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DEVELOPMENT OF A NEW FAST DRYING DETERMINANT METHOD USING RESISTIVITY FOR THE INDUSTRY OF COCONUT SHELL CHARCOAL BRIQUETTES

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The charcoal briquette industry faces the problem of the method for determining the drying stop during its production. The combustion method as the main method is time-consuming. The test needs 3 hours to get the result. In order to find a new fast method for drying determinant, the resistivity method was proposed for rainbow coconut shell charcoal briquettes. The briquettes had a length of 3.8 cm, height of 2.2 cm, and width of 2 cm with a half-tubular top side. 50 samples of each three drying conditions (wet, half-dry, and dry) of the same drying batch were collected. These conditions were determined by a drying expert of a coconut shell charcoal briquette company. Then, the resistances were measured and the geometrical factor was applied to find their resistivities. A model of resistivity in the cross-sectional layer was also applied to find the coefficients of front-tail, base-top, and side-side directions. These coefficients became a special way to find the position of the wet part in half-dry briquettes. The results of the work show that resistivities in combination with their distribution can potentially be used for fast drying stop determinant. The wet and dry briquettes have a resistivity difference order of 10^2. The resistivities of the wet and dry briquettes are 450 kiloohms and 28 megaohms for every centimeter of length, respectively. The half-dry and dry briquettes have the same order of resistivities. However, the resistivity distribution of both conditions is very different. The dry briquettes have homogenous resistivities among the measurements emphasizing the drying process of the solid. It was also found that the half-dry briquette has a surface dry part until 0.55 cm depth. The center of the briquette is still wet

Keywords: charcoal briquette, resistance measurement, fast drying determinant, resistivity method

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1. Introduction

Briquette is a kind of prospective solid fuel renewable energy for many parts of the world [1], therefore, its production has become important to study in recent years. The main reason for studying the topic is to find a method to provide affordable green energy. Charcoal briquette is considered a reasonable fuel for local communities especially the agricultural community [2]. Accordingly, local resources are becoming an important topic of discussion in the area [1]. Other popular issues are the technology and parameters for the production [3]. The charcoal briquette production consists of charcoal preparation, milling and mixing, compaction and molding, and drying.

Charcoal briquette drying is important in charcoal briquette production in terms of time, quality, and cost. Drying affects the moisture content of the briquette implying briquette quality [3, 4]. Excepting the charcoal processing, coconut shell charcoal briquette production needs 2/3 of the production time for drying in a plant applying a hot air oven. The drying time is far longer in the traditional method, which depends on simple solar drying. The intermittency of solar heat existance, temperature, and humidity variations during drying increase the drying time. Moreover, the time to move the briquette from the storage to the field where the briquettes are exposed to solar rays reduces the drying effectiveness. To reduce the drying time, a fossil fuel oven is usually applied. But this affects the drying cost and its carbon emission.

The drying time implies the cost of producing briquettes. Generally, it comes from the worker and production cycle. A longer drying time means a higher labor intensity. This also means higher investment costs to meet a specific amount productivity target. Some researchers reported that drying time determines the carbon content of the briquette. It implies the calorific values of the briquette, which is a primary quality parameter showing the quality of the briquette [5]. Therefore, drying time is an essential issue of charcoal briquette production. So, a study of fast drying determinant is relevant to conduct.

2. Literature review and problem statement

As renewable energy easily applied in many regions, charcoal briquette gets attention from many researchers, but its drying is rarely discussed. Some issues becoming the main topic of research include charcoal processing, briquette production steps and the availability of the material.

Charcoal briquettes can be produced from many organic material types, especially agriculture products. A briquette can be made from biomass waste or special wood planted for the briquette. Rice husk or straw, and palm shell or kernel, and sago are some waste that is used for briquettes. Rice husk or straw charcoal briquette can be produced with corn or cassava starch without any differences in its combustion characteristics [6]. The palm shell or kernel charcoal briquette was also reported to be a potential source of renewable energy in order to cope Ghana energy crisis [7]. The sago stem midrib can also be processed into an activated charcoal briquette [8]. Rubber wood waste for briquette production was reported as the added value of the plantation cycle [9]. As it comes from biomass, the charcoal briquette is regarded to have negative carbon emissions. Moreover, the biomass material of the briquette fuel is usually the secondary product or by-product of agriculture. Therefore, the emission goes for the main product. The emission is calculated from the processing only.

