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Multiple linear regression analysis and lagrange polynomial on pyrolysis process of coconut shell waste producing solid biochar

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ABSTRACT

Coconut shell waste has generated environmental problems in Indonesia. Due to fossil fuel shortage, coconut shell waste has been advantaged as an energy source to replace the fossil energy. A pyrolysis technique has been used to crack coconut shell waste into charcoal or solid biochar. An MLR (Multiple Linear Regression) analysis and Lagrange polynomial interpolation has been applied to the pyrolysis process related to pyrolysis temperature and time-affected charcoal characteristics. This type of analysis often used for process optimization. The charcoal characteristics are investigated in terms of their yield, water content, ash content, volatile matter, and calorific value. The experimental result shows that the highest calorific value (≈ 7750 cal/g) was obtained at 450°C and 3h with charcoal characteristics: 2.75% water content, 2.70% ash content, and 9.50% volatile matter that meets the SNI requirements. The MLR analysis has justified that the effect of pyrolysis temperature is more dominant than pyrolysis time on almost all charcoal characteristics. The Lagrange polynomial interpolation shows the highest calorific value (≈ 7784 cal/g) obtained at 500°C and 3h. The finding applying MLR analysis and Lagrange polynomial interpolation based on experimental results is a new breakthrough in this investigation.

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INTRODUCTION

Fossil fuel (oil, gas, and coal) limitations in current years caused researchers have searched for alternative renewable energy by beneficiating wastes from natural resources. Indonesia is a country with high coconut production. It was reported that average coconut production is about 3 million tons per year, and 360 thousand tons per year of coconut shell waste were produced. A new idea was generated to take advantage of coconut shell waste for energy resources by burning coconut shell waste into charcoal.

During this time, coal has been placed as a priority use for energy in many industries because Indonesia has a lot of coal reserves in South Sumatera and East Borneo. Unfortunately, Indonesian coal is rich in lignite, which has high moisture content and low calorific value. On the other hand, coal from China and Australia is richer in anthracite, which has a high calorific value and is more favorable for energy purposes. However, Indonesian coal has an advantage over its low sulfur content, which is less corrosive.

Previously, many investigations on renewable energy using natural sources and wastes were reported, as Claoston et al. (2014) advantaged empty fruit bunches and rice husk biochar for renewable energy sources, and Efiyanti et al., (2020) used several kinds of local wood for renewable energy resources. On other occasions, Junary et al. (2015) used the carbonization of palm fronds as energy resources, while Kusuma et al. (2013) conducted the burning process of coffee grounds waste and coffee shell for energy purposes. Some natural products, such as Bamboo Swat, are preferred to be used as active carbon adsorbents rather than energy resources because their water content increases after long time carbonization at high temperatures due to the opening of carbon pores adsorb more water molecules (Negara et al. 2020). As a result, the usage of this type of natural organic product for energy purposes becomes less effective.

The burning process of natural wastes to produce biochar through carbonization is usually using the pyrolysis technique. Thus,

pyrolysis is a thermal decomposition process that occurs without air or with little air to convert biomass into three different product fractions: solid residue (biochar), condensable gaseous to produce liquid product fraction (bio-oil), and gaseous product from non-condensable gaseous.

Several studies investigated the pyrolysis technique in terms of pyrolysis conditions such as pressure, temperature, time, and heating rate, as well as burner capacity. Therefore, the pyrolysis condition may strongly affect biochar characteristics in terms of calorific value, moisture content, ash content, and volatile matter. Among those characteristics, the calorific value may take important value in relation to energy value. Claoston et al. (2014) studied the effect of pyrolysis temperature on the physicochemical properties of empty fruit bunches and rice husk biochar, while Junary et al. (2015) studied the effect of carbonization temperature and time on calorific value and characteristics of bio-char from palm fronds. On other occasions, Lee et al. (2019) investigated the effect of pyrolysis and retention time on characteristics of feedstuff waste and compost for co-firing in coal power plant, while Siahaan et al. (2013) studied the optimization of pyrolysis temperature and time in charcoal carbonization from rice husk.

