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STUDY ON DRYING KINETICS OF SUMMER ONION

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Abstract

The present study was concerned with the kinetics of drying of summer onion. Drying was done in a mechanical dryer at constant air flow using blanched and unblanched onion with variable temperature (52, 60 and 68^0C) and thickness (3, 5 and 7 mm). Drying rate was increased with increase of temperature and decreased with the increase in thickness in blanched and unblanched onion. Blanched onion showed higher drying rate than unblanched onion. Drying rate constant and thickness can be expressed as power low equations. The value of index "n" were found to be 1.277 and 0.845 for onion indicating that the external resistance to mass transfer was highly significant. The effect of temperature on diffusion co-efficient follows an Arrhenius type relationship. The activation energy (E_a) for diffusion of water was found 5.781 Kcal/g-mole for unblanched and 2.46 Kcal/g-mole for blanched onion when onions were dried in mechanical dryer.

Keywords: Onion**,** drying rate constant, diffusion coefficient, activation energy.

Introduction

In Bangladesh onion is mainly used as major spices and occasionally used as salad to increase the palatability of food. It is used in various ways in all curries, fried or baked. It is also used in processed from eg. flakes, powder, paste, crush and pickles. In developed countries such as USA, Japan etc. about 45% of entire output of fresh onion is dehydrated and sold to the food processors for use in salad, tomato products, biryani and in several food preparation.

Normally onion is cultivated during the Winter season in Bangladesh. But from 2001-02 it is also grown in summer season. There are three varieties of Bangladesh Agricultural Research Institute (BARI) known as BARI-2, BARI-3 and BARI-5 which are growing in summer season and their yield is 4-5 times more than winter onion. But their keeping quality is very poor.

Among the spices grown in Bangladesh, onion ranks second in acreage and first in production (BBS, 2007). More than 8.9 lakh mt. of onions are produced from about 1.28 lakh hectare area (BBS, 2007). The imported cost of onion in 2009-10 was about 1516 crore taka (Bangladesh Bank).

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Onions are available in large quantity during the harvesting season. Most of them are not utilized properly due to over supply in peak season, lack of adequate processing technology, preservation, adequate transportation and marketing facilities. As a result about 40-50 percent post-harvest losses are observed in winter onion during storage (BARI, 2010). Even the summer onion can not be kept more than 15-30 days. The losses include decay or rotting, sprouting, physiological loss of weight, splitting of bulbs, discoloration, shrinkage, descaling and rooting.

Onion contains little amount of vitamin 'B' and 'C' and trace of iron and calcium. Besides, it has got manifold medicinal values also (Arya, 2003).

Proper drying techniques as well as proper slice thickness of product are required for obtaining good quality dried products. Drying can be accomplished in a mechanical dryer, direct sunlight or solar dryer. In the mechanical dryer, desired temperature and airflow could be maintained. Compared to sun/solar drying higher airflow and temperature can be used in mechanical drying. This leads to high production rates and improved quality products due to shorter drying time and reduction of the risk of insect infestation and microbial spoilage. Since mechanical drying is not dependent on sunlight so it can be done as when necessary.

Several drying system available in the literature for explaining thin layer drying characteristics of fruits and vegetables have been used by Yoo (1988), Sharma *et al.* (2005), Kumar *et al.* (2004), and Lopez *et al* (1995) for onion and Telis *et al.* (2003) for tomato.

On the basis of the information so far accumulated, the present work has been undertaken to study the drying behavior of summer onion slices using Cabinet drying system and to examine the effect of slice thickness of onion and temperature on different drying parameter.

Materials and Method

The study was conducted in the laboratory of the Department of Food Technology and Rural Industries, under the Faculty of Agricultural Engineering and Technology, Bangladesh Agricultural University, Mymensingh.

