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Article

The Design of Experimental Production of Briquette Solid Fuel from Oil Palm Fiber and Kernel Meal Residual

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Abstract. The objective of this research was to study the experimental design for the production of briquette solid fuel from oil palm fiber and kernel meal residue by Factorial Design. Independent variables consisted of mixture ratio of oil palm fiber to oil palm kernel meal residue, percent of coordinate volume and the briquette forming pressure whereas the dependent variables were composed of compression resistance value, impact resistance value and combustion rate. The results of the experimental design showed that at 20 tons of forming pressure, the mixture ratio of kernel meal residue to oil palm fiber 80:20 and 20 percent of coordinate volume provided the best compression resistance value of 2,636 Newton with 85.75% impact resistance value, combustion rate of 1.71 Grams/Minute, heating value of 4386.3 Calories/Gram and the density of 700 Kilograms/Cubic Meter.

Keywords: Experimental design, briquette solid fuel, oil palm fiber, kernel meal residual.

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1. Introduction

Solid fuel from biomass is an organic substance that is a carbon storage source and natural renewable energy. It can be used to produce energy such as waste from agriculture and the production process in the agricultural industry e.g. rice husk from rice mill plants, bagasse from sugar production, wood chips from wood processing, cassava waste from the production of tapioca starch. Corn cobs can be obtained from maize processing plants and coconut shell and fiber can be obtained from peeling coconut to bring coconut meat to produce coconut milk and coconut oil [1-6]. Yeast waste can be obtained from alcohol production and oil palm waste and fiber can be obtained from the extraction of crude palm oil from fresh palm fruit as shown in Fig. 1 and 2. All the aforementioned wastes can be converted to biomass fuel for green energy production [7-8]. The uses of bio-waste fuels provide substantial benefits as far as the environment is concerned. Biomass absorbs CO_2 from atmosphere during growth, and emits CO_2 during combustion for energy. The CO_2 source for biomass production comes directly from present atmosphere through photosynthesis and is totally different from fossil fuels that received the CO_2 source from paleo-atmosphere. Combustion of the biomass fuels for energy production does not increase the total amount of CO_2 global budget in the present atmosphere, whereas the reverse is true for combustion of the fossil fuel for energy production [9]. Thus, using biomass fuel for energy production is one of the interesting approaches to solve the global warming problem causing sea water rise, oceanic acidification and coral reef bleaching.

Fig. 1. Oil palm kernel meal residual.

Fig. 2. Oil Palm fiber.

