Mass Transfer during Osmotic dehydration of Apple using Sucrose, Fructose and Maltodextrin Solution

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ABSTRACT
Osmotic dehydration is a process in which partial water is removed by immersion of water containing cellular solid in a concentrated aqueous solution of high osmotic media for a specified time and temperature. It has potential advantages of less heat damage, good blanching effect, less enzymatic browning, better retention of flavour and energy saving because no phase change occurs. Osmotic dehydration of apple was carried out using aqueous solutions of sucrose, fructose and maltodextrin of different concentrations (40, 50 and 60 %) as osmotic media, at different temperature levels (40, 50 and 60 °C) and solution to sample ratio 5:1 with agitation. The experiments were carried out upto 240 min and samples were taken for analysis at an interval of 10 min upto first 60 min, followed by intervals of 30 min for the next 180 min to evaluate moisture loss and solid gain during osmotic dehydration. Both moisture loss and solid gain increased in a non linear manner with time at all concentrations of sucrose, fructose and maltodextrin at different temperatures. It was faster in the initial period of osmotic dehydration and then the rate decreased. This study has also tried to investigate the effect of sucrose, fructose and maltodextrin solutions on mass transfer during osmotic dehydration of apple. The moisture loss and solid gain, both, were higher for the samples osmosed in fructose compared to those osmosed in maltodextrin and sucrose at the same concentration and temperature of solution. Both moisture loss and solid gain increased with increasing the osmotic agents' concentration and temperature of osmotic solution. Drying data were fitted using Lewis, Henderson, Logarithmic and Parabolic models. Effective diffusivity values were determined at different temperature and values increased with increasing temperature of osmotic solution during osmotic dehydration.

Keywords: Mass transfer; Osmotic dehydration; Drying; Osmotic solution; Apple.

INTRODUCTION

Osmotic dehydration of food materials in food processing shows promise to obtain high quality food with extended shelf life. During the past two decades, many osmotic treatment research projects have been conducted throughout the world on fundamentals of unit operations, engineering aspects, industrial application, and technical economy studies [1]. More food processors are applying this new technique to improve food product quality and increase market potential [2].

Osmotic dehydration involves water-rich solid products being soaked in concentrated aqueous solution (mainly sugar or salt solution), which creates three types of counter current mass transfer:
- an important water outflow, from the product to the solution.
- a solute transfer, from the solution to the product
- a leaching out of the products own solute (sugars, organic acids, minerals, vitamins, etc.), which is quantitatively negligible compared with the first two types of transfer, but essential with regard to the composition of the final product.

During osmotic dehydration, the kinetics of water removal, the solid gain and the equilibrium moisture content are strongly affected by the kind of osmotic agent and its concentration. Different osmotic agents have been used namely, glucose, sucrose, fructose, maltodextrin, sorbitol, commercial hydrolyzed corn starch syrups with their different concentration levels. It has been observed that some percentages of NaCl added to osmotic solution improve the osmotic dehydration process and quality of fruits and vegetables. The temperature of osmotic solution affects the mass transfer kinetics during osmotic dehydration. Agitation during the osmotic dehydration reduces the mass transfer resistance at the surface of the solids and provides a uniform distribution of osmotic solution around the product but gentle agitation has little effect of the osmosis rate. The agitation ranging between 100-200 rpm was found to be useful during osmotic dehydration. It is important to use an optimum ratio of solution to sample for the economic considerations. When water
loss and solid gain are considered together, the best osmotic effect is achieved at ratio sample to solution 1: 4 to 1: 6. The study of the Osmotic Dehydration (OD) process in a wide range of operating variables leads to a better understanding of the mass transfer phenomena and makes the determination of kinetic parameters possible. In osmotic dehydration, partial water is removed by immersion of water containing cellular solid in a concentrated aqueous solution of high osmotic media for a specified time and temperature. It has the potential advantages of less heat damage, good blanching effect, less enzymatic browning, better retention of flavour and energy saving because no phase change occurs.

OD products that lose about 70 % of their water content are ready to eat and can be consumed as snack items or shakes (after grinding and mixing with milk or other liquid foods). If a fresher appearance is required, dehydration must be about 30 %, which makes it possible for medium stability products to be dried, frozen or treated with additives. These OD pre-treated products can also be used in the dairy, bakery and candy industries and also to produce fruit and vegetable concentrates. In Europe, France and Italy are the countries that have developed the most advanced technologies for osmodehydration, and in Asia, the OD candying of tropical fruits is a very popular fruit preservation method.

