Study on influence of Sample Thickness and Thermo Physical Properties on Convective Drying of Vegetables.

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Abstract: This work presents a literature study on the influence of sample thickness and thermo-physical properties of vegetable samples on drying kinetics. The required experimental data for the theoretical analysis were derived from the works of Rahman et al.[3,4]. Based on their experimental observations, the thermo-physical properties were calculated and accordingly their influence on drying kinetics of the samples was studied. The sample under study was circular shaped potato slices of diameter 0.05m and different thicknesses of 0.01m, 0.005m and 0.003m dried in a laboratory scale convective dryer [4] with same drying air temperature of 60 ˚C.

Keywords: *Heat transfer coefficient, Shrinkage effect, Convection, Diffusion.*

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I. INTRODUCTION

Drying has been one of the oldest and an indispensable process for the preservation of different food stuffs whether it may be fruits, vegetables, grains or other edible products. It has been widely practiced all over the world in many agricultural countries and in various food industries. Large quantities of food stuffs are dried to improve their shelf life, increase their availability for long duration of time post their harvest, enhance appearance, encapsulate original flavor, maintain nutritional value, reduce packaging cost, lower shipping weights and transportation costs.

The primary objective of drying is to remove moisture from the food stuffs so that bacteria, yeast, mold and other microorganisms as well as mites and insects cannot grow and spoil the food. However, drying slows down the action of enzymes (naturally occurring substances which cause foods to ripen), but it does not wholly inactivates them. Also drying sometimes may result in lowering in nutritional value of the products e.g. loss of vitamin C, and changes of color and appearance that might not be desirable.

For example, hot air drying is the most common method of drying but it most of the times leads to serious injuries such as worsening of taste, color, nutritional content, decline in the density, water absorbance capacity and shifting of the solutes from the internal part of the drying material to the surface, due to the long drying period and high temperature (Yongsawatdigul and Gunasekaran 1996; Lin et al. 1998; Maskan 2001).To avoid all these discrepancies, drying should always be done in controlled manner

II. LITERATURE REVIEW

Mathematical modeling of heat transfer during food processing has been one of the primary focus of many studies since a very long time. Modeling, we can say is essentially a mathematical way of representing processes or phenomena to explain the observed data and to predict behavior under different conditions. Drying models are also frequently used as the tools to estimate appropriate heating or cooling times for foods and thus helps in optimizing the food quality. Mathematical models are very useful in the designing and analysis of simultaneous heat and moisture transfer processes. The existing mathematical models are either too simplistic and, hence, deviate significantly from real processes or too complex to have any practical application. It is thus essential to develop a model which should not only be meaningful and relatively simple to use, but also significantly accurate to predict temperature and moisture distribution during drying.

Convective air drying involves simultaneous heat and mass transfer processes. Analysis of the transient heat transfer process during drying therefore relates to coupling heat transfer diffusion model with the equation of moisture transfer rate. Also it's been observed that the drying of food stuffs with high initial moisture content always produces considerable shrinkage during drying. Thus assuming negligible shrinkage in mathematical drying models involving heat and mass transfer equations, very often decreases the ability to reproduce the experimental drying kinetic data.

Considerable studies have been performed on the drying of agricultural products. Several theoretical studies have been carried out in the past to solve simultaneous heat and mass transfer differential equations and to predict the temperature and moisture distribution within foodstuffs using numerical solutions. Akpinar published the data on heat transfer coefficient of different food products in forced convection drying. Mcminn and Magee (1997b), in the air drying of potatoes at different process temperatures, reported that when comparing samples with the same moisture content but different degree of shrinkage due to the different drying conditions used, a lower dehydration capacity corresponded to most shrunk samples. Ratti [5] conducted detailed experimental investigations on the shrinkage effect during drying of potato, apple and carrot samples and developed a correlation between the shrinkage factor and the water content. Rovedo et al. analysed the drying of potato slabs in air flow by the simultaneous numerical solution of the differential heat balance and diffusion equations for a shrinking body.

