The study explores the effect of onion (allium cepa l.) drying using hot air dehumidified by activated carbon, silica gel and zeolite

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Abstract. Dehumidified air can be used to reduce the drying time. A batch-type tray dryer with hot air dehumidified by three different desiccants (i.e. activated carbon, silica gel and zeolite) were carried out to determine the optimum drying time. This study concerns the comparison of the between those desiccants. One mm sliced onion were dried at controlled temperature (40°C, 50°C, 60°C and 70°C). The weight of the samples were measured every 10 minutes for two hours. Results indicate that hot air dehumidified by zeolite gives the shortest drying time compared to the activated carbon and silica gel. Page and modified Page models are the most suitable model to experiment with the value of $R^2$ (0.8971 – 0.9588). The highest k value (0.6132934) is achieved through the treatment at temperature 70°C using zeolite.

1. Introduction
Onion, belonging to the lily family is one of the main ingredients used for cooking. In Indonesia, the production of onions is seasonal. During harvesting the availability of onions become abundant and prices lower. Further processing or preservation needs to be done to increase the price or keep the onion longer.

Drying is one of common methods to reduce water content in food. By reducing water, the components concentration contained in onion will increase. At the same time, drying can reduce storage space and shipping cost. Besides, drying to less than 10% water content can also inhibit microbial growth, causing shelf life extension.

Several drying method has been developed in onion drying. Drying onion in pilot scale freeze dryer, vacuum shelf-dryer, through flow-dryer, sun drying, oven, infrared drying and microwave drying in onion slices were studied in references [1][2]. However, with those methods, drying consumed more energy.

Desiccant has been used in the previous study to remove moisture from the air. It is stated from previous study that dehumidifying the drying air using desiccant can reduce the energy, and for the same energy consumption, quality degradation of nutrition can be reduce [3]. While another research stated that zeolite can be used to reduce the drying time and improve the drying efficiency of around 10-18% compared to conventional dryer [4][5][6]. Besides that, Silica gel and activated carbon are also proven to reduce the drying time [7][8][9].
The drying kinetics can be used for optimizing the drying parameters and predict the drying time to reach the desire moisture content. Several studies have been done to predict the drying parameter \([10][11][12]\). However there is no detailed studies found in literature focusing on drying kinetics of sliced onion that dried using desiccant to dehumidified drying air.

Thus, following the main frame work is to determine the effect of the use of desiccant (activated carbon, silica gel and zeolite) on the drying time and the drying rate constants of onion. For this purpose a suitable thin-layer drying is developed.

2. Materials and Methods:

2.1. Sample Preparation

The Ponorogo variety of onions (Allium Cepa L) is purchased from Johar local market located in Semarang, Central Java, Indonesia. The onions being used will be chosen based on similar diameters. The onions were peeled by knife and sliced in cross-section using Tupperware Speedy Mando in order to produce a uniform thickness (1 mm). Before use, the desiccant (activated carbon, silica gel, and zeolite) were dried in the oven at 110°C for two hours to evaporate the moisture. The temperature of tray dryer were set and controlled at 40°C, 50°C, 60°C, and 70°C. The velocity of hot air were set at 6.5 m/s. Zeolite used in this research was Zeolite 3A provided by Zeochem, Switzerland.

2.2. Drying Equipment

The drying were conducted in the three tray drying chamber sized 50 x 70 x 20 cm with 60 cm tray spaces. There is a hole at the bottom as the inlet of hot air and a hole at the side of the chamber as the outlet of the air. The hot air was produce from blower through the heater. Desiccant column places between blower and heater. Anemometer was used to measure the air flow.

2.3. Drying Experiments

The sliced onion were weighed using a digital scale before put in to the tray dryer in one layer arrangement. The drying process were run for two hours and weighed every ten minutes.

