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The Effect of Microwave Power to Sugarcane Bagasse Drying Process

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ABSTRACT

The sugarcane is a food plant widely used in daily life as a sweetener. This plant is processed in a factory to produce sugar. In sugar processing, it needed a large amount of energy where its source is bagasse. As a fuel, sugarcane bagasse still has a moisture content of around 50%, so the calorific value is quite low. The drying process is needed to increase this calorific value. Many drying processes can be used where one of them is microwave drying. The microwave drying is faster if compared to hot air. In this study, the sample of sugarcane bagasse used was chopped to a size of about 3 cm. The mass of samples used the weight of 100, 125, and 150 gr, and placed in an aluminum foil. The measurement of sample mass is done every minute. The electrical power used varies by 50%, 60%, 70%, 80%, 90%, and 100% of the maximum power of the microwave oven. The result of the study shows a proportional reduction in moisture ratio for each power percentage difference used. The heavier sample mass will result in a lower drying rate. The regression shows that the standard logarithmic equation is more suitable for the drying rate equation.

Keywords: *Sugarcane bagasse, microwave, moisture content, moisture ratio, drying rate*

1. INTRODUCTION

The sugarcane plant is a shrub that grows in the tropics and is cultivated to produce sugar (Fig. 1a). The process of sugar making in the factory are pressing, refining, separating, drying, and packing the product. In this process, various wastes will be produced, namely: bagasse, dust, and ash resulting from combustion, molasses, liquid waste, and solid from the analysis in the laboratory. The sugarcane bagasse is a by product that used as fuel in boilers and has a moisture content of up to 50% (Fig.2). In the process of making sugar, bagasse is about 35 - 40% of the weight of sugarcane processed. In 2014, the national sugarcane production was 33 million tons/year [1]. Thus, the potential of sugarcane bagasse is around 9.90 - 11.22 million tons/year. The sugarcane bagasse as a result of extraction has a composition: 46 - 52% water, 43 - 52% fiber, and 2 - 6% dissolved solids.

The sugarcane bagasse is a biomass that has many benefits. The sugarcane bagasse utilized as raw material for bioethanol has been investigated by [4–6]. Utilization as pulp raw material was investigated by [7]. The production of bio-oil with raw material for sugarcane bagasse was carried out by [8]. In addition, [9] conducted a study to obtain tar, gas, and char from sugarcane bagasse. Meanwhile, [10] carried out bagasse torrefaction to densify the energy. The use of CFD software to model the combustion of bagasse in CFD boilers were carried out by [11].

The utilization of sugarcane bagasse as fuel has been done for a long time. Currently, research on the use of sugarcane bagasse as fuel mostly directed for cogeneration technology. That technology is mixing the bagasse with coal as conducted by the researcher [12–14]. The ability of sugarcane bagasse as fuel is proven from the proximate and ultimate analysis, as shown in table 1 [15]. High moisture content values make low heating values, which are 1825 kcal/kg. High moisture content will certainly reduce boiler efficiency.

(a)

(b)

Figure 1. a) The sugarcane plant [2], and b) The sugarcane bagasse [3].

Table 1. Proximate and ultimate analysis of sugarcane bagasse [15].

Ultimate analysis		Proximate analysis	
Component	Value (%)	Component	Value (%)
Carbon	23.7	Moisture content	49
Hydrogen	3.0	Fixed carbon	7
Oxygen	22.8	Volatile matter	42.5
H_2O	49.0	Ash content	1.5
Ash	1.5		
Bulk density, kg/m^3	580		
LHV, kcal/kg	1825		

One way to increase the heating value is by drying before used as fuel. The drying process is reducing the moisture content to a certain level. In the drying process, the two processes will occur simultaneously, namely heat and mass transfer. The heat transfer occurs from the environment to vaporize moisture that is present on the surface of a material/product. The moisture that is inside the product will experience diffusion and moves to the surface due to differences of moisture concentration between the inside and the surface of the material. The rate of diffusion will be affected by molecular diffusion, capillary flow, Knudsen flow hydrodynamic flow, or surface diffusion [16].