The briquette should have charcoal processing first. Temperature is important in charcoal processing and affects the final quality of solid fuel. Malaysian bamboos were made in a kiln at 750 °C to be charcoal suitable for domestic use [10]. Increasing temperature above 600 °C for charcoal processing of sapwood and heartwood increases fixed carbon, but reduces slightly the calorific value [11]. Below the temperature, higher temperature charcoal production increases the charcoal calorific value [12]. The effect of charcoal processing temperature on quality also appears in density, durability, compressive strength, and water resistance [13].

Other studies concerning charcoal briquette production are about briquette materials, binders, and quality tests. The availability of material is essential for briquette production concerning its sustainability and economic calculation [14]. The binder composition was studied for corn and cassava starch resulting in similar quality effects [15]. The same paper also mentioned the bonding relation to the hardness of the briquette. Compaction affected the calorific value positively, but it had a negative impact on the burning rate [16]. The quality is shown with proximity tests such as moisture, volatiles, ash, fixed carbon, and calorific values [17]. The quality of the briquette was also shown by combustion temperature and ignition rate. A good briquette was reported to have a high combustion temperature and low ignition rate [8, 16]. Research on the variability of quality was reported by [18]. The research mentions that a good quality briquette has high fixed carbon, heating value, and low ash and volatiles. The works show that drying is the only relatively homogenous parameter. The material becomes an issue due to the availability of local raw materials. The study's spirit is usually based on renewable energy necessity [7]. The bonding and composition are studied to meet optimum briquette production. However, the drying study in briquette production still needs to be explored.

The briquette drying issues are generally limited to moisture content and drying technology. A review on briquette production reported that 68 % of the briquette production concerned about moisture content. The moisture content of briquettes ranges from 2.50 % to 10.4 % [3]. However, targeting specific moisture in a production step is far from the research spotlight in pursuing briquette quality. The moisture content of the product generally becomes set for a certain process. The FAO receipt book for briquetting applies preheating before compacting rather than drying after compacting [19]. Preheating makes the briquette surface temperature being 200 °C when it leaves the compacting machine. Such temperature allows the drying process during cooling. However, the specific time for drying and its physicometric conditions were not provided. A different production method applying drying in an oven at 100 °C for 24 hours was reported to reach acceptable moisture content [9]. Both approaches focus on drying time not specific moisture target. This is in opposition to the production process of charcoal briquette in an enterprise, which needs moisture content as a target variable. The way to ensure the completion of the briquetting process has not been studied yet even despite many researches of briquettes reported. The lack of a drying stopping determinant method is the main issue of this research.

The drying process of solid materials, a typical process in industry, generally consists of three steps: constant rate, first fall, and second fall. First, a constant drying rate happens when the mass transfer exists to keep constant surface humidity. This condition takes place in a saturated system. The water is homogeneously distributed. The drop water content on the surface makes the water flow from the inner part to the surface. Second, the first drying rate fall is the main character of the process when the water content on the surface is below saturation. In this situation, the internal driving force cannot spontaneously flow the water to the surface. The drying process depends on surface contact with the air. Third, the second drying fall follows as the surface's water content is under the wet bulb condition. Temperature is vital to push water to the surface [20].

Drying a briquette, the process of reducing the water content and any other liquid-solid substances of a briquette, depends on relative humidity, temperature difference, contact surface and time. The main function of drying is to reduce the water content of a material [20]. The water content of a briquette affects its calorific value and some other quality parameters. In addition to temperature, humidity became the second important parameter affecting the results of drying in coating using water base material [21]. The temperature difference between the air and the material is also an essential parameter for the drying process [22]. A higher temperature of solids than that of air allows the water content to be released due to its internal driving force. Such drying is the main principle of the contact drying method. The temperature difference between the solid and the air affects the speed of water evaporation on the surface, which becomes the principle of the convective drying approach. A lower temperature of the solid also increases the evaporation speed following the diffusive and purging principle. Such phenomena are part of the hot-air drying method. The contact surface of the air and solid implies convective evaporation. Forced convective flow is usually applied to increase the evaporation rate. The more a briquette is exposed to air, the less water content is in the briquette.

Water content is hypothesized to be the reason for the increase in the electric conductivity of the briquette. Water insertion of compacted carbon particles increases its conductivity, especially in saturated conditions. The relationship between water and carbon is less significant than water – water [23]. The amount of water content in porous carbon still affects the conductivity due to ionic transport [24]. Water has a conductivity of 3.5 10^{-5} Sm^{-1}, and amorphous carbon has a conductivity of 1.25 10^{3} Sm^{-1}, but compaction of carbon reduces its conductivity without reducing its porosity [25]. The presence of water in the carbon-compacted block increases conductivity significantly.

