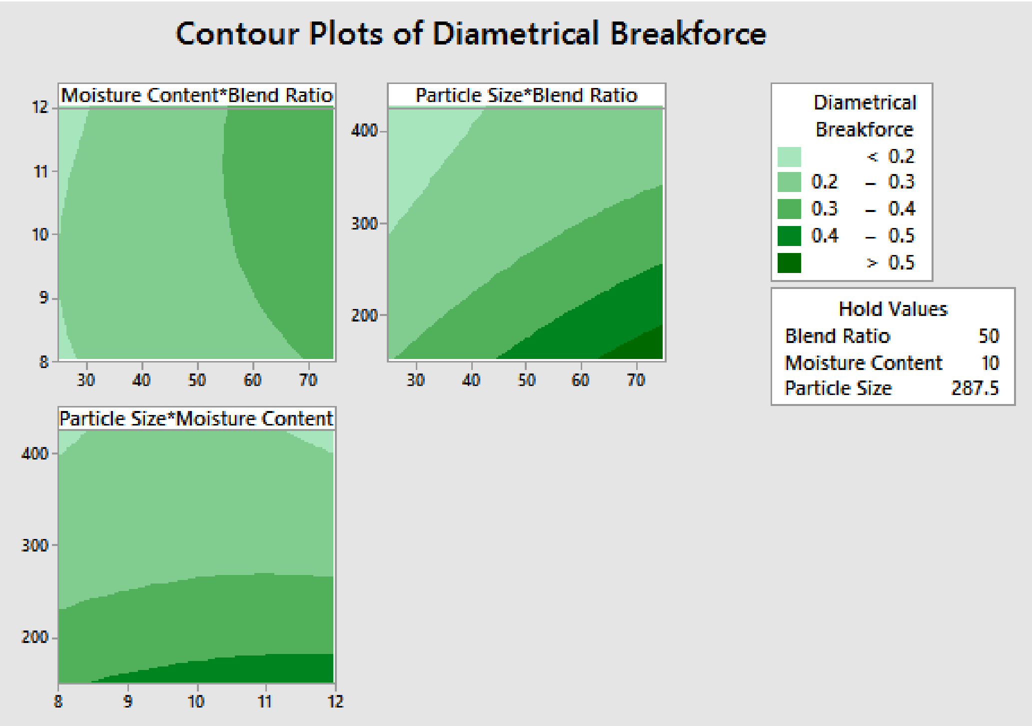

Figure 4.1 P+T Contour Plots of Biomass Fuel Pellet Strength

Based on the contour profile created by suing the RSM, the Pine and Timothy Hay biomass combination gave quite nice contours profile based on the three factors that have been highlighted before which is moisture content, particle size and the blend ratio. There are three contours created, the first contour is interrelating the moisture content vs. blend ratio, the second contour interrelating the particle size vs. blend ratio and the third contour interrelating the particle size vs. moisture content. In fact, all these three contours describing the affecting factors to the mechanical strength of the pellet and at the same time it interrelating one factor to another.

The first contour explaining that, by fix the blend ratio to be more than 55% and moisture content is controlled to be between 8-10%, the strength that will be getting is up to0.5kN till the pellet breaks. Then, to make the pellet stronger, the right combination of particle size must be put into the consideration. To make the pellet reach highest strength with more than 0.5kN before the pellet breaks, the particle size of the raw materials must be less than 200µm.Besides, the RSM executed the result from (N. Y. Harun, 2015) study and created the model of the biomass combination. The model created by the RSM carries different multiplier or coefficient depending on the factors of each biomass combination. Below is the model created for Pine and Timothy Hay biomass combination.

Table 4.1 Pine and Timothy Hay RSM Model

Equation	**P-Value**	**S**	**R-sq**	**R-sq (adj)**	**R-sq (pred)**
$S = -0.094 + 0.0038x + 0.0769y - 0.000689z - 0.00375y^2 + 0.000002z^2 + 0.0004xy - 0.000016xz - 0.000055yz$	0.0%	0.0194936	98.93	97.00	82.86

In the result, it shows that 98.93% of the model fits the data, and the adjusted R^2 is 97.00% which is decreases about 2.93%. The higher the R^2 value, the better the model fits the data. While the predicted R^2 is 82.86% and it is quite high. This model still has the high ability to predict the generalization for the new sample. Thus, this model can be used to fit with other data.

4.2 The Test for Significance of Regression

A good estimated regression model shall exp lain the variation of the dependent variable in the sample. There are certain tests of hypotheses about the model parameters that can help the experimenter in measuring the effectiveness of the model. The first of all, these tests require for the error term e_i*'s* to be normally and independently distributed with mean zero and variance s^2. To check this assumption, it can be analyzed through the graph of the normal probability of residuals for Pine and Timothy Hay.

