

## Studies on Osmotic Dehydration Characteristics of Potato under Tray Dryer



### Agriculture

**KEYWORDS :** Potato, slices, thickness, osmotic pressure, dehydration, tray dryer and treatments

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### ABSTRACT

To investigate mass transfer kinetics, osmosis was carried out in binary sugar and salt solution of varying concentrations using a solution to sample ratio of 1:5. Osmosis was conducted at 30°C temperature. At each experimental condition osmotic dehydration was carried out for different time periods. At each designated osmotic time level, the samples were analyzed for moisture content and moisture loss, and the solid gain was calculated based on mass balance. To develop osmo-hot air drying process, potatoes were first osmosed in selected osmotic solutions for selected osmotic time based on the kinetics results. The binary solutions were: 20% sugar - 10% salt, 20% sugar- 15% salt, 30% sugar - 5% salt and 30% sugar - 10% salt. Osmotic time was taken to be 1 h. During this period, most of the osmotic water loss potential was achieved and the solid gain remained low so as not to presumably affect the organoleptic characteristics adversely. Osmosed potatoes were then dried in tray dryer at 60, 70, 80°C till moisture content reached  $\leq 6\%$  d. b. Non osmosed potato dices were also dried by conventional hot air drying method-blanching and drying at 60°C for comparison. The organoleptic quality of the dried potatoes was determined and statistically analyzed. The moisture loss from and the solid gain by potato increased non-linearly with duration of osmosis at all solution concentrations and both were higher in the initial period of osmosis than the later period. Further, both moisture loss from and the solid gain by potato dices increased with the increasing salt as well as with the increasing sugar in the osmosis solution.

### Introduction

Potato is an important commercial vegetable crop in India. On the basis of area and production, India stands on fourth and third, respectively, in the world. Potato has a high level of moisture content and hence is highly perishable. Moreover, it is a seasonal produce. Potato, therefore, requires proper storage facilities like cold store for fresh produce. This involves high capital investment. Inadequate availability of storage facilities causes wide fluctuations in price during different parts of a year. Although potato is a seasonal crop, harvesting time is spread out in different parts of India, so as to make fresh potato available throughout the year. In 2010, the production of potato in India was 26.2 million tonnes from a cultivated area of 1.6 million hectare implying an average productivity of 182.86 quintals per hectare. As such, India stands third in potato production, while in the terms of crop area it is fourth in the world. Due to the perishable nature of potato, the increased production and productivity over the years have resulted in frequent gluts in the markets. This has increased pressure on cold storage facilities causing undue distress to the potato growers. Potato can be processed into flour, mash and pregelatinized starch. Potato flour can be prepared and used in the baking industry, in baby foods and as a thickener and flavouring agent in soups and sauces. Potatoes can also be used for producing mashed potatoes, potato patties, potato pancakes and potato snacks. Potato mash can be used to form dried potato products such as flakes, granules, agglomerates, sheets, pieces, potato bits, meal and particulates. Food products made from mash or dried products are claimed to have improved flavour and texture.

Research on osmotic drying of potato has been limited. Islam and Flink (1982) studied osmotic concentration of potato in salt, sugar and salt-sucrose osmotic solutions of varying concentrations with an ultimate objective of increasing throughput in subsequent solar drying. They recommended 45% sucrose-15%

NaCl salt solution for osmotic drying of potato based on the product stability after the osmotic equilibrium in 18 hours of osmosis. Lenart and Flink (1984 a), studied the equilibrium between potato and osmosis solution for an osmosis concentration process. Uptake of solids during sucrose-based osmosis results in 75% of soluble solids in the equilibrated potato coming from the osmosis solution. Lenart and Flink (1984 b) studied spatial distribution of moisture and solids in potato following osmotic concentration. Binary sucrose - NaCl osmosis solution have been reported more effective than sucrose or NaCl solution alone. Lazarides and Mavroudis (1996) studied the mass transfer kinetics during osmotic dehydration of potato in salt free osmotic medium (corn syrup solid). A two-parameter model for mass transfer kinetics during osmotic dehydration of potato was developed:

$$\text{For moisture loss kinetics: } ML_t = \frac{S_1 t (ML_\infty)}{1 + S_1 t} = \frac{(ML_\infty) t}{\frac{1}{S_1} + t}$$

$$\text{For solid gain kinetics: } SG_t = \frac{S_2 t (SG_\infty)}{1 + S_2 t} = \frac{(SG_\infty) t}{\frac{1}{S_2} + t}$$