Materials required

Fresh summer onion were collected from the Spices Research Center of BARI for conducting the laboratory study. Cabinet dryer (model OV-165 Gallenkamp Company) was used for the dehydration of summer onion. The dryer consists of several chambers in which trays of sample was dried. The velocity of air was recorded (0.6 m/s) by an Anemometer.

Mechanical drying of onion slices

For determining the effect of the temperature and the thickness on the rate of the drying onion were peeled and sliced by a slicer and samples were taken for the determination of moisture content. In some cases the onion slices were blanched in steam for five minutes using perforated wire pot. Fresh onion slices (3, 5 and 7 mm thick) were placed in trays in single layer and drying commenced in the dryer at constant air velocity (0.6 m/sec) and at a specified air dry bulb temperature (52, 62 or 68°C). Moisture content at each time interval was determined gravimetrically on the basis of initial moisture content and weight loss was used as a measure of the extent of drying.

Ficks second law of diffusion is applied to describe mass transfer during drying since food dehydration is assumed to be a diffusion process. The expression is:

$$\frac{\delta M}{\delta t} = \Delta^2 D_e M \text{ -----------------------------------}(1)$$

Where,

M= Moisture content (dry basis), T= Time and

D_e= Effective diffusion co-efficient (cm^2/sec)

To find a solution of the above unsteady state diffusion equation for one dimensional transport for the case of initial uniform moisture distribution in the sample and negligible external resistance, appropriate boundary conditions are assumed. The solution for an infinite slab (with thickness, l), when dried from one major face (Brooker *et al.*, 1974; Islam, 1980 and Crank, 1975) is:

$$MR = \frac{M_t - M_e}{M_o - M_e} = \frac{8}{\pi^2} \sum_{n=0}^{\alpha} \frac{1}{(2n+1)^2} Exp \frac{-(2n+1)^2 \pi^2 D_e t}{L^2} \text{ --------- } (2)$$

Where,

MR= Moisture ratio

M_t = Moisture content at the time t

M_o= Initial moisture content

M_e= Equilibrium moisture content respectively.

For low M_e values and for moisture ratio, MR<0.6 equation (2) reduces to:

$$MR = \frac{M_t}{M_o} = \frac{8}{\pi^2} e^{\pi^2 D_e t/L^2} = \frac{8}{\pi^2} e^{-mt} \quad or \ln MR = \ln \frac{8}{\pi^2} - mt \text{ --- } (3)$$

Where, m = $\frac{\pi^2 \; D_e}{L^2}$ = drying rate constant, sec^{-1} -----------------------------(4)

Consequently, a straight line should be obtained when plotting L_n MR versus time (t). The slope of the regression line is the drying rate constant, m for which the effective diffusion co-efficient, D_e is calculated.

The diffusion co-efficient, D_e has an Arrhenius type of relationship with drying air dry bulb temperature (abs). The relationship is as follows (Heldman, 1974).

$$\frac{dInD_e}{dT_{abs}} = \frac{E_a}{RT_{abs}}$$

$$Or, \ln D_e = \ln D_0 - \frac{E_a}{RT_{abs}} ------------------------(5)$$

Where, D_o is constant of integration and usually referred to as a frequency factor when discussing Arrhenius equation, E_a is the activation energy of diffusion of water Kcal/g-mole, R is the universal gas constant 1.98cal/g-mol, ^{0}K and T_{abs} is the absolute temperature, ^{o}k.

From equation (5), it is apparent that plotting diffusion co-efficient (D_e) versus the inverse absolute temperature on semi-logarithmic co-ordinates would lead to the evaluation of activation energy for diffusion of moisture during drying and activation energy was calculated by non-linear regression analysis.

From the semi-theoretical equation as shown in equation (3), it may be noted that the drying rate constant, m is a function of the square of thickness of the product being dehydrated, as seen in equation 4, Symbolically, this may represented as:

m = A(L)$^{-n}$

Or log(m) = log A – n log (L)---(6)

Where, A = π^2 D_e, n = 2

The above relationship shows that if external resistance to mass transfer is negligible and if simultaneous heat and mass transfer effects are taken into account, the value of the exponent of the power law equation should be 2. But the above conditions are not always satisfied and experimentally determined ‘n’ value is found to be less than 2 (Islam, 1980).