The distribution of water inside the briquette during drying depends on evaporation on its surface. The process makes a distribution of water content inside inside the briquette. According to the report [22], water distribution follows the distance from the surface. The water content on the briquette surface is less water than in depth. The water content was left in the depth of the briquette. Separate dry and wet sections appear because of the drying steps. These sections create a pattern of resistivity. Therefore, the water content after the drying process of a briquette affects its resistivity. However, the study of the resistivity effects of the water content for briquette drying is scarce. With an assumption that the more water inside inside the briquette, the lower the electric resistance is, the model of the amount of water content can be traced through its resistivity. Higher electrical resistance happens when the briquette gets drier.

The drying process is essential in briquette production, and the study of briquette drying was out of the scope of research. The moisture content is generally considered as a given parameter. On the other hand, the industry is eager to get specific moisture content of the briquette. Accordingly, the resistivity is varied according to the water content of porous material. All this suggests conducting research on briquette drying to determine specific moisture as a target using briquette resistivity for indicating drying determinant.

3. The aim and objectives of the study

The aim of the study is to develop a fast determinant of charcoal briquette drying using the resistivity method on a rainbow coconut shell charcoal briquette.

To achieve the aim, the following objectives are accomplished:

– to ensure the states of the briquettes with measuring mass, density, burning rate, and comparing the normalized burning rate and density;

– to measure and average the electric resistance of the rainbow briquette in 3 different orientations; they are side to side, front to tail, and bottom to top;

– to calculate the resistivities of the briquettes according to a geometrical factor accommodating different shapes of surfaces;

– wet and dry model; to calculate the coefficients of the model and find the depth of the wet and dry part layer of the half-dry briquette.

4. Materials and methods

4. 1. Object and hypothesis of the study

This work tries to explore the possibility of applying resistivity for stop drying determinant using rainbow coconut shell charcoal briquettes. It is based on the hypothesis that the water content in a porous material affects the resistivity of the material. Therefore, different states of the briquette can be predicted through its resistivity. The resistivity is assumed to be homogenous in wet or dry conditions. To find the resistivity, the resistances of the briquette are measured. Modification according to the shape factor of the rainbow type is applied to find the resistivity.

An element's electric resistance depends on the material's length, cross-sectional area, and resistivity. Based on the principle, a model of the cross-sectional resistance ratio will be built assuming isotropic resistivity. The resistivity distribution will be applied to predict the water content of the material, indicating the drying process condition. The model will be plotted for resistances measured for wet, half-dry, and dry charcoal determined by an experienced quality control person of a briquette company as validation.

4. 2. Rainbow coconut shell charcoal briquette

The briquettes used in the study were rainbow-type coconut shell briquettes collected from a briquette company in Klaten, Central Java, Indonesia. They had a length of 3.8 cm, a height of 2.2 cm, and a width of 2 cm. Therefore, the briquettes had a volume of 11.4 cm^3. The base of the briquette is a rectangle, and the top of the briquette is half tube. The shape of the rainbow-type coconut shell charcoal briquette is shown in Fig. 1. The radius of the semi-tubular is half of the rectangle width.

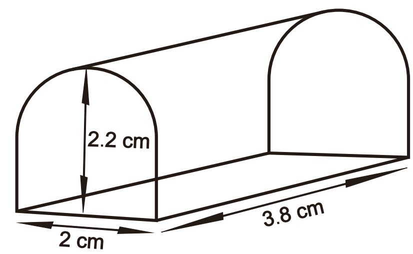

Fig. 1. Rainbow-type coconut shell charcoal briquette and its dimensions

The calorific value of the briquette is rated as 7,000 cal/gr. The briquette had a composition of 95 % coconut shell charcoal and 5 % starch of cassava flour. Thirty percent weight of demineralized water was added during mixing. Compaction with a ratio of 4:1 was conducted using a screw-type pressing machine during molding. Hot air drying was applied to the briquette for drying with an average temperature increase from room temperature to 100 °C in two days.

4. 3. Drying state model

The drying process follows the heat transfer and mass transfer principles. The water content removal as the mass transfer starts from the surface. It also happens to heat transfer. While the heat flows from the surface to the briquette's depth, there is a temperature gradient. The gradient forms a temperature contour shown in [21]. The contour also happens to the water content. The water content of the surface tends to be dryer than in depth. After the constant drying phase, the separation zone happens. There are two zones, dry and wet. Therefore, a wet and dry distribution model can be proposed for cross-section areas, as shown in Fig. 2. The wet and dry sections are distributed in horizontal and vertical cross-sections.