Where,  $ML_\infty$  and  $S_1$ ; and  $SG_\infty$ ,  $S_2$  are model parameters. The model parameters for the experimental conditions were established. The model developed for mass transfer kinetics during osmotic dehydration of potatoes predicted the experimental data very well. Osmotic dehydration prior to hot-air drying improved the organoleptic characteristics of potato dices in both its dried and rehydrated forms. All the organoleptic attributes were found to be statistically significant at 5% probability level for evaluating the quality. The recommended osmo-hot air drying process for potatoes based on organoleptic quality of dried

and rehydrated potato dices was: osmotic dehydration of potato dices in 20% sugar – 15% salt concentration for 1 hour followed by hot air drying at 70°C temperature. Mass transfer kinetics during osmotic drying of potato in binary solution however has not yet been studied and modelled. Also, organoleptic quality of osmotically dehydrated potato also needs thorough investigation since the “candying effect” of sugar uptake during osmosis in binary solution may create product difficulties in the context of potato consumption as vegetable in India. Further, osmo-hot air drying process for potato needs to be established.

## Materials and methods

Experiments were conducted in two phases – one, to investigate mass transfer kinetics of osmotic dehydration of potato and two, to develop osmo-hot air drying process based on organoleptic quality. In the first phase, osmosis was carried out in binary sugar and salt solution of varying concentration using a solution to sample ratio of 1:5. Osmosis was conducted at 30°C temperature without agitation. At each experimental condition osmotic dehydration was carried out for different time periods to investigate osmotic kinetics. At each designated osmotic time level, the samples were analyzed for moisture content and moisture loss, and the solid gain was calculated based on mass balance. In the second phase, potatoes were first osmoted in selected osmotic solutions for selected osmotic time based on the first phase results. These were then dried in tray dryer at 60, 70, 80°C till moisture content reached ≤6% d. b. The dried samples from each experiment were packed, sealed properly and kept at ambient temperature for quality analysis.

### 1.1 Materials

Fresh, good quality potatoes were procured from the local market on daily basis prior to each set of experiments. Care was taken to select compact tubers of uniform medium size and oval shape having white skin and without any defect on visual inspection. Common salt and sugar were also procured from the local market.

### 1.2 First Phase-Experimental Design

#### 1.2.1 Experiment Plan

Experiments were designed to dehydrate 10mm cube potato pieces, osmotically in binary mixture of sugar and salt solutions using a solution to sample ratio of 5 (Lenart & Flink, 1984). Salt concentrations were varied at 5, 10 and 15% by weight. Higher salt concentrations were not considered since these have been reported to result in organoleptic problems due to strong salty taste (Islam and Flink, 1982). Sugar concentrations were kept at 20% and 30%. At each experimental condition, osmotic dehydration was carried out for 10, 20, 30, 40, 50, 60, 90, 120, 150, and 180min time periods upto a maximum of 3 hours to investigate osmotic kinetics. All the experiments were replicated thrice. At each designated osmotic time period, the sample was analyzed for its moisture content, and the moisture loss, and the solid gain was calculated based on mass balance. All reported results were average values of the 3 replications.

### 2.2 Experimental Procedure

#### 2.2.1 Osmotic Solution Preparation

Osmosis solutions were prepared by blending the desired solutes on a w/w basis with distilled water. A magnetic stirrer was used to dissolve the contents. Salt and sugar were weighed on an electronic balance.