3. Mathematical Modelling of Drying Kinetics

Several drying models that are commonly used to describe the thin layer drying kinetics of a product is shown in table 1.

| Model        | Equation                        | References |
|--------------|---------------------------------|------------|
| Newton       | \( MR = \exp (-kt) \)          | [13]       |
| Page         | \( MR = \exp (-kt^n) \)        | [14]       |
| Modified Page| \( MR = \exp (-tk^n) \)        | [15]       |

MR is moisture ratio obtained from equation:

\[
MR = \frac{M_t - M_e}{M_0 - M_e}
\]  

(1)

Where \( M_t \) is moisture content at time \( t \), \( M_e \) is moisture content at equilibrium, and \( M_0 \) is initial moisture content. All the moisture content are calculated based on dry basis. Since the humidity in the drying chamber were fluctuated, the value of \( M_e \) could not be determined. So, equation 1 can be simplified to [16]:

\[
MR = \frac{M_t}{M_0}
\]  

(2)

4. Result and Discussion

Generally, temperature and the uses of desiccant will influence the drying time. Increases of temperature will reduce the drying time. At the same temperature, drying time can be reduce by the uses of desiccant. Three type desiccants are compared in this experiment.
4.1. Effect of air temperature

The drying curves of onion slices at temperature 40°C, 50°C, 60°C, and 70°C using Silica gels are shown in Figure 1. Based on Figure 1, the moisture content of onion slices decrease exponentially as time increases. As the temperature increases, the drying curves become steeper at the beginning and getting sloping at the end. It indicates that higher moisture removal happened in the beginning of the drying it is when the process was control external heat transfer and free water (water that are not bond to food structure) were leaving the samples. In the end, moisture removal were getting slower, it is when the process controlled by mass transfer and water was bounded to the food structure. Similar drying trends were observed at drying using activated carbon and zeolite.

![Figure 1](image1)

**Figure 1.** Drying curves for onion slices at various temperature (°C) using silica gel as desiccant.

4.2. Effect of Drying Using Desiccant

Onion drying through the use of dehumidification by carbon activation, silica gel, and zeolite demonstrates the gap between the zeolite and silica, activated carbon at temperature 40°C drying curves (Figure 2).

As shown in Figures 3, 4 and 5, at 50°C, 60°C and 70°C, the drying curves are almost isotropic. In this condition, not only water evaporates from the sample, but also volatile compounds contained within the onion. It is known from the previous experiment, there are 39 volatile components contained within an onion [17]. As is discussed in [18][19][20], Alliin, quercetin, thiamine and phenolic compound will start to evaporate or degradable at 50°C.

![Figure 2](image2)

**Figure 2.** Drying curves of onion at temperature 40°C at velocity 6.5 m/s using activated carbon, silica gel and zeolite as desiccant.
Figure 3. Drying curves of onion at temperature 50°C at velocity 6.5 m/s using activated carbon, silica gel and zeolite as desiccant.

Figure 4. Drying curves of onion at temperature 60°C at velocity 6.5 m/s using activated carbon, silica gel and zeolite as desiccant.

Figure 5. Drying curves of onion at temperature 70°C at velocity 6.5 m/s using activated carbon, silica gel and zeolite as desiccant.
4.3. Drying Rate Constant

Value of $k$ and $n$ are obtained from equation on Table 1 using polymath 6.0. Page and modified Page models give bigger value of $R^2$ (i.e. 0.8971 – 0.9588 in this case) compared to $R^2$ of Newton model (i.e. 0.2539 – 0.9483 in this case). The highest average of $R^2$ is given by Page equation. As the temperature increases, the value of $k$ are getting higher in all cases. The $n$ value did not show any particular trend. The higher value of $k$ in this case is achieved at 70$^\circ$C.