The use of fuel from firewood or charcoal obtained from nature has two main environmental impacts: 1) decreasing the forest area and 2) the amount of pollution caused by combustion such as smoke and toxic substances exceeding the environmental standard set. Entrepreneurs are therefore interested in using biomass fuel from the waste of production process, which is low cost and its combustion produces low smoke, low toxic substances in order to reduce energy costs and solve community environmental problems. Oil palm waste from palm oil mills is an interesting alternative biomass energy source since Thailand is the top 5 palm oil producing countries in the world. Hence, there is a lot of biomass from the waste and residues of the palm oil production. Moreover, there is a research project of policy research on integrated palm oil industry management according to the Bio-Circular-Green Economy (BCG) Model of Thai Government, therefore attracting investors. The result of continuous industrial development, together with the government's policy for the southern region to produce electricity for their own use. Hence, government needs to procure sufficient substitute energy to meet demand of the Southern region, which has a lot of leftover oil palm waste with less utilization. Thus, it is suitable for conducting a pilot research project and expanding it to use biomass power plants in other regions. From the past research studies on solid fuels from palm fiber and palm kernel meal residual revealed that most research used palm fiber content higher than palm kernel meal residual or used palm fiber only since the palm fiber has the lowest energy price of 0.92 bath/GJ as compared to the palm kernel meal residual with an energy price of 56.4 – 112.8 bath/GJ and the firewood with an energy price of 30.4 – 61.0 bath/GJ. However, as the transportation of palm kernel meal residual and palm fiber was taken into consideration for determining the suitable ratio of palm kernel meal residual to palm fiber to provide good and suitable transport characteristics. This was revealed by the result of the statistical analysis of this experimental research. The process of making solid fuels convenience for being transported and burned is a compressing process which means compressing the aforementioned bio-wastes under pressure to reduce the volume, increase the density of the fuel and cause the particles to coalesce together. If the diameter of the compressed material is larger than or equal to 30 mm, it is called the Briquette Solid Fuel as shown in Fig. 4. The desirable properties of solid fuel include: 1) transportation characteristics comprise crumbly or friable material and resistance to humidity 2) physical characteristics consist of ability of compression resistance and impact resistance and 3) combustion features include combustion rate and heating value [1-9]. Concept of choosing the amount of briquette solid fuel used in the biomass power plant companies is based on transport characteristics of briquette solid fuel. This includes the area for laying solid fuel and the solid fuel loading capacity per transport trip must have the efficiency close to the original loading capacity of fuel transport, namely charcoal briquette that is commercially available in the market with a standard diameter of 45 mm and length 200 mm. Therefore, the design was used the same size as normal charcoal briquette in the market to make it easier to manage its transport. Thus, our oil palm briquette solid fuel was produced with a diameter of 45 mm as same diameter as the market one but the length was reduced to 100 mm and a mass of about 120 g due to the large amount of volume resulting in reducing density of oil palm briquette solid fuel. The mass loss of briquette solid fuels from falling impact is likely to increase. The required density criteria of wood biomass fuels according to the Thai Industrial Standard TIS. 2772-2017 is not less than 600kg/m^3. However, our initial experiment, solid fuels from fibers and palm kernel residual could be densified to not less than 700kg/m^3. Thus, the compressed fuel was good and the compressive strength was high. High density fuels provide higher calorific values and longer combustion times. The benefit of the methods proposed in this study was that it could be used in a commercial production process since the design of a commercial experiment used the smallest sample that could represent the cost-effectiveness of the production. The experimental design method eliminated the factors that could be easily identified by the experiment. Then, it was compared with the preliminary results before the design of the experiment, such as the effect of moisture on the compressibility of the fuel briquettes, effect of moisture on the density of fuel briquettes, etc., so that only the complicated factors was used to economically analyze the experimental design according to the experimental design principles which the result was not distorted from the original one. Therefore, this research aims to study the design of experimental production of briquette solid fuel from oil palm fibers and kernel meal residual to find suitable factors of the production process for getting desirable physical features and combustion requirement using statistical methods to investigate many different levels of the experiments.

2. Study Method

Palm fiber and palm kernel meal residual purchased from palm oil mills and animal feed manufacturing companies would be dried in the sun before entering the process. Method for producing solid fuel samples from the palm fibers and residual was prepared by bringing 1000 grams of palm fiber and 1000 grams of kernel meal residual for oven drying at 105^o Celsius for 1 hour, leaving no more than 10 percent moisture, then grinding with a fine grinder and sifting through a sieve in order to pick out fibers and palm residues larger than 45 mm in size. There were both mixing with binder and without binder treatments. In this case, the cassava flour was used as the binder and then the samples were compressed by hydraulic pressure through the mold cylinder with a diameter of 45 mm at various parameters according to the experimental design. The properties of palm residue and palm fiber, which are raw materials for solid fuel production are shown in Table 1.

Table 1. Properties of palm kernel meal residual and palm fiber (raw materials) for briquette solid fuel production.

Component (wt. %)	Palm Kernel Meal Residual	Palm Fiber
Carbon	46.59	43.82
Hydrogen	6.21	5.90
Nitrogen	0.63	1.41
Sulfur	0.15	0.12
Volatile matter	74.04	74.64
Fixed carbon	22.41	19.38
Ash	3.55	5.98

The calorific values of fibers and kernel meal residual are shown in Table 2. The production cost was in accordance with the proportion of palm fiber, kernel meal residual and percentage of binder volume (coordinate volume). Currently, 5,400 baht per ton of kernel meal residual, 250 baht per ton of palm fiber and 13,000 baht per ton of binder (tapioca starch) are available in a market.

Table 2. Heat values of palm fiber and palm kernel meal residual.

