Application of Natural Air Drying on Shelled Corn in Timor

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Abstract. A study of the application of natural air drying on shelled corn in Timor using a bed-type dryer has been performed. The study aspects were limited to obtain the suitable air flow rate requirement and duration of the drying operation per day. For each aspect, the treatments were carried out simultaneously. The results showed that at the average ambient air temperature of 30.6°C and relative humidity (RH) of 73.0% the air flow rate of 0.83 L/s-kg provided the highest drying rate. Subsequently, by using the same air flow rate, three scheme of drying operations duration were used, i.e., 8 hours per day (08.00-16.00), 6 hours per day (09.00-15.00) and 4 hours per day (10.00-14.00). The average temperature and RH of ambient air condition at the second experiment were 30.3°C and 73.3% respectively. After 4 days of drying, the 8 hours per day (first scheme) treatment was able to dry the shelled corn from the initial moisture content of 27.24% w.b. to the final moisture content of 14.05% w.b. The specific energy consumption (SEC) of the first scheme was 1.75 MJ/kg. The final moisture content of the second and third schemes were 15.08 % w.b. and 18.45 % w.b. respectively with SEC of 1.41 MJ/kg and 1.21 MJ/kg respectively.
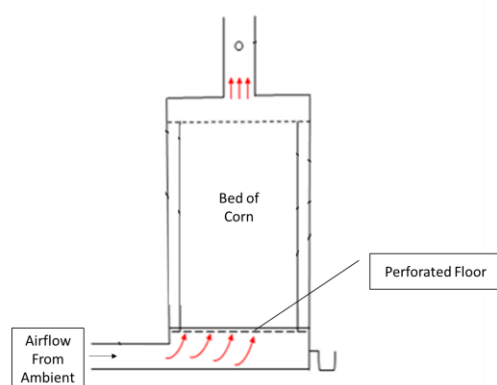
1. Introduction

North Central Timor Regency (TTU) is one of corn production centers in the Province of East Nusa Tenggara (NTT). In 2014, corn production in TTU was 647,072 tons (British Psychological Society Regency TTU 2014). Post-harvest management of corn in Timor is still limited, especially for the drying process. The drying process is usually conducted using smoking method. Such drying method has a disadvantage that is reduced sugar levels of corn. In addition to the smoking method, the drying process is also conducted by directly drying under the sun and spread over on matting and tarpaulin. Such method has weaknesses namely requires large space, more labor, longer time and contamination between the corns seeds and foreign objects so that damage occurs when stored. Artificial drying process is required to overcome these problems. Drying is one of thermal energy saving alternatives because the thermal energy requirement for drying is very high around 90%-95% of the total energy demand [1]. Geographically, Timor region has dry tropical climate that is more dry season than wet season; average rainfall is 265.9 mm, sunlight is 50%-98%, average air temperature is 22°C-34°C and air humidity is 67%-89% [2]. Such natural air condition is very potential to be used as the drying medium. [3] has been conducted a study on natural air drying on shelled corn, equipped with control system. This study used as much as 22.5 kg of corn hybrid varieties with initial moisture content 20.89% d.b and final moisture content of 16.20% d.b. He found that at ambient temperature ranging between 27.9°C-40.6°C and RH environment 39.47%-93.43%, the drying time was 10.517 hours and airflow rate was 0.01 m³/s is equal 0.4 L/s-kg. For Timor region with dry tropical climate, where during the day the ambient temperature reaches 34°C and RH below 70% are potential as to be used as for natural air drying without control
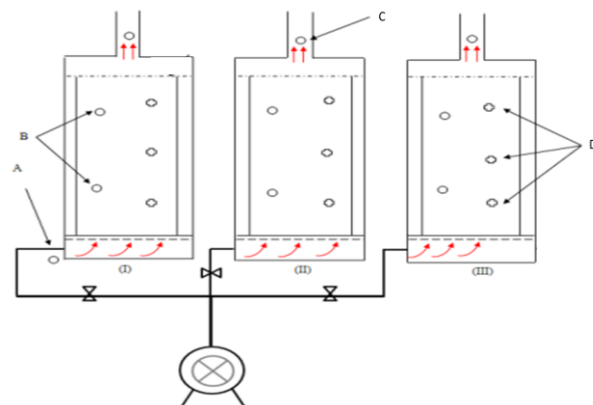
system. Therefore, a drying method is required by determining the appropriate air flow rate and operating time. Airflow rate serves as a heat carrier to evaporate and remove the moisture content. Besides the air flow rate, operating time also greatly affects the drying process. The purpose of this study is to determine appropriate air flow rate and operating time for natural air drying for shelled corn.

