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Research

Experimental Evaluation of Apple Drying Process In A Fluidized Bed Dryer

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Abstract

The drying rate of apple cubes was determined to utilize the shallow fluidized bed dryer. The drying process was performed at different drying temperatures and an air velocity of 3.1 m/s. The mass of apple cubes was measured every 5 minutes along with the wet and dry bulb temperatures and the dimension of apple cube sample. This procedure was continued until a steady state was reached. This study made available information about the relationship between drying rate and time of drying, saturated humidity, the water content in the gas phase, drying rate constant, mass and heat transfer coefficient, and shrinkage. The drying rate constant was estimated to be 14.38 (Kg water/m^2. min) and the shrinkage reached to about 0.267 after 50 minutes at drying temperature of 90 ^{o}C and an air velocity of 3.1 m/s

Keywords: Drying Process; Fluid Bed Dryer; Drying Rate Constant; Heat And Mass Transfer

Introduction

The drying process is one of the important methods of preservation of wet materials and it applicable to many industrial and agricultural products such as foodstuffs. The drying process can be carried out either mechanically or thermally. Mechanical drying can be done by several techniques such as centrifugation, filtration, or sedimentation without any change in phases while thermal drying is using heat as a source for water removal. This process is a heat and mass transfer phenomenon where water migrates from the interior of the drying product on to the surface from which it evaporates. Heat is transferred from the surrounding air to the surface of the product. A part of this heat is transferred to the interior of the product, causing a rise in temperature and formation of water vapor, and the remaining amount is utilized in evaporation of the moisture from the surface [1].

The hot air increases the heat transfer and makes the drying process much faster. The moisture content is present in two places, at the surface and internally at the core of the wet solid. The hot air decreases the moisture at the surface until it is entirely evaporated and then moved to the moisture within the wet solid, where it will move from the core to the outside surface to evaporate. Many methods of drying processes have been developed for particulate materials, including fluidized-bed and spouted-bed drying techniques. Considering the thermal efficiencies of the drying process, fluidized bed dryers are commonly used in particulate foods drying because they ensure high intensities of heat and mass transfer and high rates of drying [2]. The high quality of dried foodstuffs, including fruit, vegetables, and grain can be obtained by fluidized bed drying [3,4]. A model was developed to describe the heat and mass transfer during the drying process of carrot cubes in a spout-fluidized-bed drier [5]. They incorporated the homogeneous shrinkage of the material in their final model. The predicted changes in both the moisture content and the temperature of carrot cubes showed that the model can be successfully applied to describe moisture content, temperature, and deformation of dried particles in situations where the very high accuracy of moisture content and temperature prediction is not crucial to the investigation of the drying process. Six types of potatoes were dried using tray dryer, with and without air circulation using a fluidized bed dryer [6]. Also, samples were tested with and without bleaching. Shrinkage was found to be insensitive to temperature changes but significantly affected by blanching