Sample	Gross Calorific Value (Cal/g)		
	1	2	Average
Palm Kernel Meal Residual	4238.9	4224.4	4231.7
Palm Fiber	4450.6	4399.4	4425.0

2.1. Experimental Design

Preliminary experiments were carried out to get the highest and lowest values of each factor and determine the test range of each factor. Then, the obtained data was employed to design the experiments using the General Full Factorial Design Method [10] which is the design of factors in which each factor has different levels of experiments. The parameters used to the designed experiments were the mixture ratio of oil palm kernel meal residual to oil palm fiber, briquette forming pressure and the percent of coordinate volume (percent of binder volume) as shown in Fig. 3. Five replicates per treatment were carried out for all the designed ones. The mean values, the information and results obtained from the experiments were shown in Table 3, 5, 7 and 9 respectively.

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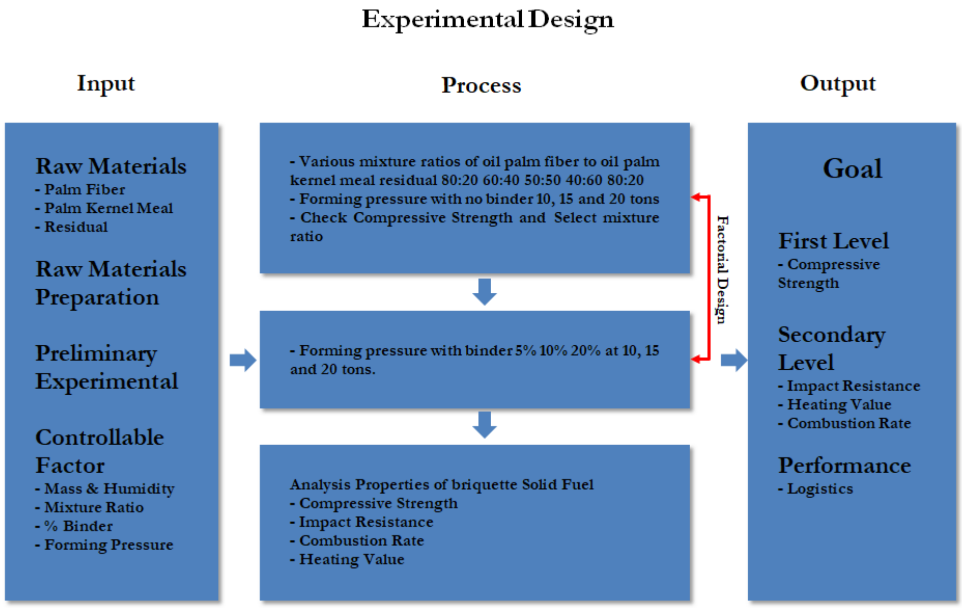

Fig. 3. Experimental design process.

2.2. Testing of Briquette Solid Fuel Characteristics

The briquette solid fuel produced according to the experimental design results was tested for investigating two characteristics: physical characteristics and combustion characteristics as shown in Fig. 4.

Fig. 4. Briquette solid fuel.

1) Physical property
   Test the ability of compression resistance
   Test the ability of impact resistance at a height of 2 meters.
   Density test (mass per unit volume)

2) Combustion property
   Combustion rate test was considered according to mass loss compared to time and heating values based on ASTM 3D3286-77 Standard by burning samples with oxygen in the bomb calorimeter under controlled conditions [11]. The calorimeter calibration was done by burning benzoic acid. The sample's heating value was calculated from the temperature observation before, during and after burning and this also provided the correction value from the heat obtained from other processes. To find the heating value of oil palm kernel meal residual blended with palm fiber the heating value will decrease when oxidation occurs before burning. Therefore, caution was taken by avoiding exposing the new prepared samples to the air for a long time and the moisture content of the samples was determined according to ASTM D3173 Standard prior to the beginning of the experiments.

3. Results and Discussion

Results of the production of briquette solid fuel at the various mixture ratios of oil palm kernel meal residual to oil palm fiber, briquette forming pressure and the average compression resistance values in the absence of coordinate volume were shown in Table 3.

After performing the aforementioned experiments according to the specifically designed conditions, the obtained data in Table 3 was used to statistically examine validity and reliability of the experimental data including: Normality Data, Independence Data and Constant Variance Data as shown in Fig. 5.