Most studies of dehydration of food materials have focused on validation of a particular model, under a limited range of drying conditions. As a result of these studies, different analytical and numerical models have been developed till date.

III. MATERIALS AND METHODS

A. *Raw Material*

The food stuff under study was a potato sample, dried in a convective oven[4]. The potatoes used for the drying experiments were purchased locally, were peeled off, washed and then sliced into circular slices of diameter 0.05m and different thicknesses of 0.01m, 0.005m and 0.003m.

The sample temperature variation, for practical purposes can be described satisfactorily by means of heat and mass balance equation given by [4]:

$$m_d(1+M)C_p\frac{dT_p}{dt} = hA(T-T_p) - n_wA\lambda \qquad (1)$$

The water mass flux per second, n_w can be expressed in terms of the water content on the dry basis, M, as

$$n_w = \left(\frac{md}{A}\right)\frac{dM}{dt} \qquad (2)$$

Substituting n_w from Eq. (2) in Eq. (1), one gets,

$$h = \frac{\left(\frac{V}{A}\right)\rho\, Cp(1+M)\frac{dTp}{dt} + \frac{md}{A}\left(\frac{dM}{dt}\right)\lambda}{(T-Tp)} \qquad (3)$$

The above equation(3) gives the heat transfer coefficient for the samples during the course of drying. When the shrinkage effect is considered for the drying samples, the heat transfer coefficient can be derived by considering the shrinkage parameter[4] while calculating the heat transfer coefficient.

IV. Results and Discussion

The experimental observations of moisture evaporated and temperature rise of the potato samples (slices) were recorded at every 15 min time interval during the drying process. The recorded experimental observations for the potato slices samples of diameter 0.05m and different thicknesses of 0.01m, 0.005m and 0.003m and at drying air temperature of 60 °C. The mean temperature of both types of potatoes samples were calculated as the average of the temperatures recorded at the surface and centre of the potato samples. Based on these results the latent heat of vaporization [10], density [9] and the thermal conductivity [7] were calculated.

Now from the recorded data we can get the heat transfer coefficient, but for this we require the differentials of moisture evaporated and the sample temperature w.r.t time as in eqn 3. To obtain the differential terms dM/dt and dT_p/dt , the data on moisture evaporated, M(dry basis) and the sample temperature T_p with time as shown in Figures 2 and 3 respectively were fitted with high order polynomials for the potatoes samples. The resulting expressions were then differentiated to obtain the numerical derivatives dM/dt and dT_p/dt.

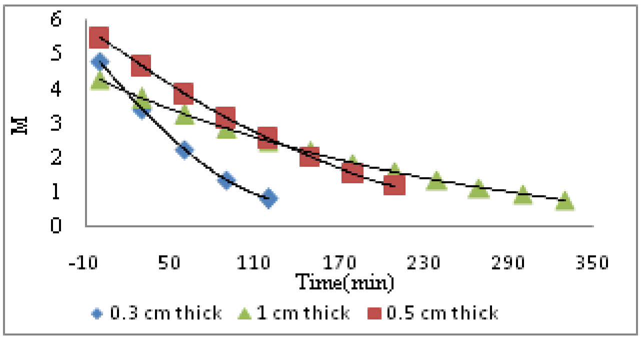

Fig 1: Moisture Evaporated vs. time for potato slices samples.

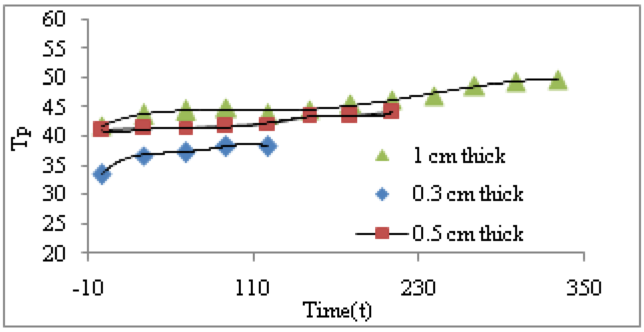

Fig 2: Sample temperature vs. time for potato slices samples.

