Simulation of natural drying kinetics of carrot (*Daucus carota* L.) on thickness variation

B Haryanto*, T R F Sinuhaji, E A Tarigan, M B Tarigan and N A Br Sitepu
Department of Chemical Engineering, Faculty of Engineering, Universitas Sumatera Utara, Medan, Indonesia.

E-mail: *bode.haryanto@usu.ac.id

Abstract. Drying is an easy method to apply and dependent on the type of sample on drying in food preservation. Natural drying uses simple materials and equipment. Sunlight uses as an energy resource to dry the sample. In this research, carrot used as drying samples with thickness variations. After 8 days, the largest weight loss value was found in sample 3 with a total reduction of 16.76 mg then, sample 2 was 8.64 mg and sample 3 was 5.10 mg. The best conditions for drying materials are open with directly exposed to direct sunlight with the average temperature was 31 °C. That was in comparing with sample in a room condition naturally at 27 °C and during raining at 25 °C. This study obtained that the kinetic drying models on carrot impacted by the sample thickness, the adding of drying time, and temperature of the drying operation area.

1. Introduction
Carrots (*Daucus carota* L.) are a type of tuber vegetable and are known to the public as a source of vitamin A. Carrots contain carotenoid compounds, especially beta-carotene (β-carotene), which are precursors of vitamin A, which can also function as antioxidants. In food technology research, studies on how to process foodstuffs are linked to nutrition, fortification of foodstuffs with essential nutrients, and the utilization of certain foodstuffs in their processing, many are carried out to meet the growing food needs [1].

Drying is the transfer of heat and water vapour simultaneously, which requires heat energy to evaporate the water content removed from the surface of the material, which is dried by the media which is usually a hot dryer [2]. Dehydration is one of the oldest food preservation methods and is a very important aspect of food processing. Longer shelf life, product diversity, and large volume reduction are the main reasons for the popularity of dried fruits and vegetables. Drying of heat-sensitive biomaterials such as fruits, vegetables, and so-called wellness, or functional foods, requires special techniques to avoid product degradation due to thermal decomposition, oxidation, or enzymatic browning. Many approaches have been tried to improve the quality of vegetable products [3].

Drying of fruits, crops, and agriculture in the open sun has been widely practiced in the world for centuries and is still by far the most common agricultural processing industry. Drying techniques specific to each region and commodity are drying techniques that are usually carried out in open sunlight. The material to be dried is formed into a thin layer on the ground/mat or plastic sheet and exposes it directly to the sun and wind; the product is sometimes stirred to ensure uniform drying [4].
Research on drying is mostly done, various methods are used to get the best results. Examples of such methods are open drying with samples such as cherry tomato [3], solar drying such as rice [5], comparative study of sun drying and solar tent such as fish [6], indoor forced convection such as papad [7] drying cabinet (tray dryer) such as cabbage [8], ginger [9], turmeric herbal [10], far-infrared dryer such as red ginseng [11], oven tray dryer such as seaweed [2], and etc.

The Lewis model proposes that during drying the material is hygroscopic. The moisture content of the material changes in the period of decreasing rate is proportional to the difference between the moisture content and the equilibrium moisture content. Page's model modified Lewis's model to get a more accurate model by adding a constant n and used it in the drying mathematical model [12].

The aim of this study is to obtain the drying kinetics model with thickness variation in carrot samples. This kinetic model is obtained from the reduction of sample weight to the sample thickness and drying time.

2. Materials and methods

The materials used in this study were carrots purchased at traditional markets in Selayang, Medan. The tools used for this research were cutters and rulers. Samples were prepared in a round shape, with three thickness variations: 0.3 cm, 0.5 cm and 1.0 cm. The material is then weighed with a digital balance device HARNIC brand model EAH901. The three samples were made into three forms, namely when indoors in sunny conditions, indoors in cloudy or rainy conditions, and when conditions are outdoors. The conditions that were recorded were outdoor conditions and the other two conditions were only used as a comparison of the amount of mass lost.

Samples were ready to be dried and placed on a tray base then exposed to direct sunlight for outdoor conditions. Drying was done openly with an online environmental temperature analysis like the example in Figure 1 and was used to determine environmental conditions such as relative humidity, precipitation, and, local air rate. This data was an approximation because of the coverage for local and large. The OPPO F11 with camera 48 megapixel was used to collect the image of the sample.

![Figure 1. Openly online environment temperature](image-url)
To determine the drying kinetics, weight reduction is measured with a digital balance HARNIC until
the change in weight is stable at the appropriate time interval. The samples weight loss on results was
calculated by equation 1:

\[
\text{Weight loss (t)} = W_0 - W_t
\]  

(1)

Calculation on the drying kinetics was applied the equation (2) [13]:

\[
\text{Drying rate} = \frac{\text{Weight (t)} - \text{Weight (i)}}{\text{dt}}
\]  

(2)

Where, \(W_0\) is the weight of wet carrot before drying and \(W_t\) is the weight of the dry carrot at specified
time are stopped after Weight lost (t) be constant.

