Relationship modelling between moisture content of flour and variables of two-cycle drying process of cassava flourusing pneumatic dryer

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Abstract. Moisturecontent (MC) is the most important variable in evaluating material drying performance, so the ability to predict MC in drying process is really important. This research aims to formulate the mathematic relationship between drying process variable pneumatically and moisture content of cassava flour in drying process 1 and 2 by applying dimensional analysis. In this research, there has been a design of pneumatic drying equipment and test using various treatments such as input capacity, drying air temperature, and drying air velocity. Based on the data analysis, the relationship between MC and drying process variables are as follow:
Drying cycle 1:

$$MC = (5{,}794287E - 22).\ \left(\frac{\rho_{pr}.D_{pr}^3}{Q_i.\theta}\right)^{1{,}4085} \left(\frac{T_u}{T_{bo}}\right)^{-2{,}2504} \left(\frac{V_u.\theta}{D_{pr}}\right)^{5{,}863}$$

Drying cycle 2:

$$MC = (2{,}36831E - 10).\ \left(\frac{\rho_{pr}D_{pr}^3}{Q_i.\theta}\right)^{1{,}059} \left(\frac{T_u}{T_{bo}}\right)^{-4{,}808} \left(\frac{V_u.\theta}{D_{pr}}\right)^{3{,}709}$$

The equations have determination coefficient value 0.85, so it has big possibility to use it as alternative to predict moisture content of dried flour.

Keywords*:* **cassava flour, pneumatic drying, dimensional analysis, moisture content**

1. Introduction

Cassava flour is a starch produced by industries that commonly have applied mechanical drying system. It is necessary to have some scientific information to develop drying process of cassava flour, considering that the drying process is a step which needs big and expensive energy (Desrosier, 2008)[4].

In some cassava or starch industries, pneumatic drying method has been used. In this method, wet cassava flour is put inside a vertical dryer pipe line in certain length, and then dry flour and air are separated using cyclone that is put at the end of the dryer pipe line.

Various variables of drying process operations, dryer machine, or grated material of cassava flour that has been dried are really important at determining the final quality of the flour drying result. In the material drying process, the main variable used to evaluate drying process performance is moisture content of the drying result.

In the flour drying, National Standardize Board 2012 or BSN requires that the maximum final moisture content is 12%wb (SNI 01-2997-1996). Meanwhile, according to Afrianti (2000) [1], the safe amount of moisture content in foodstuff is 11%wb because fungus may grow in substrates of food of which minimum content water is 12%wb, while bacteria and yeast may grow in more than moisture content of 30%wb. In the low moisture content, it is possible to store the flour because the flour is not easy to moldy or to be attacked by insects. Therefore, it is important to guarantee that the drying process is conducted well so it can generate a way to relate the variables of drying process to moisture content resulted from drying process. Zare et al (2012)[8] has conducted drying process for canola seeds in various drying air humidity, that is, 0.0005 – 0.02 kg/kg with stable temperature of 45°C. The research result shows mathematic relationship between ratio (MR) with

drying time (t), and drying constant (a,b, k_1, and k_2), experiment data (exp) in the form of the following equation:

$$MR = aexp - k_1t + bexp - k_2t \qquad (1)$$

Where, a= 2,834 − 0,563 Ln(T) 8,752H; k_1= 0,079 − 0,018 Ln(T) 0,011H; b = -1,83+0,5621 Ln(T) − 8,978H; k_2=0,542 + 0,188 Ln(T) − 1,38H

Goula and Adamopoulos (2005) [5] have done drying experiment to tomato powder in various drying air temperature and air flow rate. The research result shows mathematic relationship between moisture content (M) and drying air temperature (T_{inlet}) and drying air rate (Q_a, Q_c), in the form of this equation:

$$M = 124 - 186.T_{inlet} - 0,681.Q_a +$$
$$0,00115.Q_c + 0,00692.T_{inlet}^2 - 0,00735.Q_a^2 -$$
$$0,000003.Q_c^2 - 0,00213.T_{inlet}.Q_a \qquad (2)$$

Bunyawanichakul et al (2007)[3] has done pneumatic drying to rice seeds in various diameter of dryer pipe (0.102 – 0.203 m),input capacity of the seeds (0.5 – 1 kg/s), and drying air velocity (15 – 23 m/c) in stable temperature 110°C. The research result shows mathematic relationship between moisture content (MC) and relative humidity (RH) and rice seeds temperature (T_p) written in the following equation:

$$M = \frac{1}{100}\left[\frac{\ln(1-RH)}{-3,146 \, x10^{-6}T_p}\right]^{\frac{1}{2,464}} \qquad (3)$$

To find out mathematic equation that relates MC and drying process variables of cassava flour, it is necessary to know the drying result in its drying process condition, so it can be used to predict moisture content of cassava flour within the drying process.