Results and discussion

The effect of thickness and temperature on drying time for blanched and unblanched onion were observed.Diffusion co-efficient and activation energy for different temperature and thickness dependency of drying rate constant were also investigated with respect to blanched and unblanched summer onion in mechanical dryer.

The effect of thickness 3, 5 and 7mm of onion slices on drying rate were observed at constant temperature, airflows and relative humidity. Another experiment was conducted by using 5 mm thick onion slices at three different air dry bulb (db) temperatures such as 52, 62 and 68^{o} C to investigate the effect temperature on drying rate. The effect of blanching on drying rate was also investigated with respect to different thickness and temperature in mechanical drying.

Effect of thickness on drying behaviour of unbalanced and blanched onion slice

To determine the influence of thickness on drying behavior 3, 5 and 7 mm slices (without blanching) were dried at a constant air dry bulb temperature (60^{0}C) and at constant air velocity in a cabinet dryer. The results were analyzed by using equation (3) and moisture ratio (MR) versus drying time (hr) was plotted on a semi-log graph paper and regression lines were drawn (Fig.1). For the three different thickness of samples, the following regression equations were developed:

$MR= 1.0888e^{-0.8584t}$ (for 3 mm, t=hr)------------------------------------ (7)

$MR = 1.0631e^{-0.4984t}$ (for 5mm, t=hr)--------------------------------------- (8)

$MR= 1.0026e^{-0.2875t}$ (for 7 mm,t=hr)--(9)

The effect of different slice thicknesses on drying time is shown in Fig.1 for onion. The drying process took place in the falling rate period and no constant rate period was observed from the drying curves. From Fig.1, it was also observed that thickness had profound influence on drying time and as the thickness of the samples increased, the drying time to a specific moisture ratio also increased with resultant decrease in drying rate constant. It was also noticed that for a specific moisture ratio (MR = 0.1) 3 mm thick slice required the least time (3.78 hr), followed by 5 mm thick slice (4.7 hr), while the highest time (8.0 hr) was required to dry 7 mm thick onion slice. From the developed equations (7 to 9), it is clearly seen that the rate constant decreased with the increased in slice thickness. The decrease in rate constant, however, does not maintain linear proportionality with slice thickness.

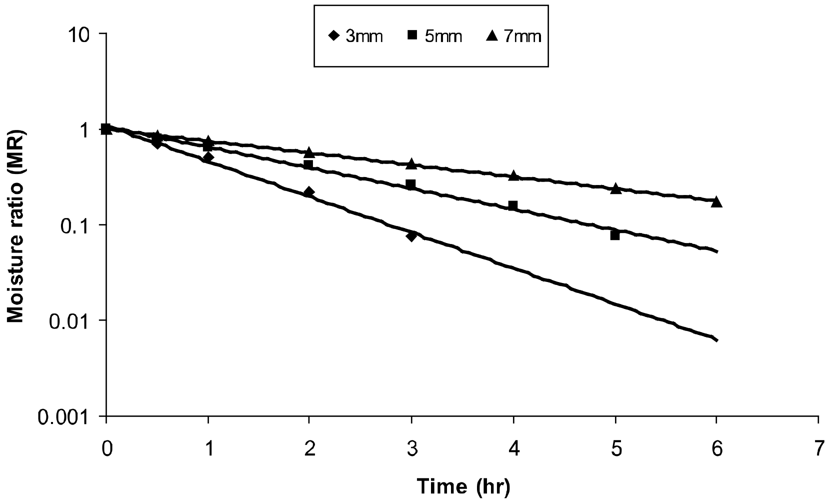

Fig.1 Influence of thickness on drying rate of unblanched onion slice.