A. *Variation in latent heat of vaporization during drying.*

The latent heat of vaporization is the quantity of energy required per kg of water to convert it into vapor. During drying, the substance being dried (potato samples) must take up this latent heat of vaporization to convert it's liquid into vapor. The energy required to vaporize the moisture present in the food material at any temperature, depends upon this temperature.

The latent heat of vaporization for potato samples of different thicknesses dried at same temperature were found to be higher for lower thickness samples as depicted in Fig 3. The sample temperature for lower thickness samples were less, so the latent heat of vaporization were higher for these samples. This is because at lower sample temperatures more energy will be required to vaporize the moisture.

As the time progresses the sample temperature is increasing with the reducing moisture content and so the latent heat of vaporization is decreasing with time.

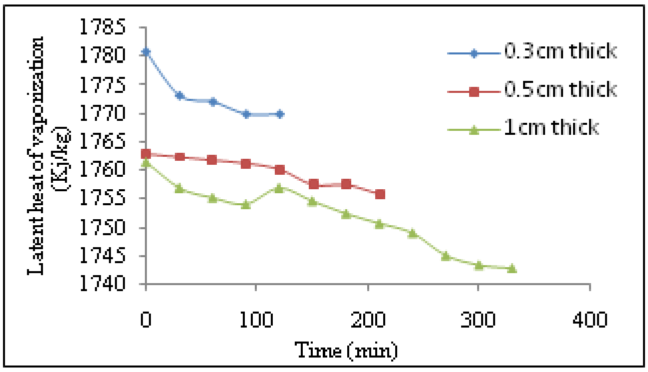

Fig 3: Typical variation of latent heat of vaporization with time for samples of different thicknesses and at drying air temperature of 60 °C

B. Variation in density of samples during drying

Initially the samples are at higher moisture content so the density is lower. As the time progresses and the moisture contents of the samples decreases with the loss of moisture, the density increases. This behaviour of increased densities at lower moisture contents can also be due to the shrinkage of drying samples. With the increase in thickness of samples and moisture contents, the densities of the samples decreases as depicted in Fig 4.

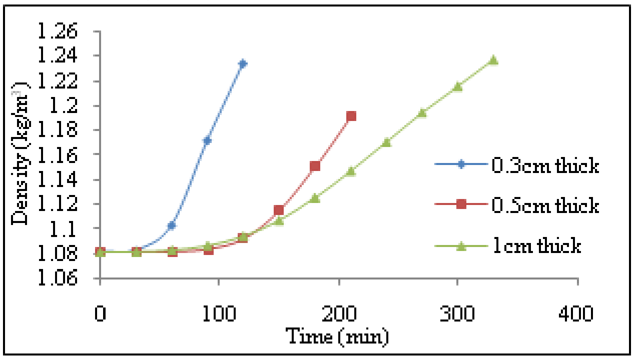

Fig 4: Typical variation of density with time for samples of different thicknesses and at drying air temperature of 60 °C.

C. Variation in thermal conductivity of samples during drying.

The heat and the mass transfer within the product structure occurs at the molecular level, with heat transfer being limited by thermal conductivity of the product structure, whereas mass transfer is proportional to the molecular diffusion of water vapor in air. The thermal conductivity of a food is thus an important property used in calculations involving rate of heat transfer. In quantitative terms, this property gives the amount of heat that will be conducted per unit time through a unit thickness of the material if a unit temperature gradient exists across that thickness.

Most high-moisture foods have thermal conductivity values closer to that of water. On the other hand, the thermal conductivity of dried, porous foods is influenced by the presence of air with its low value. Water have thermal conductivities much higher than those of the other food components (protein, fat, carbohydrates), and thus the water content of foods has a great influence on the thermal conductivity of foods. On the other hand, air has a low value of thermal conductivity, and thus porous foods are poor heat conductors.

Wang et al.(1992) [7] had reported that the thermal conductivity (k) of potato during drying majorly depends upon the moisture content of the samples. Figure 5 shows that the thermal conductivity being dependent on the moisture content of the samples decreased with the decreasing MC as the drying time progresses for different samples.