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time and air circulation. Bleaching time and air circulation were also found to affect the appearance of the dried product. The computer-aided vision was developed to analyze the effect of drying on shrinkage of potato slices [7]. It was found that all morphological features decreased steadily with drying time. Also, shrinkage of the potato slices decreased almost linearly with moisture content. They concluded that airflow direction had a significant effect on the parallel and perpendicular diameters at 60 and 70 °C and had no significant effect when the temperature was raised to 80 °C. Potato cubes were also bleached and partially dried in cabinet drier prior to puffing in high-temperature fluidized bed drier [8]. The formation of a partially dried layer on the surface of the cubes was necessary to achieve puffing. The shrinkage of any foodstuff is a common physical phenomenon during the dehydration process. These changes affect the quality of the dehydrated product and need to be taken into consideration when the prediction of moisture and temperature profile is required to study [9]. The airflow velocity effect on the kinetics of convection drying of apple, the heat transfer, and effective diffusion coefficient was investigated [10]. The drying was conducted using tray dryer at a temperature of 60 °C and rectangular shape apple samples. Two well-defined falling periods and short constant rate period at lower air velocities were observed. Increasing in airflow showed an increase in heat transfer coefficient and effective diffusion coefficient. The effect of air temperature and two different shapes (cuboidal and cylindrical) on the drying kinetics of potato in fluidized bed dryer was investigated [11]. Drying was carried out at different temperatures. During moisture transfer from potato were described by Fick's diffusion model. Two mathematical models were fitted to experimental data. The Page model gave better fit than the simple exponential model. The Arrhenius activation energy value expresses the effect of temperature on diffusivity. A laboratory scale cabinet dryer was constructed with an attached weighing balance to calculate changes in the weight of the product without removing it from the dryer [12]. The effect of process parameters (temperature and thickness) on the drying kinetics of potato showed that the drying process was characterized by a decrease in the moisture ratio with time and showed a non-linear behavior. No constant rate drying period in the entire process was obtained and all the drying process occurred in the falling rate period, showing that drying in this experiment was mainly controlled by a diffusion mechanism. The effect of air temperature and cuboidal and cylindrical shapes of drying potato in fluidized bed dryer was investigated [13]. Two mathematical models were fitted to experimental data. The Page model gave better fit than simple. The moisture content in potato decreased with increase in drying air temperature. The fluidized bed drying of potato took place in the falling drying rate period. The drying rate decreased with a decrease in moisture content of potato at different air temperatures. Drying constants in exponential and Page models increased with increase in air temperature. The mathematical model to study the drying characteristic of apple and potato during thin-layer drying was also proposed [14]. Fruits and vegetables are porous in nature and undergo pronounced shrinkage during convective drying process [15]. Potato slices were subjected to the drying process. Shrinkage varies linearly with respect to moisture content and reduction in radial dimension of potato slices and porosity undergoes rapid increase after attaining certain moisture content in final stages of drying. Cassava, yam were dried with a drying time of 150 minutes and 60°C to reduce the moisture content of cassava and yam from 75.4% to the equilibrium moisture content of 11% [16]. While the sun drying of cassava took 72 hrs with an average ambient temperature of 30°C for the same moisture change. The influences of the temperature and air flow rate of drying air on energy parameters and dehydration behavior of apple slices was studied [17]. Dehydration rate increased as the air temperature and flow rate increased. The results showed that any increment in the air temperature increases thermal and drying efficiencies while any increment in the airflow rate decreases both of them. The drying process can be used to study the drying kinetics and determine many other parameters such as drying rate, time and minimum fluidization velocity [18]. The drying kinetics can be found using equation (1) as follows:

$$\frac{dW}{dt} = kA(H_s - H_g)$$

*w*here w is mass of potato, k is the mass transfer coefficient, A is surface area of the potato cubes , H_s is saturated humidity, and H_g is the gas humidity The Antoine equation (2) can be applied to find the saturated pressure.

$$Log\ P*(\text{mmHg})=\text{A-}\frac{B}{C+T}$$

*w*here $P*$ is saturated pressure, T is wet bulb temperature, and *A, B, and C* are constant

The saturated humidity can then be calculated using equation (3):

$$Hs = \frac{MwH2O.P*}{Mw\ air(P\ atm - P*)}$$

where H_s is saturated humidity, Mwt_{H2O} is molecular weight of water, Mwt_{air} is molecular weight of air, and P is atmospheric pressure.

Hg can be measured from the wet and dry bulb temperatures using the psychometric chart. Shrinkage is the surface area of a specimen at any time divided by the original surface area before drying. In studying the surface/air relationships, it is necessary to consider mass and heat transfer simultaneously. The specific mass transfer coefficient (K') is a combination of k and surface area (m^2/min). The heat transfer coefficient is obtained from the following equation (4):

$$\frac{dw}{dt} = \frac{hA(T_{dry} - Ts)}{L}$$

Where h is heat transfer coefficient, T_{dry} is dry bulb temperature, T_S is wet bulb temperature, and L *is* latent heat of water.

$$\frac{hA(T_{dry} - T_s)}{L} = kA(H_s - H_g)$$

This expression is only valid at equilibrium when the latent heat of vaporization and the sensible heat are in equilibrium. The two expressions of mass and heat transfer are equal at equilibrium, which leads to:

For the particles to be fluidized during the drying process the gas flow through the bed has to be above the minimum fluidization velocity. The minimum fluidization velocity can be calculated from the Kunii-Levenspiel equation (6). The Galileo number (Ga) can be calculated as follows [19-21]:

$$Ga = 150 \cdot \frac{1-\varepsilon_{mf}}{\varepsilon_{mf}^3 \cdot \Phi^2} \cdot Re_{mf} + \frac{1.75}{\varepsilon_{mf}^3 \cdot \Phi} \cdot Re_{mf}^2$$

$$Ga = \frac{d^3 \cdot \rho \cdot (\rho_s - \rho) \cdot g}{\mu^2}$$

$$Re_{mf} = \frac{u_{mf} \cdot d \cdot \rho}{\mu}$$

The shape factor Φ (sphericity) is:

$$\Phi = \frac{\text{suface area of sphere equivalen volume}}{\text{surface area of flake equivalent volume}}$$

The dependence of drying rate constant K_H with drying absolute temperature T can be evaluated by applying Arrhenius type equation as follow [22]:

$K = K_o \exp [-Ea/ RT$

where,

K =drying rate constant, g air/ m2.h

K_o = Reference value of drying constant, hr^{-1}

Ea = Energy of activation. J. $mole^{-1}$. K^{-1}

R= Universal gas constant. J. $mole^{-1}$. K^{-1}

T= absolute temperature, K

Parameters Ko and Ea can be estimated using drying constant and its reference value, respectively.

The shrinkage of foodstuff is a common physical phenomenon during drying processes. This change affects the quality of the dehydrated product and should be taken into consideration when predicting moisture and temperature profiles in the dried material [23]. The percentage of shrinkage can be calculated as follows:

Where V_0 and V are the volume (ml) of apple at the beginning and at the end of the drying experiment respectively.

Experimental Work

The setup used for this study is the Sherwood Scientific Fluid Bed Dryer as shown in Figure 1.

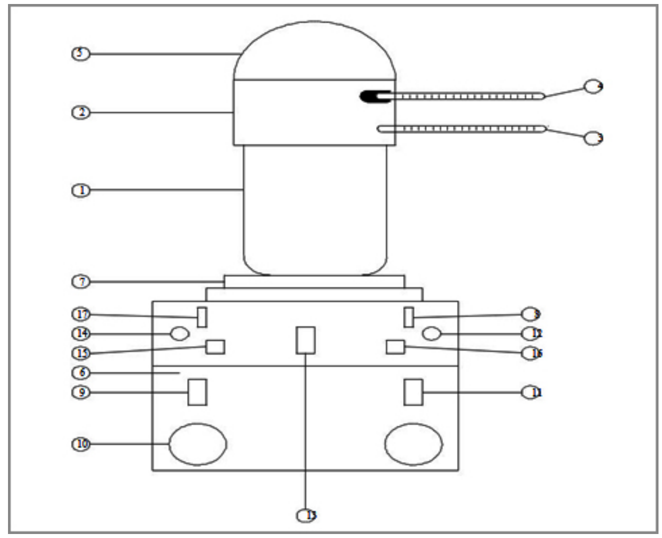

Figure1: Sherwood Scientific Fluid Bed Dryer [24]

The fluid bed dryer consists of a 2 liters glass jar (1) equipped with a metal clamp (2) that hold a dry thermometer (3) and a wet bulb thermometer (4). These are used to determine the humidity of the fluid bed exhaust air. The fluid bed is topped by a nylon bag (5) that allows the exhaust air to pass but retains any particles entrained in the air stream. The fluid bed is mounted on a fluidization unit (6). The fluid bed can be screwed on and off the mount (7). The main power supply is switched on by a switch (8). Blower delivers the airflow. The power supply to the blower is switched on by a switch (9). The air speed is controlled on the knob (10). The air is heated by an internal 2 kW heater that can be turned on and off by a switch (11). The air temperature is controlled by knob (12), the maximum temperature is 200 °C. The drying process can be run in either manual or automatic mode according to the position of the switch (13). In automatic mode, the cycle time is set by a knob (14). The cycle time can be varied between 0 and 6 hours. The cycle was started by pressing the start button (15). In manual mode, the drying processes are started by pressing the start button (15) and stopped by pressing the stop button (16). The LED (17) is lit if the main power supply is on.

