Osmotic dehydration of carrot strips and modelling

Sheetal D Deshmukh¹ Shubham Gabhane² and Dheeraj S Deshmukh³

¹Department of Food Technology, L.I.T., RTMNU, Nagpur, MS, India
²Department of Food Technology, L.I.T., RTMNU, Nagpur, MS, India
³G.H. Raisoni College of Engineering, Nagpur, MS, India
E-mail: sheetalddeshmukh11@gmail.com

Abstract. Osmotic dehydration kinetics using parameters moisture loss and solid gain during osmotic dehydration of carrot strips were studied. Carrot strips of 30x10x2 mm size were osmotically dehydrated in sugar syrup of 40°B, 50°B and 60°B. During osmotic dehydration process syrup solution to carrot sample ratio was kept 6:1. The process was carried out at various temperatures 27°C, 40°C and 50°C for time period of 15, 30, 60, 90, 120 and 180 minutes. Mass transfer kinetics of the two main parameters of process, moisture loss and solid gain data were studied using five different mathematical models. The models used include Azuara, Peleg, Magee, Power and Penetration Model. Amongst the applied model Azuara’s and Peleg model were found to be best fitted for moisture loss while for solid gain Power law and Magee’s model were found to be best fit.

Keywords: Carrot strips, Osmotic dehydration, kinetic model, moisture loss, solid gain

1. Introduction
Fruits and vegetables are important source of vitamins, minerals and fibers in human diet. Annual fruit and vegetable production in India is 81.285 and 162.186 million tonnes respectively. Thus amount of fruits and vegetable produced in India is large [1]. Fruits and vegetables losses in the developing countries are considerably high. In India, post-harvest losses of fruits and vegetables are estimated at more than 25 percent. Among the root crops grown in India, carrot is one of the most popular among the common masses in India. In India, the area under carrot cultivation is 32,019 ha with an annual production of 4.857 lakh tonnes [2]. Carrot is an important member of root vegetable. Carrot is a good source of β-carotene, thiamine, iron, vitamin C and sugar [3]. Disease like cancer can be prevented from B- carotene. 100 gram of carrot consumption daily can fulfill the daily need of vitamin A. It is very crucial nutrient for eyes and skin. It also contain sugar (source of energy), calcium, phosphorus, vitamin B and fiber for proper function of digestion and regulating nervous system [4].

However, like most fruits and vegetables carrot too is seasonal and has limited shelf life. In the season, the selling prices decreases due to abundant supply of produce into the market. They are highly susceptible to moisture loss which results in shrinkage and loss of freshness. Carrot deteriorate quickly due to microbial and biochemical activity. Considering popularity and nutritional benefit of carrot the demand of carrot during off season is expected, therefore method for preservation and extending shelf life of carrot are required. Osmotic dehydration process retains important characters of fruits and vegetables like colour, flavor, texture and nutritional composition [5]. It requires less energy than hot
air or vacuum oven drying process because water is removed by osmosis and the cell sap is concentrated without a phase transition of the solvent [6]. Thus, the two main advantages of osmotic dehydration, retaining quality of fruits and vegetables and less energy intensive makes it very popular in food processing industry.

In Osmotic dehydration process, water is removed partly by immersing fruits and vegetables in a concentrated aqueous solution of high osmotic media for particular time and temperature [7]. Higher osmotic pressure of the concentrated solution causes the diffusion of water from the tissue of fruits and vegetables into the solution. Along with the diffusion of water there is also concurrent counter diffusion of solutes (small molecules and large molecules) from the osmotic solution into the tissue. As the cell membrane of fruits and vegetable for solute transport is not perfectly selective, other solutes present in the cells can also be removed into the osmotic solution [8]. But this flow can be quantitatively neglected. Various factors affect the mass transfer in osmotic dehydration. Therefore, there is a great need to study effect of various process variables on osmotic dehydration process to select best possible conditions to obtain desired product. Mass transfer during osmotic dehydration is a complex phenomenon. Considering osmotic dehydration process very beneficial for industrial applications, simple models which give additional information on the variables that can regulate quantify the osmotic dehydration process have been developed. Therefore, the objective of the present work was to study of osmotic dehydration kinetics of carrot strips in sucrose solution having different concentrations and temperatures with fixed sample to solution ratio.