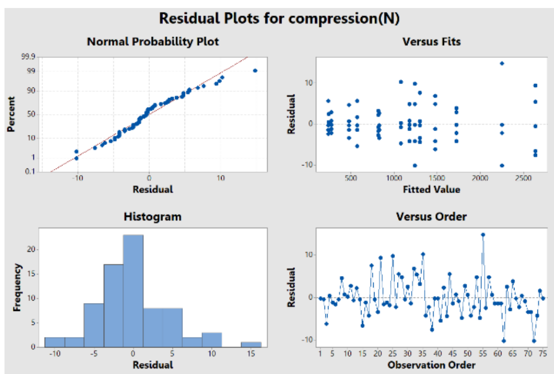

Fig. 5. Statistical testing of the hypothesis of the compression resistance value.

Table 3. Various mixture ratios of oil palm fiber to oil palm kernel meal residual, briquette forming pressure and the average compression resistance values with no coordinate volume.

Mixture Ratio of Kernel Meal Residual to fiber	Forming Pressure (Ton)	Average Compression (Newton)
	10	273
20:80	15	243
	20	240
	10	570
40:60	15	480
	20	817
	10	830
50:50	15	1300
	20	1080
	10	1240
60:40	15	1180
	20	1475
	10	2250
80:20	15	1725
	20	2636

Figure 6. Showed the normality of the hypothesis test of the data. It was found that the data was distributed around the straight line. This ensured that the obtained data was normal. Furthermore, for the data independence, there was no evidence that the value of the residue has any form or trend and the constant variance of the data indicated that the data was consistent and independent [12].

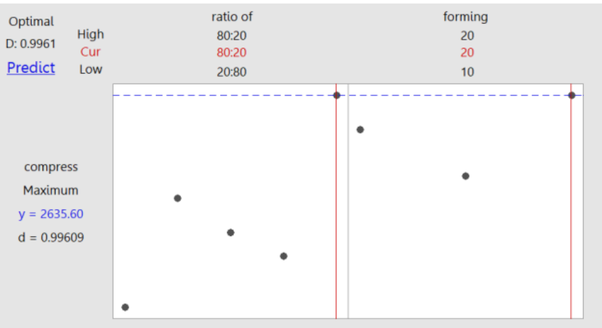

Fig. 6. Analysis of the optimal values of both factors together.

An analysis of variance was carried out to analyze factors that influenced or affected the compression resistance value (Table 4). At the confidence level of 95%, it was found that the main factors were both the mixture ratio of oil palm fiber to oil palm kernel meal residual, and briquette forming pressure had significant influence on the compression resistance value since P-value was less than 0.05 and the co-factors of both factors affected the compression resistance value as well.

Table 4. Analysis of variance (ANOVA).

Source	DF	Adj SS	Adj MS	P-value
Ratio of oil palm	4	33071808	8267952	0.000
Forming pressure	2	989675	494837	0.000
Ratio of oil palm*forming pressure	8	2201319	275165	0.000
Error	60	1469	24	
Total	74	36264270		

R-sq = 100.00%

The most optimal response of two factors using Response optimization was analyzed by giving the satisfaction value (d) to the nearest 1 (Fig. 6). It was found that the mixture ratio of kernel meal residual to oil palm fiber and forming pressure giving the optimal value of 0.99609 close to 1, indicated that it was the most suitable response of the two factors, with the mixture ratio of kernel meal residual to palm fiber at 80:20 and the forming pressure at 20 tons. However, the compression resistance value could be predicted to confirm the use of the Response optimizer by using the Optimization Plot for forecasting, and was reverified to confirm the result of the optimal value of the experimental factors. The results of the experiments including 2625, 2642, 2640, 2638 and 2636 N which were obtained from the verification were in the range of 95% PI. The average value of all the 5 obtained values was 2636.2 N within the range of 95% CI as shown in Table 5, which made this experiment more reliable [13].

Table 6. Mixture ratio of oil palm fiber to oil palm kernel meal residual, briquette forming pressure and the average compression resistance values with coordinate volume.

Mixture Ratio of Kernel Meal Residual to Fiber	Percent of coordinate volume	Forming Pressure (Ton)	Average Compression (Newton)
		10	2053
	5%	15	2144
		20	2193
		10	2158
80:20	10%	15	2253
		20	2279
		10	2178
	20%	15	2290
		20	2380

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Based on the statistical analysis in Table 5, it was found that the mixture ratio of kernel meal residual to oil palm fiber at 80:20 and the forming pressure at 20 tons was most suitable for production of briquette solid fuel. Furthermore, the researchers still continued to determine the percent of coordinate volume to make the strength of making solid fuel better. Therefore, the obtained values from the experiments in Table 1 were further investigated to get better results as shown in Table 6.