In case of blanched onion slices the following regression equation were developed:

$MR = 1.0793e^{-1.0763t}$ (for 3mm, t in hr)--(10)

$MR = 1.0196e^{-0.8963t}$ (for 5mm,t in hr)---(11)

$MR = 0.936e^{-0.5077t}$ (for 7mm, t in hr)---(12)

Comparing Fig.2. and Fig.1 and also with developed equations (7 to 9 and 10 to 12) it was clear that for the same thickness, blanched slices gave higher drying rate constant and thus dried faster than unblanched onion slices. It is seen that 3 mm slice requires least time (2.21 hr), followed by 5 mm slice (2.59 hr), while 7 mm thick slice requires the highest drying time (4.41 hr) to dry to MR=0.1. It can be shown that 40-45% time can be saved by drying 7, 5 and 3 mm thick slices, indicating increased efficiency in energy utilization for the case of blanched onion. This behavior may be due to the heating effect of the steam used for blanching of onion slices (prior to drying) with changed physical and chemical properties. Ajibola (1987) observed that the longer the blanching time the lower was the moisture content after blanching. Mokanjuola *et al* (1987) showed that moisture content of onion slices was lower after blanching. Arsdel *et al.* (1973) observed that blanching prior to dry gives increased rate constant when compared to unblanched product.

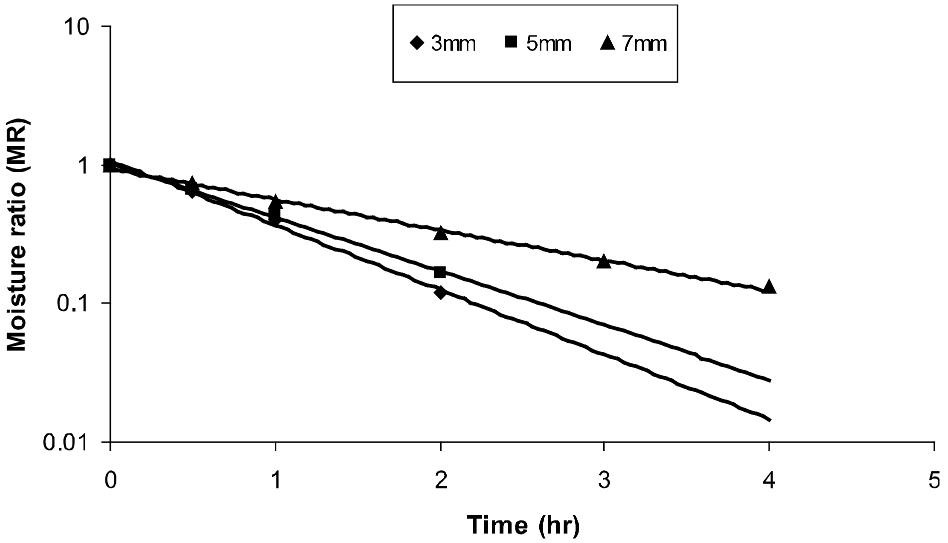

Fig. 2 Influence of thickness on drying rate of blanched onion slice.

The drying rate constants obtained from equation 7 to 9 and 10 to 12 for each sample thickness were plotted (Fig.3) against sample thickness on log-log co-ordinates as per equation (4) to determine the thickness dependence of rate constants.