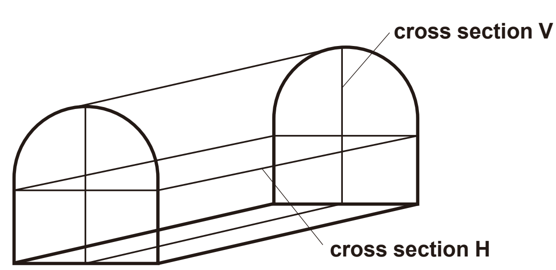

Fig. 2. Horizontal and vertical cross-sections

Assuming that the drying process in both cross-section areas is isotropic, the dry part of the cross-section is *b*. The wet part left in the center of the cross-section is signed with *a*. Additional alphabet after '*a*' shows part of the direction of the cross-section areas. *as* is used to name the wet part of the horizontal cross-section in the side-side direction. It is shown in Fig. 3. *ah* is applied for the wet part of the base-top direction in Fig. 4. *al* indicates the wet part in the front-tail direction as shown in Fig 5. It can be inferred that the horizontal cross-section has a wet part of *as* and *al*. The vertical cross-section has a wet part of *ah* and *al*.

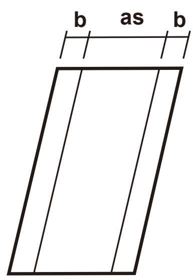

Fig. 3. Distribution of wet and dry parts in the side-side direction

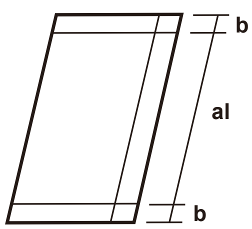

Fig. 4. Distribution of wet and dry parts in the front-tail direction

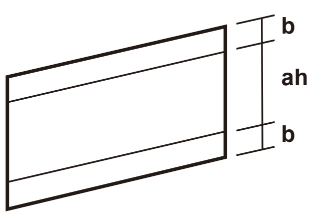

Fig. 5. Distribution of wet and dry parts in the base-top direction

Regarding the shape as mentioned in Fig. 1, only front and tail have equal distance for the cross-section. Therefore, the side-side layer needs adjustment of the cross-section area and the base-top layer needs adjustment of the distance. The cross-sections on opposite sides have the same distance. These adjustments become the geometrical factors.

4. 4. Resistance measurement

The resistance measurement of the briquettes was applied with two probes of digital ohmmeter with a sensitivity of 2 digits ranging from 0–40 megaohm. The resistance between the surfaces on opposite sides was measured on all surfaces of each briquette sample. There were 50 samples of each drying condition: wet, half-dry, and dry. The wet briquettes were the briquettes after leaving the compaction process and did not go for drying yet. Such briquettes have saturated water content. Half dry was the briquette having been in the oven for 1 of 2 days of drying. The temperature of the oven at that time was 50 °C. The dry briquettes were the briquettes leaving the oven under the QC inspection. The temperature of the oven when the drying stopped was 100 °C. The surface for the contact position of the probes and the probe distance are shown in Table 1.

Table 1

Resistance and probe position

Variable	Probe position	Probe distance (cm)
RL	Front and tail	3.8
RH	Base and top	2.2
RS	Left and right side	2

The positions of the probes as mentioned in Table 1 were on the longest distance of the cross-sections. With adjustment of the distance, the probe distance of the base-top became 1.985 cm. The distance was the average distance between the base and the top of the briquette.

4. 5. Analysis of resistance

Resistance is predicted to be proportional to the charcoal briquette length, resistivity, and its cross-section inverse. Even though the briquette has been compacted, it is still porous. In the briquette, the pores are filled with water. The water increases its conductivity. However, as the water is equally distributed through the briquette, the resistances R_L, R_H, and R_S are assumed to be proportional to each length and cross-section inverse. As the drying occurs, the resistance will increase following the reduction of the briquette's water-filled pores. Drying reduces the amount of water on the surface; therefore, the ratio of the water-filled porous part among the resistance direction will change as the briquette gets dryer.