Table 5. Reverification of both factors.

Response optimization: Compression (N)						
Parameters						
Response	Gold	Lower	Target	Upper	Wight	Importance
compression (N)	Maximum	238	2645		1	1
Solution						
Solution 1	Ratio of oil palm	Forming of pressure (Ton)		Compression (N) Fit	Composite Desirability	
	80:20	20		2635.6	0.996095	
Multiple response prediction						
	Variable		Setting			
	ratio of oil palm		80:20			
	forming of pressure (Ton)		20			
Response	Fit	SE Fit		95% CI	95% PI	
compression (N)	2635.6	2.21		(2631.17, 2640.03)	(2624.76, 2646.44)	

After conducting the experiments according to the specifically designed conditions, the data in Table 4 was used to examine statistical assumptions such as Normality Data, Independence Data and Constant Variance Data as shown in Fig. 7.

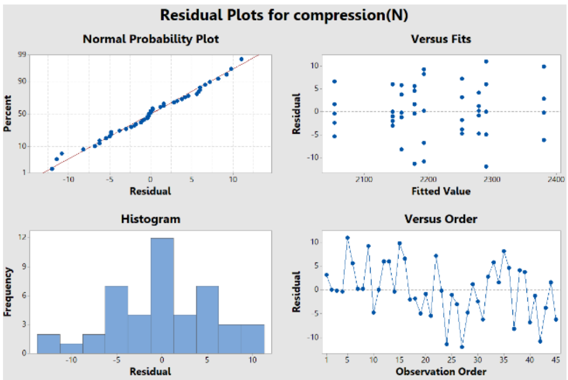

Fig. 7. Testing the hypothesis of the compression resistance value.

Figure 8. Showed the hypothesis test of the compression resistance value and the figure illustrated the hypothesis test of the normality of the data. It was found that the data was distributed around the straight line. This ensured that the information was normal. As for the data independence, there was no evidence that the value of the residue had any form or trend and the constant variance of data indicated that the data was consistent and independent [14].

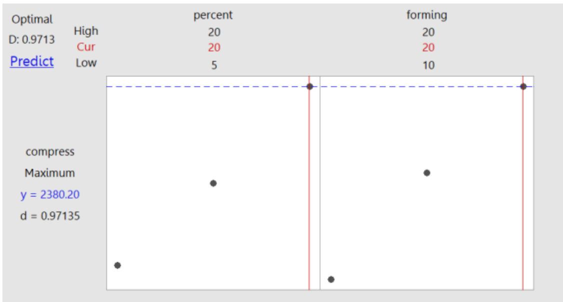

Fig. 8. Analysis of the optimal values of both factors together.

Table 7. Analysis of variance (ANOVA).

Source	DF	Adj SS	Adj MS	P-value
Ratio of oil palm	2	180616	90307.8	0.000
Forming pressure	2	182541	91270.7	0.000
Ratio of oil palm*forming pressure	4	9968	2492	0.000
Error	36	1400	38.9	
Total	44	374525		

R-sq = 99.63%

Table 7 showed variance analysis results for investigating factors that influenced or affected the compression. At the confidence level of 95%, it was found that the main factors, both the percent of coordinate volume and forming pressure had significant influence on the compression because the P-value was less than 0.05 and the co-factors of both factors also influenced the forming pressure.

The most optimal response of two factors using Response optimization were analyzed by giving the satisfaction value (d) to the nearest 1 (Fig. 9). It was found that the percent of coordinate volume and the forming pressure giving the optimal value of 0.97135 close to 1, indicated that it was the most suitable response of the two factors, with the 20 percent of coordinate volume and 20 tons of the forming pressure. However, the compression resistance value could be predicted to confirm the use of the Response optimizer by using the Optimization Plot for forecasting and was reverified to confirm the result of the optimal value of the experimental factors. The results of the experiments including 2378, 2375, 2380, 2374 and 2376 N which were obtained from the verification were in the range of 95% PI. The average value of all the 5 obtained values was 2376.6 N within the range of 95% CI as shown in Table 8, which made this experiment more reliable.

Table 8. Verification of both factors.