2. Materials and Methods

2.1. Sample Preparation
Carrots were thoroughly washed, peeled and cut into strips of uniform dimension 30×10×2 mm using kitchen knife. No pretreatment was given to sample.

2.2. Osmotic Solution Preparation
Calculated amount of sucrose was weighed and dissolved in water to make osmotic solution of different concentration (40˚B, 50˚B, 60˚B). The solution was slightly heated to hasten the dissolution of sucrose in water and avoid crystallization. The required degree of concentration obtained was ascertained by measuring Brix with the help of hand refractometer (32-62˚B range).

2.3. Experimental Procedure
Pre-weighed sample were immersed in osmotic solution of required concentration. Initial moisture content of the sample was recorded. The sample to solution ratio used was 1:6. The sample to solution ratio was kept constant at this value in each run. The osmotic dehydration was carried out in beaker placed in incubator to maintain the constant temperature. The sample was removed at time interval of 15,30,60,90,120 and 180 minutes. Then, the samples were washed with water. This will deliberately remove the solution sticked to the surface. These samples were then blotted with clean cotton cloth to remove the surplus water from the surface. The dehydrated sample obtained after each time interval were weighed and moisture content of dehydrated sample was estimated using hot air oven method at 105˚C for 5 hrs. After every time interval, moisture loss and solid gain were noted. Effect of concentration of sugar (40˚B, 50˚B, 60˚B) and solution temperature (27˚C, 40˚C, 50˚C) was also investigated. Experiments were carried out in duplicates.

2.4. Mass Transfer Parameters
Moisture Loss (WL) and Solute Gain (SG) are the two main parameter for estimating mass transfer between the hypertonic osmotic solution and sample during osmotic dehydration process.

The moisture loss (% ML) and solids gain (%SG) was determined from the following equations:-
% ML = \frac{M_iX_i - M_fX_f}{M_i} \times 100

% SG = \frac{M_f(1 - X_f) - M_i(1 - X_i) \times 100}{M_i}

M_i = \text{Initial weight of the Sample}
X_i = \text{Initial Moisture content in the Sample}
M_f = \text{Final weight of the Sample after dehydration}
X_f = \text{Final Moisture content in the Sample after dehydration}

2.5. Modelling of mass transport kinetics

The Azuara’s, Peleg’s, the Penetration, Magee’s and Power Law were the mathematical models used to fit the experimental data.

2.5.1. Azuara’s Model

Azuara et al. (1992) developed a model based on the mass balances to predict the WL and SG during osmotic dehydration [9]. The equations of the model require two adjustable parameters, and the model can estimate the mass transfer coefficients and the final equilibrium point, which is considered the main advantage. The WL and SG are given by the following equation:-

\[ \text{ML}_T \text{or SG}_T = \frac{\text{S} \cdot \text{T} \cdot (\text{ML}_\infty \text{ or SG}_\infty)}{1 + \text{S} \cdot \text{T}} \]

ML_T is moisture loss at any time t, SG_T is solid gain at any time t and S is the parameter related to the rate of water diffusion out of the food or the solute diffusion into the food.

2.5.2. Peleg’s Model

The equation proposed by Peleg (1988) can describe the moisture sorption curves that approach the equilibrium asymptotically by using two parameters, k_1 and k_2 [10]. The Peleg’s equation is given as:

\[ M = M_0 \pm \frac{t}{k_1 + k_2} \]

M is the moisture at time t and M_0 is the initial moisture, both expressed in dry weight basis. In this work, \( |M - M_0| \) is considered the water loss or solid gain. Thus, the WL and SG are given by:

\[ \text{ML}_T \text{or SG}_T = \frac{t}{k_1 + k_2} \]

k_1 and k_2 are the Peleg’s constants for ML or SG. The constant k_1 relates to the initial rate of the mass transfer and the constant k_2 relates to equilibrium values, WL_\infty or SG_\infty.

