# Modelling of drying kinetics and heat penetration studies on carrot

**Kumar Ranganathan, Sivaranjani Rangaswamy, Vijayalakshmi Subramanian, Nadansabhapathi Shanmugam**

*Abstract*— **Thermal processing and drying are the pioneer ones in preserving foods. The most widely used vegetable carrot, was subjected to drying and followed by thermal processing with brine solution. Drying was performed to reduce the moisture content with 20% variation. Soon after drying, retort processing was done in the retortable pouch with 2% brine. Heat penetration characteristics such as heating lag factor (jh) and heat penetration factor (fh) were studied and the values were ranging from 0.2770 to 0.4136 and 5 to 8.2. Various physico-chemical properties such as texture, color, water absorption, moisture content and salt infusion were analysed for studying the effect of thermal processing on carrot. The textural regain of carrot was maximum in 42% moist sample. The hardness was decreased from 26.07 ± 5.37N to 0.92 ± 0.76 N. Water absorption was determined for analyzing the water rehydration capacity of samples and was found to be highest in 22% moist carrot with the following value of 2.5664 g/g. The total lethality of carrot was ranging from 4.5 to 5.24 Mathematical modelling was done for the drying kinetics of carrot before retorting. Out of Henderson and Pabis model, Newton model and Page model, Page model was concluded as the best model with goodness of fit based on R2 value of 0.9996, RMSE value of 0.0020, Af value of 1.0116 and Bf value of 1.0007.**

*Index Terms*— **Mathematical modelling, Drying kinetics, Heat penetration studies, Physico-chemical properties, Carrot.**

## I. Introduction

As vegetables play a vital role in human diet, studying the characteristics of them is much needed for efficient processing and preservation. Out of many preservation technologies, thermal processing and drying are the prior ones. It is a complex operation which involves transient transfer of heat and mass along with several rate processes, for instance physical or chemical transformations, which, in turn may lead to changes in product quality as well as the mechanisms of heat and mass transfer (Mujumdar, 2008). Prescott and Sweet (1919) defined drying of foods as a simple and safe process involving the removal the surplus water without destruction of cellular tissues, or impairment of the energy values. Drying of fruits and vegetables cannot be done as a whole. It should be reduced in its size in forms of cubes, slices or strips.

Drying kinetics study refers to the fitting of measured drying properties such as drying rate, moisture content, and temperature, drying time, etc., into empirical equations used for predicting the drying parameters and behaviours of materials at other conditions. Mathematical drying models describe the drying phenomenon in a unified way regardless of the controlling mechanisms. There are generally 12 models to depict the drying kinetics of any foods. The coefficient of determination ($R^2$) and root mean square error (RMSE) are the major criteria used for selection of the best model equation that describes the drying curve. For goodness of fit, $R^2$ value should be high and RMSE should be low (Agarry et al., 2013). Kabiru (2013) concluded that the drying has taken place during the falling rate period and Page model described the drying behavior of the mango slices satisfactorily with $R^2$ value of 0.990. The drying behavior of single apricots was analyzed by Togrul and Pehlivan (2002) with a variety of flow rates and temperatures. In order to obtain drying data, the changes in temperatures of the apricots were recorded as well as the drying air properties. Thin-layer drying kinetics of Tomato was experimentally investigated by Garavand et al., (2011) at various air temperatures (40, 60, and 80ºC) and at three relative humidity of 20%, 40% and 60% and constant air velocity of 2 m/s. The high values of coefficient of determination and the low values of reduced sum square errors and root mean square error indicated that the Midilli et al. model could satisfactorily be used to illustrate the drying curve of tomato with an highest R2 (0.9997), the lowest SSE (0.22662) and RMSE (0.0040912) for relative humidity of 20% and air velocity of 2 m/s. The Midilli et al. model also satisfactorily described the drying behavior of tomato. Drying characteristics of sliced sugarcane was studied by Goyalde et al., (2009) and suggested the same model as concluded by Garavand et al., (2009). Jan et al., (2014), Jokic et al., (2009) and Silva et al., (2013) have experimented drying in rice pellets, apples and banana respectively.

The thermal processing of packed foods is commonly known as retorting is the application of heat for a specified lethality at specified temperature and pressure. Retort is a closed pressure vessel that uses steam from outside sources such as steam boilers or steam generators. The flexible packaging material used is made up of multiple layers and thermally resistant materials, in order to maintain the convenience and containment functions of the packaging materials. Rajkumar et al., (2010) studied the sensory evaluation of retort processed Chettinadu style goat meat curry to the F0 value of 12.1 minutes. Total lethality (F0)

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received for the product was in agreement with the findings of Ranganna (2000), who reported F0 values between 8 and 12 min for meat products. Generally, heat penetration in the canned or retorted pre-packaged products can be studied by heat transfer through the partition (packaging material) and heat transfer through the packaged product (Larousse and Bruce, 1979).