2. Materials and methods

The research was conducted in Regency of TTU, District of Kefamenanu City, Laboratory of Agriculture Faculty, University of Timor, and continued at Renewable Energy Laboratory, Department of Mechanical Engineering and Biosystem, Faculty of Agricultural Technology. The material being tested is local white shelled corn from Manusasi Village, District of West Miomaffo. Three bed dryers with each capacity of 30 kg were designed and constructed (figure 1). The shelled corn was put into the drying chamber and then the ambient air was then flowed by a blower into each drying unit. The test was performed in two stages, namely determination of air flow rate (first stage) and operating time (second stage). Both stages were carried out simultaneously using 3 dryer units as presented in figure 2. Air flow rates were measured using orifice plates, that had been calibrated with an anemometer. Measurement of moisture content is done using gravimetric method (oven). Measurement of electrical power for blower was performed using multimeter and clamp meter. In airflow rate test, air flow rate of the three drying units varied and operated continuously at the same time from 08.00-16.00. Testing of operating time is carried out with the air flow rate from previous experimental results. The first drying scheme runs from 08:00 to 16:00 every day (8 hours per day), the scheme II from 09:00 to 15:00 every day (6 hours per day), and scheme III from 10:00 to 14:00 every day (4 hours per day).

Figure 1. Schematic design of one unit shelled corn bed dryer

Figure 2. Schematic set up of bed dryer testing (A: air temperature, RH and velocity measurement, B: moisture content measurement, C: air temperature and RH measurement, D: grain temperature measurement)

2.1. Determination of Air Flow Rate

Tests on air flow rate were carried out under the same ambient air conditions as presented in figure 1 and figure 2. The air flow rate can be measured using orifice plate equipped with a pipe U manometer and calibrated using an anemometer. The calibration data was used to obtain linear equations of flow rate to the difference of the water column height to obtain equation (1). The air flow rate was obtained using equation 2 where the air velocity air velocity is calculated by equation (1).

$$V = a\,(\Delta h) + b \tag{1}$$

$$Q = V \times A \tag{2}$$

where: air flow rate (m/s), Δh= difference of water height among manometer columns (mm), a,b = calibrated constants, and Q = flow rate (m³/s), A = cross-sectional area of airway pipe

2.2. Air Temperature and Relative Humidity (RH)

Measurement of air temperature was conducted by measuring ambient temperature, inlet, bed and outlet temperature. The measurement point of bed temperature is performed at 2 points i.e., the top and bottom layer. Relative humidity measurement of dryer air is carried out by measuring the temperature of the wet bulb and dry bulb. The measurement point is carried out on ambient air, inlet and outlet.

2.3. Moisture Content

Measurements were carried out before and during the drying process with a sample weight of 10 grams at 1-hour interval. Measurements were made by gravimetric method (oven) for 24 hours at 105°C. The sampling point is made at 3 points i.e., the bottom, middle and top

2.4. Total Fan Efficiency Determination

Measurement of the total fan efficiency was done by connecting the fan to the pipe equipped with a valve. Valve opening arrangements were performed at 10 levels. The purpose of adjusting the valve opening was to obtain the total fan efficiency at the treatment of various air flow rates. The electric power consumed by the fan is calculated using the equation:

$$W = v \; x \; I \; x \; Cos \; \emptyset \tag{3}$$

where: W = Electrical power (watts), v = Voltage (volt) I = Current (ampere) Cos $\emptyset$ = Power factor. The total pressure (ΔP_{Total}) (gauge) in Pa, can be obtained by:

$$\Delta P_{Total} = \Delta P_s + \Delta P_d \tag{4}$$

$$\Delta P_d = \rho \; x \; \frac{(\frac{Q}{A})^2}{2} \tag{5}$$

Where ΔP_d = dynamic pressure (gauge) (Pa), ΔP_s = static pressure (gauge) (Pa).

The total fan efficiency can be calculated using the following equation:

$$\eta_{Total} = \frac{Q \; x \; \Delta P_{Total}}{W} \; x \; 100\% \tag{6}$$

where: η_{Total} = Fan total efficiency and W = Fan electrical power (kW).