2.5.3. The Penetration Model

According to Hawkes and Flink (1978), the experimental data can be analyzed assuming unsteady state Fickian diffusion to obtain the diffusion coefficients [11]. The WL and SG are considered, simplifying the assumptions relative to the indefinite series expressions,

\[ \text{ML}_T = \pi r^2 \text{ or SG}_T = k \cdot \sqrt{t} \]

Where, ML_T is the water loss at time t, SG_T is the solids gain at time t and K is constant related to rate of mass transfer during osmotic dehydration process.
2.5.4. Magee’s Model

This model establishes that WL and SG vary linearly with the square root of time during osmotic dehydration [12]. The Magee’s equation is as following:

\[ ML_T^{or}SG_T = A + k \sqrt{t} \]

Where, \( ML_T \) is the water loss at time \( t \), \( SG_T \) is the solids gain at time \( t \), \( A \) and \( k \) are model fitting parameters. Coefficients \( k \) represents the rate of water removal or solids intake, because of the osmotic-diffusive mechanism; meanwhile, \( A \) represents the contribution of the hydrodynamic mechanism, because of the action of capillary pressures at very short times, for mass transfer of water or solids.

2.5.5. Power Law Model

The power law (also called the scaling law) states that a relative change in time results in a proportional relative change in ML or SG. The power law [13] can be stated as:

\[ ML^{or}SG = k \cdot t^N \]

Where, \( N \) is law’s exponent which relates to degree of dependency of ML or SG on time. \( k \) is constant relating rate of ML or SG with respect to time.

2.6. Statistical Analysis and Validation of models

The statistical analysis was performed using Origin Pro 2017 (Origin Lab Corporation, USA). The models were fitted to the experimental data obtained at the different conditions tested. The model parameters were estimated by non-linear regression procedures. In order to validate the model and check the goodness of fit, the parameters such as highest coefficient of determination (\( R^2 \)), highest adjusted coefficient of determination. Adj. R2 and root mean square error (RMSE), were considered and evaluated by performing non-regression analysis. The mean absolute percentage error, also known as mean absolute percentage deviation (%M) is calculated by the formula

\[ \%M = \frac{100}{N} \sum_{t=1}^{N} \frac{\text{Experimental value} - \text{Predicted value}}{\text{Experimental value}} \]

3. Result and Discussion

During the various experiments performed on osmotic dehydration of carrot stripes it was found that with subsequent increase of all the three parameters concentration of hypertonic osmotic solution, temperature and time, an increase in moisture loss and solid gain has been observed. Initially water loss rate and solute gain rate were higher but later on it decreased.

The variables acquired in osmotic dehydration process have important effect on the constants as well as exponents of the different empirical models fitted to the moisture loss and solid gain data. Following points describes moisture loss and solute gain during osmotic dehydration of carrot stripes of several models. The values of statistical parameters, models constants and coefficients for water loss and solid gain during osmotic dehydration are given in Tables 1, 2, 3 and 4.

3.1. Empirical Models for Water Loss of carrot stripes

3.1.1. Azuara’s Model

It can be observed from Table 1 that \( R^2 \) values for moisture loss for all process conditions under experimentation were higher than 0.9 therefore, Azuara’s Model indicated good fit of model for experimental data of moisture loss. However, \( R^2 \) values obtained were slightly lower for solid gain as compared to moisture loss indicating Azuara’s Model could be best fitted for moisture loss than solid gain. Lower RMSE values and mean absolute percentage error less than 10% obtained after statistical analysis indicates the good predictability and higher acceptability of Azuara’s model. It was found that
equilibrium moisture content ($WL_\infty$) obtained after nonlinear regression analysis of Azuara’s Model increased with increase sugar syrup concentration and process temperature. Similar trend was observed for equilibrium solid gain values ($SG_\infty$). These observations are consistent with the fact that increase in concentration of osmotic agent increased concentration gradient and hence ultimately increased moisture loss and solid gain at which equilibrium is attained. Increase in temperature decreased viscosity of osmotic agent solution, increased osmo-active current and increased diffusivity which shifted equilibrium condition on higher side. The value of parameter $S$ which indicated water loss ($WL$) rate, because of osmo-convective diffusion mechanism increased with increase temperature for all process condition used during study. Also, $S$ increased with increase in concentration, except for moisture loss at 50˚C when value $S$ decreased slightly from 0.1067 to 0.0942 with increase in sugar syrup concentration from 50˚B to 60˚. Value of $S$ for solid gain which signifies rate of solute diffusion into the sample increased with increase in concentration. However, with increase in sugar syrup temperature significant changes were not seen.