Dimensional analysis has simple steps, but it gives a lot of benefits for researches to design equipment in small scale and cheap cost which is possible to use in laboratory. Furthermore, by using this dimensional analysis, designing process of pneumatic drying machine can be carried out meticulously. The aim of this research is to relate MC of flour and some variables of pneumatic drying process using dimensional analysis method. The mathematic relationship will ease the machine designer in constructing pneumatic drying machine or drying machine operator in generating moisture content of dried flour in order to meet the standard of MC determined by SNI.

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2. Research Method

Dimensional analysis is a means to find out quantitative relationship of flour product, drying machine, and drying process. In this research, to find out mathematic relationship between moisture content or MCof dried flour and some drying process variables, there have been selected some variables which are predicted to have certain relationship. Table 1 shows some independent variables that possibly have relationship with moisture content or MC of flour that is dried pneumatically.

Table 1.Independent and dependent variables in dimensional analysis of moisture content of flour.

Variable name	Symbol	Unit	Dimension
Independent variables			
a. Density of particle	ρ_{pr}	kg/m³	ML^{-3}
b. Capacity of material input	Q_i	kg/s	MT^{-1}
c. Initial material temperature	T_{bo}	°C	O
d. Drying air temperature	T_u	°C	O
e. Diameter of particle	D_{pr}	m	L
f. Drying time	θ	s	T
g. Drying time velocity	V_u	m/s	LT^{-1}
Dependent variable			
a. Moisture content	MC	-	-

Source: Witdarko, (2016)

Based on those variables, there is functional relationship that is written below:

$$MC = f\left(\rho_{pr}, Q_i, T_{bo}, \, , \, T_u, D_{pr}, \theta, V_u\right) \qquad (4)$$

$$\pi = \rho_{pr}^{c1}Q_i^{c2}T_{bo}^{c3}T_u^{c4}D_{pr}^{c5}\theta^{c6}V_u^{c7} \qquad (5)$$

There are 8 variables with 4 basic dimensions. Therefore, based on *Buckhingham*π theory (Langgar,. 1967), there will be 4 dimensionless products (π). By giving certain value for c1, c3, c5, and c7, there will be obtained:

$$\pi_1 = MC \qquad (6)$$

$$\pi_2 = \frac{\rho_{pr} \cdot D_{pr}^3}{Q_i \cdot \theta} \qquad (7)$$

$$\pi_3 = \frac{T_u}{T_{bo}} \qquad (8)$$

$$\pi_4 = \frac{V_u \cdot \theta}{D_{pr}} \qquad (9)$$

π values are then arranged in the form of the following functional relationships:

$$MC = C \cdot \left(\frac{\rho_{pr} D_{pr}^3}{Q_i \cdot \theta}\right)^a \left(\frac{T_u}{T_{bo}}\right)^b \left(\frac{V_u \cdot \theta}{D_{pr}}\right)^c \qquad (10)$$

Constant C, a, b, and c can be determined based on the data of research result carried out by changing the equation (10) in the form of log.

2.1 Materials

Material used in the research is 200 kg of white cassava. Cassava is then peeled and washed, then shred using grating machine. To reduce water in the grated cassava, it is pressed using hydraulic press machine. Every 1000 gram of grated cassava is pressed in 50 kg/cm^2 for 10 minutes. The solid grated cassava, after being pressed, is then decomposed manually into wet flour. The wet flour that passes 60 mesh sieve but left in 80 mesh sieve is used as the sample of material to be dried, and based on Stoess (1983)[7], the size of the flour is included in fine materials. The average moisture content of the sample of wet flour is 40 – 42%wb. Proceeding to next process, the sieved flour is dried using flash dryer that has been constructed through two processes.