The apple was skin peeled, cut into small uniform cubes of about 4 mm, and predetermined amounts were used in subsequent tests. The air speed and hot air were kept at constant values of 3.10 m/s and 90 °C, respectively. The equipment was operated and the hot air was flown through the empty bed until the temperature reached a constant value. The apple cubes were then introduced to the jar. The mass, dry and wet bulb temperatures and dimensions of the apple cubes were measured every 5 minutes until a constant mass was reached [24].

Results And Discussion

The drying rate of apple was plotted against drying time on a histogram plot (Figure 2). The plot shows a decrease in drying rate with time. Also, the drying rate was plotted with the average time and the results are shown in Figure 3. The results show that the drying rate is fastest up to 30 minutes and then remains almost constant at times higher than 35 min.

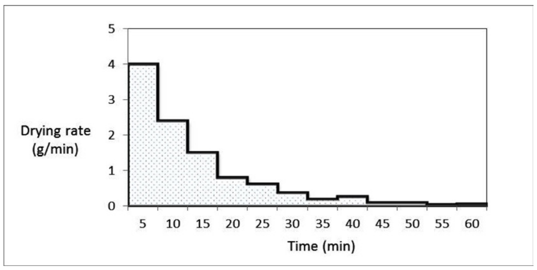

Figure 2: Drying rate of apple as a function of time

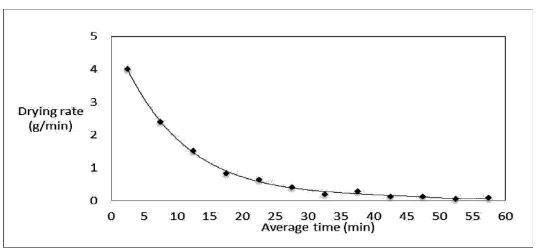

Figure 3: Drying rate of apple versus the average time

The gas humidity was calculated from the information of the wet and dry bulb temperature using the psychometric chart and the results are plotted in Figure 4. The trend in Figure 4 shows that the apple-drying rate is inversely related to the gas humidity with a zero rate for gas humidity values of more than 0.1. The saturated humidity was calculated using Antoine equation from the wet bulb temperature information and the results are shown in Figure 5. Similar to Figure 4, Figure 5 exhibited a decrease in the apple-drying rate with increasing humidity.

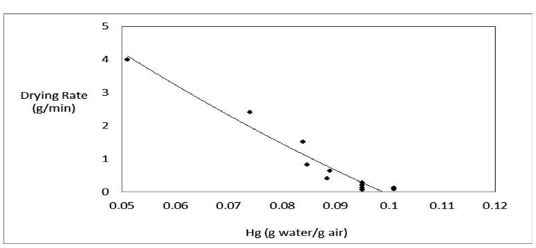

Figure 4: Drying rate of apple with gas humidity

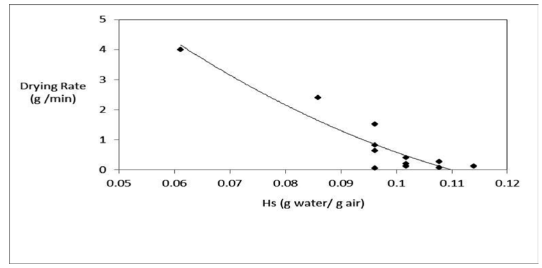

Figure 5: Drying rate of apple with saturated humidity

Figure 6 illustrates the relationship between the apple drying rate and the humidity variance (Hs-Hg). The slope of the best straight line K_H is equal to 14.38 (Kg water/ m^2.min)

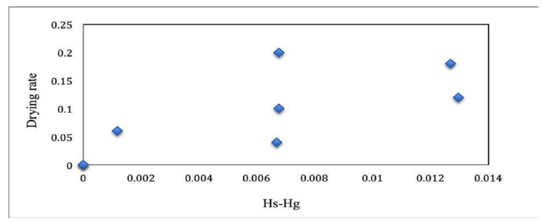

Figure 6: Drying rate of apple with (Hs-Hg)