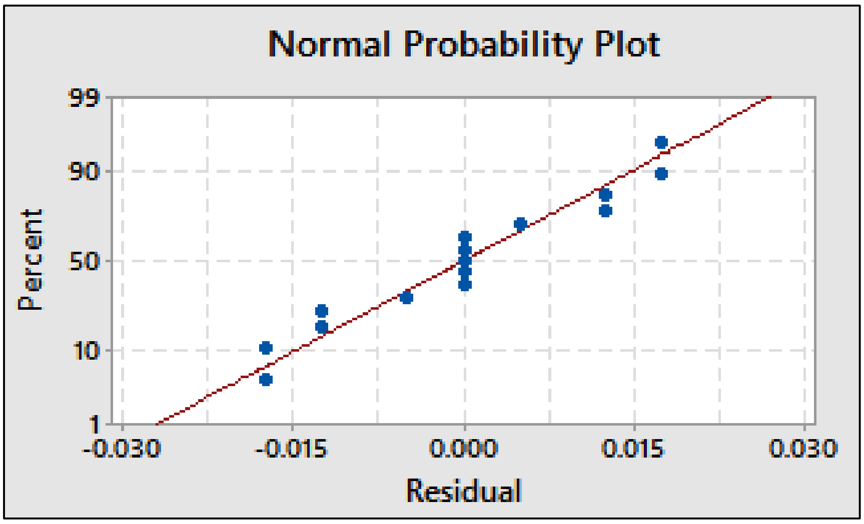

Figure 4.2 Normal Probability Plot of the Residual

Based on the graph above, the residuals plot approximately along a straight line, then the normality assumption is satisfied. In this study, the residuals can be judged as normally distributed; therefore normality assumptions for both of the responses are satisfied.

How well the estimated model fits the data can be measured by the value of R^2.The R^2 lies in the interval [0,1]. When R^2 is closer to the 1, the better the estimation of regression equation fits the sample data. In general, the R^2 measures percentage of the variation of y around ȳ that is explained by the regression equation. However, adding a variable to the model always increased R^2, regardless of whether or not that variable statistically significant. Thus, some experimenter rather using adjusted- R^2. When variables are added to the model, the adjusted- R^2 will not necessarily increase. In actual fact, if unnecessary variables are added, the value of adjusted - R^2will often decrease. Based on the Pine and Timothy Hay regression result, Both of $R^2$and adjusted -R^2 are statistically significant for the response variables.

4.3 Model Testing by Using Pine Based

Then the created model for Pine and Timothy Hay will be used to test with the other combination of Pine basis as the forestry biomass. The combination will be used to be tested is the combination of Pine (P) and Reed Canary Grass (RCG) and the combination from Pine and Switchgrass (SW). The x_1 represents the blend ratio, x_2 represents the moisture content and x_3 represents the particle sizes. The result of the testing as in the table below.

Table 4.3(a) The Testing Result for Pine and Reed Canary Grass

Type of Combination	x_1 , x_2, x_3	Error (%)
P + RCG (8% moisture content)	25, 8, 150	0.21
	25, 8, 300	0.69
	25, 8, 425	**0.07**
	50, 8, 150	**0.12**
	50, 8, 300	0.29
	50, 8, 425	0.33
	75, 8, 150	0.26
	75, 8, 300	0.32
	75, 8, 425	0.52
P + RCG (10% moisture content)	**25, 10, 150**	**0.16**
	25, 10, 300	0.47
	25, 10, 425	0.32
	50, 10, 150	**0.18**
	50, 10, 300	**0.20**
	50, 10, 425	0.25
	75, 10, 150	0.36
	75, 10, 300	0.26
	75, 10, 425	0.34

P + RCG (12% moisture content)	**25, 12, 150**	**0.12**
	25, 12, 300	0.70
	25, 12, 425	1.05
	50, 12, 150	0.28
	50, 12, 300	0.26
	50, 12, 425	0.74
	75, 12, 150	0.46
	75, 12, 300	**0.12**
	75, 12, 425	0.37

Table 4.3(b) The Testing Result for Pine and Switchgrass

Type of Combination	x_1 , x_2, x_3	Error (%)
P + SW (8% moisture content)	25, 8, 150	0.58
	25, 8, 300	**0.15**
	25, 8, 425	**0.01**
	50, 8, 150	0.29
	50, 8, 300	**0.10**
	50, 8, 425	0.39
	75, 8, 150	0.34
	75, 8, 300	**0.04**
	75, 8, 425	0.41
P + SW (10% moisture content)	25, 10, 150	0.50
	25, 10, 300	**0.13**
	25, 10, 425	0.50
	50, 10, 150	0.23
	50, 10, 300	0.19
	50, 10, 425	0.41
	75, 10, 150	0.21
	75, 10, 300	**0.02**
	75, 10, 425	0.24

P + SW (12% moisture content)	25, 12, 150	0.64
	25, 12, 300	0.25
	25, 12, 425	0.97
	50, 12, 150	**0.18**
	50, 12, 300	0.21
	50, 12, 425	0.50
	75, 12, 150	**0.12**
	75, 12, 300	**0.14**
	75, 12, 425	0.46

From both table, the combination of the factors that giving below than 20% of error will be chosen to verify the model.