The Lewis model assumes that the material is thin enough or the air velocity is very thin and that the
drying air conditions such as temperature and relative humidity (\(R_H\)) were constant. The Page model
adds the constant \(n\) and is used in the Lewis mathematical model, the equation becomes (equation 3)
[12]:

\[
\text{MR} = \frac{M_t - M_e}{M_i - M_e} = e^{kt^n}
\]  

(3)

Where \(M_t\) is the moisture content (dry basis) at various times \(t\); \(M_e\) is the equilibrium water content; \(M_i\)
is the initial moisture content of the ingredients; and \(k\) is the drying constant; and \(MR\) is as moisture
content ratio. This study was measured the drying kinetic model based on reduction of sample weight
to the sample thickness and drying time by applied equation (1) and (2) [13].

3. Results and discussion
In Table 1 explains the samples used in this study. There are three samples of carrot with different
thickness. The weight of samples increasing by increased the thickness.

| Table 1. Identification of the physical properties of carrots obtained in the experiment |
|-----------------------------------------------|
| Sample | Thickness (cm) | Shape   | Weight (mg) | Rho (mg/ml) |
|--------|----------------|---------|-------------|-------------|
| 1      | 0.3            |         | 5.74        |             |
| 2      | 0.5            | Rounded | 9.56        | 1.29        |
| 3      | 1.0            |         | 18.5        |             |

Figure 2 shows the model of kinetics drying at the first day. During seven hours drying time the
sample weight was decreased as for the sample 1, the initial weight 5.74 mg became 0.86 mg. For sample
2 the initial weight was 9.56 mg for seven hours and the weight was 2.82 mg. The sample 3 the initial
weight was 18.50 mg for seven hours was decreased to 8.10 mg. The weight reduction from the
beginning of drying to the seventh hour according to the equation (1) were 4.88 mg for sample 1, 6.74
mg for sample 2 and 10.40 mg for sample 3. This shows a portion of the weight in the sample has
disappeared into the air, the mass loss is the water content in carrots.

The purpose of the drying process is to reduce the water contained in the material [14]. The speed at
which water is released from the material is influenced by several factors, which in general are divided
into two groups, namely external factors and factors within the material itself. The external factor is the
state of the environment where the material is located. Temperature, humidity and airflow circulating in
it are environmental factors. Natural drying is a way of drying without regulating the three external
factors that affect the rate of decrease in water content. The temperature, humidity and airflow
circulating around the material depend on nature (weather) where the material is dried. Therefore, the natural drying process requires a long time [15].

![Figure 2. The drying kinetics model on first day](image1)

![Figure 3. Drying trend by adding the days, day 1st until day 8th](image2)

Figure 3 is a profile form showing the reduction in overall sample weight to constant sample weight shown on the eighth day. In Figure 3, the constant weight in sample 1 after H1 to H2 was 0.64 mg, for sample 2 after H5 to H6 was 0.92 mg and sample 3 after H7 to H8 was 1.74 mg. In sample 1 the weight reduction from the beginning of drying to the end of drying at the eighth day according to the equation (1) was 5.10 mg, for sample 2 was 8.64 mg and sample 3 was 16.76 mg.

When a material is sun-dried the material is spread in a thin layer on flat ground and exposed to the sun, wind, and other atmospheric conditions. In this system, heat and mass transfer occur simultaneously; solar radiation heats the exposed surface of the material bed and part of this energy is transferred from the surface to the base of the bed by conduction from material to material and by convection of air within the bed to raise the temperature of material deeper within the bed. As the bed heats, the water vapour deficit between the air within the bed and the materials increases, and the grain
begins to dry. This cause the air deeper in the bed will be cooler and more saturated with water vapour than air near the surface of the bed. For this reason, the samples need to rotate of shallow beds to the surface to increase the rate of drying. Some of the heat absorbed by the material bed can also be lost by conduction to the ground below the material bed [5].

From the study process, it was found that the biggest decrease in the weight of the sample on the first day of drying. In accordance with the previous explanation that sunlight heats the top surface of the sample and around the base of the sample. The heat will also be conducted to touch the base of the sample. The displacement process also takes place in a capillary manner when the top of the sample starts to dry. Water moves through the sample pores to diffuse into the air. the base portion of the sample heats and speeds up the capillary and diffusion processes. In the last days, the rate of mass reduction begins to decrease because a certain amount of water content is trapped in the material. Need more heat to release the retained water.

Figure 4. The weight loss of samples in various condition: raining in room (A), in room (B) and open area (C)

Figure 4 shows weight loss of samples when performed under various conditions. Condition A was the samples that is treated under rain conditions in a closed room. Condition B was the samples in a room condition conditions naturally and C was treated in outdoor conditions with direct sunshine. The measured temperature was the average temperature of each condition when in condition A, the average temperature was 25°C, at B was 27°C, and at condition C was 31°C. From Figure 4 explains the reduction in total weight with the highest occurs in condition C or in conditions outdoors. The best conditions for drying materials are open conditions that are directly exposed to sunlight. In accordance with the results shows the graph in the case of C with the highest position in all treatment on each samples.