Partial dehydration, solute impregnation and direct formulation constitute typical reasons for applying osmotic processing to fruits and vegetables as a basic step in a large variety of processing schemes [3]. Mass transfer phenomena taking place between the product and the osmotic medium are strongly affected by the nature of the raw material (i.e. species, variety, maturity level, shape and size, pretreatment) and the process variables (i.e. composition/ concentration of osmotic medium, medium/product ratio, temperature, contacting time, process duration) [3,4,5,6]. The performance of the osmotic unit operations depends, among other parameters, on the type and properties of the osmotic solutions used. From the mass transfer point of view the most important osmotic solution parameter is its water activity lowering capacity in terms of water activity or osmotic pressure - this is an important property for the purpose of dehydration. Due to the simultaneous mass transfer occurring, i.e. water transport from the food to the osmotic medium and solute transport from the osmotic medium to the food, additional information on the solute size and solute activities are also important.

Removing water when fruit is immersed in a solution of high osmotic pressure agent extends the shelf-life of food. Fruit is very rarely used as whole for this process. In the case of bananas, if the fruit is cut in pieces or bits, enzymatic browning produces undesirable and deleterious changes in the appearance, thus sensory properties of fruit and control of enzymatic browning is recommended. The osmotic process can be used to obtain fruits and vegetables with differential characteristics and with a better shelf life, ready-to-eat, or just as a pre-processing to drying, freezing, pasteurization, canning or frying as related by Raoult-Wack [5]. A good understanding of the process mass transfer kinetics is of great importance for a rational application of osmotic dehydration in fruits, obtaining efficient treatments and specific products formulations.

Transfer of water and osmoactive substance is accompanied by a stream of natural solutes leaking from the tissue into the hypertonic solution [7, 8]. Osmotic dehydration depends on the parameters of the process, on the material properties and its chemical constitution. Rate and dewatering degree of the material and changes in its chemical composition depend on the kind of osmotic substance used, the kind and the size of raw material, as well as the ratio of material to osmotic solution, temperature, dehydration time and the construction of the apparatus. Rate of osmotic dehydration is the highest at the beginning of the process. It results from the largest difference of osmotic pressure between osmotic solution and the cell sap of dehydrated material and small mass transfer resistance at this stage of the process [8, 9]. The aim of this work was to analyse influence of tissue structure on mass transfer during osmotic dehydration of different plant materials.

Fruit and vegetable dehydration by immersion in osmotic solutions has been of rising interest during the last decades since it can improve food quality when combined with air, freeze or vacuum drying or other preservation techniques, such as freezing. Apple is grown in the states of Jammu & Kashmir, H.P. and some hilly regions of U.P. and Uttaranchal (India). The total production is estimated at 1.2 million tonnes [10]. Apples are also grown in areas of northeast. The peak season for apple is August to December. Some quantities are available in the month of June from Uttaranchal as well.

The objectives of the this study were to study the effect of different osmotic agents, temperature of solution, time of immersion and solution concentration on moisture loss and solid gain during osmotic dehydration of apple pieces, followed by fitting of the drying models and estimation of effective diffusivity.
MATERIALS & METHODS

Experiments were conducted to study the effect of different osmotic agents, temperature of solution, time of immersion and osmotic agents concentration on water loss and solid gain during osmotic dehydration of apple pieces. Apple (Delicious apple) used for the experimentation was procured from the market. Apples were washed, peeled manually and cut into pieces of uniform size of (10×20 mm) with 4 - 5 mm thickness in water. Samples were blanched in hot water (near boiling water) to inactivate enzymes. The pieces were then removed from water and, their surfaces gently blotted with absorbent paper [11]. The sample was then used for osmosis and for initial moisture content determination. The average initial moisture content of the apple was found to be 89 % (wb). Sucrose, fructose and maltodextrin were used as the osmotic agents. Osmotic solution was prepared with distilled water by w/w basis of different concentration. A flask shaker was used for the osmotic dehydration. During osmotic dehydration, twelve 500 ml beakers were filled with 150 ml osmotic solution, 30 gm of samples immersed in each beaker. One beaker at a times were taken out from the shaker at times of 10, 20, 30, 40, 50, 60, 90, 120, 150, 180, 210 and 240 min from the beginning of osmosis. Based on the preliminary experiments and review of literature, three concentration levels (40, 50 & 60 %) of sucrose, fructose and maltodextrin were used at temperature levels (40, 50 & 60 °C) [12, 13, 14, 15, 16]. During all experiments, constant agitation of 100 rpm was done. After each time of osmosis, samples were removed from the osmotic solution and dipped in distilled water and were shaken manually for some time at room temperature to rinse out absorbed osmotic liquid. The rinsed pieces were placed on blotting paper to remove excess water and weight on an electronic balance. Osmosed sample were then used for determination of moisture.

