Drying Characteristics of Crackers from Sorghum Using Tray Dryer in Different Drying Air Velocities

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***Abstract*—A tray dryer using source of energy from biomass and solar was developed to dry sorghum crackers. In this dryer, solar dryer was combined with a heating system of drying air through pipes above the furnace while cooking sorghum stem's juice. This research investigated drying characteristics of sorghum crackers using the dryer in various drying air velocities. This drying air velocity was conducted at 0.0176; 0.0194 and 0.0272m^3/s. The higher drying air velocity blown into the dryer through pipes above the furnace, the lower temperature of drying air. There is a little different of drying air and crackers temperature in each tray. Sorghum crackers were dried from 186.78% d.b. to approximately 13.88% d.b. The mechanism of drying consists of constant rate period and falling rate period. The constant value during constant rate period in each drying air velocity was 0.0109; 0.0102 and 0.0098%/s while during falling rate period velocity was 0.0085; 0.0089 and 0.0085%/s. The drying air velocity affected constant value during constant period significantly. These models were valid to predict moisture content during drying and describe the drying process in the dryer.**

***Index Terms*—drying characteristic, sorghum crackers, tray dryer, drying air, velocity**

I. Introduction

Many people develop food which made from the mixture of some material, in order to create some diversification and increase the added value of some material and the positif effect of food. Crackers are very common snack as crispy food item, can be made from the mixture some flour i.e. potato, banana and tapioca [1]. The dough is shaped and gelatinized by steaming. The gelatinized dough is cooled, sliced and dried until the moisture content reaches around 10 percent [2]. The dried slices have ability to expand during frying.

In this research, sorghum crackers was made from the mixture of sorghum flour, tapioca flour and wheat flour with ratio 50: 40 and 10. Sorghum was used to substitute wheat. Sorghum has been reported as starch production suitable for diabetic and obese people [3]. This diversification is arranged in order to increase the usage of sorghum flour and decrease the health effect of gluten in wheat flour. Before frying, sorghum crackers is dried until the specific level of water content which give high level ability to expands during frying. They expand into a low density porous product to create its cripsiness, The degree of expansion is one of the important quality parameters of crackers [4].

The ability to expand of the crackers is affected by the composition and the method of drying. Drying is a process applied to reduce the moisture content of food product. This process also reduce their water content to decrease water activity until a level when the growth of microorganism, enzymatic reactions and other deteriorative reactions are inhibited in order to extend their shelf life [5]. The excellent process of drying can give the level of water content which is safe to be stored and able to expand larger during frying.

Drying process can be done in various methods based on the type of available energy as well as the physical and chemical properties of materials which will be dried. Naturally, drying can be applied by using direct solar dryer as a source of energy. The material can be spread in one or more levels of tray, arranged in tray dryer. An artifial drier is equipped with fan, heating system etc. The fan blows the heated or unheated drying air into the bottom of tray dryer [6].

Sorghum crackers were dried in a tray dryer, which is equipped with fan and heating system of air drying. To add the energy from solar, this dryer used energy from biomass fuel in a furnace. The dryer consists of a furnace as source of energy to heat drying air undirectly. The smoke from fuel in the furnace was discharged to environment through two pipes which were installed at the back of the furnace, so the drying air was clean without smoke contamination. The drying air was blown into drying chamber at the bottom of the tray dryer through two pipes which were set above the furnace. These pipes were buried in sand above the furnace to get heat from sand. Heat was transfered from furnace to sand continuously while cooking. The fuel burning was used to cook the juice while heat drying air which was blown above the furnace in order to use the fuel effectively.

This dyer was designed to solve the problem of crackers drying during rainy and overcast, so the crackers could be dried faster until the expected water level. It

Manuscript received January 21, 2016; revised August 2, 2016.

doi: 10.18178/joaat.3.4.258-264

would avoid the losses by product deterioration and speed up the production process. It was very important to evaluate the drying process and determine the drying characteristics in the dryer because the quality of final dried product depends on the entire drying conditions [7]. This research investigated the drying characteristics of sorghum crackers using the dryer in different drying air velocities.

II. Materials and Methods

A. *Materials*

The material dried in this research was sorghum crackers. This crackers were made from sorghum flour: tapioca flour and wheat flour with ratio 5:4:1 (w/w) mixed with other ingredients. The dough of their mixture was steamed and sliced. The diameter and thickness of each slice was 4.5cm and 2mm respectively.