2.5. Determination of Electricity Energy Consumption

Electrical energy consumption was calculated using flow rate (Q), total pressure (ΔP_{total}) and the total fan efficiency specified in equation (11) are expressed as follows:

$$W_{cal} = \frac{Q \; x \; \Delta P_{Total}}{\eta_{Total}} \tag{7}$$

The electrical energy during the drying process is calculated by the equation:

$$E = W_{cal} \; x \; t \tag{8}$$

where: E = Electrical energy drive fan (MJ), W_{cal} = Electric power fan calculation results (Watt), t = Drying time (s)

The specific energy consumption is calculated by the equation:

$$KES = \frac{E}{M_{vap}} \tag{9}$$

where KES = Specific energy consumption (MJ/kg), M_{vap} = Mass of moisture vaporized from corn (kg)

2.6. Three (3) Tons Drying Simulation

Generally, application of shelled corn drying at farmer level is in large scale. In the simulation, application of drying is designed with the assumption of 3000 kg capacity, that is by extends the space, but the bed height remains. The use of such fan shall comply with the pressure and air flow rate for the assumption of 3000 kg capacity. In the fan used, the pressure is the same as the experiment while airflow rate is increased so that the volume per seed mass is met. The fan used is a commercial fan [4]. The performance curve can be seen at http://www.fantech.com.Au/images/PDF /Catalogue/performanceeg. The website may disappear after a certain period.
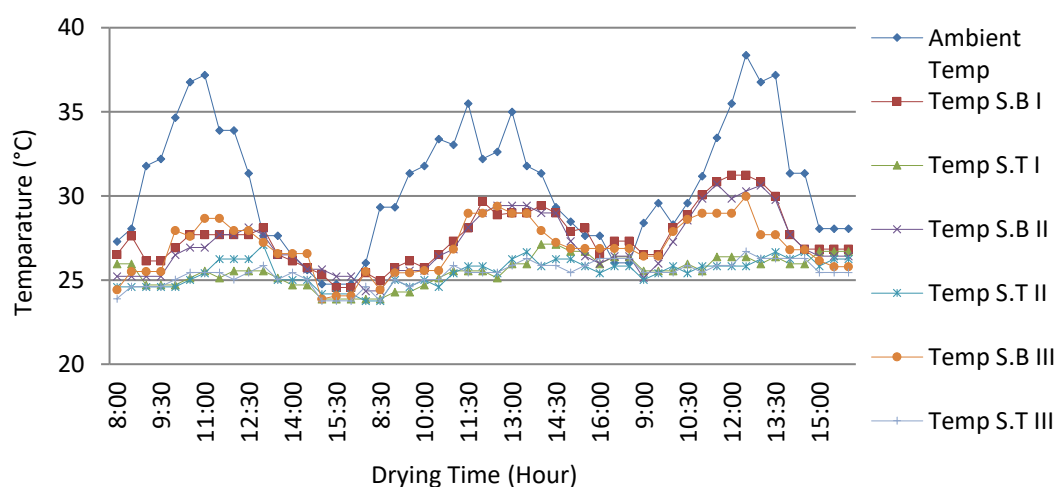
3. Results and discussion

