COMPARISON OF THE KINETICS OF OSMOTIC DRYING APPLES IN SUGAR BEET MOLASSES AND SUCROSE SOLUTIONS

POREĐENJE KINETIKE OSMOTSKOG SUŠENJA JABUKE U MELASI ŠEĆERNE REPE I RASTVORIMA SAHARoze

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ABSTRACT

Osmotic dehydration of apple was carried out using sugar beet molasses and sucrose solutions in different concentrations (40.0%, 60.0% and 80.0% for sugar beet molasses; 30%, 50% and 70% for sucrose solutions), at constant temperature of 45°C, under atmospheric pressure. At different time intervals (up to 5h) of contact with the osmotic media, total mass, solids gain, water loss and moisture content were determined for each sample. Comparison of the most important kinetics parameters during osmotic dehydration in sugar beet molasses and sucrose solution was performed. Better results were achieved in case when sugar beet molasses was used as hypertonic solution. The experimental data modeling was successfully achieved employing an empirical model suggested by LabFit Curve Fitting Software and high values of the coefficient of correlation was reached. All the results obtained allow concluding that the osmotic dehydration kinetics strongly depends on type and concentration of osmotic solution and contact time.

Key words: osmotic dehydration, sugar beet molasses, mass transfer kinetics.

INTRODUCTION

Several processes involving water removal are commonly employed to preserve food materials or long periods of time allowing their consumption. Drying operation is the most employed method, but shows several disadvantages as high energy consumption and temperature. In these thermal conditions, and especially at initial periods when the water activity of food material is normally very high, physical process and chemical reactions promoted by temperature can take place. In order to decrease undesirable processes, in the last years several authors have shown that the use of partial dehydration of foodstuffs as pretreatment employing mass transfer operations governed by no-thermal driving forces as the osmotic dehydration (OD) can be useful (Chenlo et al., 2007).

Osmotic dehydration is governed by osmotic pressure difference between the food material (hypotonic medium) and concentrated osmotic solution (hypertonic medium). The diffusion of water is accompanied by the simultaneous counter diffusion of solute from the osmotic solution into the tissue. Since the membrane responsible for osmotic transport is not perfectly selective, other solutes present in the cells can also be leached into the osmotic solution (Rastogi and Raghavarao, 2004).

For fruits and vegetables dehydration, the most commonly used osmotic agents are sucrose and sodium chloride and their combination. Glucose, fructose, maltodextrin and sorbitol also can be used for osmotic dehydration (Ispir and Togrul, 2009). Recent research has shown that use of sugar beet molasses as hypertonic solution improves OD processes (Koprivica et al., 2009). Sugar beet molasses is an excellent medium for osmotic dehydration, primarily due to the high dry matter (80%) and specific nutrient content. An important advantage from nutrient point of view, of sugar beet molasses use as hypertonic solution, is enrichment of the food material in minerals and vitamins, which penetrate from molasses in the plant tissue (Koprivica et al., 2008).

The rate and dewatering degree of the material and changes in its chemical composition depend on the sort of the osmotic solution used, the kind and the size of raw material, as well as the ratio of material to osmotic solution, temperature, dehydration time, and type of apparatus. Rate of osmotic dehydration is the highest at the beginning of the process. It results from the largest difference of osmotic pressure between the osmotic solution and the cell sap of the material and small mass transfer resistance at this stage of the process (Moreira and Sereno, 2003).

Some models have been proposed to predict water and solute transfer during osmotic treatment (Hawkes and Flink, 1978; Magee, Hassaballah et al., 1983; Saurel, et al., 1994; Yao and Le Maguer, 1996), but experimental data are necessary to use them both to improve the understanding of the phenomena and the process design.

Existence of a simple mathematic model is very important from a practical point of view, because in that case it is possible...
to predict the duration of the process for the desired moisture content and vice versa.

Purpose of this work was to study influence of main process variables such as concentration of osmotic solution and operation time on osmotic dehydration of apple. Also, objective of study was to investigate mass transfer during osmotic dehydration and to find appropriate mathematical model which describes osmotic dehydration of apple in sugar beet molasses and sucrose solution.

MATERIAL AND METHOD

Apple samples were purchased in a local market in Novi Sad, Serbia and stored at 4°C until use. Initial moisture content was 86.49 ± 0.25%. Prior to the treatment, the apples were thoroughly washed and cut into cubes, dimension 1x1x1 cm.

Sugar beet molasses and sucrose solutions in different concentrations (40.0%, 60.0% and 80.0% for sugar beet molasses; 30%, 50% and 70% for sucrose solutions) were used as osmotic solution. Sugar beet molasses was obtained from the sugar factory Pecinci, Serbia. Initial dry matter content in sugar beet molasses was 83.68%. For dilution of sugar beet molasses distilled water were used. In all experiments, a weight ratio of solution to carrot samples of 4:1 was used, considered high enough to neglect concentration changes during the process. The experiments were conducted under atmospheric pressure at 45°C.