Moreover, coconut shell charcoal can be used for coal co-firing in developing new renewable energy. This study aims to obtain the best pyrolysis temperature and time in the manufacture of high-calorie coconut shell charcoal to meet the requirements of SNI 06-4369-1996. This research has been carried out by breaking the coconut shell and then burning it in a pyrolysis reactor at temperatures of 350°C, 450°C, and 550°C and at pyrolysis times of 2h, 3h, and 4h. The charcoal characteristics are addressed to yield, water content, ash content, volatile matter, and calorific value are examined based on SNI 06-4369-1996.

A Multiple Linear Regression (MLR) as statistical analysis has been introduced to scrutinize the pyrolysis effects in terms of temperature and time on biochar characteristics. In addition, a Lagrange polynomial interpolation in numerical analysis has explored the pyrolysis process to seek optimization of the study. Both MLR analysis and Lagrange polynomial interpolation applying experimental results from cracking of coconut shell waste producing solid biochar can be viewed as the new finding of this study. In fact, only a few specific publications on MLR analysis and Lagrange polynomial for power issues. However, few book publications on statistical and numerical analyses have been applied in other fields, such as geometric morphology in biology (Zelditch et al. 2012), energy and environmental dimension (Dincer et al. 2018), energy optimization based on modeling and assessment (Ziebik and Hoinka 2013), and design in bioprocess engineering (Boudrant and Legrand 2010).

EXPERIMENTAL

Materials and Equipment

Coconut shell bunches in dried condition were breaking into smaller cuts. Raw materials collection and cleaning were done manually, and 2kg of materials were weighed and prepared for carbonization.

An Automatic Calorimeter – K88890 was applied for the pyrolysis process of dried coconut shell bunches. This investigation used a digital balance, hammer, Petri disc, oven, furnace, and desiccator as accessories. Figure 1 shows the materials and equipment applied in this study.

Thermal decomposition process

Pyrolysis was conducted in an Automatic Calorimeter by arranging the pyrolysis temperature (350^{o}C, 450^{o}C, and 550^{o}C) and pyrolysis time (2h, 3h, and 4h).

Charcoal characterizations

The sample results as biochar solids were examined, addressing yield, water content, ash content, volatile matter, and calorific value at given pyrolysis temperatures (350^{o}C, 450^{o}C, and 550^{o}C) and times (2h, 3h, and 4h).

Evaluation process

A series of calculations have been conducted to apply (i) MLR (Multiple Linear Regression) analysis in order to scrutinize the effects of pyrolysis temperature and time on bio-char characteristics; and (ii) Lagrange polynomial interpolation to inspect more closely on pyrolysis process in relation to temperature and time affected biochar calorific value.

An SPSS Statistical Package (version 20) has been used to execute the MLR (Multiple Linear Regression) analysis following the Guidance of George and Mallery (2011). The Lagrange polynomial equation Pytlak (1999) has examined in more detail the pyrolysis effects on biochar calorific value by applying a numerical method.

RESULTS AND DISCUSSION

Effects of pyrolysis temperature and pyrolysis time on charcoal characteristics.

Table 1 shows the results of this study with regard to pyrolysis temperatures (350^{o}C, 450^{o}C, and 550^{o}C) and pyrolysis time (2h, 3h, and 4h) on charcoal yield, water content, ash content, volatile matter, and calorific value.

The sample results are assayed to SNI 06-4369-1996. Table 1 shows that the volatile matter obtained for 24.50% (> 20%) and its calorific value was found to be approximately 6629 cal/g (< 7000 cal/g) at 350^{o}C, and 2h does not meet the SNI standard. Furthermore, the highest calorific value was found to be approximately 7.750 cal/g, with 30.10% yield, 2.75% water content, 2.70% ash content, and 9.50% volatile matter at 450°C and 3h (Table 1).

Figure 1 (a) pyrolysis equipment; (b) coconut shell bunches; (c) coconut shell charcoal.

