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Thin Layer Modeling of Corn Grains Using a Hybrid Solar Dryer with Lpg

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Abstract:- The hybrid sun drying method combines sun drying with additional heating, namely LPG. So that the drying process can take place more quickly and effectively. The three drying methods that will be compared are Open Sun drying, solar dryers, and solar hybrids. The open sun drying operation is carried out using only direct sunlight. The solar drying operation was carried out using a solar dryer without additional heating, while the drying operation with a hybrid solar dryer varied the drying temperature at 40, 50 and 60 °C. The results showed that the average moisture content of corn grains was 13.95% for 10.5 hours, 13.75% for 6 hours, 13.65% for 7 hours, 13.45% for 5 hours, and 13.65 % for 4.5 hours in Open Sun drying, drying without additional sunlight. heater, and solar drying hybrid with temperature variables of 40, 50 and 60ºC. The average drying rates were 0.212 g/minute, 0.364 g/minute, 0.318 g/minute, 0.439 g/minute and 0.477 g/minute. The results of the thin layer modeling show that the Two Term model is the most accurate and suitable model for describing the drying characteristics of corn grains for all variables.

Keywords:- *Grains; Hybrid Solar Drying; Moisture Content; Moisture Ratio; Thin Layer.*

I. INTRODUCTION

Cereal grains can provide more energy to humans than any other plant. Among these cereal grains is corn. One of the most important physiological factors for grain storage is its moisture content. The water content in plants that are growing naturally is still fairly high. Corn is mostly harvested at a moisture content of 22% to 35% (wet) to avoid the risk of frost, insects, disease and kernel damage during harvest [1]. Drying is one of the oldest and most widely used food preservation methods by humans which can reduce moisture, reduce the water activity of a product, ensure microbial stability and guarantee the expected product shelf life. Corn for food, especially in this case animal feed, must be stored as a dry product with a moisture content below 14% [2].

In various areas, especially in remote villages, the corn drying process still uses a conventional process, namely drying under the open sun (open sun drying). Even though it is cheap and easy to do, traditional drying has several drawbacks, including the possibility of product contamination due to dirt, dust and insects, and spoilage due to sudden and unexpected rain [3]. the product becomes unhygienic because it is placed in an open space, so sometimes sun-dried products cannot be sold on the market [2]. In addition to drying directly in the sun, corn takes 3-5 days of drying to reach the required standard corn moisture content [4].

One solution to overcome the disadvantages of solar drying is to use a “hybrid” solar dryer. This dryer consists of a solar dryer equipped with a conventional energy source such as LPG gas or biomass. This is so that the solar dryer can be operated even when the weather is bad or even during the rainy season because it does not have to depend entirely on solar energy. In addition, drying can be done continuously to save time. [5]. Emissions from burning biomass can also create air pollution which causes various health problems. These emissions contribute to an increase in atmospheric gases such as volatile and semi-volatile organic compounds (VOC_s), CO, NO_x, CH_2O, CH_4, and SO_2 [6]. Using LPG which is more environmentally friendly can overcome the problem of air pollution. So in this research, an experiment will be carried out drying corn using a hybrid solar dryer with LPG gas. Until now there is still little research that discusses hybrid drying in agricultural products, especially in corn.

Damage to foodstuffs can be caused by delays in the drying process, drying processes that take too long or too quickly and uneven drying processes. Temperatures that are too high or sudden changes in temperature can also cause damage to the corn grains [7], therefore a drying model is needed which can be used as a reference for modeling the drying of thin layers of corn grains. Based on the description above, it is necessary to research to obtain a thin layer model that is most suitable for corn grains.