The two expressions of mass and heat transfer are equal at equilibrium, which leads to:

$$\frac{hA(T_{dry}-Ts)}{L} = kA(H_s - H_g)$$

Let h' represents the terms (h.A), Ta=T_{dry}, Ts= T_{wet} and the latent heat of water (L = 2257 kJ/kg)

=1.59 W/K

Drying behavior of solids can be described by measuring the loss of moisture content versus time. Continuous weighing, humidity difference, and intermittent weighing were performed [25]. The moisture content of drying apple was plotted as a function of time (Figure 7). The figure shows a decrease in the moisture content due to evaporation with drying time.

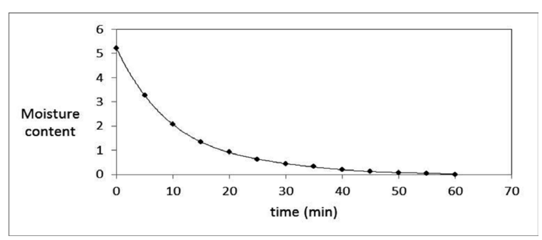

Figure 7: Moisture content of apple with time

The moisture content drops by more than 60% during the first 10 minutes, the moisture content had evaporated within 60 minutes. The drying curve of apple can be divided into three main regions; the constant, first falling and second falling period. The constant period is independent of the moisture content. Additionally, in this stage, a continuous film of water covers the solid. Depending on the porosity of the solid, the water may be removed either superficially (non-porous) or from the interior (porous). The moisture content continues to decrease until it reaches a critical moisture content point (beginning of the falling period). The falling period can occur either through liquid diffusion or capillary flow (this again depends on porosity). The moisture content versus time is sharply decreasing from 5.1 to 1.3 g water/g dry solid from starting drying times to 15 minutes. After that, the rate of decrease in the moisture content becomes less, which means a lower drying rate. This lower rate is due to lower moisture content as time progresses. Lower moisture content results in lower driving force and thus lower mass transfer. The collapse of the drying curves at the beginning of the process indicates that drying is controlled by external conditions. When the curves deviate from each other, internal mass transfer resistance mainly controls drying. The drying curve can estimate by plotting the drying rate versus the moisture content (Figure 8).

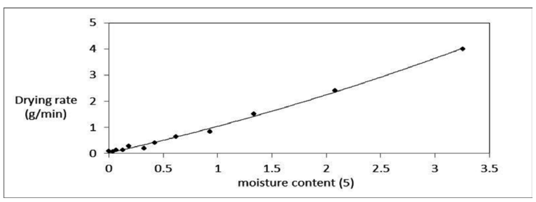

Figure 8: Drying curve of apple

Drying process generally occurs in two different periods; namely constant rate period and falling rate period. It is seen that constant drying rate period is very short and falling rate period can be divided into two parts, first and second falling rate period. The work was repeated with the same air velocity of 3.1 m/s but the drying temperature was changed to 70 ^{o}C and 80 ^{o}C to apply Arrhenius type equation to determine the activation energy. The Arrhenius equation was applied. Figure 9 showed that the activation energy was equal to 19.736 Kjoule / mole.

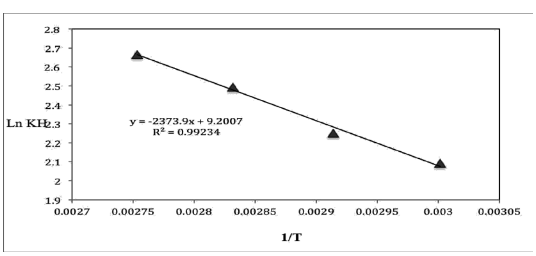

Figure 9: Arrhenius equation application

The shrinkage is the surface area of a specimen at any time divided by the original surface area before drying. The shrinkage of apple cubes was measured each time interval (5 min) and plotted as a function of time as given in Figure 10. The shrinkage was measured by measuring the dimensions of apple cube sample before and after drying the ratio of the surface area before and after drying was regarded as shrinkage ratio. The shrinkage ratio was dropped to a value of 0.267 within 50 min and almost stayed constant until the end of the experiment.