The relationship is represented by a power law (regression) equation which follows as;

$m = 3.5806L^{-1.2725}$--(13)

$m=2.9181L^{-0..8437}$ ---(14)

Where, m= drying rate constant (hr^{-1}), L= sample thickness (mm)

From equation 13, it is seen that value of index ‘n’ of the power low equation is 1.272. This value is quite lower than 2 as predicted by Fick’s unsteady state equation (3) indicating that the external resistance to mass transfer was highly significant and internal resistance to mass transfer did not control the drying process under the given conditions. This conditions resulted primarily due to low airflow rate (<1 m/s), since similar samples did not indicate the presence of external mass transfer resistance under conditions of high air velocity (>2 m/s) as noted by Islam and Flink (1982 b). Islam (2003) found an n value of 1.57 for mechanical drying of indigenous varitey of onion and Hai (2002) found 0.49 for banana using similar air velocity (0.6m/s). Kamruzzaman (2005) dried aroids under similar conditions and found ‘n’ value of 1.15. Islam (1980) found an ‘n’ value of 1.70 while drying potato using significantly higher airflow rates (2.5

m/s). The above discrepancy of ‘n’ values is primarily due to airflow rate and thickness range used and indicated the relative importance of external or internal mass transfer resistance. Internal mass transfer resistance is affected by product thickness, structure and composition. Simultaneous heat and mass transfer effects also play an important role in this regard. Islam (1980) while working with potato, showed that by taking into account of the simultaneous heat and mass transfer effect value of ‘n’ could be corrected to 2 from 1.7. Alzamora *et al.* (1978) using significantly high air velocity (13 m/s) to greatly reduce external mass transfer resistance, found the dependence of drying rate constant to be somewhat lower than the second power of sample thickness and lower value was attributed to simultaneous heat and mass transfer effects.

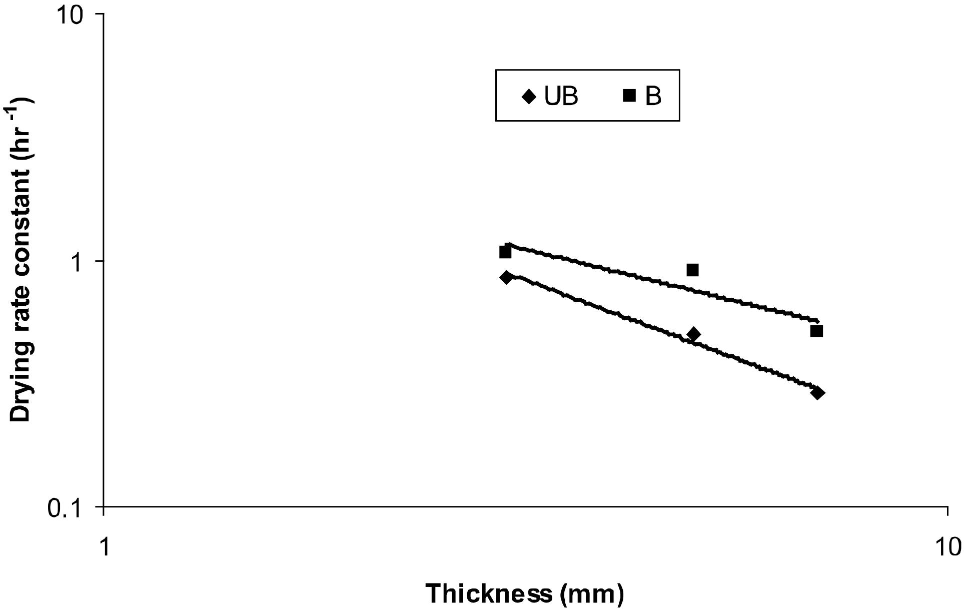

Fig.3 Effect of thickness on drying rate constant of blanched and unblanched onion slice.

From above equation 14, the value of ‘n’ is 0.845 for blanched products whereas for unbalanced products it was found 1.277. Aziz (2001) found different n value for blanched and unblanched cassava which were 0.776 and 0.79 respectively. The difference in n values and drying rate constants at a given thickness, between blanched and unblanched samples may be attributed to relative importance of external or internal resistance to heat and mass transfer offered by the samples, undergoing drying.