4.4 Model verification by Using Spruce Based

Then, the combination of the factors that giving percentage of error below than 20% will be used to verify the model by using the same combination of parameters. For the verification of the model, Spruce as based forestry biomass will be used to combine with other agriculture biomass. but using the Spruce as based forestry biomass. The combination

Table 4.4 The Verification Result for Spruce Based Forestry Biomass

Type of Biomass	**x_1 , x_2, x_3**	**Error (%)**
S + RCG	25, 10, 150	1.0
	25, 12, 150	1.0
	50, 8, 150	16.0
S + SW	25, 10, 150	11.0
	25, 12, 150	14.0
	50, 8, 150	11.0
S + T	25, 10, 150	1.0
	25, 12, 150	2.0
	50, 8, 150	12.0

After done the verification of the model by using Spruce based biomass, these three combinations of biomass fitted well with some range of the factors. The model fitted well with the range of the blend ratio is between 25 – 50 percent of the woody biomass. The amount of the woody biomass is needed in the mixture because the chemical content of the woody sample plays a more dominant role, as compared to the agricultural sample, in blended biomass (N. Y. Harun, 2015). So it is clearly shows that the blend ratio is one of the affecting factors of the mechanical strength of biomass fuel pellet.

In the verification result, the model fitted with the moisture content in the range of 8 – 12%. This is the optimum range for moisture content in biomass raw material to form a pellet. To get the most durable biomass fuel pellet is by controlling the moisture content in the range of 8 - 15% (Tooyserkani, 2012).

Then, for the particle size of raw material of the biomass, the model shows it fitted well with the particle size of 150μm and below. Particle size is also one of the important factors need to bear in mind to form a pellet, it is because large particle size will have more porosity and the pellet formed is not durable enough and cracks, and if the size is too small, the fuel pellet might be contaminated when it is formed (Warajanont, 2013).

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The effect of blending agricultural biomass with woody biomass on the physical, chemical and mechanical properties of the pellet was investigated. The RSM model created based from the past experimental study done by (N. Y. Harun, 2015) is based on the data of combination of Pine and Timothy Hay biomass. This is because this model is the most significant and reliable model.

Besides, the result shows that the mechanical properties of the pellet, such as the strength is really depending on the physical properties of the raw materials, such as, particle size, moisture content and the blending ratio of the biomass itself. Particle size was the most influential parameter that affects the strength of the pellet. In this study, it really shows that, under certain range of particle size, the strength of the pellet become higher. For example the combination biomass of Pine and Timothy Hay, the highest strength of the pellet located in the range of below than 200µm particle size under controlled moisture content and blending ratio.

This model developed and tested with error less than 20% of the combination of several biomasses from the similar species. The model also been verified by other combination with less than 20% with the same combination. So, it can be concluded that, this biomass strength model can be used for the range of the similar species with the factor of moisture content in the range of 8 – 12%, blend ratio is in the range of 25 – 50%, and the particle size in the range of 150µm and below.

5.2 Recommendation

As the research of fuel pellet biomass is indefinitely wide, heterogeneous, and complex, various future works can be performed to extend the research work to ensure more promising outcome. Below are the recommendations for this study:

i. More accurate result can be obtained if the researcher considers other factors such as the lignin content, porosity, and etc. of the biomass materials.
ii. Specific composition of the species needs to be taken into account to correlate the similarity with the reference species.
iii. The model created need to base on the local resources because the resources from different country may carry heterogeneous characteristic of the biomass.
iv. Fixed pressure and temperature during the pelletization process can help to standardize compaction process of the pellet.

REFERENCES

Bradley, Nuran. (2007). The Response Surface Methodology. *The RSM Design and Method, 32*(5), 616 - 623.

Inesa Barmina, Agnese Lickrastina, Raimonds Valdmanis, Maija Zake, Alexandr Arshanitsa, Valentin Solodovnik, Galina Telysheva. (2013). Effects of Biomass Composition Variations Gasification and Combustion Characteristics. *Engineering for Rural Development, 41*(2), 323 - 330.

Mecys Palsauskas, Tadas Mauricas. (2013). Use of Mixed Biofuel for Pellet Production. *Engineering for Rural Development, 23*(2), 222 - 231.

N. Y. Harun, M. T. Afzal. (2015). Chemical and Mechanical Properties of Pellets Made from Agricultural and Woody Biomass Blends. *American Society of Agricultural and Biological Engineers, 58*(4), 416 - 429.

Warajanont, Sonthi. (2013). Effect of Particle Size and Moisture Content on Cassava Root Pellet Fuel′S Qualities Follow the Acceptance of Pellet Fuel Standard. *International Journal of Renewable and Sustainable Energy, 2*(2), 74 - 81.

Wolfgang Stelte, Jens K. Holm, Anand R. Sanadi. (2012). The Importance of the Pelletizing Pressure and Its Dependency on the Processing Conditions. *Fuel Pellets from Biomass, 81*(1), 3121 - 3129.

Z. Tooyserkani, S. Sokhansanj, X. Bi, C. J. Lim. (2012). Effect of Steam Treatment on Pellet Strength and the Energy Input in Pelleting of Softwood Particles. *American Society of Agricultural and Biological Engineers, 55*(6), 2265 - 2272.

APPENDICES

Appendix A

Appendix B