Drying with a cyclone was carried out by [17]. In the two forms of a cyclone, it was obtained that the moisture ratio will be proportional to the temperature and inversely proportional to the flow rate of the bagasse, which is dried. Ref. [18] reported a decrease in water content from 50% to 38% through a pneumatic drying. Ref [19] mentioned a decrease from 47% to 35% with the fluidized bed method that uses a temperature of 250 ^{o}C temperature. Ref. [20] found a decrease in water content from 50% to 23.2% by using a cyclone dryer. The hot air with a temperature of 300 0C was used to dry the bagasse.

The study of thermal drying and the kinetic decomposition with non-thermal thermogravimetric analysis was done by [21]. This research provides information on kinetic drying equations modeled by Page more accurately with equations as in the equation below:

$$MT_{tP} = \exp[k(T)]\left(\frac{T-T_o}{\beta}\right)^n \quad (1)$$

where:
k = Arrhenius constant temperature
T = temperature, ^{0}C
T_o = initial temperature, ^{0}C
n = Page constant
β = heating rate (^{0}C/s)

Microwave is part of an electromagnetic wave with a frequency of 300 MHz to 300 GHz or a wavelength of 1 mm to 1 m. Microwave can move the atoms of a molecule so that there will be friction between molecules. Molecular motion is due to electric fields that change direction created by microwave radiation. This friction will cause heat friction. Microwave radiation that is applied to water molecules will create friction of water molecules in the material. The hot water will evaporate and will come out into the surrounding air

The water is the type of dielectric material. The nature of dielectric material does not conduct electricity. This material consists of dipole/neutral molecules where each molecule has a balanced charge of + and - at both ends of the molecule. Water is composed of Hydrogen and Oxygen atoms that combine to make molecules. In a water molecule, positive charges gather on hydrogen, and negative charges gather on oxygen. Electric current cannot pass through the dielectric material. Heating a dielectric material by microwave must use high-frequency currents (more than 1 MHz). To be able to penetrate the dielectric material, a high voltage is required. This high voltage produces an electric field that changes direction very quickly and vibrates the molecule of the dielectric material. Thus, the molecules in it will rub against each other and produce even heat throughout the dielectric material. The factors that can influence the drying of a microwave are power, frequency, type of microwave, wave continuity, particle size and bulk density, sample mass, initial moisture content, and temperature [22]. The other studies on microwave drying were carried out by [23–26].

This study aims to investigate the characteristics of bagasse drying by microwave with varying power.

2. METHOD

The material used in this research is bagasse from the XYZ sugar factory located in Langkat Regency, North Sumatra. The measurement of moisture content when research is the moisture content as receive. Bagasse is chopped first with a size of about ± 3 cm. The mass of sugarcane bagasse samples used were 100, 125, and 150 gr respectively and placed in microwaveable aluminum foil, which weighed 14.13 gr, as shown in figure 2. The dryer used in this experiment is the microwave oven of SHARP R-728 (W) IN 25 liters. The dimension in length, width, and height are 514 x 249 x 308 mm. This microwave has a maximum power of 900 W with 11 power levels and 2.45 MHz frequencies.

The experiments were performed first by measure the mass of the sample with the SF-400 weighing scales with an accuracy of 0.01, as shown in figure 2. Microwave oven set with power and time settings. In this experiment, the power used is 50, 60, 70, 80, 90, and 100% of the maximum power. These powers correspond to 450, 540, 630, 720, 810, and 900 Watts. The sample mass, together with the basket, is measured every minute when the experiment occurred. Drying is completed when the weight of the sample mass is constant, which means there is no more water in the bagasse.