The resistivity of the briquette is assumed to be equal and depends only on the water filling the pores. This resistivity shows the character of the material. Following the strategy in geophysics, the resistivity of a material can be traced from a measurement as equation (1). R_e and R_{eApp} are the resistivity of the material and its measurement result or apparent resistivity. K is the geometric factor representing the material's geometrical approach:

$$R_e = KR_{eApp}. \qquad (1)$$

The shape of the rainbow briquette needs cross-section adjustment of the measured resistance, namely the cross-section factor. The factors are calculated assuming that the cross-sections of the briquette are equal on the opposite sides where the probes are located. For the front-tail side, both cross-sections are equal; the cross-section factor is equal to its cross-section. The half-conic shape affects the cross-section for the base-top and right side-left side. The cross-section factors are calculated from equation (2):

$$cross-section\ factor = \frac{volume}{probe\ distance}. \qquad (2)$$

The assumed resistivity of the briquette with any water content is homogenous. Then, the resistance between the front and tail (R_L) is proportional to its length coefficient (L) – as mentioned in equation (3):

$$R_L = LR_e. \qquad (3)$$

A similar approach can be applied to the resistance of left and right (R_S), and base and top (R_H). They are proportional to the width coefficient (S) and height coefficient (H), respectively, as mentioned in equation (4) and (5):

$$R_S = SR_e, \quad (4)$$

$$R_H = HR_e. \quad (5)$$

The wet condition gives a primary ratio proportional to its length. It is 3.8:2.2:2. It shows the ratio L_W:H_W:S_W. The subscript W of the coefficient means the wet condition. The ratio L_{HD}:H_{HD}:S_{HD} and L_D:H_D:S_D parts of the wet briquette in each direction in half dry and dry condition, respectively. The relationships of each coefficient will be:

$$R_{SHD} = asS_W R_{eW} + 2bS_W R_{eD}, \quad (6)$$

$$R_{HHD} = ahH_W R_{eW} + 2bS_W R_{eD}, \quad (7)$$

and

$$R_{LHD} = alL_W R_{eW} + 2bS_W R_{eD}, \quad (8)$$

with R_{eW} and R_{eD} being the specific resistance of the element in the wet and dry condition, respectively. It is also assumed that the wet area is located bS_W from the surface. Applying the ratio at wet, we can get:

$$R_{HHD} = 1.1ahS_W R_{eW} + 2bS_W R_{eD}, \quad (9)$$

and

$$R_{LHD} = 1.9alS_W R_{eW} + 2bS_W R_{eD}. \quad (10)$$

Equations (6)–(10) show that all of the resistances are functions of the width of the briquette and the specific resistance of the wet and dry states. Eliminating the second terms can be done by interoperating those equations. This gives equations (11)–(13). They are:

$$R_{HHD} - R_{SHD} = (1.1ah - as)S_W R_{eW}, \quad (11)$$

$$R_{HHD} - R_{LHD} = (1.1ah - 1.9al)S_W R_{eW}, \quad (12)$$

and

$$R_{LHD} - R_{SHD} = (1.9ah - as)S_W R_{eW}. \quad (13)$$

(11)–(13) only have S_w and R_{eW} as the coefficient ratio of side-to-side length and wet briquette resistivity, respectively. The coefficient allows calculating the first terms of equations (6)–(8).

5. Development of drying determinant using resistivity

5. 1. Ensuring briquette states

5. 1. 1. Density, burning rate

Density is the main difference between wet, half-dry, and dry briquettes due to the water content difference. The water content in the wet briquette is higher than in the others. Therefore, its density is the highest. The half-dry one also has a slightly higher density than the dry briquette. The wet briquette has a density higher than 1.4 g/cm^3. The dry briquette has a density of 1.14 g/cm^3. Accordingly, more than 3 g of water evaporated during drying. This accounts for nearly 30 % of the mass.

The average mass and density of the different water content of the briquette can be seen in Table 2. The table shows that wet briquette has the highest density and burning rate. Oppositely, the dry briquette has the lowest density and burning rate. In addition to differences in mass and density, the burning rate of the briquette also depends on the water content. The wetter, the higher the burning rate is. The difference between wet and dry briquette burning rates is about 0.04–0.05 g/min. The number is around 30 % of the burning rate mass of the dry briquette. This confirms the mass difference between dry and wet briquettes. In addition, 30 % water content does not affects the carbon combustion of the briquette. But it will decrease the calorific values of the briquette. Some heat is used for evaporating water.