The initial and final moisture content of sample was determined by using hot air oven method recommended by Ranganna [17] for fruits and vegetables.

\[
MC(\%wb) = \left( \frac{W + W_1 - W_2}{W} \right) \times 100
\]

(1)

Where \(W =\) Net weight of sample taken (g), \(W_1 =\) Weight of dish (g), and \(W_2 =\) Weight of dish plus oven dried sample (g)

The moisture loss (ML %) was measured by the following equation suggested by Lenart and Flink [11] and Hawkes and Flink [18].

\[
ML(\%) = \frac{M_0 - M}{W} \times 100
\]

(2)

Where \(M_0 =\) Wt of initial moisture (g), \(M =\) Wt of final moisture (g), and \(W =\) Initial wt of sample (g).

The solid gain (SG %) was measured by the following equation suggested by Lenart and Flink [11] and Hawkes and Flink [18].

\[
SG(\%) = \frac{S - S_0}{W} \times 100
\]

(3)

Where \(S =\) Wt of final solid (g), \(S_0 =\) Wt of initial solid (g), and \(W =\) Initial wt of sample (g)

Mathematical Modelling of osmotic dehydration process

Osmotic drying data were fitted by using the following drying models:

(1) Lewis model

\[
M.R = \exp(-kt)
\]

(4)

(2) Henderson model

\[
M.R = a \exp(-kt)
\]

(5)

(3) Logarithmic model

\[
M.R = a \exp(-kt) + c
\]

(6)

(4) Parabolic model

\[
M.R = a + bt + ct^2
\]

(7)
Where M.R = Moisture loss ratio
\[ M.R = \frac{(M - M_e)}{(M_0 - M_e)} \]

\( M_0 \) = initial moisture content, \( M \) = Moisture content after time \( t \), \( M_e \) = Equilibrium moisture content, \( t \) = Time period, min, and \( a, b, n \) and \( k \) are constants,

The models were fitted to the experimental data for each condition of osmotic dehydration using Σ- Plot.

**Estimation of Effective Diffusivity**

The method of slope was used to estimate the effective diffusivity of apple under different osmotic dehydration condition. The solution of Fickian equation was used for this

\[ M.R = \frac{8}{\pi^2} \exp\left(-\pi^2 D_{eff} t / 4L^2\right) \]

Where, \( D_{eff} \) = effective diffusivity, \( t \) = time, and \( L \) = length

**RESULTS & DISCUSSION**

The present study was undertaken to study the mass transfer kinetics during osmotic dehydration of apple pieces at different temperatures and osmotic solution concentrations. The osmotic agents used were aqueous solutions of sucrose, fructose and maltodextrin of varying concentrations. Use of different time periods was made to investigate osmotic kinetics for different experimental conditions. At each osmotic time level, the moisture loss and solid gain was calculated based on mass balance.

**Effect of osmosis time on moisture loss**

The effects of sucrose, fructose and maltodextrin of different concentrations on the moisture loss with respect to time of osmosis at different temperature are shown in Figure 1. This is a representative plot showing the moisture loss as a function of osmosis time for varying concentrations of sucrose (40%, 50% and 60%) at a temperature of 40 °C. Similar plots have been obtained from the experimental data for maltodextrin and fructose at temperatures of 50 °C and 60 °C; though they have not been depicted in the paper due to the constraints of space. It is observed from these figures that the moisture loss increases in a non linear manner with time at all concentrations of sucrose, fructose and maltodextrin at different temperatures. Moisture loss is faster in the initial period of osmotic dehydration and then the rate decreases. This is because osmotic driving potential for moisture transfer keeps on decreasing with time as the moisture keeps moving from sample to solution [18]. After some period of osmotic dehydration, the rate of moisture loss is reduced, because of faster gain of solid at initial period in the apple pieces that fill the path of evaporation; hence restricting the loss of moisture.