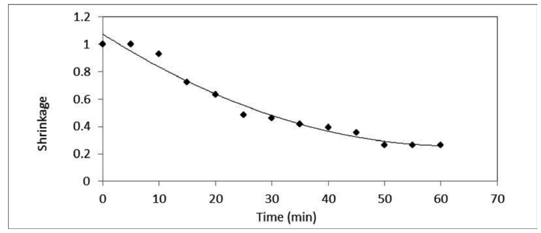

Figure 10: Shrinkage versus time for apple drying process at 90oC and blower velocity of air is 3.10 m/s

Figure 10: Shrinkage versus time for apple drying process at 90^{o}C and blower velocity of air is 3.10 m/s

The color of the drying apples looks more yellowish than the fresh one and the drying pieces were not completely dried although the difference in mass with time was almost negligible so that it was still soft with hardcover. This was believed that it is the time to terminate the experimental work**.**

The work was repeated twice at a constant time interval. The sample was carefully selected from the same quality of apple and at the same time and the experimental procedure was followed precisely. It was found that the difference between the mass of drying apple, the dry and wet bulb temperatures were accepted and within the experimental error of about 5%. It was believed that this percentage was accepted due to the difference in water content in the apple pieces.

Conclusions

The drying process of apple was performed by exposing a wet sample to a stream of a hot flowing air helped in understanding different important concepts related to the drying process. The apple drying rate curve has been established and different drying stages have been identified. The moisture content decreased with time at a high rate than at constant rate until finally, the drying rate starts decreasing. Also, the mass and heat transfer coefficients were experimentally estimated. The shrinkage reached a value of 0.267 at a drying time of 50 minutes.

Appendix:

$\frac{dW}{dw}$

is drying rate (Kg/min)

K is the mass transfer coefficient ($\frac{Kg}{m2s}$)

θ is the drying time (min)

A is the surface area of the material

$P*$ is the saturated pressure in mmHg

A, B, and C are constants related to the material used (water)

K_H is the drying rate constant (Kg water/ m^2.min)

H_s is the saturation humidity in the gas phase (kg water/ kg dry air)

H_g - is the Water content in the gas phase (kg water/ kg dry air)

Ts is the surface temperature (°C)

T is the dry is the dry bulb temperature (°C)

Tw is the wet bulb temperature (°C)

A: Area of heat transfer (m^2)

h is the heat transfer coefficient ($W/m^2 \cdot K$)

L is the latent heat of the water (Kj/Kg) at a certain temperature

Ga is the Galileo number

Re_{mf} is the particle Reynolds number at minimum fluidization d is the particle diameter [m]

ρ_s is the particle density

u_{mf} is the gas velocity at minimum fluidization

ε_{mf} is the porosity of the bed at minimum fluidization.