Table 1 Effects of pyrolysis temperature and time on charcoal characteristics

Sample	time (h)	temp (°C)	yield (%)	water content (%)	ash content (%)	volatile matter (%)	calorific value (cal/g)	note
01		350	32.00	3.42	2.50	24.50	6629.7874	SNI declined
04	2	450	30.55	2.90	2.57	10.90	7650.3431	SNI accepted
07		550	28.55	3.50	3.09	9.14	7666.5955	SNI accepted
02		350	31.50	3.20	2.63	19.57	7161.8148	SNI accepted
05	3	450	30.10	2.75	2.70	9.50	7750.9646	SNI accepted
08		550	28.00	4.26	3.80	8.92	7643.1729	SNI accepted
03		350	31.35	2.95	2.75	18.36	7244.7499	SNI accepted
06	4	450	29.6	3.41	3.00	9.18	7666.8345	SNI accepted
09		550	27.00	4.51	4.50	8.14	7597.5227	SNI accepted

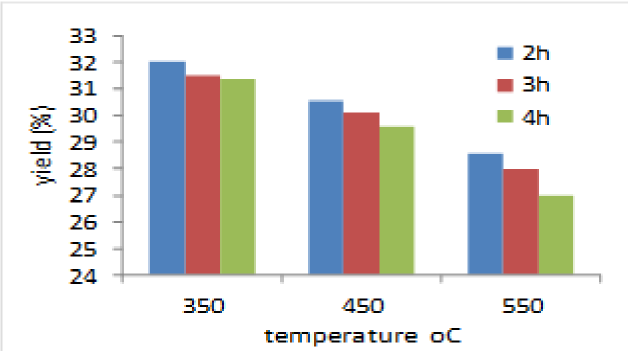

Figure 2 Charcoal yield obtained at pyrolysis temperatures and time

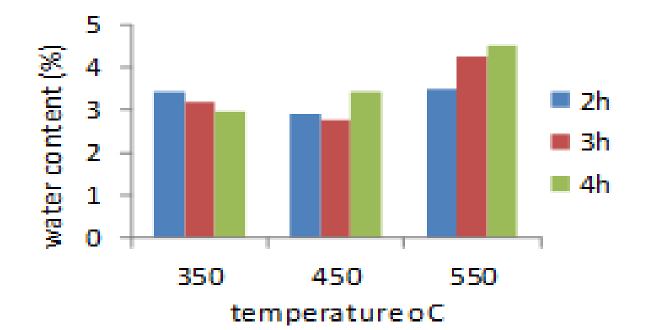

Figure 3 Charcoal water content obtained at temperatures (350°C, 450°C, dan 550°C) and pyrolysis time (2h, 3h, and 4h)

Figure 2 shows that charcoal yield experienced reduction ongoing with increased pyrolysis temperature and time. The reduction of charcoal yield caused by temperature elevation is due to greater primary decomposition (Singh et al. 2015) related to material decomposition to produce condensed gas and non-condensed gas (Basu 2018). The longer pyrolysis time causes increased charcoal temperature and reduces heat transfer retention (Sadaka et al. 2014). This study shows a 32% yield at 350°C and 2h with an initial 640 g charcoal mass.

Figure 3 shows the reduction of water content at 350°C and 450°C and pyrolysis time of 2h, 3h, and 4h. However, the water content increased again at 550°C. This peculiar behavior was reported in the Bamboo Swat sample (Negara et al. 2020). This matter is caused by carbon pores opening due to prolonged heating resulting in more water molecules adsorbed (Lestari et al. 2017). As seen in Fig. 3, at 450°C and 550°C at 4h, the charcoal produced is more useful for adsorbent purposes rather than for co-firing due to its hygroscopic properties. The effect of pyrolysis temperature and time on water content is shown in Figure 3.