#### 2.2.2 Osmotic Dehydration

For each replication of an experiment, 270g prepared sample, 1500ml osmotic solution, ten 500ml beakers were taken. Ten beakers were taken for taking one sample out after each of the 10 designated time intervals for investigating mass transfer kinetics during osmosis. Beakers were filled with 125ml osmotic solution each and were kept in an incubator to preheat the solution to the experimental temperature. After attaining the desired temperature, 25g of prepared potatoes was immersed in

each beaker. This provided a solution to sample ratio of 5. Fifteen gram prepared potatoes were used for determining initial moisture content. One beaker at a time was taken out from the incubator at the designed times of 10, 20, 30, 40, 50, 60, 90, 120, 150, and 180 minutes from the beginning of osmosis and potato cubes taken out of the beakers. The cubes were then placed in 500ml beaker with 200ml distilled water and were shaken manually for 30s at room temperature to rinse out superficially adsorbed osmotic liquid. The rinsed cubes were placed on blotting paper to remove excess water and weighed on an electronic balance. Osmosed samples were then used for determination of moisture content.

### 2.3 Measurement of Dependent Variables

#### 2.3.1 Moisture Content Determination

Moisture content was determined by hot air oven method recommended by Ranganna, 1997 for fruits and vegetables which has successfully been used for potato, carrot, etc. (Lenart and Flink, 1984; Ghosh, 2002). Samples, 5g each were dried at 100°C in oven for 16-18 hr. Weighing of sample was performed in moisture boxes by electronic balance of 0.0001g accuracy and 150g capacity. Hot air oven was thermostatically controlled with an accuracy of ± 1.0°C and was equipped with mercury thermometer, 110°C. After drying, moisture boxes were covered with lid and kept in desiccators containing silica gel for 1 hour, for cooling. Moisture content was calculated by:

$$\text{Moisture content (\% d. b.)} = \frac{W_2 - W_3}{W_3 - W_1} \times 100 \quad \dots (1)$$

Where,

W1 = weight of dish, g

W2 = weight of sample before drying with dish, g

W3 = weight of sample after drying with dish, g

### 2.2.4 Data Analysis

#### 2.4.1 Moisture Loss during Osmosis

Based on review of earlier works (Lenart and Flink, 1984; Hawkes and Flink, 1978), the moisture loss (ML) was characterized using the following equation:

$$\text{ML, \%} = \frac{\text{Initial moisture, g} - \text{Final moisture, g}}{\text{Initial weight of the sample, g}} \times 100 \quad \dots (2)$$

#### 2.4.2 Solid Gain during Osmosis

The salt gain (SG) was measured by the following equation as suggested by Lenart and Flink, 1984; Hawkes and Flink, 1978.

$$\text{SG, \%} = \frac{\text{Final Solids, g} - \text{Initial Solids, g}}{\text{Initial weight of the sample, g}} \times 100 \quad \dots (3)$$

It was assumed that the amount of solid leaching out of potato during osmosis is negligible (Lazarides et al., 1995; Ghosh, 2002; Sutar, 2003). Mathematical Modelling Azuara et al., (1992) developed a two-parameter model from mass balance considerations to predict the kinetics of osmotic dehydration and the final equilibrium point. They verified the model using ten different sets of kinetic data on the osmosis of apple, pine apple, and beef from the literature and observed that the model could well predict the kinetics of osmosis process and the equilibrium point. Further, the model could be used to estimate the equilibrium point using data obtained during relatively short period of osmosis and could then be used successfully to predict the whole osmotic dehydration process upto the equilibrium point. In addition, the model could be related to the Fick's second law for non-steady one-dimensional diffusion and the apparent diffusion coefficients could be readily estimated. The model could characterize osmotic dehydration of different types of foodstuffs without restrictions of geometric considerations. The other published models (Conway et al., 1983; Lenart and Flink, 1984; Beristain et al., 1990; Biswal et al., 1991; Ertekin and Cakalo, 1996;

Pokharkar and Prasad, 1997, 1998) for osmotic dehydration were usually specific to processing conditions and geometric considerations. Additionally these models would not predict the equilibrium point. In some cases, the water loss and the solid gain have been directly modelled as a function of process conditions and the time of osmosis without considering equilibrium point and hence the driving potential for mass transfer. In view of the above, it was decided to develop the kinetic model for osmotic dehydration of potatoes in this study in the form of equations proposed by Azuara et al., (1992). If the equations were not to make accurate predictions, further modelling would follow.