B. *Experimental Apparatus*

Fig. 1A and B show the schematic picture of the tray dryer. In this dryer, solar dryer is combinated with heating system of drying air through pipes above the furnace while cooking sorghum stem's juice. Other apparatus used in this research consist of thermocouple TM-903A 4 channels; thermohygrometer SK-90TRH; airflowmeter TN-27; weigher AW 220 and oven.

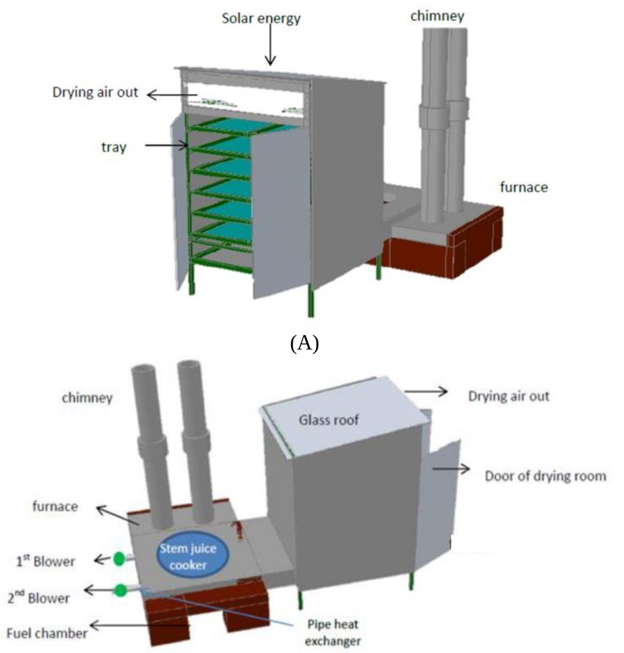

Figure 1. Schematic dryer: front look (A), backside look (B).

C. *Experimental Procedures*

In this research, 20kg of sorghum crackers were dried using tray drier, shown in Fig. 1. After, the biomass in the furnace were blamed, the temperature of drying air on each tray was measured every 30 minutes in empty condition and of drying condition. Sorghum crackers were spread on every 6 level of trays in drying room. The moisture content of sorghum crackers were measured every 30 minutes. The experiment was performed at three various drying air velocity at 0.0176; 0.0194 and 0.0272m^3/s.

During constant rate period, the amount of water surface was available to be evaporated to the surrounding. The moisture content decreased constantly. The drying rate was determined in (2), derivated from (1). The rate of free water from internal body to the surface was lower than the evaporation rate [8].

$$\frac{dM}{dt} = -k \tag{1}$$

$$M_t = -k.t + M_0 \tag{2}$$

When the amount of free water was insufficient to be evaporated continuously, drying rate would be decreased gradually, called falling rate period. During this period, the rate of drying was assumed equal with the difference of the moisture content in each drying time (M_t) and the equilibrium moisture content (M_e) as written in (3), based on Newton model [9]. It created MR as dimensionless of moisture ratio, calculated using (4), derived from (3). The constant value of drying rate during falling rate period was determined by (5), derived from (4) [10]. The value was used to predict moisture content during drying in falling rate period, written in (6).

$$\frac{dM}{dt} = -k\,(M_t - M_e) \tag{3}$$

$$MR = \frac{(M_t - M_e)}{(M_o - M_e)} = e^{-k.t} \tag{4}$$

$$Ln\frac{(M_t - M_e)}{(M_o - M_e)} = -k.t \tag{5}$$

$$M_t = e^{-k.t}.(M_t - M_o) + M_e \tag{6}$$

III. Result and Discussion

A. *The Effect of Drying Air Velocity on the Temperature of Drying Chamber*

In this research, small portion of energy was supplied from solar radiation which was penetrating glass roof [11] and absorbed into drying chamber and the fuel combustion in the furnace. The solar energy was absorbed by the drying air directly.

The heat of fuel combustion in the furnace was absorbed by the sand in heating box which was spread above the furnace for cooking the sorghum stem juice. The energy in this sand was absorbed by the drying air blown into drying chamber through two pipes which is buried in the sand. The air blown into drying chamber through these pipes were conducted at three levels of drying air velocity for 0.0176; 0.0194 and 0.0272m^3/s.