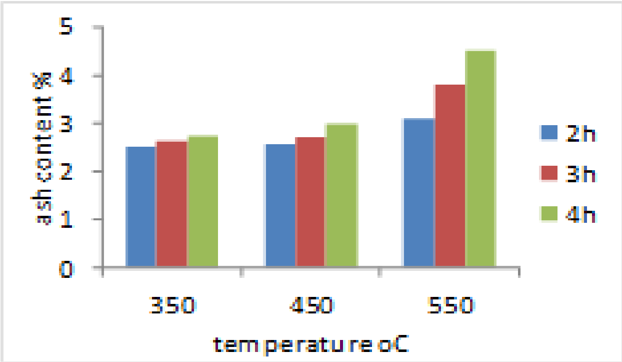

Figure 4 Charcoal ash content obtained at temperatures (350°C, 450°C, dan 550°C) and pyrolysis time (2h, 3h, and 4h)

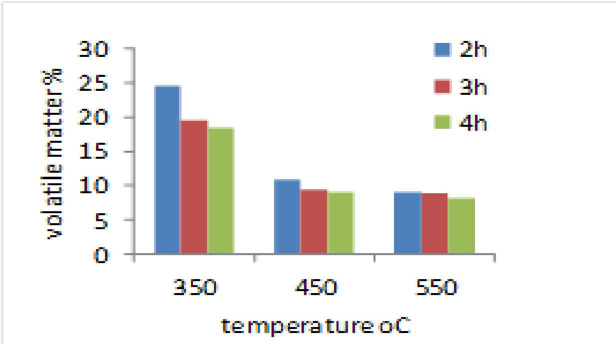

Figure 5 Charcoal volatile matter obtained at temperatures (350°C, 450°C, dan 550°C) and pyrolysis time (2h, 3h, and 4h)

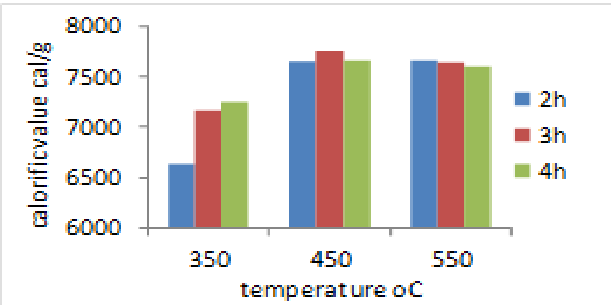

Figure 6 Charcoal calorific value obtained at temperatures (350°C, 450°C, dan 550°C) and pyrolysis time (2h, 3h, and 4h)

Ash matter in charcoal is a metal oxide consisting of nonvolatile minerals in the pyrolysis process, and the ash content strongly influences charcoal product quality (Siahaan et al. 2013). Figure 4 shows the effects of pyrolysis temperature and time on ash content that there is a consistency between temperature elevation and increasing pyrolysis time, causing increased ash content.

Elements such as C, H, N, O, and S were evaporated during pyrolysis, while inorganic salts (minerals) were not removed, so the concentration of mineral residue increased (Claoston et al. 2014). High ash content may reduce the calorific value of charcoal (Wardani et al. 2018). The effect of pyrolysis temperature and time on ash content is shown in Figure 4Figure 5 shows the effects of pyrolysis temperature and time on a volatile matter that looks consistent as generally increasing temperature and longer pyrolysis time caused a reduction of volatile matter. However, at 550°C, the change of volatile matter is almost not significant with increasing pyrolysis time (2h, 3h, and 4h).

The volatile matter can be used as a measurement of the smoke quantity produced during the burning process. More volatile matter evaporated more smoke amount produced (Iskandar et al. 2019) and followed by charcoal burning and flaming, resulting increased heating rate (Kusuma et al. 2013). If the heating rate increases, it means the fuel matter becomes more consumptive.

Furthermore, it is seen that at 350^{o}C and 2h, the charcoal produced did not fulfill the SNI 06-4369-1996 requirement because its volatile matter was higher than 20%. This is because pyrolysis time is too short, so much more volatile matter still remains in the charcoal. According to the theory, higher temperatures and longer carbonization yield more quantity of volatile matter removed and discarded (Rahmadani et al. 2017). The effects of pyrolysis temperature and time on the volatile matter are shown in Figure 5.

Calorific value is the most important factor for pyrolysis products because the main goal of this study is to advantage of coconut shell waste yielding charcoal for co-firing, replacing fossil fuel energy. The calorific value is defined as the amount of energy released per mass unit in the burning process (Wardani et al. 2018). This study obtained the highest calorific value of 7750.96 cal/g at 450^{o}C and 3h. The effects of pyrolysis temperature and time on the calorific value of charcoal are shown in Figure 6.