Response optimization: Compression (N)						
Parameters						
Response	Gold	Lower	Target	Upper	Wight	Importance
compression (N)	Maximum	2048	2390		1	1
Solution						
Solution 1	Ratio of oil palm	Forming of pressure (Ton)		Compression (N) Fit	Composite Desirability	
	20	20		2380.2	0.971345	
Multiple response prediction						
Variable		Setting				
ratio of oil palm		20				
forming of pressure (Ton)		20				
Response	Fit	SE Fit		95% CI	95% PI	
compression (N)	2380.20	2.79		(2374.54, 2385.86)	(2366.34, 2394.06)	

From the statistical analysis in Table 8, it was found that at 20 percent of coordinate volume and 20 tons of the forming pressure were most suitable for production of briquette solid fuel with the mixture ratio of kernel meal residual to fiber at 80:20, which was already analyzed in Table 1. On the other hand, the researchers wanted to know the percent of mass loss both with and without the percent of coordinate volume in order to make the production of solid fuel more complete. The researchers then further conducted their experiments as shown in Table 9 and 12.

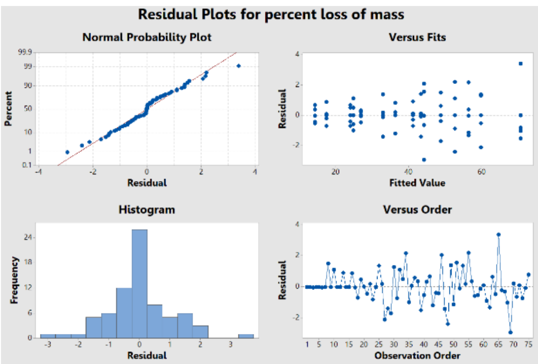

Fig. 9. Testing the hypothesis of the compression resistance value.

After the experiments were conducted according to the specified conditions to obtain the data in Table 9, this data was used to examine statistical hypothesis, including Normality Data, Independence Data and Constant Variance Data and the result of the examination was shown in Fig. 10.

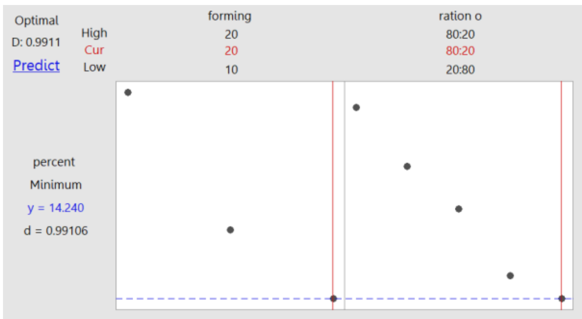

Fig. 10. Analyzing the optimal values of both forming pressure and mixture ratio together.

Figure 10. Showed the investigation of the assumption of normalization of the data. It was found that the data was distributed around the straight line to ensure that the data was normal. For the data independence, there was no evidence that the value of the residue had any form or trend and the constant

variance of data indicated that the data was consistent and independent.

Table 9. Rate of the mixture ratio of fiber to kernel meal residual, forming pressure and the average impact resistance value in the absence of coordinate volume.

Forming Pressure (Ton)	Mixture ratio of fiber to kernel meal residual	Mass before Impact Testing (Gram)	Mass after Impact Testing (Gram)	Mass Loss (Gram)	% Average Mass Loss
10	20:80	120	35.2	84.8	70.7
	40:60	120	48.3	71.7	59.8
	50:50	120	52.3	67.7	56.4
	60:40	120	67.1	52.9	44.1
	80:20	120	68.0	52.0	43.3
15	20:80	120	56.9	63.1	52.6
	40:60	120	61.5	58.5	48.8
	50:50	120	76.5	43.5	36.3
	60:40	120	90.3	29.7	24.8
	80:20	120	91.3	28.7	23.9
20	20:80	120	70.5	49.5	41.2
	40:60	120	80.5	39.5	32.9
	50:50	120	87.7	32.3	26.9
	60:40	120	99.1	20.9	17.4
	80:20	120	103	17.0	14.2

Table 10 showed analysis of variance to investigate the factors that influenced or affected the percent of mass loss. At the confidence level of 95%, it was found that the main factors were the mixture ratio of fiber to kernel meal residual and forming pressure having significant influence on the percent of mass loss since the P-value was less than 0.05 and the co-factors of both factors had influence on the percent of mass loss as well [15].