Table 2

Mass, burning rate, and density of the briquette in each condition

Condition	Average mass (g)	Burning rate (g/min)	Density (g/cm^3)
Wet	16.71	0.221	1.465
Half-dry	13.06	0.199	1.146
Dry	13.00	0.175	1.140

5. 1. 2. Comparing the normalized burning rate and density

Normalization of the density and burning rate is calculated from the density and burning rate of wet briquettes. The normalization of the densities and burning rates was conducted according to the density of wet briquettes. Therefore, both normalizations of wet briquettes are ones. The comparison of the burning rate normalization and the density normalization can be used to predict whether water is distributed equally in the half-dry briquette. The comparison of the normalized burning rate and density of the briquettes in every condition is shown in Fig. 6.

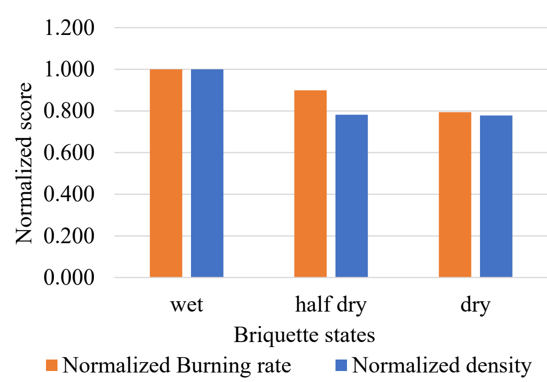

Fig. 6. Comparison of normalized burning rate and density

The half-dry briquette has the highest dissimilarity between the normalization of the burning rate and the normalization of the density. The wet briquette has equal normalizations of density and burning rate. The dry briquette has a slightly difference between the burning rate normalization and the density normalization. The half-dry briquette is slightly different from the dry one, but it has a clear difference in burning rate. This means that water is not equally distributed in the half-dry briquette.

5. 2. Average resistance of rainbow briquettes

Table 3 mentions the average resistances of the wet, half-dry, and dry briquettes. *RL*, *RH*, and *RS* are the resistances of the front-tail direction, base-top direction, and side-side direction, respectively. *RL*s have the highest resistance among the other direction resistances. *RS*s tend to be the least resistances.

Table 3

Average resistances of wet, half-dry and dry condition

Condition	*RL*	*RH*	*RS*	Unit
BS (Wet)	151.1031	101.7528	63.1401	kOhm
SK (Half-Dry)	9.0814	6.62156	5.82362	MOhm
KR (Dry)	7.613911	6.198	5.32784	MOhm

Table 3 shows that generally, the resistance of the wet briquette is in kiloohms, while the resistances of other conditions are in units of megaohm. This indicates that the water content significantly affects the resistance. The water content increases the conductivity of the briquette. The length of the bands representing probe position distances affects its resistance. However, the resistance of dry conditions tends to be less than half dry in all conditions.

5. 3. Resistivities of briquettes

Applying the cross-section factor to the average resistance, the briquette resistivities for every centimeter and 1 cm of the square cross-section according to its direction are shown in Table 4. The cross-section factors of the briquette are shown in Table 5. The factors reflect the effects of the ends of the cross-section area where the probes are located.

Table 4

Resistivities of wet, half-dry and dry condition for every 1 cm^2 of the cross-section

Condition	*L*	*H*	*S*	Unit
RW	$5.698 \cdot 10^{-01}$	$4.694 \cdot 10^{-01}$	$3.204 \cdot 10^{-01}$	M·ohm·m
RHD	$3.424 \cdot 10^{1}$	$3.055 \cdot 10^{1}$	$2.955 \cdot 10^{1}$	M·ohm·m
RD	$2.871 \cdot 10^{1}$	$2.859 \cdot 10^{1}$	$2.704 \cdot 10^{1}$	M·ohm·m

Table 5

Cross-section factor of resistivity

Direction	Cross-section factor (cm^2)
L	3.771
H	4.613
S	5.074

The half-dry has the highest resistivity, but it has less homogeneous resistivity than the dry. This can be seen in Table 4. The element resistivity of 1 square centimeter briquette of the front-tail at half-dry was $3.424\ 10^{-1}$ M·ohm·m. But the left-right side resistivity of an element of 1 square centimeter was $2.955 \cdot 10^{-1}$ M·ohm·m. The dry briquette has $2.871 \cdot 10^{-1}$ M·ohm·m and $2.704 \cdot 10^{-1}$ M·ohm·m of the front-tail and side-side resistivity, respectively. The resistivity range of the half-dry briquette is 4.69 M·ohm·m, while the dry briquette has a resistivity range of 1.67 M·ohm·m.