The temperature of the drying chamber was shown in Fig. 2A. The higher air velocity blown into the dryer through pipes above the furnace, the lower temperature of drying air. It is suitable with previous research by Fajriyah [12], stated that the higher drying air velocity, the lower temperature in drying chamber. The temperature of drying air was affected by the energy absorbed by the air based on the time contact passing above the furnace. Moreover, temperature of drying chamber was affected by the speed of fuel combustion and the intensity of solar radiation. The temperature was measured during 380 minutes in empty condition, shown in Fig. 2A.

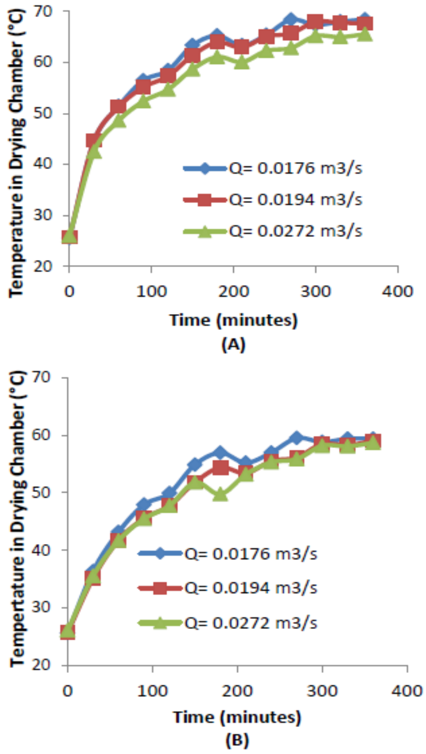

Figure 2. Temperature profile in drying chamber: (A) empty condition; (B) drying condition

The temperature of drying chamber during drying when sorghum crackers were dried in the drying chamber were lower than empty condition, shown in Fig. 2B. This temperature decreased when the material were spread on trays. Some energy was transferred to crackers because of their difference in temperature. The energy was used to increase temperature of sorghum crackers as a sensible heat and to evaporate their water content as a laten heat. It caused the temperature of drying chamber lower than empty condition from 7 to 9 ℃. The highest temperature was about 60 ℃. It was suitable temperature for drying cracker to be available in their expansion during frying.

The heat taken by drying air was distributed in each tray in the chamber, shown in Fig. 3. Temperature in each tray was based on the distance between tray and the bottom of drying chamber where drying air were supplied. There was a little different temperature in each tray. It showed good air circulation which was important to dry the crackers together. The temperature at the bottom of drying chamber was the highest [13].

The heat in drying air in each tray was transferred into the crackers because of the difference temperature between the air and crackers. The energy was used to increase their sensible heat and to evaporate their water content. This temperature affected the evaporation velocity of water content in crackers. It was stretched between 45.21 and 46.97 ℃. The velocity was also affected by the relative humidity of drying air, which were higher by the higher level of tray as accumulation of water evaporated by the crackers in the lower level. They were stretched between 30.17% in plenum chamber to 48.52%.

B. The Change of Cracker's Moisture Content during Drying

Fig. 4A-C showed moisture content of sorghum crackers during drying in three variation level of drying air velocities. Sorghum crackers were dried from initial water content of 65.13% (wet basis) to final moisture content 12.19% (wet basis) or 186.78% (dry basis) to 13.88% (dry basis) during 6 hours. They were dried within drying air velocities of 0.0176; 0.0194 and 0.0272m^3/s causing different temperature of drying air. It influenced the velocity of their drying as energy to evaporate. Drying also was influenced by relative humidity. Crackers were dried from initial condition to reach the expected water content of 12% (wet basis). This is the safe value as the maximum water content value according to Indonesian National Standard of Rice Cracker (SNI 01-4307-1996) [14]. This process could protect crackers with higher water activity in initial condition into the lowest water activity, which was more safe to keep longer because they couldnot be used for activity of microorganism, mold and bacteria.

Drying process by this specific tray dryer gave final water content lower than sun drying (14% wet basis) recording to Sumarno [15] who investigated the comparation between sun drying, cabinet drying and their combination. It was resumed 7 hours to reach 14% by sun dryer, 8 hours to reach 5% by cabinet dryer and 7.5 hours to get 6% by their combination.