II. MATERIAL AND METHOD

A. Corn Grain Pretreatment

Fig 1. Solar dryer

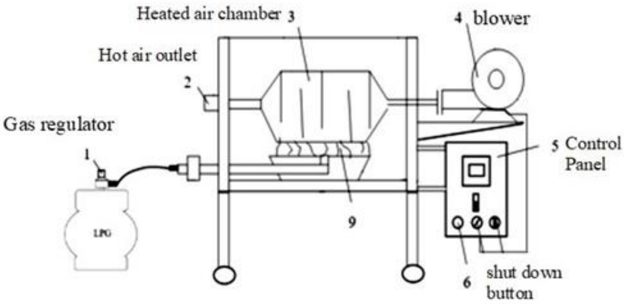

Fig 2. blower and burner unit schematic

The main material needed in this study was 5 kg of corn grains taken from the corn garden of the Faculty of Animal Husbandry and Agriculture, Diponegoro University, Semarang, Indonesia. Corn that has been harvested is separated from the cob, then the shelled corn that has been obtained is first tested for its moisture content using the oven method according to standards recognized by the Association of Official Agricultural Chemists (AOAC) [8], namely drying it in an oven at 105°C until the weight of Corn Grain is constant. Furthermore, the initial moisture content of corn grains was obtained by 26%.

While the equipment used in this study used a hybrid solar dryer consisting of a drying chamber unit covered with UV plastic to withstand heat from sunlight in the drying chamber as shown in Figure 1, as well as a blower and burner unit as illustrated in Figure 2. heating or burner resources using 3 kg LPG. In analyzing the initial moisture content of corn grains, tools are needed, namely an oven, a porcelain cup, and a desiccator. The measuring instruments used are the KRISBOW Electronic Kitchen Scale 5 kg Slim Plate digital scales, solar radiation measuring instruments, namely the BONAD SM206 Solar Power Meter, the KRISBOW Temperature and Relative Humidity meter, and the KRISBOW air velocity meter Flexible Thermo Anemometer Unit.

B. Experimental Procedures

The drying process is carried out using three drying methods, starting at 09:00 West Indonesia Time, until the moisture content of the corn grains is less than 14%. The first way is to dry the Corn Grains in the sun. The second method consists of natural drying using a solar dryer without additional energy from LPG. The third method consists of a solar hybrid dryer and additional LPG energy, with temperature variations of 40ºC, 50ºC and 60ºC. The gas regulator in the LPG is regulated and maintained continuously to ensure that the temperature in the drying chamber follows the desired temperature variable.

During the experiment, the weather was sunny with only a few clouds. The experiment started by weighing up to 100 g of Corn Grains for each tray. Experimental data were recorded every 30 minutes. Grain mass data were obtained using digital scales. Relative humidity, temperature, and solar radiation intensity (in ambient air and drying chamber) were measured using a temperature relative humidity meter and a solar intensity meter.

C. Moisture Content Analysis

To calculate the water content, the weight of dry and wet vermicelli must be obtained. Furthermore, Equation (1) can be used to calculate the moisture content of vermicelli based on % wet (M) [9], Mi is the mass of wet Corn Grains (g) while Md is the mass of dry Corn Grains (g).

$$M = \frac{Mi - Md}{Mi} \, x \, 100 \qquad (1)$$

D. Drying-Rate analysis

The drying rate can be calculated by dividing the weight loss of corn grains in the next two measurements by the drying time interval (t), as shown in equation (2) [9]:

$$\mathbf{DR} = \frac{\mathbf{M_i - M_d}}{\mathbf{\Delta t}} \qquad (2)$$

E. Mathematical Modelling

A total of seven thin film drying models were tested for suitability with experimental drying data to obtain the most suitable drying model in describing the drying characteristics of Corn Grains using a hybrid solar dryer. The thin layer model equations and the variables involved describe the heat transfer and mass transfer that occur during the drying of corn grains, both external and internal transfers [10]. Modeling is done using MATLAB software. Table 1 shows the thin-layer drying models and their equations [11].

Table 1. Thin layer drying models

No	Models Name	Model
1	Newton	$MR = \exp(-kt)$
2	Page	$MR = \exp(-kt^n)$
3	Modified Page	$MR = \exp[-(kt)^n]$
4	Henderson and Pabis	$MR = a \exp(-kt^n)$
5	Logarithmic	$MR = a \exp(-kt) + b$
6	Wang and Singh	$MR = 1 + at + bt^2$
7	Midilli et al.	$MR = a \exp(-kt) + bt$

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Where MR is the moisture ratio, t is the time (min), k is the drying constant (s^{-1}), and n, a, and b are the constant values of the dimensionless model. The MR is a dimensionless variable and its value can be determined using the following equation (3) [12].