Higher resistivity of the half-dry than dry briquette resistivity happens due to the character of the water content of the porous material. Amorphous carbon has higher conductivity than water. But the saturated water porous material allows ionic flows as aforementioned in the introduction. When the water was trapped inside the briquette, the cross-section of the briquette is smaller than that of the dry briquette. this implies higher resistivity of the half-dry briquette than that of the dry one. The range of resistivity also confirms the situation as the front-tail resistivity difference between half-dry and dry is higher than the side-side resistivity difference between both.

Averaging the resistivity in Table 4 informs the general resistivity of the briquette as shown in Table 6. The resistivity confirms that the wet briquette has much lower resistivity than half-dry and dry ones. The order of difference is 10^2. The wet briquette has a resistivity order of ten kilo ohm, while the half-dry or the dry briquette has a resistivity order of mega ohm. Therefore, it is easy to differentiate between the wet briquette and the half-dry or the dry briquette.

Table 6

Average resistivity of the briquette for 1 square centimeter

Condition	Resistivity (mega·ohm·m)	Standard deviation of resistivity (mega·ohm·m)
Wet	$5.196 \cdot 10^{-1}$	$1.254 \cdot 10^{-1}$
Half-dry	$3.240 \cdot 10^{1}$	2.472
Dry	$2.865 \cdot 10^{1}$	$9.340 \cdot 10^{-1}$

Applying equation (1) to the data of resistivity, the averages and their standard deviation can be found as shown in Table 6. The half-dry and the dry briquette have different resistivity distributions, even though they have the same order. Both have an order of mega ohm, but the half-dry standard deviation of the resistivity is 2.47 mega·ohm·m while the dry briquettes have a standard deviation of 0.93 mega·ohm·m. The dry briquette has less resistivity deviation than half-dry.

5. 4. Coefficients of the model and the depth of the wet part of the half-dry briquette

The resistivities given in Table 4 can be used for calculating equations (11), (12), and (13) to find –208.91, –7.1629, and –1.0983 for *ah*, *as*, and *al*, respectively. They are the coefficients of the model that can be used for calculating the position of the wet part of the half-dry briquette.

Application of the numbers to equation (5) can bring *b* as 0.553. The number means that 0.553 cm from the surface of the average half-dry briquette is dry while the rest is still wet. This is also confirmed by the work [26] explaining that after 5 hours of drying, the briquette surface was dry but the inside was damp. The rest of the briquette is still wet when the briquette is considered half-dry. In the dry briquette, this wet part disappears.

6. Discussion of the development of a fast drying determinant for the coconut shell charcoal briquette using resistivity

The dry briquette density of 1.14 g/cm^3 was very close to the average of the briquettes reviewed by [3]. The reviewed briquette densities ranged from 0.43–3.03 g/cm^3 with an average of 1.16 g/cm^3. This confirms the quality of the studied briquettes when they are dry.

The burning rate, mass and density as mentioned in Table 2 are proportional to each other. It can be interpreted that the heat was used to evaporate the wet briquette's water content. In other words, the burning rate is proportional to the fired fixed carbon and does not depend on water content. The wet briquette contains the largest amount of water, therefore it has the highest burning rate. For equal carbon combustion, the wet briquettes lost the highest amount of water.

The comparison of the normalized burning rate with the normalized density indicates that another essential factor took place for the half-dry briquette, as shown in Fig. 6, which is the water content location. The wet and dry briquettes have comparable normalized burning rates and density. However, the half-dry briquette has a significant difference in burning rate and density. The factor confirms the reason for the quality control people preferring to check the drying state using combustion rather than mass, even if the method needs a longer time to do. It can be inferred that a half-dry briquette relates to the combustion quality. The person does not focus on the density as the way to check because there is very little difference in density between half-dry and dry briquettes as shown in Fig. 6. The difference between the normalized burning rate and density trends in a half-dry briquette can be interpreted as the fact that the wet and dry parts exist separately in a half-dry briquette. The wet briquette has a relatively homogeneous water content among all of the briquettes. The dry briquette also has homogeneous conditions of being no water. The normalized density and normalized burning rate difference shows this homogeneity.