Fig. 4A-C showed the changes in water content of sorghum crackers. There were a significant declining at beginning process of drying. It showed evaporation of free water on the surface of the material. The moisture content diffused to the surface material [16]. It showed that there were enough water in crackers to accomodate evaporation process because of the difference in partial vapour pressure between crackers surface and its surrounding. It caused the water to diffuse rapidly.

Drying process of sorghum crackers showed constant rate period and followed by falling rate period in Fig. 4. The moisture content decreased sharply in the first period and then decreased gradually until equilibrium condition. The first period showed contant rate period. It occurred when the surface water were available to be evaporated constantly [8]. Whenever almost of free water had been evaporated, the rate of the decreasing water content would be more slow than before because it evaporated bound water which was supplied slowly from the inside of the material. The rate decreased until final moisture content as the equilibrium moisture content [17] was reached. It was 12.19% (wb). It was described that the falling rate period.

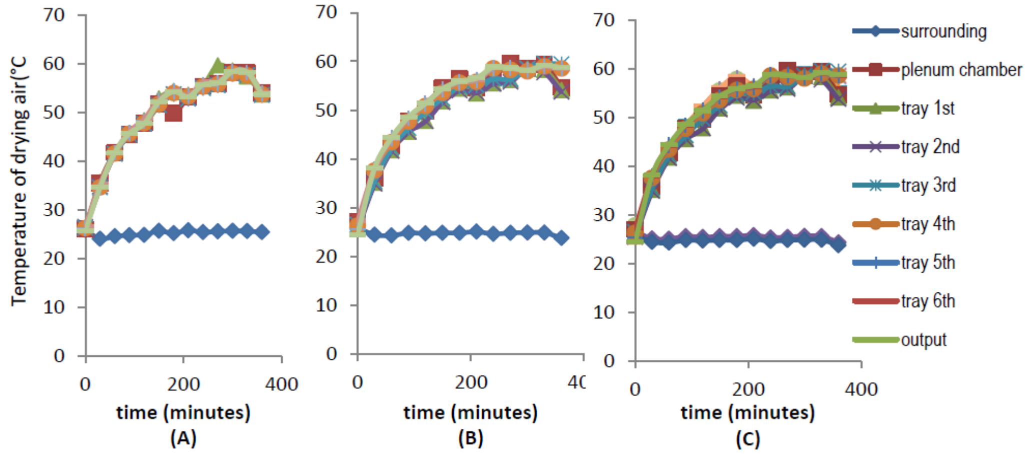

Figure 3. Temperature in drying air in each level of tray in air velocity: (A) 0.0176m^3/s; (B) 0.0194m^3/s; (C) 0.0272m^3/s

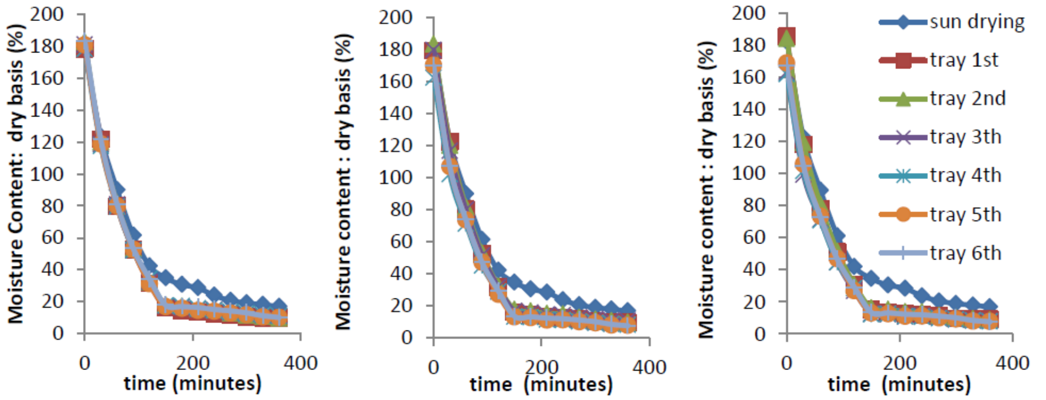

Figure 4. The moisture content of crackers during drying in air velocity: (A) 0.0176m^3/s ; (B) 0.0194m^3/s; (C) 0.0272m^3/s