$$MR = \frac{M - M_e}{M_0 - M_e} \quad (3)$$

M is the moisture content of the corn grains at a certain time (% wet basis), M_o is the initial moisture content of the corn grains, and M_e is the equilibrium moisture content of the corn grains. However, compared to M or M_o, the M_e value is relatively very small, so its value can be omitted [13]. Then a simpler form of equation (4) will be obtained, namely:

$$MR = \frac{M}{M_o} \quad (4)$$

To find out how well the thin layer models fit with the experimental data, three parameters were used in this study, namely the coefficient of determination (R^2) and Root Mean Square Error (RMSE). The model that best fits the experimental data is the model with the highest R^2 value and the lowest RMSE value. The formulas for these two parameters are shown in equations (5) and (6) [14]:

$$RMSE = \sqrt{\frac{1}{N}\sum_{i-1}^{N}\left(MR_{exp,i}MR_{pre,i}\right)^2} \quad (5)$$

$$R^2 = \frac{\left[\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{exp}\right)\left(MR_{pre,i}MR_{pre}\right)\right]^2}{\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{exp}\right)^2 \sum_{i=1}^{N}\left(MR_{pre,i} - MR_{pre}\right)^2} \quad (6)$$

Where MR_{exp} is the moisture ratio of the experimental data, MR_{pre} is the moisture ratio predicted by the thin layer model, and N is the number of observations.

III. RESULT AND DISCUSSION

A. Moisture Content Analysis

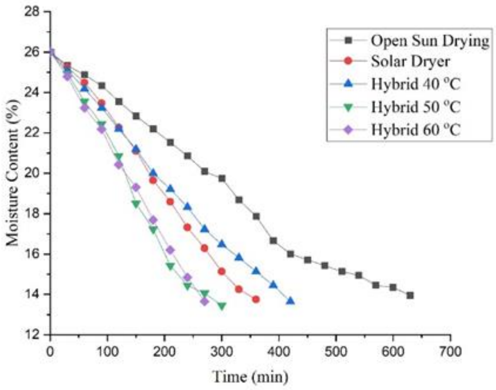

Fig. 3 Corn Seed Moisture Content Curve In Different Drying Methods

Figure 3 is the drying curve of Corn Grains namely time (hrs) vs moisture content (%). At first, the water content in the Corn Grains was measured by the oven method and the result was 26%. In Figure 3 it can be seen that the longer the drying time, the water content in the corn will also decrease. The water content in corn grains that is allowed according to the Indonesian National Standard is 14%. The final results of corn seed moisture content in open sun drying, solar drying without additional heating, and hybrid solar dryer with temperature variables of 40ºC, 50ºC and 60ºC were 13.95%, 13.75%, 13.65%, 13.45% and 13.65.

it was found that the fastest drying occurred in hybrid solar drying with a temperature variable of 60ºC with a drying time of 4.5 hours and a moisture content of 13.65% was obtained. The drying time is inversely proportional to the drying temperature, the higher the drying temperature, the faster the drying process [15]. This is because the greater the heat energy used, the greater the mass of liquid that evaporates from the surface of the material so that the process of diffusion of water from within the material to the surface of the material will be faster, and the moisture content of Corn Grains will decrease rapidly.