Temperature, humidity, and airflow circulating are environmental factors. Natural drying is a way of drying without regulating the three external factors that affect the rate of decrease in water content. The temperature, humidity, and airflow circulating around the material depend on nature (weather) where the material is dried. Therefore, the natural drying process requires a longer time [15]. Figure 5 is shown the changing of surface characteristic before Figure 5A and after drying Figure 5B. This shows a portion of the weight in on thickness variation the sample has disappeared into the air, the mass loss is the water content in carrots then change the surface and internal physical of the carrot.
4. Conclusions
From the research process, it was found that the largest decrease in drying days was at the initial time. In the last days, the mass loss rate began to decrease because some water content was trapped in the material. More heat is needed to release retained water. In this study, the largest weight loss value was found in sample 3 which was round and 1.0 cm thick with a total reduction of 16.76 mg. The best conditions for drying materials are open conditions that are directly exposed to direct sunlight, this condition is the highest temperature compared to other conditions.

References
[1] Yudiar H, Lindayani L and Nugrahedi P Y 2012 Perubahan kandungan karoten dan aktivitas antioksidan pada wortel (Daucus carota) selama proses perebusan [Changes in carotene content and antioxidant activity in carrot (Daucus carota) during the boiling process] VITASPHERE 2 pp 27–36
[2] Suherman S, Djaeni M, Kumoro A C, Prabowo R A, Rahayu S, and Khasanah S 2018 Comparison drying behavior of seaweed in solar, sun and oven tray dryers MATEC Web of Conferences 156 pp 1–4
[3] Ismail O and Akyol E 2016 Open-air sun drying: the effect of pretreatment on drying kinetic of cherry tomato Sigma J Eng & Nat Sci 34 pp 141–51
[4] Sodha M S, Dang A, Bansal P K and Sharma S B 1985 An analytical and experimental study of open sun drying and a cabinet type dryer Energy Convers. and Mgmt 25 3 pp 263–71
[5] Meas P, Paterson A H J, Cleland D J, Bronlund J E, Mawson A J, Hardacre A, and Rickman J F 2011 Effect of different solar drying methods on drying time and rice grain quality International Journal of Food Engineering 7 5 pp 1–11
[6] Ojutiku R O, Kolo R J, and Mohammed M L 2009 Comparative study of sun drying and solar tent drying of Hyperopisus bebe occidentalis Pakistan Journal of Nutrition 8 7 pp 955–71
[7] Kumar M, Khatak P, Sahdev R K and Prakash O 2011 The effect of open sun and indoor forced convection on heat transfer coefficient for the drying papad Journal of Energy in Southern Africa 22 2 pp 40–6
[8] Sakhale B K and Pawar V N 2007 Studies on the effect of drying modes on quality of dehydrated...
cabbage Jurnal. Teknol. dan Industri Pangan 8 pp 55–8
[9] Haryanto B, Hasibuan R, Alexander, Ashari A and Ridha M 2018 Herbal dryer: drying of ginger (Zingiber officinale) using tray dryer. IOP Conf. Ser.: Earth Environ. Sci 122 pp 1–5
[10] Haryanto B, Hasibuan R, Lubis A H, Wangi Y, Khosman H and Sinaga A W 2020 Drying rate of turmeric herbal (Curcuma longa L) using tray dryer Phys. Conf. Ser. 1542 pp 1–6
[11] Ning X, Liu D, Lee J and Han C 2015 Drying characteristics and quality of red gingseng using far-infrared rays Journal od Ginseng Research 39 pp 371–5
[12] Muhandri T, Gina N R, Subarna, and Purwiyatno H 2018 Model laju pengeringan spaghetti jagung menggunakan tray dryer (Drying model of corn spaghetti using tray dryer) J. Teknol. dan Industri Pangan 26 2 pp 171–8
[13] Lee D, Dongyoung, Jung D S, Jung HM, Mo C, and Lee S H 2018 Investigation of drying kinetics and color characteristics of white radish strips under microwave drying J. Biosyst. Eng. 43 3 pp 237–46
[14] Purwanto D 2009 Pengaruh pengeringan alami dan buatan terhadap kualitas kayu galam untuk bahan mebel (The influence of natural and artificial drying foward the quality of galam wood (Melaleuca Cajuputi) for furniture material) Jurnal Riset Industri Hasil Hutan 1 pp 1-7
[15] Hidayat S and Suparman K 1985 Sifat pengeringan alami dan pengeringan sinar matahari sebelas jenis kayu asal kalimantan barat (Air and solar drying properties of eleven timber species from West Kalimantan) Jurnal Penelitian Hasil Hutan 2 2 pp 5-9