## 2.5 Second Phase-Experimental Design

### 2.5.1 Experiment Plan

Potato cubes (10mm), were first osmotically dehydrated in selected osmotic solutions for a selected osmotic time based on the first phase results and were then dried in tray dryer at 60, 70, 80°C. These temperatures were chosen because potato is reported to be conventionally dried at a temperature of 60°C (Siddappa, 1986). However, Mishra (1991) reported that potato cubes should be dried at an air temperature of 70°C or higher to obtain final moisture content below 12% (db). But, higher temperature above 80°C could inhibit drying rates due to case-hardening (Sankat et al., 1996). Drying was continued up to a moisture content of  $\leq 6\%$  db (IS: 4626). No attempt was made to control relative humidity. This was because the control of humidity increases the process cost. Samples were periodically removed and weighed during the drying experiments to ensure that the final moisture content had been achieved. Each experiment was replicated thrice. The dried samples from each experiment were packed in zip-lip low density polyethylene (LDPE) bags, sealed properly and kept at ambient temperature for further quality analysis. The quality analysis determinants of osmo-air dried potato were sensory characteristics - taste, colour, odour, appearance & overall acceptability.

### 2.5.2 Experimental Procedure

#### 2.5.3 Osmo-Hot Air Drying

For each replication of an experiment, 170g prepared potato cubes sample was taken. A 15g sample was used for initial moisture content determination. Remaining 150g sample was first osmotically dehydrated for a time period as determined in the first phase of the study. This sample size would provide sufficient osmo-hot air dried product for quality parameters evaluation. A 15g osmo-dried sample was used for the determination of moisture content after osmosis. Left out osmo-dried sample was used for subsequent hot-air drying which was carried out in a tray dryer. The tray dryer was set at the desired temperature and was allowed to run for about 30min to attain steady state condition. The temperature control was within  $\pm 10^\circ\text{C}$ . The osmo-dried samples were hot-air dried upto  $< 6\%$  db moisture content. To determine the final moisture content, the sample was periodically removed during drying period and weighed on an electronic balance which took about 20 s. The dried samples were cooled in a desiccator containing silica gel for 1h, packed in zip-lip low-density polyethylene (LDPE) bags, sealed properly and kept at ambient temperature for quality analysis (sensory evaluation).

#### 2.5.4 Preparation of Conventional Hot-Air Dried Products Control for Quality comparison

In order to prepare conventional hot air dried product, 100g of prepared potato dices were first blanched in near-boiling water for 5 minutes. The sample was then blotted with blotting paper to remove excess water and weighed. The sample was then dried at  $60^\circ\text{C}$  air temperature in tray dryer upto  $\leq 6\%$  d. b. moisture content. A 15g prepared sample was used for initial moisture content determination.

## 2.6 Measurement of Dependent Variables

### 2.6.1 Sensory Evaluation

The organoleptic quality of dehydrated potatoes was determined with the help of a ten-member consumer panel using a 9-point

hedonic scale following standard procedure given by Bureau of Indian Standards (IS: 6273, 1971). The evaluation of dried product was done in its two forms - as dried potato and as rehydrated potato. In case of dried dices, the organoleptic aspects evaluated were - colour, appearance, flavour and acceptability to purchase. The aspects considered for rehydrated potatoes were colour, appearance, taste, flavour, and overall acceptability. The evaluation sheet is shown in the Table 1 and 2. The score sheets were provided to the panellists with the product and were requested to mark the product according to their linking. In between testing different samples, the panel members were given fresh water to rinse the mouth. The average scores of all the 10 panellists were computed for different characteristics.