The difference of resistivity order can be easily used to determine the briquette that is not in wet condition. The distribution of resistivity data can be used to differentiate the half-dry and the dry briquette. The resistivities of the half-dry one tend to be spread, while the dry briquettes are homogenous. The difference of the half-dry briquettes can be in the order of 1 mega·ohm·m. The variation of the dry briquettes resistivities is less than 1 mega·ohm·m. Therefore, the strategy to check the stopping time of drying is as follows:

– collecting 10 briquettes randomly from the oven;

– measuring the resistances of each briquette in 3 directions;

– calculating the resistivities of the briquettes according to equation (1);

– if the resistivities < 1 mega·ohm·m, the briquettes are still wet;

– if the resistivities > 1 mega·ohm·m, check the standard deviations of the resistivities;

– if the standard deviation > 1 mega·ohm·m, the briquettes are still half-dry;

– if the standard deviation < 1 mega·ohm·m, the briquettes are dry. The drying process can be stopped. Otherwise, the oven has to be on for continuing the drying process.

The work can improve the decision time for charcoal briquette drying. The proposed approach does not need a combustion test. The normal combustion time for the briquette was 3 hours. However, some calculations are needed due to statistical calculation and logical decision procedure. Application development to help the operator can be done to make the method work easily. The operator just focuses on measuring the resistance of the briquettes.

In addition to the need to create an application to make the calculation easier, the method has the disadvantage of the necessity to collect randomly more than 10 briquettes from the oven. Opening the oven to collect the briquette for resistance measurement generally changes the condition of the oven. The temperature of the oven decreases and the humidity increases due to air flow from the outside. Accordingly, this affects the drying time. A skillful operator for collecting briquettes is important to limit the effect. This is also the reason for collecting briquettes in three conditions only rather than collecting drying time data.

The cross-sectional method provides information of the wet and dry parts model of rainbow briquettes. The coefficients earned from equations (11)–(13) can be used to find the location of the wet part from the surface. The wet part of average half-dry briquettes is located 0.553 cm from the surfaces. The dry part was on the surface until 0.553 cm. The wet part has a resistivity of 5.20 kiloohm·m. The dry part has a resistivity of 28 megaohm·m. The combination of the dry and wet parts of the briquette makes the bulk resistivity of the half-dry briquette higher than that of the dry briquette. The wet briquette has a lower resistivity than the dry one if the water content allows ions flowing across. In the case the wet part is enclaved inside the dry part, the ionic flow cannot exist. Therefore, the half-dry briquette seems to have a smaller cross-section than the dry briquette. Consequently, the half-dry briquette has a higher resistivity than the dry one.

The possibility to determine the location of the wet part enclaved inside the briquette is useful for other research on briquette drying. Different conditions of the briquettes provide different locations of the wet part. Small variations of the drying time difference can be conducted to understand more the mechanism of briquette drying. This will be useful to predict the optimal drying treatment of briquettes.

7. Conclusions

1. Three different briquette conditions were studied in terms of density, burning rate, and visual. The density of the wet briquettes was 1.4 g/cm^3. The dry coconut shell charcoal briquette density was 1.14 g/cm^3. The dry briquette is more porous than half-dry and wet, which can be seen using a microscope. The burning rates are also different. It is clear that there were three different conditions of the briquettes. Accordingly, the normalized densities were not linear to normalized densities. This indicates that the wet part was enclaved inside the half-dry briquette.

2. The wet rainbow briquette resistance has an order of kiloohm. The half-dry and dry briquette resistance has an order of megaohm. The clear difference of wet and dry indicates the possibility of applying the resistivities for drying stop determinant, especially to differentiate the wet and not wet.

3. The calculated average resistivities of the coconut shell charcoal briquette were 450 kiloohms, 3.1 megaohms, and 2.8 megaohms for the wet, half-dry, and dry briquette, respectively. The dry briquettes tend to be more homogenous in resistivity than half-dry briquettes. The dry briquette has less deviation than half-dry. This means that the resistivity distribution can be applied to differ the half-dry and dry briquettes.

4. The proposed cross-sectional model can inform the wet part of the half-dry briquette. With the coefficients of −208.91, −7.1629, and −1.0983 for the bottom-top, side-side, and front-tail wet part, it could be calculated that the half-dry briquette has the dry part just 0.553 cm from the surface. The other part inside the briquette is still wet.

While the resistivities can differ the wet from half-dry or dry briquette, the distribution of the resistivities can differ the dry from the half-dry briquette. Therefore, a combination of resistivities and their distribution can be applied for stopping drying as it can show the condition when the briquette is already dry. Practically, the briquette employee can use an ohmmeter to measure the briquette samples during the drying process. Such a process can be done faster than waiting for the conventional approach by a quality control person using a combustion test. In addition, the model can also show the position of the wet and dry parts of the half-dry briquettes.

Conflict of interest

The authors declare that the work does not have any conflict of interest.

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Data availability

The manuscript has data included as electronic supplementary material.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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