### Table 1. Regression coefficient and statistical parameters for Azuara’s Model

| Temp (˚C) | Conc (˚B) | Moisture Loss | Solid Gain |
|----------|-----------|---------------|------------|
|          |           | $WL_\infty$  |            | $SG_\infty$ |
|          |           | $S$         | $R^2$     | Adj.$R^2$ | RMSE | $S$   | $R^2$ | Adj.$R^2$ | RMS | $M$ |
| 27       | 40        | 58.205      | 0.024     | 0.990     | 0.987   | 1.355 | 3.367 | 5.465 | 0.018 | 0.952 | 0.940 | 0.264 | 7.8251 |
| 27       | 50        | 59.268      | 0.04      | 0.982     | 0.978   | 1.642 | 2.909 | 5.941 | 0.025 | 0.879 | 0.848 | 0.458 | 10.363 |
| 27       | 60        | 62.199      | 0.047     | 0.996     | 0.995   | 0.733 | 1.314 | 6.398 | 0.049 | 0.919 | 0.899 | 0.358 | 5.8074 |
| 40       | 40        | 60.093      | 0.045     | 0.942     | 0.927   | 3.246 | 6.716 | 6.103 | 0.015 | 0.955 | 0.944 | 0.286 | 6.9485 |
| 40       | 50        | 61.532      | 0.065     | 0.974     | 0.967   | 1.787 | 2.845 | 7.051 | 0.028 | 0.913 | 0.892 | 0.460 | 8.9328 |
| 40       | 60        | 64.670      | 0.066     | 0.992     | 0.990   | 1.034 | 1.130 | 7.242 | 0.058 | 0.874 | 0.843 | 0.483 | 6.1515 |
| 50       | 40        | 61.108      | 0.059     | 0.962     | 0.953   | 2.311 | 3.704 | 7.590 | 0.028 | 0.914 | 0.893 | 0.487 | 8.8195 |
| 50       | 50        | 63.176      | 0.106     | 0.971     | 0.964   | 1.536 | 1.958 | 7.81  | 0.042 | 0.857 | 0.822 | 0.632 | 8.5615 |
| 50       | 60        | 68.438      | 0.094     | 0.973     | 0.966   | 1.709 | 2.201 | 8.417 | 0.046 | 0.911 | 0.889 | 0.504 | 6.3571 |

#### 3.1.2. Peleg’s Model

It can be observed from Table 2 that $R^2$ values for moisture loss for all process conditions under experimentation were higher than 0.9 therefore, Peleg’s Model indicated good fit of model for experimental data of moisture loss than solid gain for process conditions under the study (Table 2). It can also be observed from data obtained that $k_1$ is greater than that of $k_2$ indicating initial rate of mass transfer is greater than that of equilibrium mass transfer rate. It can be noted from data presented in Table 2 that kinetic parameter $k_1$ decreased with increase in concentration for moisture loss (except for moisture loss at 50˚C when value $k_1$ increased slightly from 0.1484 to 0.1552 when sugar syrup concentration was raised from 50˚B to 60˚B). Since reciprocal of constant $k_1$ indicated the initial rate of mass transfer, therefore decrease in $k_1$ with increase in concentration signified increase in initial rate of
mass transfer with increase in concentration. This is consistent with fact that increase in concentration increases net driving force and hence increase rate of mass transfer. It is also found that constant $k_1$ decreased with increase in temperature for moisture loss for all the process conditions under study indicating increase in equilibrium solute uptake by sample when process temperature as well as sugar syrup concentration were raised. Also, the value of parameter obtained for constant $k_1$ and $k_2$ were lower for moisture loss than solid gain by several magnitudes indicating high rate of moisture loss dominating the osmotic dehydration process.