Table 10. Analysis of variance (ANOVA).

Source	DF	Adj SS	Adj MS	P-value
Ratio of oil palm	4	10243.3	5121.67	0.000
Forming pressure	2	8424.5	2106.12	0.000
Ratio of oil palm*forming pressure	8	175.5	21.94	0.000
Error	60	84.1	1.4	
Total	74	18927.5		

R-sq = 99.56%

The results of the most optimal response of two factors were investigated using Response optimization to analyze the results by giving satisfaction value (d) to the nearest 1 (Fig. 11). It was found that the mixture ratio of palm fiber to kernel meal residual and forming pressure giving the optimal value of 0.99106 close to 1, indicated that it was the most suitable response of the two factors, with the mixture ratio of kernel meal residual to palm fiber at 80:20 and the forming pressure at 20 tons resulting in the least percent of mass loss in the absence of coordinate volume [16]. However, the percent of mass loss could be predicted to confirm the use of the Response optimizer by using the Optimization Plot for forecasting, and was reverified to confirm the result of the optimal value of the experimental factors. The results of the experiments including 13.5, 14.3, 14.7, 15.6 and 14.8 N which were obtained from the verification were in the range of 95% PI. The average value of all the 5 obtained values was 14.58 N within the range of 95% CI as shown in Table 11, which made this experiment more reliable.

Based on the statistical analysis in Table 9, it was found that the mixture ratio of kernel meal residual to palm fiber at 80:20 and forming pressure at 20 tons was the most suitable for solid fuel production and causing the least percent of mass loss in the case of absence coordinate volume. However, the researchers continued to study in the case of presence of coordinate volume in order to make the research complete and practical [17-19]. Thus, the following experiments were further conducted as illustrated in Table 12.

Table 11. Verification of both factors.

Response optimization: Compression (N)					
Parameters					
Response	Gold	Lower	Target	Upper	Wight	Importance
percent loss of mass	Maximum		13.7	74.1	1	1
Solution						
Solution 1	Forming of pressure (Ton)	Ratio of oil palm	percent loss of mass Fit	Composite Desirability		
	20	80:20	14.24	0.991060		
Multiple response prediction						
	Variable	Setting				
	forming of pressure (Ton)	20				
	ratio of oil palm	80:20				
Response	Fit	SE Fit	95% CI	95% PI		
percent loss of mass	14.240	0.530	(13.181, 15.229)	(11.645, 16.835)		

Table 12. Forming pressure and the average impact resistance value in the presence of coordinate volume.

Forming Pressure (Ton)	Percent of Coordinate Volume	Mass before Impact Testing (Gram)	Mass after Impact Testing (Gram)	Mass Loss (Gram)	% Average Mass Loss
10	5	120	96.2	23.8	19.3
	10	120	98.8	21.2	17.5
	15	120	99.3	20.7	17.2
15	5	120	120	0	0
	10	120	120	0	0
	15	120	120	0	0
20	5	120	120	0	0
	10	120	120	0	0
	15	120	120	0	0

After the experiment was conducted according to the specified conditions, the data in Table 9 was analyzed at 5, 10 and 15 percent of coordinate volume and forming pressure at 15 and 20 tons. It was found that the percent of mass loss was so low that almost no mass loss and it was further statistically analyzed in both the main and co-factors as shown in Fig. 11 and 12.

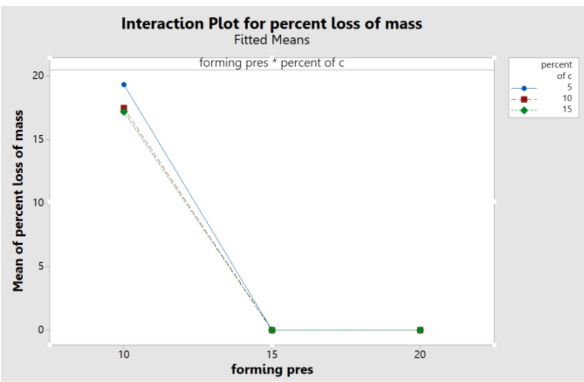

Fig. 11. Effects of common factors affecting the percent of mass loss.