B. Drying Rate Curve Analysis

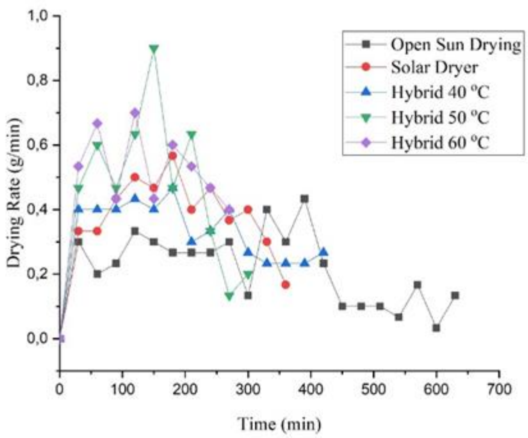

Fig 4. Corn Seed Drying Rate Curve in Different Drying

In Open Sun drying, solar drying, and hybrid solar drying with temperature variables of 40ºC, 50ºC , 60ºC , the average drying rate was 0.212 g/min, 0.364 g/min, 0.318 g/min, 0.439 g/min, and 0.477 g/min. The fastest drying rate occurred in a solar hybrid dryer with a temperature variable of 60ºC followed by a temperature variable of 50ºC , an unheated solar dryer, a solar hybrid dryer with a temperature variable of 40ºC and the slowest was Open Sun drying. This is because the main factor affecting the drying rate is temperature, where the higher the drying temperature, the faster the drying rate [16]. In addition, in this study the drying rate of the solar dryer was faster than that of the solar hybrid at 40ºC, because the weather was hotter when the drying experiment was carried out using a solar dryer without additional heating, so the temperature in the drying chamber was higher and the drying process ran faster.

It was found that the drying rate decreased with increasing drying time. This is because the water content in a material also decreases [17]. So it can be seen that the fastest drying rate occurs at the beginning of the drying time, then continues to decrease for each variable. This is because on the surface of the material there is a lot of water, in this case granules, which are classified as free water. Whereas with increasing time and drying of the material, what is left behind is water bound to the cells of the material so that the decrease in the water content of the material becomes smaller and finally constant. The free water content evaporates easily because it is in the liquid phase which fills the cell cavities and spaces between cells. Whereas bound water is more difficult to remove because it is hygroscopically attached to the cell wall [18].

C. Thin Layer Drying Modeling

Table 2. The values of the model constants along with the R^2 and RMSE values of the thin layer drying corn grains modeling.

Method	Model	Parameters	RMSE	R^2
Open Sun Drying	Newton	k = 0.02811	0.0188	0.9847
	Two-term	a = 0.9557 k_1= -0.015 b = -1.88E-02 k_2= 0.0221	0.0146	0.9908
	Page	k = 0.003 n = 0.55	0.0350	0.9473
	Modified Page	k= 0.0047 n= 0.6248	0.0449	0.9131
	Henderson and Phabis	a = 0.57 k =0.9924	0.0442	0.9159
	Logarithmic	a = 0.516 k = 0.0923 b =0 .08637	0.0333	0.9521
	Midili et al	a = 0.9997 k = 0.0321 n = 0.1129 b = 0.0119	0.0251	0.9730
Solar Dryer	Newton	a = 0.0583	0.0269	0.9711
	Two-term	a = 0.9923 k_1= -0.0251 b= -1.77E-02 k_2= 0.02131	0.0149	0.9912
	Page	k = 0.0025 n = 1.1522	0.0354	0.9501
	Modified Page	k = 0,0095 n = 1.5213	0.0339	0.9542
	Henderson and Phabis	a = 0.56 k = 0.9930	0.0304	0.9632
	Logarithmic	a = 0.2998 k = 0.0812 b = 0.1985	0.0823	0.7297
	Midili et al	a = 0.9997 k = 0.0321 n = 0.027 b = 0.0152	0.0219	0.9808
Solar Hybrid (40ºC)	Newton	a = 0.1548	0.0106	0.9950
	Two-term	a = 0.9870 k_1 = -0.0252 b = -1.88E-02 k_2 = 0.0214	0.0046	0.9991
	Page	k = 0.0015 n = 1.1578	0.0117	0.9939
	Modified Page	k = 0.0150 n = 0.5812	0.0433	0.9165
	Henderson and Phabis	a = 0.55 k = 0.9721	0.0255	0.9711
	Logarithmic	a = 0.2912 k = 0.1 b = 0.1874	0.0633	0.8215
	Midili et al	a = 1 k = 0.0412 n = 0.0283 b = 0.0167	0.0209	0.9806
Solar Hybrid (50ºC)	Newton	k = 0.0548	0.0263	0.9758
	Two-term	a = 0.9998 k_1 = -0.0999 b = -3.11E-02 k_2 = 0.0051	0.0203	0.9856
	Page	k = 0.0055 n = 1.1128	0.0435	0.9338
	Modified Page	k = 0.0252 n = 0.8213	0.0310	0.9663
	Henderson and Phabis	a = 0.5489 k= 0.9812	0.0257	0.9768
	Logarithmic	a = 0.412 k = 0.1456 b = 0.1586	0.0621	0.8647
	Midili et al	a = 1 k = 0.0432 n = 0.0420 b = 0.060	0.0328	0.9623
Solar Hybrid (60ºC)	Newton	k = 0.0125	0.0202	0.9829
	Two-term	a = 1 k_1 = -0.101 b = -3.58E-02 k_2 = 0.015	0.0113	0.9946
	Page	k = 0.0017 n = 1.1151	0.0174	0.9874
	Modified Page	k = 0.031 n = 0.85	0.0186	0.9855
	Henderson and Phabis	a = 0.5501 k = 0.9254	0.0245	0.9748
	Logarithmic	a = 0.4156 k = 0.1514 b = 0.1585	0.0563	0.8675
	Midili et al	a = 1 k = 0.0445 n = 0.0410 b = 0.0580	0.0251	0.9736