Table 2. Peleg’s Model

| Temp (˚B) | Conc (˚B) | Moisture Loss | Solid Gain |
|----------|-----------|---------------|------------|
|          |           | $k_1$ | $k_2$ | $R^2$ | Adj.$R^2$ | RMSE | %M | $k_1$ | $k_2$ | $R^2$ | Adj.$R^2$ | RMSE | %M |
| 27       | 40        | 0.7159001720.99010.98771.35553.36749.8400.18290.9520.940 | 0.715 7.8262 |
| 27       | 50        | 0.42170.98270.97841.64272.90996.5690.16830.879 | 0.848 0.421 10.363 |
| 27       | 60        | 0.33910.9610.99660.99580.73381.3153.1710.15630.919 | 0.899 0.339 5.8077 |
| 40       | 40        | 0.36960.01660.94220.92773.24626.71767.6550.16380.955 | 0.944 0.369 6.9475 |
| 40       | 50        | 0.24880.01630.9740.96751.78792.84554.9960.14180.913 | 0.892 0.248 8.935 |
| 40       | 60        | 0.23320.01550.99220.99021.03421.12082.3500.13810.874 | 0.843 0.233 6.1507 |
| 50       | 40        | 0.27520.01640.96290.95362.3113.69834.6760.13170.914 | 0.893 0.275 8.8184 |
| 50       | 50        | 0.14840.01580.97150.96441.53691.95835.0510.1280.8570.822 | 0.148 8.5622 |
| 50       | 60        | 0.15520.01460.97320.96651.70972.2012.5630.11880.911 | 0.889 0.155 6.3558 |

3.1.3. Magee’s Model

Coefficient of determination for solid gain were greater than 0.9 for all process conditions under the study (Table 3). Therefore, Magee’s model represented good fit for solid gain data. The values of Adj. $R^2$ were comparable to the $R^2$, so the use of Magee’s model for solid gain analysis could be generalized. The RMSE and M values were also comparatively lower for solid gain data hence given model had good predictability and accuracy for process consideration under study. The constant $A$ signifies the hydrodynamic mechanism for the action of capillary pressures at less times for mass transfer of water. It showed a major increase with increase in concentration [15] as well as temperature of the osmotic solution. The value of constant $A$ also increased with increased in value of concentration and temperature for solid gain (except at 60˚B when value of $A$ decreased from 5.5106 to 2.3630 when temperature was raised from 40˚C to 50˚C). Parameter $k$ of Magee model for moisture removal represented rapid variation. This has not supported with results of current study that water or moisture loss increased with increase in the concentration and temperature of the osmotic solution. Thus Magee model was improper in evaluating the mass transfer characteristics for moisture loss. Parameter $k$ did not depict any clear trend for variation of solid gain with temperature. However, it did have clear trend for variation of solid gain with change of concentration. The value of $k$ which indicated rate of solute uptake increased with increase in temperature. This observation was similar to the observation made for
solute uptake with variation in temperature during the study. Thus, Magee’s law was partially successful in analysis and explaining solid gain, particularly for variation of solid gain with temperature.

| Table 3. Regression coefficient and statistical parameters for Magee’s Model |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Temp (˚C)       | Conc (˚B)       | Moisture Loss   | Solid Gain      |                 |                 |                 |                 |                 |                 |
|                 |                 | A               | k               | R²              | Adj.R²           | RMSE            | %M              | A               | k               | R²              | Adj.R²           | RMSE            | %M              |
| 27              | 40              | 5.47463.36520.9470.9345 3.1230 | 9.2770.32800.30680.99680.996 0.06881.492 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| 27              | 50              | 14.5133.08470.9490.9374 2.7945 | 5.1030.80050.32850.96690.958 0.24004.524 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| 27              | 60              | 18.6013.05910.9190.8996 3.5664 | 6.4251.91690.32070.99840.998 0.05033.910 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| 40              | 40              | 16.9042.99830.7680.7101 6.5011 | 14.710.53380.34380.99900.987 0.04391.099 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| 40              | 50              | 24.3862.70800.9270.9095 2.9855 | 4.8531.06590.39200.97280.966 0.25894.429 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| 40              | 60              | 26.0932.80550.8990.8747 3.6953 | 5.9792.51060.34780.98910.986 0.14432.072 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| 50              | 40              | 22.5402.77020.8310.7891 4.9252 | 9.1021.17200.41840.98300.978 0.21754.024 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| 50              | 50              | 34.3912.18260.8950.8688 2.9489 | 4.2901.91090.41600.95800.947 0.34364.747 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| 50              | 60              | 34.6022.55100.9280.9110 2.7863 | 4.0192.36300.43020.99860.998 0.06303.789 |                 |                 |                 |                 |                 |                 |                 |                 |                 |