2.2 Equipment

Fig. 1 shows pneumatic machine that has been constructed for this research. Heater source uses LPG gas with high-pressure burner and regulator that can be adjusted by setting the tap spin on the regulator and burner. Burner is placed inside a square furnace box with an adjustable opening airflow inlet. The adjustment of the dryer airflow velocity is conducted by adjusting the width of the furnace cover. The blower fan uses 735 watt of centrifugal sirocco blower that absorbs hot air and funnels it into the dryer pipe. Wet flour is put through feeding hopper equipped with a screw conveyor and 367-watt small blower as a supporting material. This feeding hopper is installed on the straight pipe above centrifugal blower. The dried material input rate can be adjusted by setting the spin speed of screw conveyor.

Drying process takes place along the dryer pipe line. Meanwhile, the separation of hot air, dust, and dry flour is carried out inside cyclone unit placed at the end of dryer pipe.

2.3 Research Procedure

The research is started by turning on the pneumatic dryer machine (flash dryer), then adjusting drying temperature, drying air flow velocity, and material input rate as specified. In this research, drying air temperature is varied for three levels, that is, 145°C, 160°C, and 175°C. Likewise, the velocity of drying air flow is varied in three levels, that is, 17.12 m/s, 18.10 m/s, and 19.29 m/s. The dried material input rate is varied into 0.0371 kg/s, 0.0509 kg/s, and 0.0616 kg/s. Other data needed for dimensional analysis such as ρ_{pr}, D_{pr}, and T_{bo} are made stable into 1266 kg/m^3, 0.2596 mm, and 30.43^{o}C respectively. Meanwhile, θ(Drying time) is measured during the drying process. In the drying process of cycle 1 and 2, temperature of environment is 29°C - 30°C, with relative humidity is 69%-70%.
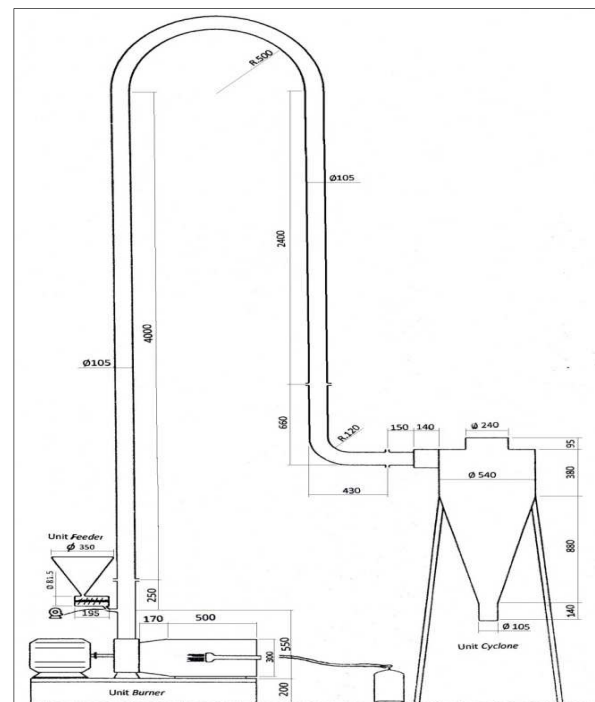

Fig. 1.Pneumatic mechanical dryer equipment (flash dryer)

3. Result and Discussion

Based on the data collected during the research, there will be dimensional analysis to determine constant values of equation that has been formulated. Using log form of equation (10), then constant values C, a, b, and c obtained in cycle 1 is 5.7E-22, 1.4085, -2.2504, and 5, while cycle 2 is 2.3E-10, 1.059, -4.808, and 3.709, so mathematic relationship between MC

and drying process variables can be written in equation (11) and (12).

Drying cycle 1 is:

$$= (5,794287E - 22). \frac{MC}{\left(\frac{\rho_{pr} . D_{pr}^3}{Q_i.\theta}\right)^{1,4085} \left(\frac{T_u}{T_{bo}}\right)^{-2,2504} \left(\frac{V_u.\theta}{D_{pr}}\right)^{5,863}} \quad (11)$$

Drying cycle 2 is:

$$MC = (2,36831E - 10). \left(\frac{\rho_{pr} D_{pr}^3}{Q_i.\theta}\right)^{1,059} \left(\frac{T_u}{T_{bo}}\right)^{-4,808} \left(\frac{V_u.\theta}{D_{pr}}\right)^{3,709} \quad (12)$$