Figure 2. Material and experiment equipment

The moisture content of a substance can be expressed as a wet base. Where the basis of wet basis is the mass of water in the product with the total mass of the product and expressed with:

$$MC_{WB} = 100 \ x \ \frac{M_o - M_d}{M_o} \quad (2)$$

where:
MC_{WB} = moisture content wet base, %
M_o = initial mass = mass of dry matter + mass of water, (gr)
M_d = mass of dry matter (gr)

In this study, the moisture ratio was used to replace the moisture content. The moisture ratio is the ratio between moisture content at time t with equilibrium moisture content and calculated by the equation:

$$MR = \frac{MC_t}{MC_0} \quad (3)$$

where:
MR = moisture ratio
MC_t = moisture content at time t (%)
MC_o = moisture content at initial (%)

The drying rate is the rate of decrease in the percentage of water content over time as shown in figure 3. The equation calculates the drying rate:

$$DR = \frac{MC_1 - MC_2}{\Delta t} \quad (4)$$

where:
DR = drying rate, % / minute
MC_1 = moisture content at time t, %
MC_2 = moisture content at time t + 1 minute, %
Δt = time interval, minute

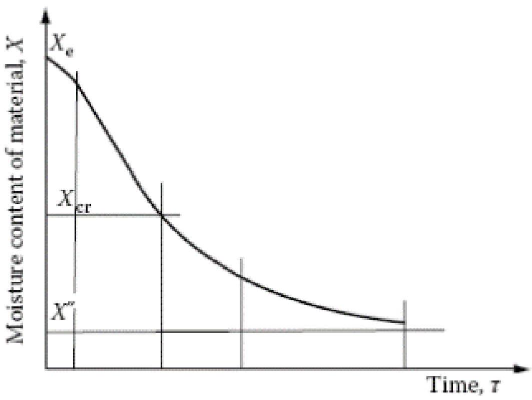
The drying rate equation for each period can be formulated as below. The drying equation for a constant rate period:

$$\frac{(M_{(t)} - M_C)}{(M_o - M_C)} = \exp(-k_1 t_C) \quad (5)$$

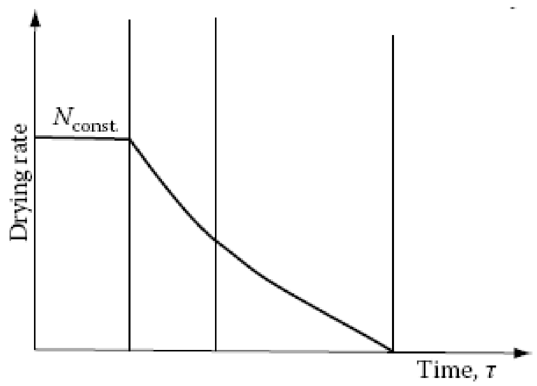
The drying equation for the fall rate period:

$$\frac{(M_{(t)} - M_E)}{(M_C - M_E)} = \exp(-k_2 t_E) \quad (6)$$

where:
M = moisture content
M_o = initial moisture content
M_c = critical moisture content
M_E = equilibrium moisture content
t_c = time to reach M_C,
t_E = time to reach M_E,
t = drying time = $t_C + t_E$
k = drying constant which can be used to assess the constant rate period (as k_1), and for fall rate period (k_2), k value obtained from experiments



(a)



(b)

Figure 3. (a) Moisture content curve and (b) drying rate [16].

3. RESULTS AND DISCUSSION

3.1 Moisture Ratio

The initial moisture content of sugarcane bagasse used for all experiments was around 60%. This moisture content is shown in table 2.