3.1.4. Penetration Model
The value of R² obtained for penetration model both for solid gain as well as moisture loss were significantly lower than 0.9 for most of the process condition indicating lack of fit of penetration model for both solid gain as well as moisture loss for conditions used during the study. Also, RMSE were comparatively higher and mean absolute percentage error exceeded 10% in most of the cases thus penetration model had poor predictability and accuracy for given data (Table 4). Therefore, use of penetration model for analyzing moisture loss or solid gain could not be validated. The value of parameter k which indicates rate of water transfer from the sample and solute uptake in the sample due to osmo-diffusive mechanism enhanced with rise in concentration of osmotic agent and temperature both for moisture loss as well as solid gain. Though penetration model did not provided good fit for solid gain or moisture loss data, it did account for the various trends observed during study.
Table 4: Regression coefficient and statistical parameters for Penetration Model

| Temp (˚C) | Conc (˚B) | Moisture Loss | Solid Gain |
|-----------|-----------|---------------|------------|
|           |           | k  | R² | Adj.R² | RMSE | %M | k  | R² | Adj.R² | RMSE | %M |
| 27        | 40        | 3.9288 | 0.9172 | 0.9172 | 3.5111 | 8.0612 | 0.3405 | 0.983 | 0.983 | 0.1415 | 4.8249 |
| 27        | 50        | 4.5786 | 0.6951 | 0.6951 | 6.1685 | 14.0112 | 0.4109 | 0.89730.8973 | 0.3779 | 9.7908 |
| 27        | 60        | 4.9738 | 0.5075 | 0.5075 | 7.9006 | 15.8001 | 0.518 | 0.56610.5661 | 0.746214.3466 |
| 40        | 40        | 4.7384 | 0.4722 | 0.4722 | 8.7726 | 15.091 | 0.3988 | 0.96980.9698 | 0.2111 | 6.0601 |
| 40        | 50        | 5.2183 | 0.0158 | 0.0158 | 9.8452 | 17.6388 | 0.5018 | 0.88560.8856 | 0.4745 | 9.5055 |
| 40        | 60        | 5.4915 | 0.0437 | -0.0437 | 10.6643 | 18.4938 | 0.6062 | 0.36430.3643 | 0.9841 | 15.737 |
| 50        | 40        | 5.0904 | 0.1641 | 0.1641 | 9.8041 | 17.8739 | 0.5391 | 0.88950.8895 | 0.4952 | 9.5458 |
| 50        | 50        | 5.7228 | 1.7986 | -1.7986 | 13.6215 | 21.6592 | 0.6127 | 0.713 | 0.713 | 0.803613.0634 |
| 50        | 60        | 6.1128 | 1.1427 | -1.1427 | 13.6747 | 20.519 | 0.6735 | 0.63340.6334 | 0.919913.6923 |

3.1.5. Power Law Model

For moisture loss, the values of R² were greater than 0.9 for most of process conditions, though less than those obtained by Azuara’s Model and Peleg’s Model. Therefore, Power Laws model had good fit for moisture loss at process conditions under the study. Comparatively lower values of RMSE, M values less than 10% (for most of the cases) and Adj, R² values comparable to that of the R² value indicated satisfactory accuracy, predictability and generalization of power law model for moisture loss for different process conditions under the study. For solid gain, R² values were greater than 0.9 for all process conditions. Adj, R² values were closer to that of the R² values, RMSE were smaller and M values were less than 5% in most of the cases (Table 4) indicating good predictability, accuracy and generalization of power law model for solid gain. Since R² values for solid gain were more than that for moisture loss under identical process conditions, therefore, Power law represented solid gain data more accurately than moisture loss data. The parameter k which represents the rate of water loss increased with increase in temperature for all process consideration under study. Parameter k also increased with concentration in most process conditions except at 50˚C when k decreased slightly from 26.5370 to 26.3239. The value of rate constant k for solute uptake also displayed clear trend and it increased with rise in sugar syrup concentration in addition to temperature. The results obtained are consistent with the observation made during the study. The value of N which indicated degree of dependency of both parameters moisture loss and solid gain on time decreased with increase in concentration and temperature. This signified that increase in concentration or temperature decreased the influence of time on moisture loss or solid gain. This is because with increase in concentration and temperature of osmotic agent, rate of mass transfer increases at any given time and process achieves equilibrium quickly. Thus, reducing the influence of immersion time on moisture loss or solid gain.