TABLE I. CONSTANT VALUE OF DRYING RATE IN SORGHUM CRACKER'S DRYING DURING CONSTANT PERIOD

Air flow rate m^3/s	k value during constant period (%/ minutes)							
	Sun drying	Tray dryer						
		1st tray	2nd tray	3rd tray	4th tray	5th tray	6th tray	Average
0.0176	-0.0103	-0.0106	-0.0111	-0.0108	-0.0106	-0.0101	-0.0125	-0.0109
0.0194	-0.0106	-0.01	-0.0109	-0.0102	-0.0101	-0.0102	-0.0097	-0.0102
0.0272	-0.0105	-0.0095	-0.0099	-0.0099	-0.0098	-0.01	-0.01	-0.0098

TABLE II. CONSTANT VALUE OF DRYING RATE IN SORGHUM CRACKER'S DRYING (K VALUE) DURING FALLING RATE PERIOD

Air flow rate m^3/s	k value (%/ minutes)							
	Sun drying	Tray dryer						
		1st tray	2nd tray	3rd tray	4th tray	5th tray	6th tray	Average
0.0176	-0.0106	-0.0067	-0.0075	-0.0084	-0.0103	-0.0098	-0.0079	-0.0085
0.0194	-0.0101	-0.0067	-0.0102	-0.0076	-0.0083	-0.009	-0.0114	-0.0089
0.0272	-0.0102	-0.0065	-0.0075	-0.008	-0.008	-0.009	-0.0122	-0.0085

At the beginning period of drying, the moisture content decreased constantly, showed constant rate period. The moisture losses were equal with the amount of moisture in crackers [18].

The constant value of its rate, analyzed by (1) were shown in Table I. The value (k value) was determined as the slope between the decreasing of initial moisture content each time as the function of drying time.

Table I showed the decreasing on the average of k value with the increasing of air flow rate used in drying. The k values were affected by drying temperature which decreased while the increasing of air flow rate used in drying. At the beginning of drying, removing free water on the surface of product which is influenced by the amount dry air across the surface [11] to carry the moisture faster. But the smallest flow rate in this dryer was enough to carry large amount of vapour which had to be evaporated during drying. If the air velocity was enough to carry the vapor, dried could be taken in low temperature. It affected the final product quality because of many changes which took place, structural and physic-chemical modifications during drying [19]. The levels of drying air velocity gave minimum influence to the values directly [20]. So, the rate was depended on each temperature of process as source of energy. But, the temperature of drying air in this dryer was affected by the level of drying air velocity.

The higher temperature of drying air at the lower velocity, the higher k value showed the faster moisture loss from the product [18]. It shortened the drying time.

At higher temperature, the movement of water in their layer from the inside to the surface of cracker increased faster. Moreover, the capacity of drying air as medium to evaporate and carry the moisture increased [21]. The driving force of its evaporation was the differences vapor pressure between the surface of material and the drying air. The difference was affected by temperature of drying as energy to remove the water and to decrease pressure vapor of the air. The drying air which was blown into drying chamber continuously caused heat transferred into the crackers. This energy was used to increase their temperature as sensible heat and to evaporate their water as latent heat.

The drying rate in each tray were not different each other significantly. It was suitable with the temperature in each tray which was uniform. It showed that the circulation of drying air was enough to distribute the air into each tray in order to distribute the drying energy and to carry the vapour.

The drying rate in tray dryer was significantly different from the sun drying. The k value of sun dryer during constant rate period was 0.01047%/ minutes. It was lower than k value using tray dryer at the air velocity was $0.0176 m^3/s$. It showed that sun drying could reach the final moisture content longer. It also dried more amount of crackers than sun drying which need a lot of area. Full capacity of this dryer was 20kg of sorghum crackers which was arranged in 6 trays, could be effective to replace sun drying in cracker's process.

The k value of drying rate during falling rate period was determined by (5) based on Newton's Law of cooling as mass transfer approach [22]. The values were shown in Table II. This k value in each tray was not different significantly. This value was slightly smaller than sun drying (0.0103%/ minutes) because of the free water had been evaporated during constant period. In this period the k value were depend on the air velocity which influenced the temperature of drying air [23].

C. Prediction of Moisture Content in Sorghum Cracker during Drying

The mechanism of this drying consists of constant rate period and falling rate period. The dry basis moisture content (MC db) of sorghum crackers during constant period was predicted using each k value by (2), while the moisture content of sorghum crackers during falling rate period was predicted using each k value by (6), based on Lewis model [23]. They were integrated as the prediction of moisture content during drying. Fig. 5 compare experimental (measured) and predicted moisture content of cracker versus drying time in each levels of drying air velocity. The predicted moisture content was not different with the measured moisture content, shown in Fig. 5.