| Model       | Inlet air temperature ($^\circ$C) | $k$     | $n$     | $R^2$     |
|-------------|----------------------------------|---------|---------|-----------|
| Newton      | 40                               | 0.01202 | -       | 0.9482771 |
|             | 50                               | 0.0166569 |        | 0.6485885 |
|             | 60                               | 0.01894 | -       | 0.4380969 |
|             | 70                               | 0.0228677 |        | 0.2539724 |
| Page        | 40                               | 0.0228393 | 0.8569379 | 0.9587871 |
|             | 50                               | 0.1583008 | 0.4963901 | 0.9071706 |
|             | 60                               | 0.2698583 | 0.4053131 | 0.8738877 |
|             | 70                               | 0.4399394 | 0.337128  | 0.8971311 |
| Modified Page | 40                               | 0.0121527 | 0.8569563 | 0.9587871 |
|             | 50                               | 0.0243961 | 0.4963966 | 0.9071706 |
|             | 60                               | 0.0394893 | 0.4053158 | 0.8738877 |
|             | 70                               | 0.0875427 | 0.3371282 | 0.8971311 |

Table 2. Equation parameters at different drying temperatures of onion drying using Silica Gel

| Models      | Inlet air temperature ($^\circ$C) | $k$     | $n$     | $R^2$     |
|-------------|----------------------------------|---------|---------|-----------|
| Newton      | 40                               | 0.0146123 |        | 0.8462686 |
|             | 50                               | 0.0199569 |        | 0.7318957 |
|             | 60                               | 0.0208569 |        | 0.4621262 |
|             | 70                               | 0.0374015 |        | 0.6197191 |
| Page        | 40                               | 0.0647272 | 0.6677245 | 0.9257036 |
|             | 50                               | 0.1403522 | 0.5641071 | 0.8981541 |
|             | 60                               | 0.2892069 | 0.4113594 | 0.8881075 |
|             | 70                               | 0.6132934 | 0.4673095 | 0.9279793 |
| Modified Page | 40                               | 0.016575  | 0.6677385 | 0.9257036 |
|             | 50                               | 0.0307798 | 0.5641065 | 0.8981541 |

Table 3. Equation parameters at different drying temperatures of onion drying using Zeolite
Table 4. Equation parameters at different drying temperatures of onion drying using Activated Carbon

| Models       | Inlet air temperature (°C) | k     | n     | R²      |
|--------------|-----------------------------|-------|-------|---------|
| Newton       | 40                          | 0.0100877 | -     | 0.8662375 |
|              | 50                          | 0.0136969 | -     | 0.8471669 |
|              | 60                          | 0.0160462 | -     | 0.5491463 |
|              | 70                          | 0.0100877 | -     | 0.8662375 |
| Page         | 40                          | 0.036611  | 0.7123319 | 0.9206009 |
|              | 50                          | 0.0809658 | 0.6026892 | 0.9752443 |
|              | 60                          | 0.184576  | 0.4535152 | 0.8783947 |
|              | 70                          | 0.4040137 | 0.1679923 | 0.9596444 |
| Modified     | 40                          | 0.0096281 | 0.7123362 | 0.9206009 |
| Page         | 50                          | 0.015439  | 0.6026947 | 0.9752443 |
|              | 60                          | 0.0248873 | 0.4361697 | 0.8863723 |
|              | 70                          | 0.054458  | 0.1679926 | 0.9596444 |

5. Conclusion
In this work, drying process of onion slice was investigated in a drying chamber using dehumidified hot air. The drying curves was determined and used to generalize data. The result showed that air temperature affects the drying time. The drying parameter (k) increases respectively with the increase in the drying air temperature. Other main finding is that zeolite is the best desiccant to reduce the drying time at low temperature.