The evaluation of experimental and predicted values of several osmotic dehydration models for moisture loss and solute gain were studied visually given in the Figure1 and 2. The values of moisture loss were predicted very well by azuara, pelegs and power law models. In this work the experimental and predicted
values of Azuara model for moisture loss were similar to a great extent for osmotic dehydration of carrot stripes. (Figure 1).

The relative validity of the different models fitted to the solute gain data can also be denoted from the predicted curves shown in Figure 2. It specifies that the experimental and predicted values of Magee and Power law model for solute gain were similar to a great extent for osmotic dehydration of carrot stripes (Figure 2).

Figure 1. Predicted and experimental values of moisture loss with time for 400Brix and temperature 250°C using different models

Figure 2. Predicted and experimental values for Solid Gain with time at 400Bx at 250°C using different models

4. Conclusion

Osmotic dehydration process of carrot stripes was successfully predicted by the various models used in this work. For predicting water loss Azuara, Peleg’s and Power law model were found to be best whereas
for predicting data of solid gain, Magees and Power law model were found appropriate. This is due to lower RMSE values and mean absolute percentage error less than 10% obtained after statistical analysis indicates the good predictability and higher acceptability of these models. Coefficient of determination for solid gain and moisture loss were greater than 0.9 for all process conditions used in these models.

5. References

[1] Ministry of Statistics and Programme Implementation, 2016, HORTICULTURE - Statistical Year Book India 2016, Major Fruits and Vegetables producing countries in the world, India.

[2] Food and Agriculture Organisation of United Nations, FAOSTAT, 2010, Carrot and Turnip Production and Area under Cultivation in India, Rome, Italy.

[3] V. Changrue and V. Orsat, 2009, Osmotically dehydrated microwave vacuum drying of carrots, Canadian Biosystems Engineering, Vol.51, pp.3.12-3.19.

[4] P.M. Araujo, J.R.L. Fonseca, M.M.A. Magalhaes and M.F.D. Medeiros 2014, Drying of carrot slices with Osmotic dehydration; African Journal on Biotechnology, Vol.13, pp.3061-3067.

[5] Pokharkar, S. M., & Prasad, S. (1998). Mass transfer during osmotic dehydration of banana slices, Journal of Food Science and Technology, Vol.35(4), pp.336-338.

[6] U. D. Chavan, 2012, Osmotic Dehydration Process for Preservation of Fruits and Vegetables, Journal of Food Research, Vol. 1, No. 2, 202-209.

[7] Ponting JD, 1973, Osmotic dehydration of fruits - recent modifications and application, Proc. Biochem, Vol. 8, pp.18-20.

[8] Kowalska H., & Lenart, 2001, Journal of Food Engineering, Vol. 49, pp.137–140.

[9] Azuara, E., Beristain, C. I. and Garcia, H. S., 1992, Development of a mathematical model to predict kinetics of osmotic dehydration, Journal of Food Science and Technology, Vol. 29, pp. 239-242.

[10] Peleg, M., 1988, An empirical model for the description of moisture sorption curves, Journal of Food Science and Technology, Vol. 53, pp. 1216–1219.

[11] Hawkes, J. and Flink, J. M., 1978, Osmotic concentration of fruit slices prior to freeze dehydration, Journal of Food Processing and Preservation, Vol.2, pp. 265–284.

[12] Magee, T. R. A., Hassaballah, A. A. and Murphy, W. R. 1983, Internal mass transfer during osmotic dehydration of apple slices in sugar solutions, Irish Journal of Food Science Technology, Vol. 7(2), pp. 147-154.

[13] M.S. Rahman., 1992, Osmotic dehydration kinetics of food, Indian Food Industry, Vol. 15, pp. 20-24.

[14] Fernanda R. Assis, Rui M.S.C. Morais And Alcina M.M.B. Morais, 2016, Mathematical modeling of osmotic dehydration kinetics of apple cubes, Journal of Food Processing and Preservation, Wiley Periodicals, Inc., pp. 1-16.

[15] Kulwinder kaur & A K Singh, 2013, Mathematical modeling of mass transfer for osmotic dehydration of beetroot (BETA VULGARIS L.), International Journal of Agricultural Science and Research, Vol. 3(4), pp. 1-10.