### 2.6.2 Rehydration Procedure for Sensory Evaluation

The rehydration of dehydrated potato dices was done using Indian Standards, IS: 4626-1968 procedure. The samples were cooked in a beaker, containing one part sample to ten parts of 1% sodium chloride solution by weight for 30min., and then allowed to cool at room temperature for 45min. Excess solution was drained and surface water was removed with the help of absorbent paper. The samples were served for sensory evaluation.

## Result and Discussion

### 3.1 Effect of Solution Concentration and Time of Osmosis

The effect of salt concentration in the binary salt-sugar osmotic solutions having 20% sugar on the moisture loss and solid gain with respect to time of osmosis is shown in Fig. 1. depicts the effect of salt concentration with 20% sugar in the binary solution. Similarly, the effects of sugar in the binary salt-sugar osmotic solution having 10% salt concentrations are shown in Fig. 2. It was observed from these figures that the moisture loss as well as the solid gain increased nonlinearly with time at all concentrations. Both the moisture loss and solid gain were faster in the initial period of osmosis and then the rate decreased. This was expected because osmotic driving potentials for moisture as well as solids transfer will keep on decreasing with time as the moisture keeps moving from sample to solution and the solids from solution to the sample. Further, progressive solid uptake would result in the formation of high solids subsurface layer, which would interfere with the concentration gradients across the sample-solution interface and would act as a barrier against removal of water and uptake of solids (Hawkes and Flink, 1978).

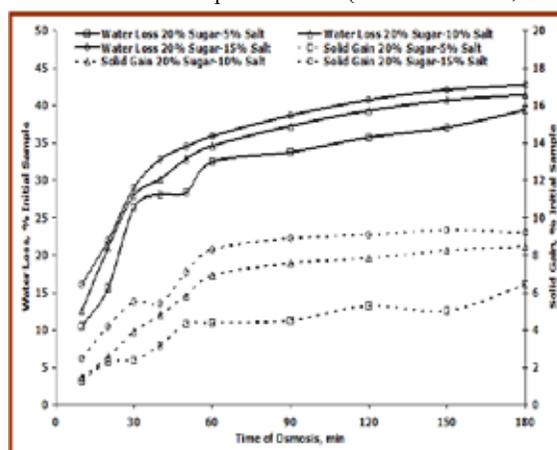
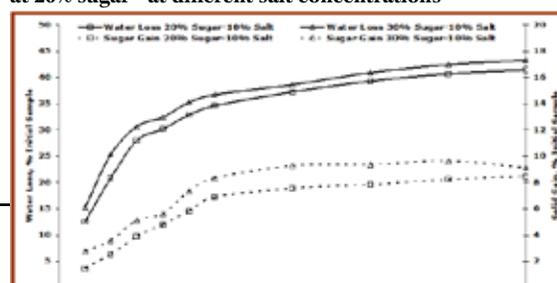


Fig. 1 Moisture loss and solid gain curve of potato osmosed at 20% sugar - at different salt concentrations



**Fig. 2 Moisture loss and solid gain curve of potato osmosed at 10% salt - at different sugar concentration**

**3.2 Osmotic Mass Transfer Kinetics Model**

**3.2.1 Proposed Model**

A two parameter equation based on mass balance developed by Azuara et al. (1992) was used, in order to predict the kinetics of dehydration during the osmotic process, and to determine the final equilibrium point. The proposed model was:

$$ML_t = \frac{S_1 t (ML_\infty)}{1 + S_1 t} = \frac{ML_\infty t}{\frac{1}{S_1} + t} \quad \dots (1)$$

$$SG_t = \frac{S_2 t (SG_\infty)}{1 + S_2 t} = \frac{(SG_\infty) t}{\frac{1}{S_2} + t} \quad \dots (2)$$

where,

$ML_t$  = Fraction of moisture loss by potato at time t  
 =  $\frac{\text{Amount of moisture lost, g}}{\text{Amount of initial moisture in potato, g}}$