Table 2. The initial moisture content of the sample

Sample mass (gr)	50 P (%)	60 P (%)	70 P (%)	80 P (%)	90 P (%)	100 P (%)
100	58.52	58.99	59.54	59.70	58.77	56.50
125	60.90	61.02	62.66	60.98	58.50	59.35
150	59.78	59.35	61.98	58.28	57.28	57.07

The moisture ratio for experiments using Microwave with sample masses of 100, 125, and 150 gr is shown in figures 4 a, b, and c. All experiments have a consistency where less power will result in a lower moisture ratio as well. The greater power will dry the bagasse faster. A power difference of 10% also shows a correlation almost simultaneously with a decrease in the moisture ratio. The drying during the first 5 minutes produces a nearly straight line for all applied power. It shows that the drying process takes place with a decrease in moisture content almost the same for every minute. On drying with a sample mass of 100 grams, the visible ratio of moisture to 50 P has a greater distance to the 60 P power line. While the 60 P to 100 P power lines have almost the same distance, it indicates that the rate of decrease in moisture content is lower than the rate of power increment.

In experiments with a sample mass of 125 gr, it is seen that the power of 90 P and 100 P had almost the same in the moisture ratio. While at 50 P, 60 P, 70 P, and 80 P have the same relative difference. It indicates that changes in power produce proportional changes in moisture ratio. On the drying with a sample mass of 150 gr, the difference between the moisture ratio of 50 P, 60 P, and 70 P is proportional to the difference in power. In contrast, between 70 P and 80 P has a more significant difference. Besides, the difference in moisture ratio between 50 P, 60 P, and 70 P has a difference in moisture ratio, which is proportional to the difference in drying power.

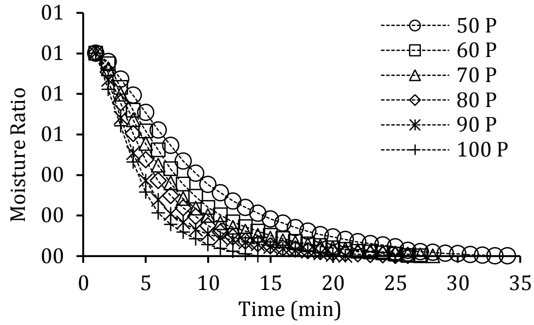


Figure 4a. The ratio of moisture vs time at different power with a sample mass of 100 gr.

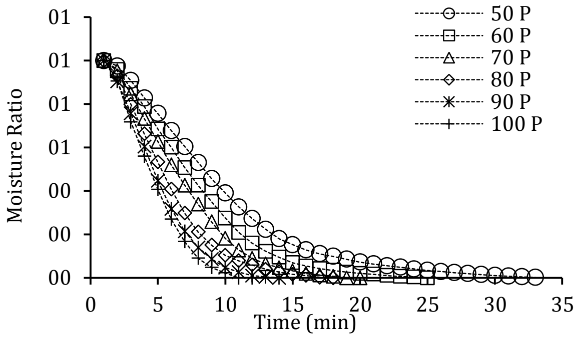


Figure 4b. The ratio of moisture vs time at different power with a sample mass of 125 gr.

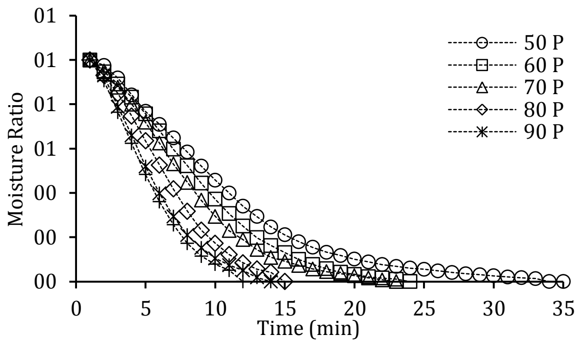


Figure 4c. The ratio of moisture vs time at different power with a sample mass of 150 gr.

3.2 Drying Rate

The drying rate for all experiments using a microwave is shown in Figures 5a, b, and c. All experiments showed that in the first minute, a low drying rate was produced. This period is the preparation period for drying. In this time, there is an increase in sugarcane bagasse temperature from outside air conditions to reach the drying temperature. After an increase in temperature, it will be followed by a constant drying rate followed by a fall rate period. In the preparation period, this is seen at the lowest power of 50 P, which results in the lowest drying rate.