Moreover, Figure 6 shows a fluctuating pattern of calorific values due to pyrolysis temperature and time effects. However, the highest calorific value was obtained at 450^{o}C and 3h. Furthermore, at 450^{o}C and 550^{o}C at 4h, the calorific values of charcoal were reduced continually. The reduction of calorific values has a correlation with the results of water content and ash content. Increased water content causes a reduction of carbon content and the calorific value of charcoal. The other was caused by high temperature and the longtime pyrolysis process, causing damage to the carbon layer (Siahaan et al. 2013). The damage to carbon layers causes a reduction of calorific value because carbon content is randomly proportional to calorific value (Junary et al. 2015). The damaged carbon wall is changed into ash material, yielding a reduction of calorific value (Negara et al. 2020).

Generally, in order to produce charcoal with good quality, i.e., high carbon content (high calorific value) and low content of volatile matter, it is suggested to select charcoal raw material with low content of cellulose because cellulose is likely to yield other products, which is condensable and incondensable. The degradation of biomass raw material is related to the decomposition of hemicellulose at about 300^{o}C cellulose at 350 °C, while lignin decomposed step by step at 250−500 °C so that all components forming biomass, giving a contribution to the formation of pyrolysis products.

Moreover, hemicellulose is easily degraded at the initial step of the pyrolysis process because its structure is amorphous and easily hydrolyzed, followed by the formation of cellulose with long chain polymer and hydrogen bond so that the structure of cellulose will be more ordered and forms crystalline domain. Lignin is broken at the final step of pyrolysis because lignin contains a strong chemical bond with a high degree of aromatic content and is more ordered as branching phenyl propane units with moderate carbon content (Efiyanti et al. 2020).

Table 2 SNI 06-4369-1996 regulation

Parameter	Requirements
Water content	6% (max.)
Ash content	5% (max.)
Volatile matter	20% (max.)
Calorific value	7000 cal/g (min)

The investigation results regarding the charcoal characteristics generally meet the requirement of SNI standard (Table 2). Table 3 is presented, giving information on coal use in PLTU power plants.

Table 3 Characteristics of coal used in PLTU power plants.

Parameter	Average content
Water content	23.6% (max.)
Ash content	7.8% (max.)
Volatile matter	30.3% (max.)
Calorific value	5242 cal/g (min.)

Lestari et al., (2016)

Multiple Linear Regression Analysis

The analysis is applied to study the effect of pyrolysis temperature and time on calorific value, water content, ash content, and volatile matter of charcoal product based on experimental data shown in Table 1 from the statistical point. The analysis has been executed by applying SPSS 20. The results are shown in Table 4 – 9. The method follows the SPSS Guidance from (George and Mallery 2011).

Effects of pyrolysis temperature and time on the calorific value of charcoal

Table 4 shows the output of SPSS based on data from Table 1 for the effects of pyrolysis temperature and time on the calorific value of coconut shell charcoal with the ‘enter’ method in Multiple Regression Analysis. Model 1 defines the multiple linear regression equation with pyrolysis temperature and time as independent variables or predictors, while the calorific value of charcoal is a dependent variable.

Table 5 shows the ANOVA (Analysis of Variance) result described that Model 1 was accepted with a significant level of 0.07 ($p \leq 0.05$), or in other words, pyrolysis temperature and time gave effects on the calorific value of charcoal.

Table 6 shows the result of multiple linear regression that the effect of pyrolysis temperature is more dominant than pyrolysis time on calorific value as described by the value of the Beta coefficient for temperature (0.733), which is much higher than the value of the Beta coefficient for pyrolysis time (0.223), and also the significance of temperature (0.03 < 0.05) is much more remarkable rather than the meaningless significance of pyrolysis time (0.43 >> 0.05).

Table 4 Output of multiple regression analysis

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.766	0.587	0.450	272.44790

Predictors: (Constant), pyrolysis temperature (°C), pyrolysis time (h)

Table 5 ANOVA result of multiple regression analysis.