$ML_\infty$  = Fraction of moisture loss by potato at equilibrium  
 =  $\frac{\text{Amount of moisture lost at equilibrium m, g}}{\text{Amount of initial moisture in potato, g}}$

t = Time, min

$S_1$  = Constant related to the rate of water diffusion out from potato, min<sup>-1</sup>

$SG_t$  = Fraction of solid gained by potato at time t  
 =  $\frac{\text{Amount of solids gained, g}}{\text{Amount of initial solids in potato, g}}$

$SG_\infty$  = Fraction of solid gained by potato at equilibrium  
 =  $\frac{\text{Amount of solids gained at equilibrium m, g}}{\text{Amount of initial solids in potato, g}}$

$S_2$  = Constant related to the rate of solids diffusion in the potato, min<sup>-1</sup>

The Equations 1 and 2 indicate that  $t$  or  $t$  represent the time required for half of the diffusible matter (water or solids) to diffuse out or enter in the product respectively. Further, as the time t, becomes much greater than the values of  $\frac{1}{S_1}$  or  $\frac{1}{S_2}$  (that is,  $t \gg \frac{1}{S_1}$ ), the water loss or the solid gain,  $ML_t$  or  $SG_t$ , approaches equilibrium value,  $ML_\infty$  or  $SG_\infty$ , asymptotically. In above Equations (1 & 2), the values of parameters  $S_1$ ,  $ML_\infty$ ,  $S_2$  and  $SG_\infty$  can be estimated from short duration osmotic kinetic data by performing linear regression on or by graphical plotting of the above equations in the linearized form. Equation 1 and 2 can be linearized in the following form:

$$\frac{t}{ML_t} = \frac{1}{S_1 (ML_\infty)} + \frac{t}{ML_\infty} \quad \dots (3)$$

$$\frac{t}{SG_t} = \frac{1}{S_2 (SG_\infty)} + \frac{t}{SG_\infty} \quad \dots (4)$$

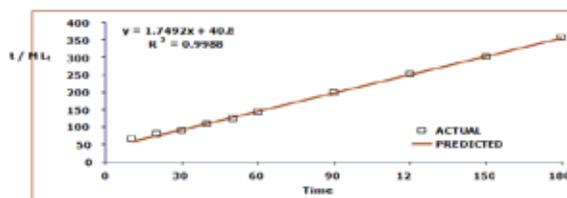
So, if the experimental plots of  $\frac{t}{ML_t}$  vs t and  $\frac{t}{SG_t}$  vs. t were to show linearity, the parameter values could be deter-

mined from the intercept and the slope. The model, Equations 1 and 2 could then be used to predict the mass transfer kinetics.

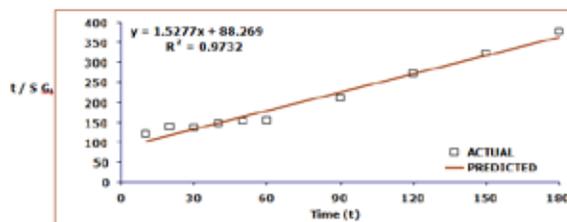
**3.2.2 Development of Model for Osmotic Mass Transfer Kinetics in Potato**

The values of  $\frac{t}{ML_t}$  and  $\frac{t}{SG_t}$

as calculated from the moisture loss and solid gain data plotted against time in Fig. 1 and Fig. 2. A linear trend was observed in all cases. Straight lines were, therefore, fitted by performing linear regression and the parameter values were determined. The values of  $ML_\infty$  and  $S_1$  for moisture loss kinetics (Eq. 3) and of  $SG_\infty$  and  $S_2$  for solid gain kinetics (Eq. 4) so obtained along with the R2 values. The R2 values were all above 0.9521 showing a very good fit of the proposed model in its linearized form to the experimental data in all cases.