3.1. Effect of Air Flow Rate on Drying Process

Air flow requirements for grain drying can be expressed as air flow rate required for each kg of dried grain in L/s-kg. In this study, the air flow rate of 0.025 m³/s is equal to 0.83 L/s-kg, 0.020 m³/s is equivalent to 0.67 L/s-kg whereas 0.015 m³/s is equivalent to 0.5 L/s-kg. Figure 3 shows that the greater the rate of air flow, decrease in moisture content will be faster. In the test, the decrease of moisture content at flow rate of 0.83 L/s-kg is reach 16.67% w.b, 0.67 L/s-kg was 18.71% w.b and 0.5 L/s-kg was 20.85% w.b. Air flow rate is very influential on the drying process [5]. Larger air flow rate will result in differences in drying air temperature and moisture content between the bed becomes smaller and shorter drying time. This finding is supported by [6] which state that the higher air flow rate, the higher ability to evaporate water.
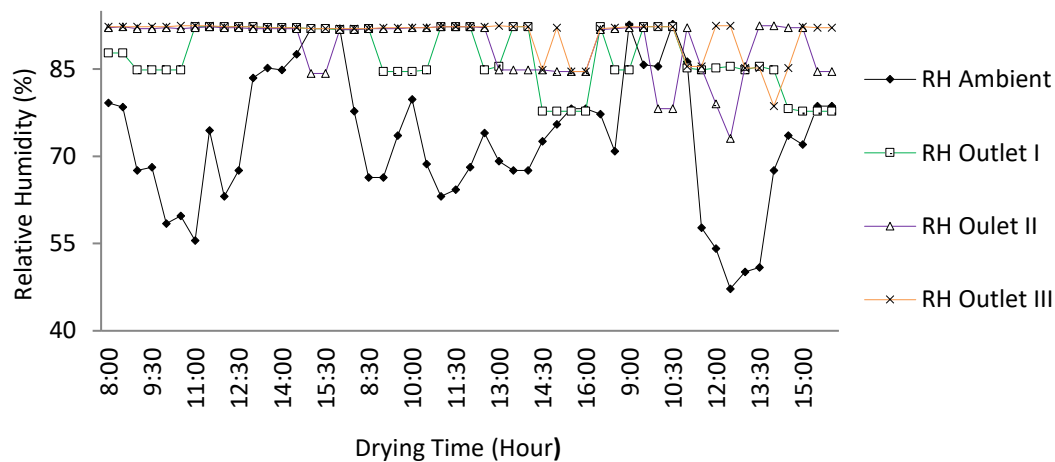
3.2. Changes in Temperature and RH on Air Flow Rate Test

The experiment was carried out for 3 days with 24 hours of drying time. Figure 3 shows the graph of ambient temperature fluctuations with the bed temperature over time during drying. During the drying process, the ambient temperature and inlet temperature tend to fluctuate due to fluctuating weather. The average ambient temperature is 30.62°C. In figure 3, it is also seen that during the drying process the lower pile temperature stays higher than at the upper pile temperature. It is because the incoming ambient air will be first coming on the bottom of the pile and before flowing into the upper pile, causing the upper pile temperature tends to be lower. At the same ambient temperature, the air flow rate of 0.83 L/s-kg results in greater drying rate. Higher air flow rate results in more moisture and easier to volatilize. It can be seen from the temperature difference between the lower and upper piles at the highest air flow rate of 0.83 L/s-kg, especially at the end of drying (third day).

Figure 3. Plots of temperature versus drying time (T refer to upper, B refer to lower layer, while I, II and III refer to 0.83, 0.67 and 0.5 L/s-kg of air flow rate, respectively)
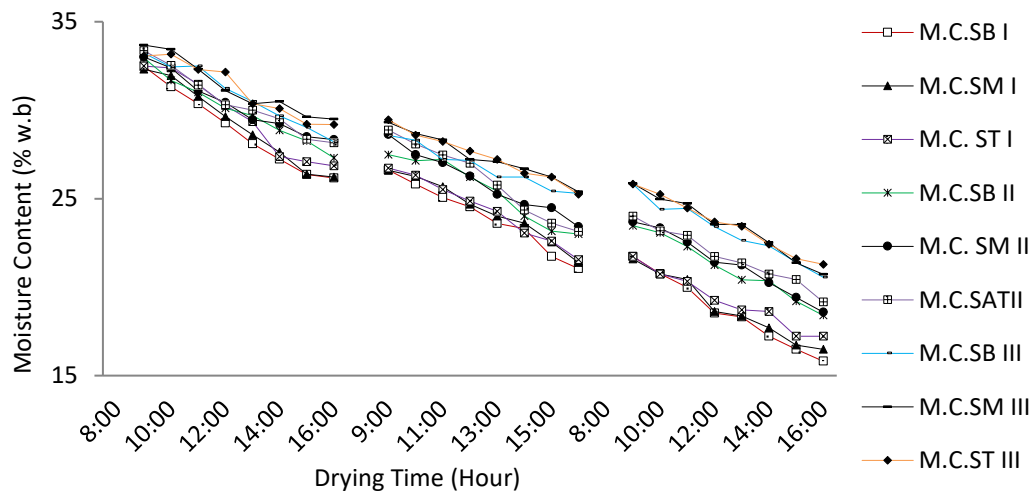
Figure 4 shows a change in RH during the drying process. The graph shows that the difference between RH ambient and RH outlet is very significant, where RH ambient is higher than RH outlet, but RH ambient starting to decrease at 14:30 to 16:00. RH outlets on each drying unit are affected by the air flow rate. It can be seen from the highest RH outlet value at the air flow rate of 0.83 L/s-kg, although the drying rate is the highest since it also contains more air, it results in low RH. The average relative humidities of the outlet portion at the highest to lowest air flow rate are 86.78%, 89.03%, and 90.83% respectively. The greater the temperature and air flow, the lower the relative humidity produced, causing more vapors absorbed by the drying air. The highest air flow rate 0.83 L/s-kg has low relative humidity so that the capability of drying air to absorb vapors can be able to get higher.