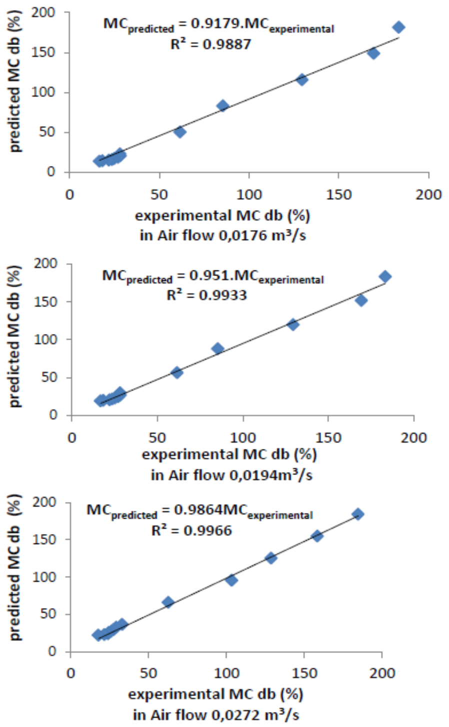

Figure 5. The predicted moisture content and measured moisture content of crackers

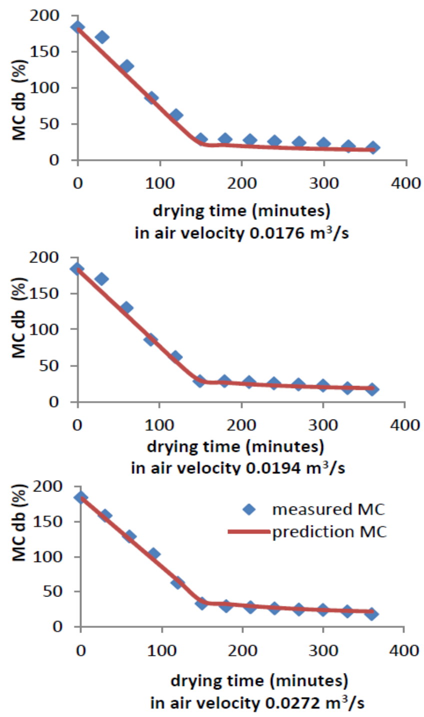

Figure 6. The validation process between experimental moisture content and predicted moisture content of crackers

The validation process between the measured or experimental moisture content dry basis (experimental MC db) and predicted moisture content dry basis (predicted MC db) of sorghum crackers during drying were shown in Fig. 6.

Fig. 6 showed that all values of the gradient were ranged between 0.9179 and 0.986, the value of R^2 was ranged between 0.9887 and 0.9966, which indicated a good fit. It was used to verify the model for actual moisture content [20] for crackers drier in this drier. These models were valid to predict the moisture content during drying [23]. Both of two mathematical models were used to describe the drying process within the dryer [22].

IV. Conclusion

Specific tray dryer was developed to dry crackers from sorghum flour while cooking sorghum's stems juice. In this dryer, energy from solar radiation absorbed by glass roof was combined with heating system of drying air through pipes above the furnace while cooking sorghum stem's juice. The dryer which was conducted at drying air velocity for 0.0176; 0.0194 and 0.0272m^3/s dried sorghum crackers from dry basis moisture content 186.78% to approximately 13.88% during 6 hours,

The higher drying air velocity blown into the dryer through pipes above the furnace, the lower temperature of drying air. There was a little different of temperature of drying air and crackers in each tray. It had effect on the mechanism and the drying rate in each tray.

The mechanism of this drying consists of constant rate period and falling rate period. The constant value during constant rate period in each drying air velocity were 0.0109; 0.0102 and 0.0098%/s while the constant value during falling rate period in each drying air velocity were 0.0085; 0.0089 and 0.0085%/s. The level of drying air velocity affected this constant value during constant period significantly. The model fitted to the process using these parameters was valid used to predict the moisture content of crackers during drying and suitable to describe the drying process in the dryer.

Acknowledgment

We gratefully acknowledge to Faculty of Agricultural Technology, Universitas Gadjah Mada which supported this project. Thank for laboratory assistant that was very help full during the research.

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