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	633503.29	2	316751.6	4.3	0.07
	Residual	445367.16	6	74227.86		
	Total	1078870.45	8			

Dependent variable: calorific value in charcoal (cal/g)
Predictors: (Constant), pyrolysis temperature (°C), pyrolysis time (h)

Table 6 Multiple linear regression output with effects of pyrolysis temperature and time on the calorific value of coconut shell charcoal.

Model 1	Unstandardized Coefficients		Standard Coefficient	t	Sig.
	B	Std. Error	Beta		
(Constant)	5762.2	608.37		9.47	0.00
Pyrolysis time in hour	94.73	111.23	0.223	0.852	0.43
Pyrolysis temp. (°C)	3.108	1.112	0.733	2.79	0.03

Dependent variable: calorific value in charcoal (cal/g)

Table 7 Multiple linear regression output with effects of pyrolysis temperature and time on the water content of coconut shell charcoal.

Model 1	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	0.883	1.112		0.794	0.457
pyrolysis time (h)	0.175	0.203	0.252	0.861	0.422
Pyrolysis temp. (°C)	0.004	0.002	0.649	2.21	0.069

Dependent variable: water content in charcoal (%)

Effects of pyrolysis temperature and time on the water content of charcoal

The same procedure as the effects of pyrolysis temperature and time on the calorific value above has also been done on the water content of charcoal, as shown in Table 7 using data from Table 1. Table 7 shows the output of the effects of pyrolysis temperature and time on the water content of coconut shell charcoal by applying the 'enter' method in multiple regression analysis. Model 1 describes the multiple regression equation with pyrolysis temperature and time as predictors, while water content is a dependent variable. Moreover, Table 7 shows the output of multiple linear regression analysis as the temperature effect is much more dominant than the effect of pyrolysis time as described by the Beta coefficient of temperature (0.649) higher than the Beta coefficient of pyrolysis time (0.252). Besides, the significance for temperature (0.069) in margin value is still accepted compared to that for pyrolysis time (0.422 >> 0.05), which is meaningless.

Effects of pyrolysis temperature and time on ash content of charcoal

Applying the same procedure as above, Table 8 shows the multiple linear regression output of the effects of pyrolysis temperature and time on ash content using data from Table 1. Model 1 expresses the multiple linear regression equation using the 'enter' method with pyrolysis temperature and time as predictors, while the ash content of charcoal is a dependent variable. Moreover, Table 8 shows that the multiple regression analysis resulting in pyrolysis temperature is strongly dominant in the ash content of charcoal with a Beta coefficient for pyrolysis temperature (0.756) while for pyrolysis time (0.450). The meaningful value of significance for temperature (0.008 << 0.05) compared to that for pyrolysis time (0.059 ≈ 0.05) in marginal value.

Effects of pyrolysis temperature and time on the volatile matter of charcoal

Applying the same procedure as above, Table 9 shows the multiple regression output addressing to effects of pyrolysis temperature and time on the volatile matter of charcoal using data from Table 1. Furthermore, applying the 'enter' method in multiple regression analysis, Table 1 shows the multiple regression equation expressed as Model 1 with pyrolysis temperature and time defined as predictors, while a volatile matter of charcoal as a dependent variable. The result is similar to the phenomenon of pyrolysis temperature and time on calorific value, water content, and ash content that the temperature is still more dominant rather than the pyrolysis time on the volatile matter of charcoal. Moreover, as seen in Table 9, the Beta coefficient for pyrolysis temperature (0.868) had a significant effect on the volatile matter rather than the pyrolysis time with a Beta coefficient (0.212). Table 9 also shows a strong significance level for the temperature effect (0.003 << 0.05) compared to the meaningless Beta effect for pyrolysis time (0.291). The negative sign in the Beta coefficient (Table 9) indicates inversely proportional meaning, in other words, increasing pyrolysis temperature and time yielding decreased volatile matter.

In addition, the ANOVA results show that pyrolysis temperature and time effects on the volatile matter of charcoal have a strong, meaningful significance value of 0.008 due to the dominant temperature effect on volatile matter.

Table 8 Multiple linear regression output with effects of pyrolysis temperature and time on ash content of coconut shell charcoal.