Figure 4. Plots of RH versus drying time (I, II and III refer to 0.83, 0.67 and 0.5 L/s-kg of air flow rate, respectively).

3.3. Changes in the Moisture Content on Air Flow Rate Test
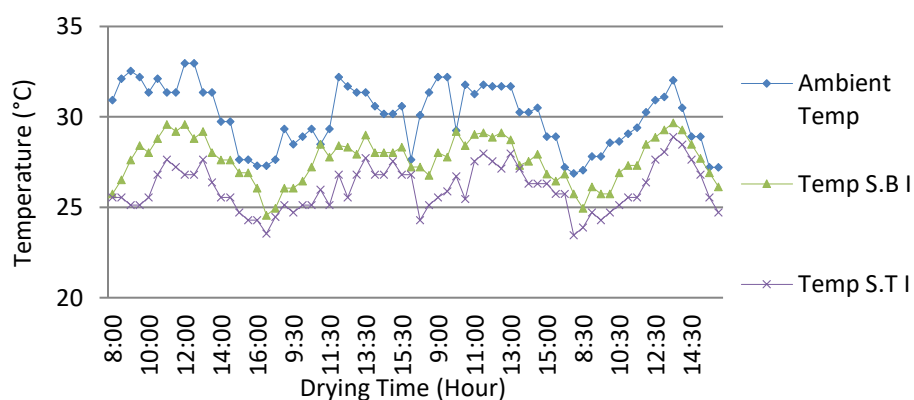
Figure 5 shows the effect of air flow rate on changes in corn moisture content. The decrease of the moisture content of the three air flow rate test is not significant, but the fastest decrease found in higher air flow rates. At the air flow rate of 0.83 L/s-kg, the average of air ambient was 30.62°C, RH was 72.96% with the initial average moisture content 33.11% w.b can decrease the moisture content until the final average moisture content was 16.67% w.b. Figures 5 the decreasing moisture content in the lower layers is always lower for the overall airflow rate treatment. It is because in the lower layers the thickness of the pile closer to the inlet temperature so that faster vapor evaporation occurs than the material resulting in a greater decrease in water content. The thinner or smaller the maize layer, the faster and bigger the decrease of the moisture content of the corn kernels per time unit [7]. However, in the lower, middle and upper layers of the decline, the difference between moisture content is not too large. It is because during the drying process carried out stirring 2-3 times a day so that in the maize layer mixing between corn kernels with different moisture content so that the uniformity of moisture content between layers of corn.

Figure 5. Effect of airflow rates on decrease in moisture content versus drying time (T refer to upper, M to middle, B to lower layer, while I, II and III refer to 0.83, 0.67 and 0.5 L/s-kg of air flow rate, respectively
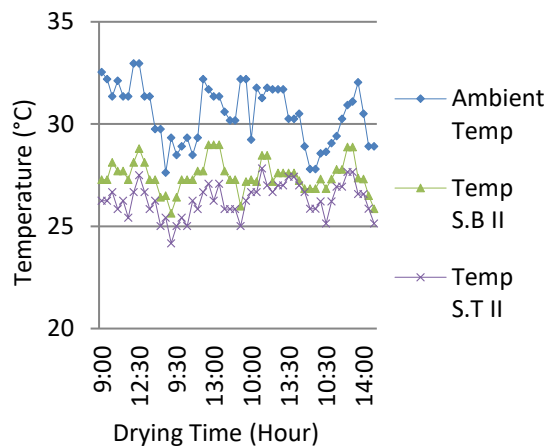
3.4. Changes in Temperature and RH on Operation Time Test