For sample masses weighing 100, 125, and 150 gr, the drying rate is 2.43; 1.54 and 1.49 %/minute. The higher the weight of bagasse, which is dried, the smaller the percentage decrease in moisture ratio. It is because the same amount of energy is used to dry more material. A larger pile of stuff will also prevent the wave from penetrating the deepest or lower part. After this preparation period, then a constant drying rate is followed. During this period, the drying rate was almost the same for several minutes as in 80 P between the 2nd and 3rd minutes for a sample mass of 100 gr. This condition can also be seen at 50 P, 100 P for a sample mass of 100 gr. The weight of the sample 125 gr is 90 and 70 P at minutes 2, 3, and 4. For a sample mass of 150 gr, this constant rate period can be seen more clearly at power 70, 80, and 90 P.

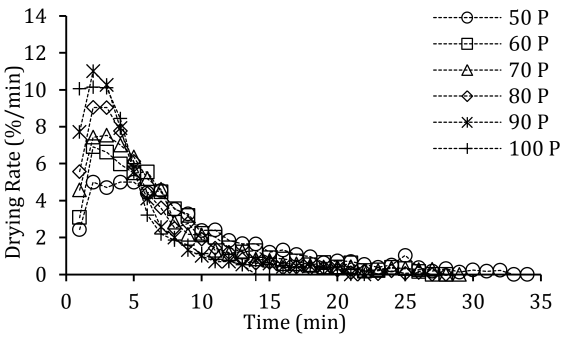


Figure 5a. The drying rate for power varies with a sample mass of 100 gr.

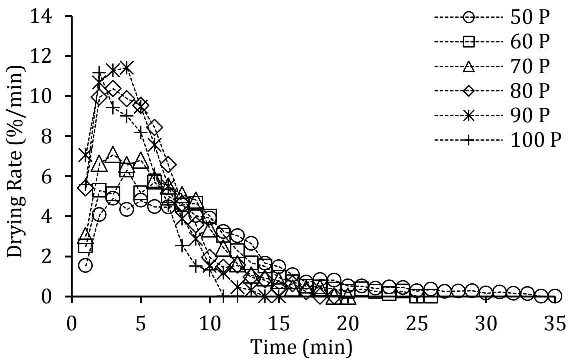


Figure 5b. The drying rate for power varies with a sample mass of 125 gr.

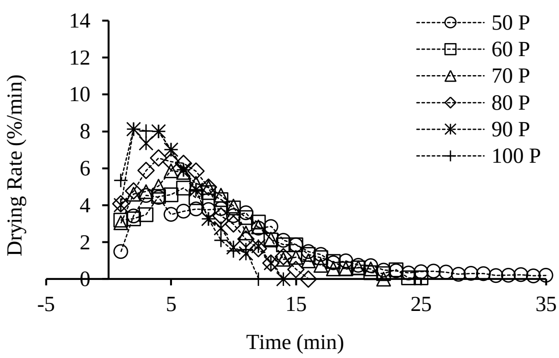


Figure 5c. The drying rate for power varies with a sample mass of 150 gr

After a period of constant rate, the drying will be followed by the first stage of the fall rate, which generally occurs at 5 to 10 minutes. This condition is indicated by the slope of the steep drying rate line. The final state of this period is a critical condition where the drying rate will be controlled by diffusion from the fiber's interior to the surface. From all experiments, the first phase fall rate period occurs faster at 100 P power. It indicates that at 100 P power, moisture evaporation occurs, which is higher than in the other power.

The drying rate is slow in experiments with a mass of 100 gr seen for 50 P power. The end of the first phase fall rate period for power 50, 60, 70, and 80 is 10 to 15 minutes. In experiments with masses of 125 and 150 gr, it is seen that the end of the first phase fall rate period for power 50, 60, and 80 is at minutes 10 to 15.