Model 1	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	-0.618	0.820		-0.753	0.480
pyrolysis time (h)	0.348	0.150	0.450	2.324	0.059
Pyrolysis temp. (ºC)	0.006	0.001	0.756	3.903	0.008

Dependent variable: ash content in charcoal (%)

Table 9 Multiple linear regression output with effects of pyrolysis temperature and time on the volatile matter of coconut shell charcoal.

Model 1	Unstandardized Coefficients		Standard Coefficient	t	Sig.
	B	Std. Error	Beta		
(Constant)	44.73	6.975		6.41	.001
pyrolysis time (h)	-1.477	1.275	-.212	-1.15	.291
Pyrolysis temp. (°C)	-.060	.013	-.868	-4.74	.003

Dependent variable: volatile matter in charcoal (%)

Table 10 Pyrolysis temperature as a function of calorific value at 2h.

Temp. °C	350 (Xo)	450 (X_1)	550 (X_2)	400 (X_{400})	500 (X_{500})
Calor. value cal/g	6629.79	7650.34	7666.60	?	?

Lagrange Polynomial Interpolation

The numerical method has been applied to find optimization of the pyrolysis process in terms of pyrolysis temperature and time on the calorific value of charcoal produced from the pyrolysis of coconut shell waste. The MLR analysis has justified that the effect of pyrolysis temperature on biochar characteristics is more dominant. Since the main goal is emphasized biochar energy and therefore, the Lagrange polynomial interpolation focused on the effect of pyrolysis temperature on the calorific value of solid biochar.

On account of that reason, the Lagrange polynomial interpolation is only limited to the effect of pyrolysis temperature (350°C, 450°C, dan 550°C) on calorific values at given pyrolysis time (2h, 3h, and 4h).

Effect of pyrolysis temperature on calorific value at 2h.

In order to examine this study, Table 10 presented a correlation of pyrolysis temperature and calorific value of bio-char at 2h applying data from Table 1.

Since the Lagrange polynomial passes through 3 known points, i.e., X_1Y_1, X_2Y_2, and X_3Y_3, thus, the general formula of the Lagrange polynomial is as follows:

$$P(x) = L_0(x)Y_0 + L_1(x)Y_1 + L_2(x)Y_2$$

At 400°C,

$$p_{400} = y_0 \frac{(x - x_1)(x - x_2)}{(x_0 - x_1)(x_0 - x_2)} + y_1 \frac{(x - x_0)(x - x_2)}{(x_1 - x_0)(x_1 - x_2)} + y_2 \frac{(x - x_0)(x - x_1)}{(x_2 - x_0)(x_2 - x_1)}$$

$$L_{0(400)} = (6629.79)\frac{(400 - 450)(400 - 550)}{(350 - 450)(350 - 550)} = 2486.17$$

$$L_{1(400)} = (7650.34)\frac{(400 - 350)(400 - 550)}{(450 - 350)(450 - 550)} = 5737.76$$

$$L_{2(400)} = (7666.60)\frac{(400-350)(400-450)}{(550-350)(550-450)} = -958.33$$

Hence, the calorific value yield of bio-char was found to be 7265.60 cal/g (400°C, 2h).

At 500°C,

$$p_{500} = y_0 \frac{(x - x_1)(x - x_2)}{(x_0 - x_1)(x_0 - x_2)} + y_1 \frac{(x - x_0)(x - x_2)}{(x_1 - x_0)(x_1 - x_2)} + y_2 \frac{(x - x_0)(x - x_1)}{(x_2 - x_0)(x_2 - x_1)}$$

$$L_{0(500)} = (6629.79)\frac{(500 - 450)(500 - 550)}{(350 - 450)(350 - 550)} = -828.72$$

$$L_{1(500)} = (7650.34)\frac{(500-350)(500-550)}{(450-350)(450-550)}$$
$$= 5737.76$$

$$L_{2(500)} = (7666.6)\frac{(500-350)(500-550)}{(550-350)(550-550)}$$
$$= 2874.98$$

Hence, the calorific value yield of bio-char was found to be 7784.02 cal/g (500°C, 2h).

Effect of pyrolysis temperature on calorific value at 3h.