From Fig. 11, it was found that the forming pressure of 10 tons had an effect on the percent of mass loss of solid fuel. The forming pressure at 15 and 20 tons had no effect on the percent of mass loss of solid fuel. However, the researchers had to test the main factors to confirm that the forming pressure or percent of coordinate volume or both factors made no influence on the percent of mass loss of solid fuel in the case of presence of coordinate volume.

From Fig. 12, each factor was considered to found that the amount of coordinate volume did not affect the percent of mass loss of solid fuel since any percent of coordinate volume employed gave almost the same percent of mass loss of the solid fuel. The other main factor was forming pressure. It was found that at 15 and 20 tons of forming pressure gave zero percent of mass loss. From the aforementioned analysis, it could be concluded that the percent of the coordinate volume did not affect the percent of mass loss of solid fuel. In the case of forming pressure, only 10 tons of forming pressure affected the percent of mass loss of solid fuel whereas at 15 and 20 tons of forming pressure had no effect on the percent of mass loss of solid fuel [20].

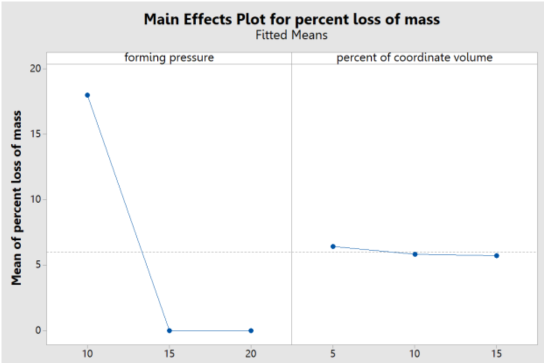

Fig. 12. Impact of the main factors affecting the percent of mass loss.

The fuel combustion rate per unit of time was shown in Table 13. The results of the test of the properties of the solid fuel produced were shown in Table 14.

Table 13. Combustion rate measured by mass loss per unit of time.

Mass (Gram)	Mass Loss (Gram)	Time (Second)
120	0	0
105	15	5
92	13	10
82	10	15
72	10	20
64.5	7.5	25
57.5	7	30
50.5	7	35
44	6.5	40
37.5	6.5	45
31	6.5	50
24.6	6.4	55
18.2	6.4	60
11.9	6.3	65
5.6	0	70

Table 14. Properties of the produced briquette solid fuel.

Factor	Value
Mixture ratio of kernel meal residual to palm fiber	80:20
Forming Pressure	20 Tons
% of Coordinate Volume	15%
Compression Resistance	2636 Newton
% of Impact Resistance	85.75%
Combustion Rate	1.71 Grams/Second
Heating Value	4368.3 Calories/Gram
Density	700 Kilograms/Cubic Meter

4. Conclusion

Results of the experimental design revealed that oil palm fiber and kernel meal residual was suitable to produce briquette solid fuel by using the mixture ratio of kernel meal residual to palm fiber at 80:20, 20% of coordinate volume and 20 tons of forming pressure. The produced solid fuel will give the following physical characteristics: compression resistance of 2636 Newton, impact resistance of 85.75%, density of 700 kilograms per cubic meter and the combustion characteristics are combustion rate of 1.71 grams per second and heating value of 4386.3 calories per gram.

From the research objectives, it is necessary to have the suitable property of oil palm briquette solid fuel for being transported to biomass power plants in other regions. Therefore, the compression resistance factor was mainly taken into consideration, the experimental result showed that the ratio of palm kernel meal residual to palm fiber = 80:20 at 20% binder volume gave the best value. However, if the other factors were taken into consideration such as the production cost, it was found that the ratio of palm kernel meal residual to palm fiber = 20:80 gave the lowest cost. Furthermore, referring to the study of research on solid fuels from fibers and other oil palm residue [21], it was found that briquette solid fuels with good compression resistance, in addition to provide good transportation characteristics, also has a good effect on the burning rate and the calorific value of the solid fuel as well. The next step of the study is to compile and check the satisfaction of the biomass power plant managers or owners that what properties of biomass briquette solid fuel interest them between the briquette solid fuel having good transport characteristics by reducing breakage caused by compression and the briquette solid fuel with the lowest raw material prices, rapid combustion and more damage during transportation Which property is the good choice that power plant managers or owners give

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more importance to? Thus, this is needed to assign the weight of importance for each relevant property prior to determine the most suitable proportion of the raw materials for the production of oil palm briquette solid fuel commercially.

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