Figures 6, 7, and 8 show changes in ambient temperature, inlet temperature, pile temperature during the drying process. The average ambient temperature of the three 32-hour operating time schemes (08: 00-16: 00), 24 hours (09: 00-15: 00) and 16 hours (10: 00-14: 00) are 30.03°C, 30.49°C, and 31.03°C, respectively. Based on the graph, it is shown that the potential of ambient temperature as a drying medium is at 10:00 to 14:00, but the rate of decrease in moisture content was slow. It is due to a shorter operating time of 4 hours per day whereas a faster drop in moisture content is an operating time scheme of 8 hours per day. The longer the drying time, the more water vapor is evaporated so that the decrease in moisture content will get higher. The graph also shows that, during the three schemes of the drying process, the lower pile temperature is higher than the upper pile temperature. Based on the temperature data, it can be concluded that the determination of the effective drying time is important so that the drying process can be conducted on the time when the ambient temperature is potential only. It can be seen in the 3rd scheme treatment where only with 4 hours operating time per day (16 hours) the moisture content decrease can reach 18.70% bb, whereas if drying is done with scheme 1 then the drying time can take up to 24 hours.
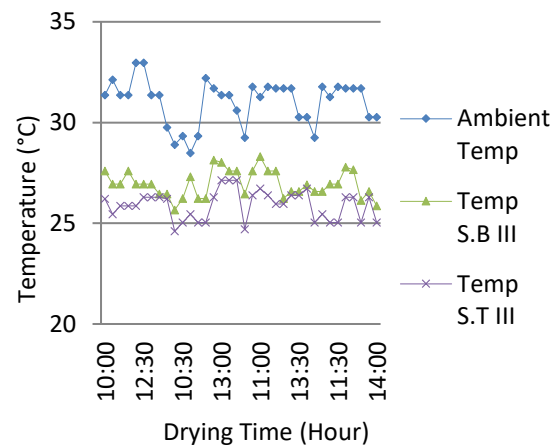

Figure 6. Plots of air ambient temperature and bed temperature versus drying time of the first scheme (32 hours). (T refer to upper, B to lower layer).
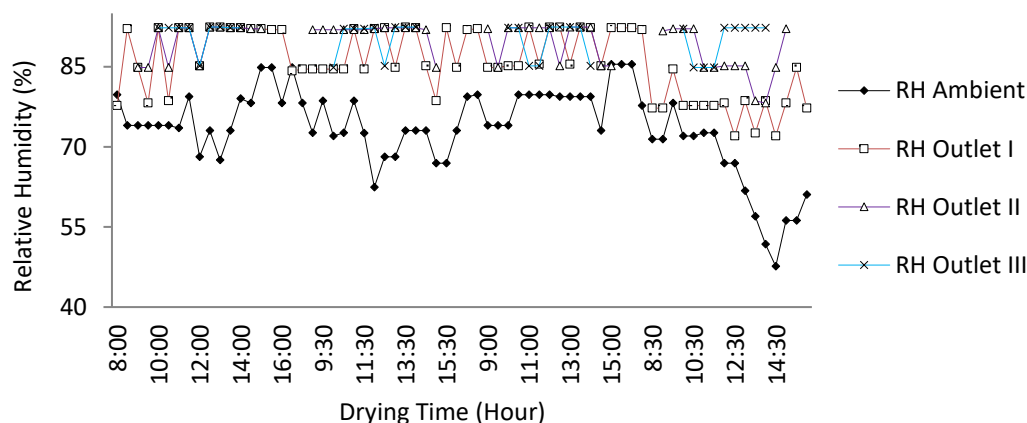
Figure 7. Plots of air ambient temperature and bed temperature difference versus drying time of the second scheme (24 hours) (T refer to upper, B to lower layer).

Figure 8. Plots of air ambient temperature and bed temperature difference by time of the scheme versus drying time of the third scheme (16 hours). (T refer to upper, B to lower layer).

Figure 9 shows the change of air ambient RH and outlet RH by time. Due to on the graph, during drying takes place, air ambient RH is lower than the outlet. Air ambient RH was 73.16% on average while outlet RH is 89.95%. Temperature increase due to the length of drying time may affect RH. The higher air temperature of the dryer, air RH is lower. Such low relative humidity will cause higher heat and mass transfer from material to air [8].
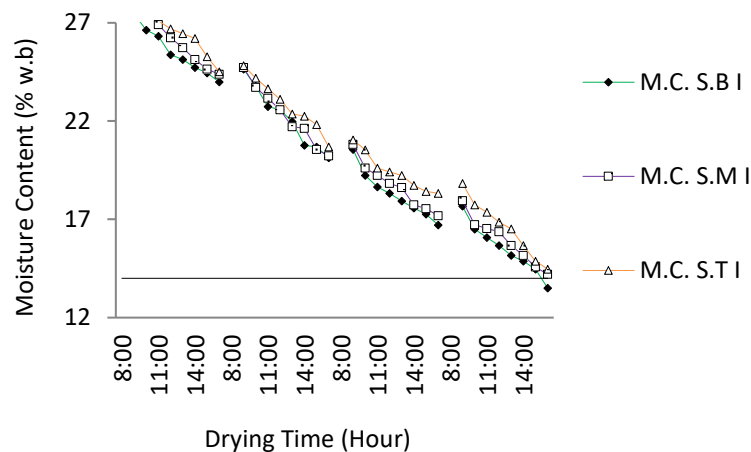