3.3 Drying Rate Equation

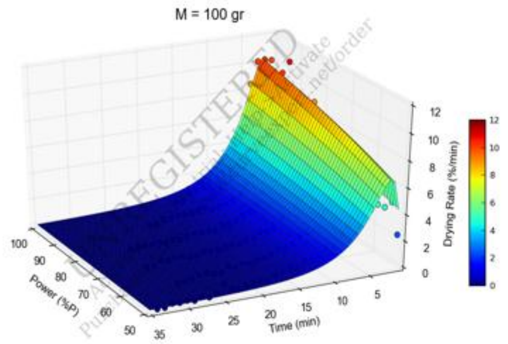
The equation of the drying rate in experiments using microwaves is obtained from the results of the regression of the drying rate data for each sample mass. Regression is performed using the CurveExpert Professional software version 2.3.0. The independent variables used are power and time. This regression produces three equations of drying rate for each sample of mass, as shown in figure6. The best equation model obtained is the normal log equation model. The general form for standard log equations is:

$$y = ae^{-\frac{1}{2}\left(\frac{\ln P-b}{c}\right)^2+\left(\frac{\ln t-d}{e}\right)^2} \quad (7)$$

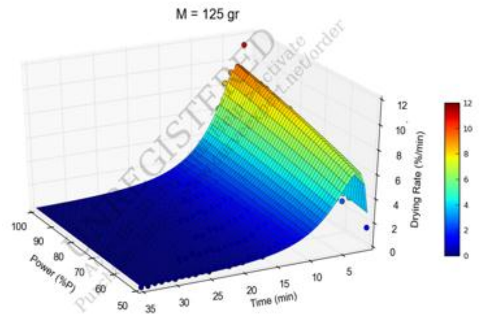
Table 3. The regression parameter

Parameter	100 gr	125 gr	150 gr
P		% Power	
t		Time (minute)	
a	1.43×10^1	2.097×10^1	7.21×10^1
b	5.93	7.478	1.18×10^1
c	1.63	2.290	3.46
d	7.87×10^{-1}	1.041	9.46×10^{-1}
e	8.53×10^{-1}	8.13×10^{-1}	8.74×10^{-1}
Std error	0.776	0.973	0.797
r	0.960	0.941	0.941
r^2	0.921	0.885	0.860

The coefficients for each equation, P, t, a, b, c, d, and e are shown in Table 3, which is the standard error, the correlation coefficient r, and the coefficient of determination r^2. It can be seen that the r and r^2 values of the regression equation are high enough so that this is valid enough for all experiments conducted. The best correlation coefficient is obtained in experiments with a sample mass of 100 gr.



(a)



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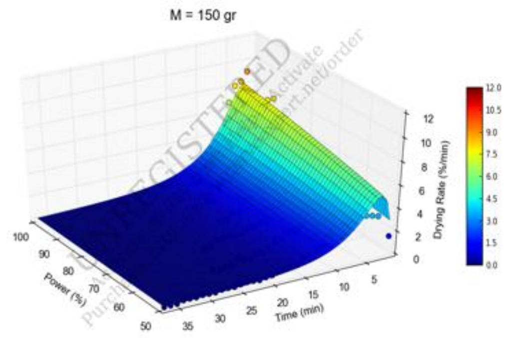

(c)

Figure 6. Results of regression for sample masses of a) 100 gr, b) 125 gr, and c) 150 gr.

4 CONCLUSIONS

This research was conducted to dry sugarcane bagasse in the microwave. The mass of bagasse used is 100, 125, and 150 gr. The size of the bagasse used is about 3 cm. The mass measurement is done every minute for each experiment. The power used varies from 50% to 100% with a 10% interval, and the maximum power is 900 W.

The higher power will dry faster with a proportional difference in water content for each range of power used. Decreasing the water content up to 6 minutes looks a reasonably consistent decrease. The drying rate equation model follows the standard log equation for all masses tested. The values of r and r^2 are high enough so that the regression equation is quite valid.

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