Mass transfer studies lasted 5 hours and samples were taken out of the osmotic solution at different times (20, 40, 60, 90, 120, 180, 240 and 300 min). After removal apple samples were washed with water and gently blotted to remove excessive water. The samples were weighed and analyzed for dry matter content.

Dry matter content of the samples was determined by the oven drying method according to AOAC (AOAC, 2000). The samples were kept in an oven (Instrumentaria Sutjeska, Serbia) at 105°C for 24 h until a constant weight was attained. Dry matter content were increased almost 5 times which implicate this fruits can be used as a row material in the different food processing or could be suitable pre-treatment for other preservation technique (convective drying, freeze drying...). Solid content in sugar beet molasses after osmotic dehydration process was 74.03%. It is still high value and molasses can be used again as the osmotic solution. With this relative simple food preservation method, low energy required and nutritionally favorable, dry matter content were increased almost 5 times which implicate that this fruits can be used as a row material in the different food processing or could be suitable pre-treatment for other preservation technique (convective drying, freeze drying...). Solid content in sugar beet molasses after osmotic dehydration process was 74.03%. It is still high value and molasses can be used again as hypertonic solution in another OD process (Mišljenović et al. 2009). 70% sucrose solution was good for OD process, but in comparison with sugar beet molasses it has a lot of disadvantages, primarily long and difficult preparation, crystallization of dissolved sucrose during the process and sucrose is more expensive than sugar beet molasses.

RESULTS AND DISCUSSION

The essence of the osmotic dehydration process is to obtain high dry matter content in the treated samples in order to increase microbiological and enzymatic stability. Figure 1 and figure 2 show changes in dry matter content in the samples of apple during osmotic dehydration as a function of the concentration and dehydration time. The increase in concentration and immersion time during the osmotic dehydration resulted in higher content of dry matter in the samples of apple. The highest value of dry matter content in apple samples, after 5 hours, (63.42%) was achieved when 80% solid content sugar beet molasses was used as the osmotic solution. With this relative simple food preservation method, low energy required and nutritionally favorable, dry matter content were increased almost 5 times which implicate that this fruits can be used as a row material in the different food processing or could be suitable pre-treatment for other preservation technique (convective drying, freeze drying...). Solid content in sugar beet molasses after osmotic dehydration process was 74.03%. It is still high value and molasses can be used again as hypertonic solution in another OD process (Mišljenović et al. 2009). 70% sucrose solution was good for OD process, but in comparison with sugar beet molasses it has a lot of disadvantages, primarily long and difficult preparation, crystallization of dissolved sucrose during the process and sucrose is more expensive than sugar beet molasses.

In Eq. 4 $t$ is immersion time, $C$ is concentration of osmotic solution, $P$ represents WL, SG or Dry matter. $a$, $b$ and $c$ are parameters in Eq. 4. All analysis was carried out by using Lab Fit Curve Fitting Software and Microsoft Excel.

**Fig. 1. Changes of dry matter content during osmotic dehydration of apple in sugar beet molasses ( ■ – 80% sugar beet molasses; ■ – 60% sugar beet molasses; ■ – 40% sugar beet molasses)**

**Fig. 2. Changes of dry matter content during osmotic dehydration of apple in sucrose solutions ( ■ – 70% sucrose solution; ■ – 50% sucrose solution; ■ – 30% sucrose solution)**

This model (Eq. 4) fits satisfactorily the experimental data and makes possible to estimate kinetic parameters for any osmotic solute concentration and contact time.
Fig. 3. Water loss (WL) during osmotic dehydration of apple in sugar beet molasses
(● – 80% sugar beet molasses; □ – 60% sugar beet molasses; ▲ – 40% sugar beet molasses)

Fig. 4. Water loss (WL) during osmotic dehydration of apple in sucrose solutions
(● – 70% sucrose solution; □ – 50% sucrose solution; ▲ – 30% sucrose solution)

Increasing the dehydration time caused greater loss of water from the sample. Higher concentrations of molasses and sucrose increased the osmotic pressure in the hypertonic solution, and therefore the driving force for dehydration was higher. The highest water loss (0.7612 g / g of initial sample weight) was observed in the sample which was dehydrated in molasses with 80% solid content for 5 hours. Water loss was most intensive during first 2 hours of dehydration. Explanation for this is the highest difference in osmotic pressure between fruit tissue and surrounding solution at the beginning of the process.

Fig. 5. Solids gain during osmotic dehydration of apple in sugar beet molasses
(● – 80% sugar beet molasses; □ – 60% sugar beet molasses; ▲ – 40% sugar beet molasses)

The SG value indicates the degree of penetration of solids from the osmotic solution in the samples. The objective of osmotic dehydration is the removal of water from plant tissue and, at the same time, minimizing the penetration of substances from the osmotic solution into the plant tissue. However, in the case when sugar beet molasses is used as hypertonic solution, the penetration of mineral substances, vitamins, etc. to the tissue can be considered as favorable because the nutritional value of thus treated fruits and vegetables is higher. Penetration of the solute, primarily sucrose molecules, from the osmotic solution into the sample can be limited by applying starch edible coatings (Mišlenović et al., 2009).