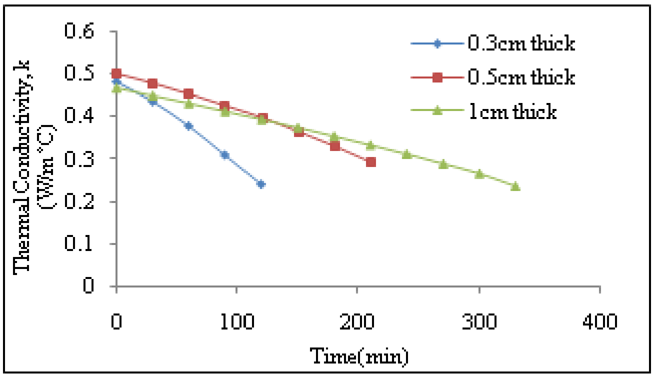

Fig 5: Typical variation of thermal conductivity, k with time for potato samples of different thicknesses and at drying air temperature of 60 °C.

D. Drying Rate

The sample thickness and surface area per unit mass are the important geometrical considerations relative to internal and external mass transport respectively.

As can be seen in fig 6, the highest drying rate is obtained for the 0.3 cm thick potato slices i.e. it dried more rapidly. This is obvious as the moisture in the thinner sample would have to travel shorter distance towards the surface to evaporate. Therefore, less time is needed for it to be dried.

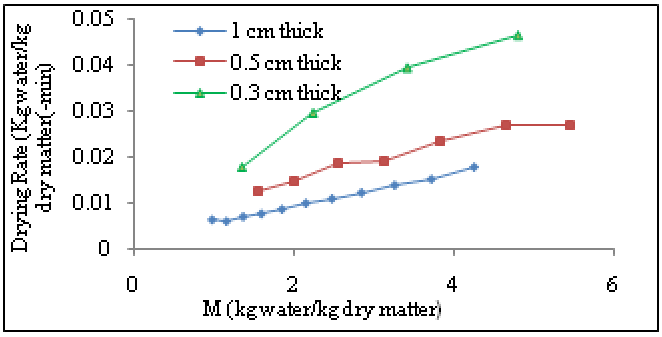

Fig 6: Drying rate vs. MC for potato slices samples of different thicknesses at drying air temperature of 60 °C.

V. CONCLUSION

In the present study, theoretical analysis on the influence of sample thicknesses and thermo-physical properties (latent heat of vaporization, thermal conductivity and the density) of drying samples on the drying kinetics were investigated. Based on the experimental data of Rahman et al.[3,4] the thermo-physical properties were calculated and then the theoretical analysis was done. The results of this analysis indicates that :

- Reducing sample thickness can enhance the drying rate and hence the moisture removal rate. Thus, reducing the drying time required to reach the equivalent moisture content.
- The latent heat of vaporization for potato samples of different thicknesses dried at same temperature were higher for lower thickness samples. The latent heat of vaporization were higher for lower thickness samples.
- With the progress of time the sample temperature is increasing with the reducing moisture content and so the latent heat of vaporization is decreasing with time.
- With the increase in thickness of samples and moisture contents, the densities of the samples decreases.

- The thermal conductivity (k) of potato during drying depends upon the moisture content of the samples, decreased with the decreasing MC as the drying time progresses and is independent of drying air temperatures.

NOMENCLATURE

A	surface area (m^2)
A_v	specific area per unit volume (1/m)
Cp	specific heat capacity (kJ/kg °C)
h	heat transfer coefficient (W/m^2 °C)
k	thermal conductivity of potato (W/m °C)
M	moisture content, dry basis (kg water/kg dry matter)
m_d	mass of dry matter (kg)
n_w	mass flux per second (kg/m^2 s)
t	drying time (s)
T	temperature of drying air (°C)
T_p	temperature of sample surface (°C)
V	volume of sample (m^3)

Greek letters

λ	latent heat of vaporization of sample (kJ/kg)
ρ	density of potato (kg/m^3)

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