Φ is the shape factor of particle, sometimes called the sphericity

References

1. El-Ghetany HH (2006) Experimental investigation and empirical correlations of thin layer drying characteristics of seedless grapes. Energy Conversion and Management 47(11-12): 1610-1620.
2. Hatamipour MS, Mowla D (2002) Shrinkage of carrots during drying in an inert medium fluidized bed. J Food Eng 55(3): 247–252.
3. Reyes A, Alvarez PI, Marquardt FH (2002) Drying of carrots in a fluidized bed. I. Effects of drying conditions and modeling Dry Technol 20(7): 1463–1483.
4. Mhimid A, Ben Nasrallah S, Fohr JP (2000) Heat and mass transfer during drying of granular products simulation with convective and conductive boundary conditions. Int J Heat Mass Transfer 43(15): 2779–2791.
5. Ireneusz Białobrzewski [a], Magdalena Zielin´ska [a], Arun S Mujumdar [b], Marek Markowski [a] (2008) Heat and mass transfer during drying of a bed of shrinking particles – Simulation for carrot cubes dried in a spout-fluidized-bed drier. International Journal of Heat and Mass Transfer 51(19-20): 4704–4716.
6. Hatamipour MS, Hadji Kazemi, Nooralivand A, Nozarpoor A (2009) Drying characteristics of six varieties of sweet potatoes in different dryers. Food and BioProducts Processing 85(3):171-177.
7. Alireza Yadollahiniaa, Acefeh Latifib, Reza Mahdavi (2009) New method for determination of potato slice shrinkage during drying. Computers and electronics in agriculture 65(2): 268–274.
8. Varnails AI, Brennan JG, MacDougall DB (2001) A proposed mechanism of high temperature puffing of potato. Part I. The influence of bleaching and drying conditions on the volume of puffed cubes. Journal of Food Engineering 48(4): 361-367.
9. Mayor L, Sereno AMM (2004) Modeling shrinkage during convective drying of food materials: a review. Journal of Food Engineering 61(3): 373-386.
10. Velic D, Planinic M, Tomas S, Bilic M (2004) Influence of air flow velocity on kinetics on convection apple drying. Journal of Food Engineering 64(1): 97-102.
11. Sushant B Bakal, Gyanendra P Sharma, Somnath P Sonawane, Radhachran C Verma (2012) Kinetics of potato drying using fluidized bed dryer. Journal of Food Science and Technology 49(5): 608-613.
12. Rifat Jabeen, Tahmeed Aijaz, Khalid Gul (2015) Drying kinetics of potato using a self-designed cabinet dryer. Cogent Food &Agriculture 1(1): 1-5.
13. Sushant B Bakal, Gyanendra P Sharma, Somnath P Sonawane, Radhachran C Verma (2012) Kinetics of potato drying using fluidized bed dryer. J Food Sci Technol 49(5): 608–613.
14. Fateh Singh, Katiyar VK, Singh BP (2014) Mathematical Modeling to Study Drying Characteristic of Apple and Potato. International Conference on Chemical Environment & Biological Sciences (CEBS-2014) Sept. 17-18 Kuala Lumpur (Malaysia).
15. Prajeeta J, Gopirajah R, Anandharamakrishnan C (2015) Shrinkage and porosity effects on heat and mass transfer during potato drying. Journal of Food Engineering 144: 119–128.
16. Okoronkwo CA, Nwufo OC, Nwigwe KN, Ogueke NV, Anyanwu EE (2013) Experimental Evaluation of A Fluidized Bed Dryer Performance. The International Journal Of Engineering And Science (IJES) 2(6): 45-53.
17. Mohsen Beigi (2016) Energy efficiency and moisture diffusivity of apple slices during convective drying. Food Sci Technol Campinas 36(1): 145-150.
18. Christie J Geankoplis (2003) Transport Processes and separation process principles (Includes Unit Operations) 4th edition Prentice-

Hall International Inc USA.

19. Keavins DL, ed Fluidization Technology vol I and II Washington DC Hemisphere Publishing Co in association with McGraw-Hill I(1975) II(1976).

20. Kunii D, Levenspiel O (1968) Ind Eng Chem. Process Design Devel 7(4): 481-596.

21. Kunii D, O Levenspiel (1991) Fluidization Engineering 2nd Ed (Boston: Butterworth).

22. Sushant B Bakal, Kishor H Gedam, Gyanendra Prakask Sharma (2010) Drying characteristics and kinetics of fluidized bed dried potato. Agriculture and Food Science 19(2): 127- 135.

23. Darko Velić, Mate Bilić, Srećko Tomas, Mirela Planinić, Ana Bucić-Kojić, et al. (2007) Study of the Drying Kinetics of "Granny Smith" Apple in Fluid Bed Dryer Agric conspec Sci 72(4): 329-334.

24. Christensen, KV, Al Zubaidi, Aidan A (2002) Chemical Engineering Laboratory Manual. 2nd edition American University of Sharjah, School of Engineering, American University of Sharjah UAE.

25. Mujumdar, Arun S (2014) Principles, classification, and selection of dryers In Handbook of Industrial Drying fourth ed CRC Press 1348: 1075.