REFERENCES
[1] Debnath S, Hemavathy J, Bhat KK. Moisture sorption studies on onion powder. Food Chem. 2002;78:479–82.
[2] Arslan D, Özcan MM. LWT - Food Science and Technology Study the effect of sun, oven and microwave drying on quality of onion slices. LWT - Food Sci Technol [Internet]. 2010;43(7):1121–7. Available from: http://dx.doi.org/10.1016/j.lwt.2010.02.019
[3] Atuonwu JC, Jin X, van Straten G, Deventer Antonius HC van, van Boxtel JB. Reducing energy consumption in food drying: Opportunities in desiccant adsorption and other dehumidification strategies. Procedia Food Sci [Internet]. 2011;1:1799–805. Available from: http://linkinghub.elsevier.com/retrieve/pii/S2211601X11002653
[4] Djaeni M, Bartels P, Sanders J, van Straten G, van Boxtel AJB. Process integration for food drying with air dehumidified by zeolites. Dry Technol. 2007;25(1):225–39.
[5] Djaeni M, Aishah N, Nissaulfasha H, Buchori L. Corn Drying with Zeolite in The Fluidized Bed Dryer under Medium Temperature. J Technol Sci. 2013;24(2):13–8.
[6] Djaeni M, Aishah N, van Boxtel AJB, Kiono BFT. A Novel Energy Efficient Adsorption
Drying with Zeolite For Food Quality Product: A Case Study in Paddy and Corn Drying, 2013.

[7] Nagaya K, Li Y, Jin Z, Fukumuro M, Ando Y, Akaishi A. Low-temperature desiccant-based food drying system with airflow and temperature control. J Food Eng. 2006;75(1):71–7.

[8] Foley NJ, Thomas KM, Forshaw PL, Stanton D, Norman PR. <[4HC]Kinetics of Water Vapor Adsorption on Activated Carbon.pdf>, 1997;101(7):2083–9.

[9] Tso CY, Chao CYH. Activated carbon, silica-gel and calcium chloride composite adsorbents for energy efficient solar adsorption cooling and dehumidification systems. Int J Refrig [Internet]. 2012;35(6):1626–38. Available from: http://dx.doi.org/10.1016/j.ijrefrig.2012.05.007

[10] Sharma GP, Verma RC, Pathare PB. Thin-layer infrared radiation drying of onion slices. J Food Eng. 2005;67(3):361–6.

[11] Praveen Kumar DG, Hebbar HU, Ramesh MN. Suitability of thin layer models for infrared-hot air-drying of onion slices. LWT - Food Sci Technol. 2006;39(6):700–5.

[12] Sarsavadia PN, Sawhney RL, Pangavhane DR, Singh SP. Drying behaviour of brined onion slices. J Food Eng. 1999;40(3):219–26.

[13] Lewis W. The Rate of Drying of Solid Materials. Journal Ind Eng Chem. 1921;65(1):427–31.

[14] Diamante LM, Munro PA, North P, Zealand N. Mathematical Modelling of The Thin Layer Solar drying of Sweet Potato Slices. Sol Energy. 1993;51(4):271–6.

[15] Mota CL, Luciano C, Dias A, Barroca MJ, Guiné RPF. Convective drying of onion: Kinetics and nutritional evaluation. Food Bioprod Process. 2010;88(2–3):115–23.

[16] Lu PM. Effects of pretreatments on the quality of open-air and solar dried apricots. 1996;137–41.

[17] Lekshmi P, Shobi M. GC-MS Characterization of Volatile Odorous Compounds in Allium Cepa. Nanobio Pharm Technol. 2014;(October).

[18] Karaaslan M, Yılmaz FM, Çesur Ö, Vardin H, Iknici A, Dalgiç AC. Drying kinetics and thermal degradation of phenolic compounds and anthocyanins in pomegranate arils dried under vacuum conditions. Int J Food Sci Technol. 2014;49(2):595–605.

[19] Chen Z, Xu MJ, Wang C, Zhou H, Fan L, Huang X. Thermolysis kinetics and thermal degradation compounds of alliin. Food Chem [Internet]. 2017;223:25–30. Available from: http://dx.doi.org/10.1016/j.foodchem.2016.12.011

[20] Lombard K, Peffley E, Geoffriau E, Thompson L, Herring A. Quercetin in onion (Allium cepa L.) after heat-treatment simulating home preparation. J Food Compos Anal. 2005;18(6):571–81.