Fig. 6. Solids gain (SG) during osmotic dehydration of apple in sucrose solutions
(● – 70% sucrose solution; □ – 50% sucrose solution; ▲ – 30% sucrose solution)

Solid gain, during the osmotic dehydration of apple, showed a tendency to increase with increasing the immersion time. In case when sucrose solutions were used as hypertonic solution, higher concentrations of osmotic solution caused higher values of SG parameters. Regularity in the influence of concentration of sugar beet molasses on the SG value was not observed.

Table 1. WL/SG values after 5 hours of osmotic dehydration of apple with sugar beet molasses

<table>
<thead>
<tr>
<th>WL/SG</th>
<th>80% sugar beet molasses</th>
<th>60% sugar beet molasses</th>
<th>40% sugar beet molasses</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.16</td>
<td>0.09</td>
<td>0.06</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Table 2. WL/SG values after 5 hours of osmotic dehydration of apple with sucrose solution

<table>
<thead>
<tr>
<th>WL/SG</th>
<th>70% sucrose solution</th>
<th>50% sucrose solution</th>
<th>30% sucrose solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.07</td>
<td>0.05</td>
<td>0.02</td>
<td></td>
</tr>
</tbody>
</table>

Effectiveness of the osmotic treatment can be evaluated with WL/SG ratio. High values of this ratio indicate an extensive dehydration with minimal solid uptake. On the other hand, a small WL/SG ratio indicates that during the process comes to significant diffusion of solids from osmotic solution in samples with minimal water loss (i.e. candying). Highest value was achieved in apple osmodehydrated in 80% sugar beet molasses (water loss was 16.60 times highest than solid uptake) and that osmotic solution showed best characteristics in this experiment.

Table 3. Parameters in Eq. 4 for dry matter, water loss and solids gain (dehydration with sugar beet molasses)

<table>
<thead>
<tr>
<th>Parameter in Eq. 4</th>
<th>Dry matter</th>
<th>WL</th>
<th>SG</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>0.709457</td>
<td>0.009814</td>
<td>0.041230</td>
</tr>
<tr>
<td>b</td>
<td>0.352146</td>
<td>0.327507</td>
<td>0.322157</td>
</tr>
<tr>
<td>c</td>
<td>0.538573</td>
<td>0.570379</td>
<td>-0.354163</td>
</tr>
<tr>
<td>Coefficient of correlation</td>
<td>R</td>
<td>0.9721</td>
<td>0.9932</td>
</tr>
</tbody>
</table>
In order to correlate the experimental data for each of the analyzed variables (dry matter, WL and SG) equation with three parameters (Eq. 4), suggested by LabFit Curve Fitting Software, was used. The purpose of this analysis is to obtain a simple equation able to take into account both the variables (time, concentration) simultaneously. Parameter values for this model are shown in Table 3 for osmotic dehydration with sugar beet molasses and in Table 4 for dehydration with sucrose solution. High values of coefficient of correlation (R=0.9292 – 0.9932) show that this equation satisfactory fits experimental data. Best correlation was achieved for prediction of water loss.

**CONCLUSION**

Results in this work allow to determine effect of concentration and immersion time on dehydration and impregnation kinetic of apple using sugar beet molasses and sucrose solutions. In all cases higher solution concentration and longer immersion time give higher water loss from apple samples. The highest content of dry matter (63.42%) was achieved during osmotic dehydration with 80% sugar beet molasses. Taking into account the WL/SG ratio as quality parameter, dehydration with 80% sugar beet molasses showed the best results. Suggested mathematical model satisfactory fits experimental data. Knowing parameters in this equation is very important from practical point of view and allow optimization and better control of the process.

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**REFERENCES**


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**Table 4. Parameters in Eq. 4 for dry matter, water loss and solids gain (dehydration with sucrose solution)**

<table>
<thead>
<tr>
<th>Parameter in Eq. 4</th>
<th>Variables</th>
<th>Dry matter</th>
<th>WL</th>
<th>SG</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td></td>
<td>0.109075</td>
<td>0.000708</td>
<td>0.000114</td>
</tr>
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<td>b</td>
<td></td>
<td>0.272275</td>
<td>0.346777</td>
<td>0.285439</td>
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<tr>
<td>c</td>
<td></td>
<td>1.042855</td>
<td>1.157601</td>
<td>1.188004</td>
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<tr>
<td>Coefficient of correlation</td>
<td>R</td>
<td>0.9796</td>
<td>0.9918</td>
<td>0.9860</td>
</tr>
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</table>