Based on the equations, it is shown a relationship between each dimensionless products and MC of the dried material. Relationship of $\left(\frac{\rho_{pr} D_{pr}^3}{Q_i\theta}\right)$ towards MC where this research $\left(\frac{\rho_{pr} D_{pr}^3}{Q_i\theta}\right)$ is varied from 3E-08–5E-08. It can be seen that the influence of Q_i and D_{pr} towards MC is opposite each other; if Q_i goes up, MC goes down, or otherwise, if D_{pr} goes up, MC goes up. Looking at the graph of Picture 2, it can be seen that the effect of D_{pr} towards MC is bigger than the effect of Q_i towards MC. Therefore, the relationship between $\left(\frac{\rho_{pr} D_{pr}^3}{Q_i\theta}\right)$ and MC forms linear line with positive slope, meaning that the greater the diameter of particles, the greater MC of flour obtained. In drying cycle 1, the drying process forms a linear line which is greater than drying cycle 2.
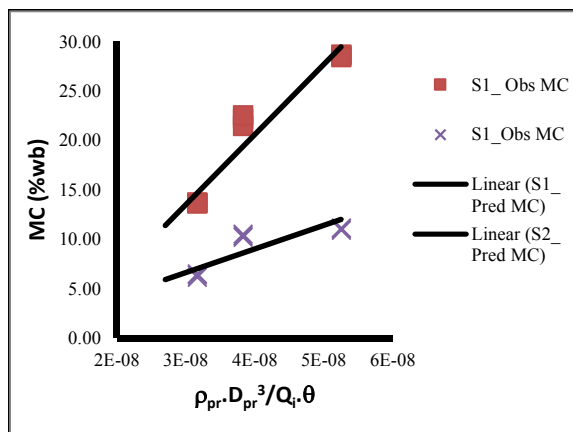

Fig.2.Graph of the relationship between $\rho_{pr}.D_{pr}^3/Q_i.\theta$ and MC

The relationship of drying air temperature ration towards initial material temperature with content water of dried flour, which in this study, $\left(\frac{T_u}{T_{bo}}\right)$ is varied from 4.7139-5.6892 can be seen in Picture 3. In cycle 1 and 2, drying shows that $\left(\frac{T_u}{T_{bo}}\right)$ ratio is getting bigger,

which means that the difference of material and drying air is getting bigger. The greater the temperature difference between material and drying air, the more the heat transfer from air to material will increase. It is due to the fact that temperature difference is driving force of the heat transfer. The more the heat transfer increases, the bigger the ability to evaporate water from the material, so moisture content of the dried material decreased.
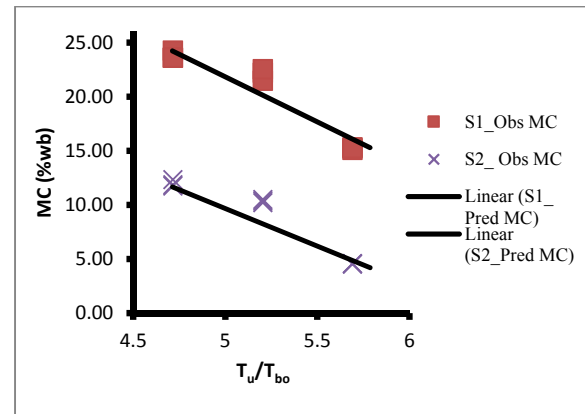