Figure 9. Plots of RH versus drying time (I, II and III refer to the first, second and third operation scheme).
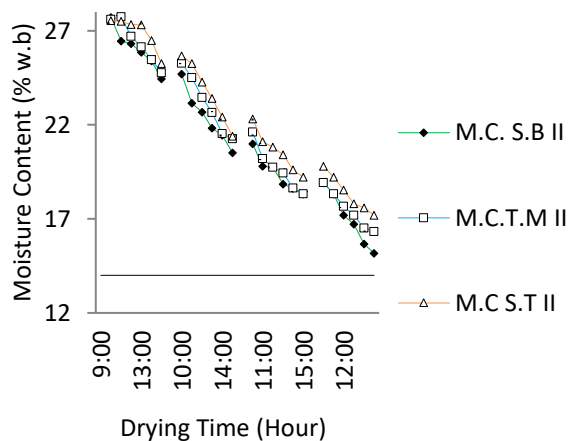
3.5. Changes in Moisture Content on Operation Time Test

Figure 10, 11 and 12 shows the change in moisture content of shelled corn bed. In the testing process, air ambient temperature is 30.32°C on average, and air ambient RH was 75.84% on average. The test was performed on initial moisture content 27.24% w.b until the final moisture content 14.05% w.b on average. During the drying process, moisture content decrease is not significant, but a decrease in moisture content is faster by longer drying time. Operation time at this stage was 32, 24 and 16 hours. The average of the final moisture content of the three drying variables was 14.05% w.b, 16.23% w.b and 18.70% w.b. The decrease in moisture content between the lower, middle and upper beds is not significant. It is because stirring was conducted 2-3 times a day during the drying process. In the stirring
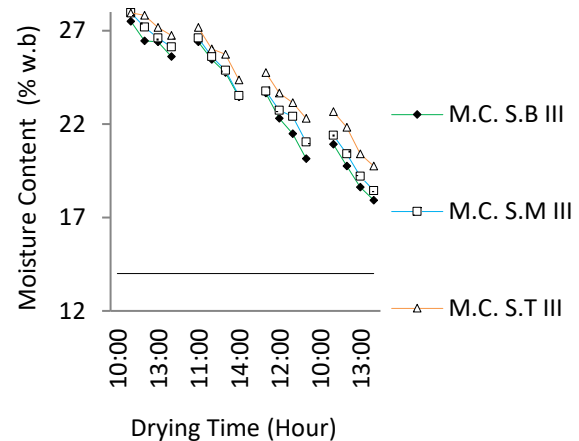
process, there will be mixing between dry and wet grains resulting in difference between the lower, middle and top bed. In the testing process, moisture content decrease in the lower bed is faster; the middle and top bed is very slow. It is because the thicker the corn bed, the possibility of heat distribution of drying air is further hampered by the density of the corn grains resulting in a slow decrease in moisture content.

Figure 10. Plots of moisture content versus drying time of the first scheme (32 hours) (T refer to upper, m to middle and B to lower layer).

Figure 11. Plots of moisture moisture content versus drying time of the second scheme (24 hours) (T refer to upper, m to middle and B to lower layer).

Figure 12. Plots of moisture moisture content versus drying time of the third scheme (16 hours) (T refer to upper, m to middle and B to lower layer).

3.6. Fan Efficiency
Table 1. Shows the average value of total fan efficiency. Due to the table, it can be seen that, in general, the fan test has a maximum total efficiency of 19.29% and an average total efficiency of 14.70%. The value of fan cost Ø was 0.82. From the calculations, the fan has low efficiency.