Effect of temperature on drying time of unblanched and blanched onion slice

5 mm thick onion slices were dried in mechanical drier using three different air dry bulb temperatures (52^0C, 60^0C, and 68^0 C) to determine the influence of temperature on drying time. The experimental data were analyzed by using equation (3) and plots of moisture ratio versus drying time were made on semi-log co-ordinate and regression lines were drawn (Fig.4). Accordingly, the following equations were developed:

$MR= 1.0359e^{-0.3377t}$ (for 52^0 C t in hr)-- (15)

$MR = 1.0199e^{-0.4621t}$ (for 60^0C t in hr)--- (16)

$MR= 1.0399e^{-0.513t}$ (for 68^0 C t in hr)-- (17)

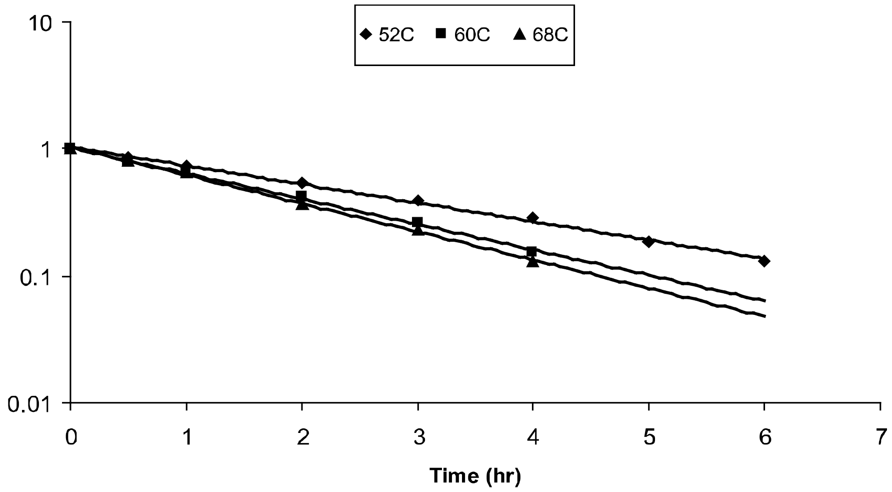

Fig.4 Influence of temperature on drying rate of unblanched onion slice.

From Fig.4 and the developed equation (15 to 17) it is clearly seen that when temperature is increased, drying rate constant is also increased. The drying time to a specific moisture ratio was decreased with the increase in drying temperature at constant sample thickness. As a result drying rate constant increased with increasing temperature. It was also noticeable that for a specific moisture ratio, the least drying time was achieved at 68^o C, followed by 60°C, while the highest drying time was required at 52°C to dry 5 mm onion slice.

In case of blanched onion slices the following regression equations were developed:

$MR= 1.1077e^{-0.9832t}$ (for 52^0 C t in hr)---(18)
$MR = 1.2125e^{-1.099t}$ (for 60^0C t in hr)-- (19)
$MR= 1.2709e^{-1.1752t}$ (for 68^0 C t in hr)---(20)

From the drying rate constant, the diffusion co-effcients were calculated. By plotting diffusion co-efficient (D_e) versus inverse absolute temperature ($1/T_{abs}$) in a semi-log scale (as per equation 5) a regression line was drawn (Fig.5). The equation of the straight line can be represented as (Fig. 5).

From the slope of the resultant straight line, activation energy (E_a) for diffusion of water was calculated and found to be 5.78 Kcal/g mole. This finding is in agreements with the results of Islam (2003). He stated that the activation energy (E_a) for diffusion of water for Bangladeshi and Indian onion slices were found to be 5.44 and 6.81 Kcal/g mole respectively.