Fig 3.Graph of the relationship between T_u/T_{bo} and MC

Relationship between dimensionless product $\frac{\theta . V_u}{D_{pr}}$ and MC can be seen in Picture 4, in which this research $\left(\frac{\theta . V_u}{D_{pr}}\right)$ is varied from 750483.82 – 845609.40. In drying cycle 1, if diameter of the dried material particle and the drying time are stable, the rise of air flow rate will result in the increase of content water of the dried material. It is due to the rise of air flow velocity which results in the rise of residence time of material heating. In drying cycle 2, if diameter of the dried material particle and the drying time are stable, the rise of air flow velocity will result in the rise of moisture content of the dried material, but the positive slop has tendency to increase low moisture content.
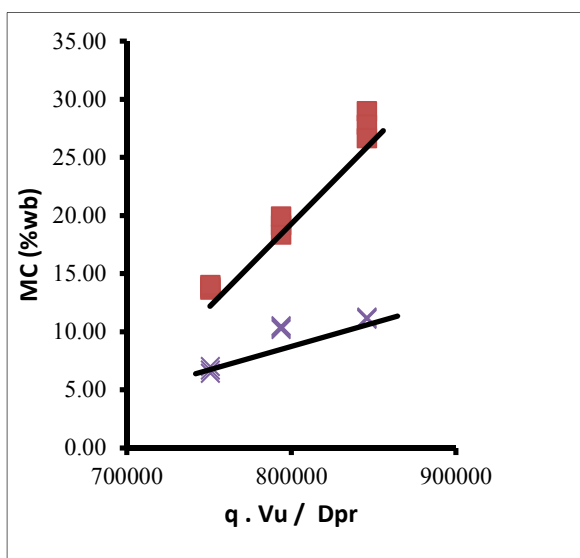
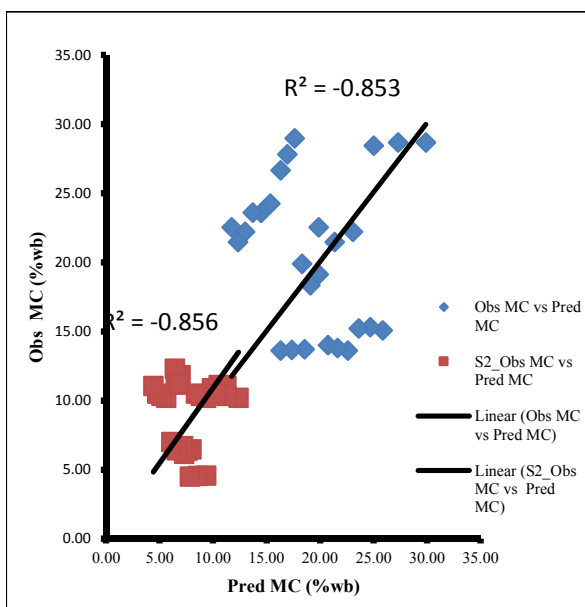Fig 4.Graph of the relationship between $V_u/D_{pr}.\theta$ and MC

Fig 5.Graph of the relationship between prediction MC and observation MC

By using equation (11) and (12), calculation to determine MC value of dried material can be proceeded. Comparison between prediction MC value in equation (11) and (12) with MC value of flour that can be measured directly in environmental condition with temperature of 29°C and relative humidity of 70% can be seen in Picture 5. Based on the picture, it is shown that moisture content values of prediction result are able to predict MC value of the observation result, of which proximity can be seen from the relatively-high determination coefficient value (0.85). Based on the result, it is expected that equation (11) and (12) can

be used to predict MC value of pneumatic-dried material well.

4. Conclusion

Based on the research result, it can be concluded that MC of pneumatic-dried flour is influenced by several factors such as ρ_{pr}, Q_i, T_{bo}, T_u, D_{pr}, and V_u.Mathematically, the relationship between variables with MC value of dried flour can be formulated by applying dimensional analysis in the form of functional relationship below:

Drying cycle 1:

$$MC = (5{,}794287E - 22).\left(\frac{\rho_{pr}.D_{pr}^3}{Q_i.\theta}\right)^{1{,}4085}\left(\frac{T_u}{T_{bo}}\right)^{-2{,}2504}\left(\frac{V_u.\theta}{D_{pr}}\right)^{5{,}863}$$

Drying cycle 2:

$$MC = (2{,}36831E - 10).\left(\frac{\rho_{pr}.D_{pr}^3}{Q_i.\theta}\right)^{1{,}059}\left(\frac{T_u}{T_{bo}}\right)^{-4{,}808}\left(\frac{V_u.\theta}{D_{pr}}\right)^{3{,}709}$$

Dimensionless product that influences moisture content most on the equations is $\left(\frac{T_u}{T_{bO}}\right)$.The equation is applied for value $\left(\frac{\rho_{pr}.D_{pr}^3}{Q_i.\theta}\right)$ of 3E-08–5E-08, $\left(\frac{T_u}{T_{bO}}\right)$ of 4.7139-5.6892, and $\left(\frac{V_u.\theta}{D_{pr}}\right)$ of750483.82-845609.40.

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