Table 2:- The values of the model constants along with the R^2 and RMSE values of the thin layer drying corn grains modeling

There are seven types of drying models tested in this study to detect the Moisture Ratio behavior of drying corn grains, to find out which model is suitable for describing the drying characteristics of corn grains, the moisture ratio values from the experimental results are entered into the seven thin layer drying models as shown in table 1 From this test, constant values and correspondence values are obtained for each model tested as shown in table 2.

The model with the smallest R^2 and RMSE values has the best fit with the experimental data obtained. This shows that the Two Term model is the best model for presenting the drying of thin layers of corn grains because it has a large suitability value for the characteristics of thin layers of corn grains.

The average R^2 and RMSE values of the Two Term model for each method are 0.9922 and 0.0131, followed by the Newton model (average R^2 and RMSE of 0.9819 and 0.0205) and the midili model (average R^2 and RMSE of 0.9740 and 0.0251). These results are different from research on thin layer modeling of drying corn grains using a convective dryer [19], where the most suitable model is the logarithmic model. This difference in results can be affected by different operating conditions and dryers.

Figure 5 shows a comparison of the experimental results with the simulation results using the two-term model at a drying temperature of 60°C. It can be observed that the simulated moisture ratio values converge or are close to a straight line (representing the experimental results). This indicates that the two term model is suitable for describing the drying characteristics of corn grain using a hybrid solar dryer.

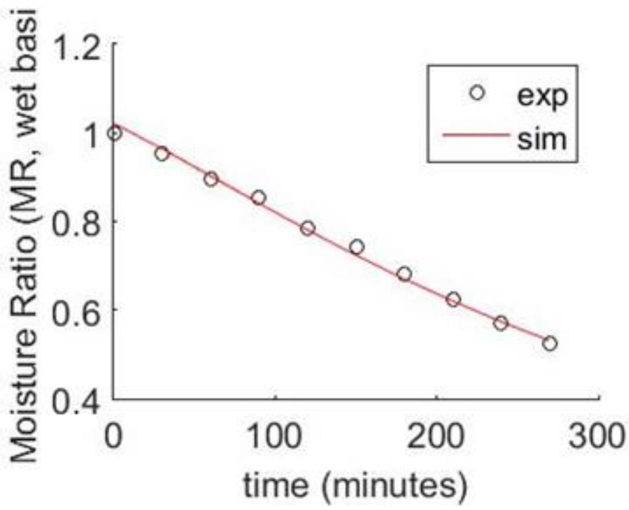

Fig 5. A moisture ratio of experimental results and simulation results of the two term model at drying temperature of 60°C corn grains

IV. CONCLUSION

The fastest drying occurred in a solar hybrid dryer with a temperature variable of 60ºC with a drying time of 4.5 hours, a moisture content of 13.65%, and a drying rate of 0.477 g/min. Then the drying rate will decrease with increasing drying time. In addition, the Two Term model is the best model for presenting the drying of corn grains thin layers, because it has a large suitability value for the characteristics of the corn grains thin layer. The average value of R^2 and RMSE of the Two Term model for each method is 0.9922 and 0.013.

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