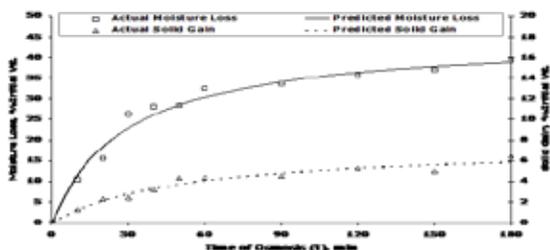
**Fig. 3 Linear plot of the equation 4.3 for determination of  $ML_\infty$  and  $S_1$  at 20% sugar-10% salt concentration**



**Fig. 4 Linear plot of the equation 4 for determination of  $SG_\infty$  and  $S_2$  at 20% sugar-10% salt concentration**

**3.3 Process Development for Osmo-Hot Air Drying of Potatoes**

The potato dices were dried under different osmo-hot air drying conditions. Osmotic drying was carried out for 1 h as this has been reported to be the productive duration of osmosis (Ghosh, 2002; Sutar, 2003) prior to hot-air drying. During this period, most of the osmotic water loss potential is achieved and the solid gain remains low so as not to presumably affect the organoleptic characteristics adversely. In the present study on potato also, similar results were observed, section 1. The binary salt-sugar osmotic solution concentrations investigated for osmo-hot air drying process were: 20% sugar – 10% salt, 20% sugar– 15% salt, 30% sugar – 5% salt and 30% sugar – 10% salt. These osmotic solutions resulted in a moisture loss of around 35% of initial potato weight and a solid gain of around 7% in 1 h osmosis, Fig. 1- Fig. 2. The osmotic solution having concentration of 20% sugar – 5% salt and 30% sugar – 15% salt were not considered as the first one resulted in only about 30% moisture loss, Fig. 2, where as the second one yielded a high solid gain of about 9%, Fig. 1 in 1 h osmosis. Osmosed potatoes were then hot air dried to < 6% db moisture content at the hot air drying temperatures of 60, 70, and 80°C. Potatoes were also dried by conventional hot-air drying method – blanching and drying at 60°C – for comparison with osmo-hot air drying process. The organoleptic quality of the dried potatoes were then determined and statistically analyzed to establish the best osmo-air drying process for potatoes.



**Fig. 5 Observed and predicted moisture loss and solid gain curves by the developed model at 20% sugar - 5% salt concentration**

### Conclusions

The moisture loss from potatoes and the solid gain by potatoes increased non-linearly with duration of osmosis at all solution concentrations and both were higher in the initial period of osmosis than the later period. Both moisture loss from potatoes and the solid gain by potatoes increased with the increasing salt as well as with the increasing sugar concentration in the osmosis solution. A two-parameter model for mass transfer kinetics during osmotic dehydration of potato was developed:

$$\text{For moisture loss kinetics: } ML_t = \frac{S_1 t (ML_\infty)}{1 + S_1 t} = \frac{(ML_\infty) t}{\frac{1}{S_1} + t}$$

$$\text{For solid gain kinetics: } SG_t = \frac{S_2 t (SG_\infty)}{1 + S_2 t} = \frac{(SG_\infty) t}{\frac{1}{S_2} + t}$$

Where,  $ML_\infty$  and  $S_1$ ; and  $SG_\infty$  and  $S_2$  are model parameters. The model parameters for the experimental conditions were established. The model developed for mass transfer kinetics during osmotic dehydration of potatoes predicted the experimental data very well. The model could be used to estimate osmotic equilibrium point using data for relatively short period of osmosis and could then be used to predict osmotic mass transfer up to the equilibrium. The model was not restricted by the geometry of the product. Osmotic dehydration prior to tray drying improved the organoleptic characteristics of dehydrated potato. The recommended osmo-hot air drying process for potato based on organoleptic quality was: osmotic dehydration of potato dices in 20% sugar and 10% salt osmotic solution for potato for 1 hour followed by hot air drying at 70°C temperature.

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