In order to examine this study, Table 11 presented a correlation of pyrolysis temperature and calorific value of bio-char at 3h applying data from Table 1.

Thus, the Lagrange polynomial interpolation

at 400°C,

$$L_{0(400)} = (7161.82)\frac{(400-450)(400-550)}{(350-450)(350-550)}$$
$$= 2685.68$$

$$L_{1(400)} = (7750.97)\frac{(400-350)(400-550)}{(450-350)(450-550)}$$
$$= 5813.23$$

$$L_{2(400)} = (7643.17)\frac{(400-350)(400-450)}{(550-350)(550-450)}$$
$$= -955.40$$

Hence, the calorific value yield of bio-char was found to be 7543.51 cal/g (400°C, 3h).

At 500°C,

$$L_{0(500)} = (7161.82)\frac{(500-450)(500-550)}{(350-450)(350-550)}$$
$$= -895.23$$

$$L_{1(500)} = (7750.97)\frac{(500-350)(500-550)}{(450-350)(450-550)}$$
$$= 5813.22$$

$$L_{2(500)} = (7643.17)\frac{(500-350)(500-450)}{(550-350)(550-450)}$$
$$= 2866.20$$

Hence, the calorific value yield of bio-char was found to be 7784.19 cal/g (500°C, 3h).

Effect of pyrolysis temperature on calorific value at 4h.

In order to examine this study, Table 12 presented correlation of pyrolysis temperature and calorific value of bio-char at 4h applying data of Table 1.

Thus, the Lagrange polynomial interpolation

at 400°C,

$$L_{0(400)} = (7244.75)\frac{(400-450)(400-550)}{(350-450)(350-550)}$$
$$= 2716.78$$

$$L_{1(400)} = (7666.84)\frac{(400-350)(400-550)}{(450-350)(450-550)}$$
$$= 5750.13$$

$$L_{2(400)} = (7597.52)\frac{(400-350)(400-450)}{(550-350)(550-450)}$$
$$= -949.69$$

Hence, the calorific value yield of bio-char was found to be 7517.22 cal/g (400°C, 4h).

At 500°C,

$$L_{0(500)} = (7244.75)\frac{(500-450)(500-550)}{(350-450)(350-550)}$$
$$= -905.60$$

$$L_{1(500)} = (7666.84)\frac{(500-350)(500-550)}{(450-350)(450-550)}$$
$$= 5813.23$$

$$L_{2(500)} = (7597.52)\frac{(500-350)(500-450)}{(550-350)(550-450)}$$
$$= 2866.19$$

Hence, the calorific value yield of bio-char was found to be 7773.82 cal/g (500°C, 4h).

Table 11 Pyrolysis temperature as a function of calorific value at 3h.

Temp. ºC	350 (Xo)	450 (X_1)	550 (X_2)	400 (X_{400})	500 (X_{500})
Calor. value cal/g	7161.82	7750.97	7643.17	?	?

Table 12 Pyrolysis temperature as function of calorific value at 4h.

Temp. ºC	350 (Xo)	450 (X_1)	550 (X_2)	400 (X_{400})	500 (X_{500})
Calor. value cal/g	7244.75	7666.84	7597.52	?	?

The Lagrange polynomial interpolation shows the highest calorific value found to be 7784.19 cal/g (500ºC, 3h), while other pyrolysis condition shows 7784.02 cal/g (500ºC, 2h), which is slightly different from the highest value. Longer pyrolysis time may consume more energy. The experimental result shows the highest calorific value found to be 7750.97 cal/g (450ºC, 3h). Therefore, Lagrange polynomial interpolation is a substantial tool in seeking good optimization of a process using experimental data.

CONCLUSION

The MLR analysis is quite successful in inspecting more closely the pyrolysis effect on solid biochar yield using experimental data related to the pyrolysis of coconut shell waste producing charcoal for energy needs. The Lagrange polynomial interpolation is moderately helpful in seeking for optimization process based on experimental data of coconut shell waste cracking. The study yields a new finding in the extension of experimental results from the knowledge of statistical and numerical methods applying thermal cracking of coconut shell waste yielding solid bio-char for energy need as a case study.

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