Table 1. The Average value of total fan efficiency testing

Voltage (V)	Ampere (A)	Power (W)	Cos $\emptyset$	$\eta_{Total\,Max}$ (%)	$\eta_{Total\,rata-rata}$ (%)
218.22	1.2	216.4	0.82	19.29	14.70

3.7. Electric Energy Consumption During Drying Process
In the two stages test, the drying process is carried out effectively (fan condition turns on). At the final stage, air flow rate of drying process lasts for 3 days. Electricity consumption during drying process was 4.88 MJ, while specific energy consumption (SEC) was 0.80 MJ/kg. Table 2 shows energy consumption for 8 hours per day operating time which lasted for 4 days. Due to the table, the highest electrical energy consumption is on the first day while the lowest is on the fourth day. It is because the initial corn moisture content is still very high causing the drying process is mostly for water vapor of material surface thereby increasing the use of electrical energy. Electricity consumption during the drying process was 7.99 MJ, while SEC was 1.75 MJ/kg.

Table 2. Electricity consumption of Scheme I with operating time 8 hours per day

Shelled Corn Dryer	Average Initial Water Content (% w.b)	Average Final Water Content (% w.b)	Effective Drying Time (Hours)	Electrical Energy (MJ)	KES (MJ/kg)
	27.24 % bb				
First Day		24.25	8	2.46	2.07
Second Day		20.26	8	2.26	1.50
Third day		17.78	8	1.84	1.69
Fourth day		14.05	8	1.43	1.37
Total				7.99	1.75

Table 3 shows electrical energy consumption for operating time 32, 24, and 16 hours. The table shows that the highest energy consumption is on 32 hours drying treatment. Consumption of electrical energy during the drying process is 8.01, 6.01 and 4.0 MJ, while SEC is 2.42, 1.82, and 1.21 MJ/kg of respectively.

Table 3. Electrical energy consumption

Scheme Shelled Corn Dryer	Average Initial Moisture Content (% w.b)	Average Final Moisture Content (% w.b)	Effective Drying Time (Hours)	Electrical Energy (MJ)	KES (MJ/kg)
	27.24 % bb				
First		14.05	32	8.01	2.42
Second		15.08	24	6.01	1.82
Third		18.45	16	4.00	1.21

3.8. Three (3) Tons Drying Simulation
Table 4 shows electrical energy consumption and commercial fan cost. Due to the analysis, the commercial fan used for 3 ton drying is a fan with an airflow rate of 2.5 m^3/s or equivalent to 0.83 L/s-kg, static pressure 150 Pa and power 650 watt. The total efficiency of the fan was 72% [4]. Electrical energy consumption for 32 hours of operation time was 20.8 kWh. Given the value of electricity tariff was Rp 1.500/kWh then the total cost was Rp 31,200, and the cost was Rp 10/kg. According to [9], the cost of corn dryer per kg was Rp 90.

Table 4. Electric energy consumption and commercial fan cost

Pressure (Pa)	Air Flow Rate (m³/s)	η Total (%)	Power (W)	Electrical Energy (kWh)	KES (MJ/kg)	Cost (Rp)	Cost Per Kg
150	2.5	57	650	20.8	0.16	31.200	10

4. Conclusions

In natural air drying for shelled corn with 40 cm thick thicknesses conducted at 08:00-16:00, the airflow rate was 0.83 L/s-kg yields the highest drying rate of 1.25% bk/hr compared to the air flow rate 0.67 L/s-kg and 0.5 L/s-kg resulting in an airflow rate was 1.13% bk/h and 1.01% bk/hr respectively. In the operating time scheme test which gives the fastest drying rate of 4 hours per day (10:00-14:00) with a drying rate of 0.93% bk/h while the operating scheme 8 and 6 hours of drying rate is low (0.74% bk/h and 0.64% bk/h). The specific energy consumption (SEC) in the test scheme of operating time of 4 hours per day (10: 00-14: 00) was the lowest of 1.21 MJ/kg compared to the operating scheme of 8 and 6 hours respectively 2.42 MJ/kg and 1.82 MJ/kg. In a specific daily energy consumption (SEC) test of the 8-hour operating time scheme tends to decrease over the drying time was 2.07, 1.50, 1.69 and1.75 MJ/kg. The simulation of 3-ton drying capacity with 32 hours of drying time under ambient air conditions provides a specific energy consumption was 0.16 MJ/kg equivalent to energy cost per kg was Rp 10.

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