$De = 1.8023e^{-2909.4/T_{abs}}$ --(21)

$D_e = 0.0316e^{1240.3/T_{abs}}$ --- (22)

Where,

De = Diffusion co –efficient (cm^2/s), T_{abs} = Absolute temperature ^0K

The activation energy was calculated by the same method as described for unblanched slices and the value of activation energy for diffusion of water from blanched slices was found 2.46 Kcal/g-mol (Fig.5). The activation energy for diffusion of water from blanched onion is lower (2.46 Kcal/g-mol) than that obtained for unblanched (5.78 Kcal/g-mol, table.1) onion slices indicating the effect of blanching on drying. Aziz (2001) found activation energy 11.06 and 13.05 Kcal/g-mol for diffusional of water from blanched and unblanched cassava. The differences in activation energy value may be due to changes in structure following blanching.

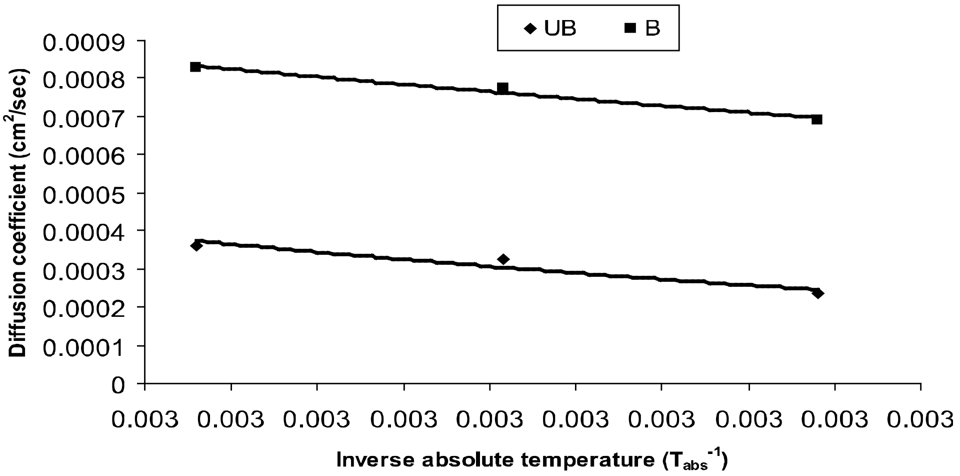

Fig.5 Influence of temperature on diffusion coefficient of blanched and unblanched onion slice

Table.1 Different drying parameter of mechanical drying system.

Product type	Drying method	Product thickness (mm)	Drying Temp. (^{0} C)	Slope (m) hr	Diffusion coefficient (cm^2/sec)	Value of exponent (n value)	Activation energy (Kcal/ g-mole)
Unblanched summer onion (BARI-2)	Mechanical	3 5 7	60	0.8584 0.4984 0.2875	2.17x10^{-6} 3.51x10^{-6} 3.96x10^{-6}	1.277	-
Do	Do	5	52 60 68	0.3377 0.4621 0.5130	2.38x10^{-6} 3.25x10^{-6} 3.61x10^{-6}	-	5.78
Blanched summer onion	Do	3 5 7	60	1.0763 0.8963 0.5077	2.73x10^{-6} 6.31x10^{-6} 7.00x10^{-6}	0.845	-
Do	Do	5	52 60 68	0.9832 1.0990 1.1752	6.92x10^{-6} 7.73x10^{-6} 8.27x10^{-6}	-	2.46

Conclusion

From the above study it appeared that mechanical dryer can be used for commercial production of dehydrated onion. The rate of drying depends on air velocity, temperature, thickness etc. Drying time of onion to a specific moisture ratio (eg. MR=0.1) increased with increase in sample thickness, while the rate constant has a power law relationship with thickness and the value of index of the equation was quite below 2 indicating presence of significant external resistance to mass transfer and increased airflow resulted in higher drying rate. Diffusion coefficient (calculated from rate constants) follow an Arrhenius type relationship with temperature and the activation value found was higher for unblanched onion than blanched onion (5.78 vs 2.46 Kcal/g-mole). Developed equations based on Fick's 2nd law together with activation energy values could be used for process design and optimization and high quality nutritious product. Thus, large number of skilled and semi-skilled persons would be employed in the related industries.

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