**Effect of osmotic agent’s types and its concentration on moisture loss**

From Figure 1, it is clear that the moisture loss increases with increasing the osmotic agents’ (sucrose, fructose and maltodextrin) solution concentration at constant temperature of solution. The moisture loss is higher for sample osmosed in fructose compared to those osmosed in maltodextrin and sucrose at same concentration and temperature of solution. This can be attributed to the fact that monosaccharide such as fructose has low molecular weight, and therefore it has a more profound effect on water activity depression than polysaccharides such as maltodextrin and sucrose. The moisture loss is observed to be higher at the concentration of 60%.

**Effect of osmotic solution temperature on moisture loss**

It is evident from Figure 1 that the moisture loss of apple pieces increases with increasing the temperature of the osmotic solution. The moisture loss is higher at 60°C temperature of the osmotic solution, above which enzymatic browning and flavour deterioration begin to take place. Moisture loss after 240 min osmotic dehydration ranges between 36.5 – 49.78 % of initial weight of apple pieces.
Effect of osmosis time on solid gain

The effect of sucrose of different concentrations on the solid gain with respect to time of osmosis at different temperatures is shown in Figure 2. Similar plots have been obtained for the other osmotic agents but have not been displayed in this manuscript because of space constraints. It is observed in Figure 2 that the solid gain also increases in a non linear manner with time at all concentrations and temperatures of different osmotic agents. Solid gain is faster in the initial period of osmotic dehydration and then the rate decreases. This is because the osmotic driving potential for solid transfer keeps on decreasing with time as the solids keep moving from solution to sample. Further, more solid uptake results in the formation of high solid subsurface layer, which interferes with the concentration gradients across the sample-solution interface and act as a barrier against uptake of solids [22].

Effect of osmotic agent’s types and its concentration on solid gain

From the Figure 2 it is clear that the solid gain increases with increasing the osmotic agents’ solution concentration at constant temperature of solution. The solid gain was higher for sample osmosed in fructose as compared to those osmosed in maltodextrin and sucrose at the same concentration and temperature of solution. This is attributed to the fact that solid uptake is inversely correlated with the size of the molecule of osmotic agents. The solid gain is higher at the concentration of 60 %.

Effect of osmotic solution temperature on solid gain

It is observed from Figure 2 that the solid gain in apple pieces increases with increasing the temperature of the osmotic solution. The solid gain is higher at 60°C temperature of the osmotic solution, above which enzymatic browning and flavour deterioration begin to take place.

Validity of the models

The Lewis, Henderson, Logarithmic, and Parabolic models were tested by fitting the experimental data using SigmaPlot™. The R² and MSE values for each of the tested models are given in Table.1.

<table>
<thead>
<tr>
<th>Model</th>
<th>R²</th>
<th>MSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lewis</td>
<td>0.976</td>
<td>0.00478</td>
</tr>
<tr>
<td>Henderson</td>
<td>0.9823</td>
<td>0.00466</td>
</tr>
<tr>
<td>Logarithmic model</td>
<td>0.988</td>
<td>0.00160</td>
</tr>
<tr>
<td>Parabolic</td>
<td>0.9789</td>
<td>0.00525</td>
</tr>
</tbody>
</table>

It can be seen from Table 1 that the Logarithmic model gives the best values in terms of highest R² and lowest MSE our data.
Effective Diffusivity

The effective diffusivity values as calculated by Eq. (8), ranged from $1.348 \times 10^{-10}$ to $3.926 \times 10^{-9}$ m$^2$/s. It is observed that the values of $D_{eff}$ increased with increasing the temperature of osmotic solution.

CONCLUSION

From the results it can be concluded that the moisture loss from the apple pieces and the solid gain by the apple pieces increased non-linearly with duration of osmosis at all osmotic solution concentrations. The rate of moisture loss and solid gain both were higher in the initial period of osmosis than in the later period. Moisture loss and solid gain also increased with increasing the osmotic agents concentration and temperature of the solution. The moisture loss and solid gain both were higher for samples osmosed in fructose compared to those osmosed in maltodextrin and sucrose solution at 60 °C. On For all the three osmotic agents, moisture loss and solid gain both were higher at a concentration of 60 % and 60 °C temperature of solution.

REFERENCES