The purpose of a heat penetration study is to determine the heating and cooling behaviour of a product in a specific retort system for the establishment of safe thermal processes and evaluating process deviations. Plotting of the logarithmic difference between either retort temperature and product temperature (heating curve) or product temperature and cooling medium temperature (cooling curve) versus time is referred as a heat penetration curve (HP Protocol, 2004). The penetration of heat through the product can be either by convection or conduction or by both. The best way to estimate the heat penetration factor fh and the heating lag factor jh, is by measuring the heat penetration in the slowest heating point, which is the coldest core of the packaged product. The time taken for a heat penetration curve to traverse one log cycle is called the heat penetration factor fh value. By definition equation of the heating lag factor jh,

$$j_h = \frac{T_r - T_{pih}}{T_r - T_{ih}}$$

This can be obtained by extrapolating the pseudo initial heating temperature with the help of graph. While conducting experiments on retort processing of goat meat curry, Rajkumar et al., (2010) studied heat penetration parameters such as, heating lag factor (Jh), cooling lag factor (Jc), cook value, heat rate index (Fh). Jhah et al., (2014) reported the heat penetration characteristics such as heating lag factor and cook value. PremAnandh (2014) optimized the thermally processed flavored milk in retort pouches having three layer configurations and standardized shelf stable ready-to- drink rose flavored milk packed in non-transparent and transparent retort pouches, by processing to a lethality values of F0 3.95 and 3.8 respectively. Heating rate index (fh) of non-transparent and transparent pouches were 6.70 and 6.66. Heating lag factor (Jh) of the respective pouches were found to be 0.31 and 0.28.

## II. 2. Materials and Methods:

### A. Sample preparation

Rigid, fresh, uniformly sized and damage less carrot were procured and were washed cleanly with tap water and then peeled manually for removing the skin. Immediately after peeling, these carrots were washed with soft water and were cut into rectangular pieces of dimension 40mm x 20mm x 10mm.

### B. Drying of carrots

The initial moisture content of the samples was measured using the moisture analyzer, in order to fix the moisture variations. The initial moisture content of the carrot was found to be 82%. As the study was to process the carrot at different moisture levels, the samples were dried in Air dryer with constant airflow rate. The temperature was maintained at 80°C ± 3°C inside the dryer. These samples were dried to desired moisture level i.e., 62%, 42% and 22%.

### C. Preparation of Brine solution

The osmotic solution generally used for vegetables is the Brine solution. 2% brine solution is used as the medium for carrot retorting for providing uniform heating.

### D. Retort processing

Heat penetration studies were studied by retort processing of Carrots. Before processing, the vegetables were filled in the retort pouches of specialized composition [polypropylene nylon (PP/Nylon/PP), polyester cast propylene (PET/C.PP) and polyester aluminium foil cast polypropylene (PET/Aluminium foil/C.PP)], along with brine solution. The contents are filled in 200ml capacity stand-up retort pouches. As for the carrot processing, there are four variations with respect to its moisture content, the combination of carrots and brine was determined by considering increase in volume after processing. For fresh carrots, 100 g of carrots and 100 g of brine was packed. For 62% moist carrot, 75 g of carrot and 125 g of brine was filed and packed. Similarly, for 42% and 22% moist carrot, 50 g carrot, 150 g brine and 25 g carrot and 175 g of brine was filled respectively. Then, before retorting, high temperature probes are pierced in each sample for studying heat penetration, followed by the $F_{\circ}$ value (lethality). Another probe is kept for measuring the kettle temperature of the retort. After loading the filled pouches inside the retort, the lid of retort is fixed air tight, ensuring no leakage. The contents are retorted at gradual increase of temperature till 121°C. After releasing the pressure inside the retort kettle, the pouches were taken out and studied for the further experiments.

### E. Texture profile analysis

The Texture profile analysis was conducted using Universal Testing Machine (Model: Llyod Instruments) with hemispherical probe of diameter 2 mm. Hardness 1 and Hardness 2 were measured for each and every sample. The test was conducted for all the samples of different moisture content ranges, as well as the fresh ones (without subjecting to drying). Along with these samples, control samples were also tested i.e., the samples kept without retorting. To obtain the most accurate results, replications were made for each sample and mean value was found.

### F. Color measurement

The L, a and b values of the samples were measured using "Hunter Lab colorimeter" (Model: Colour Flex EZ, Hunter Lab, USA). Along with that dL*, da* and db* were also measured. For this also, all samples including the control samples were tested and reported. The samples used for measuring color were selected carefully without any cuts and cracks. Replications were made to find out the mean value of the color. The color of brine, before and after retorting were also tested and reported.

### G. Determination of Moisture content

Moisture content of all the samples were measured using Moisture analyzer ( Model: "Precisa XM 60", Make: Precisa Gravimetrics, AG, CH-Dietikon"). The changes in moisture content of the samples, after putting in brine and after processing, were noted on % wet basis. The samples were removed from the brine solution and were completely blotted for removing the external excess moisture. The samples were then cut cross- sectionally, to measure the internal moisture of the sample. The moisture content of samples before retorting and after retorting was observed.

### *H. Determination of Salt infusion*

Salt infusion is defined as the amount of salt infused through the solid produce. The salt infusion through the vegetables before and after processing in retort is found out using the procedure for estimating the total chlorides as given in Ranganna (2000), using the formula:

$$\text{Total chlorides (\%)} = \frac{\text{(Sample Titre} - \text{Blank Titre) X N of AgNO}_3\text{X 3.546}}{\text{Weight of the sample free of moisture}}$$

### *I. Water absorption in the product*

Water absorption refers to the amount of water transferred from the medium into the product. This can be expressed by means of the expression below. This equation was derived from the water loss expression used by Jefferson (2014). As the process involves only water transfer from the medium to the product, the equation was revised into water absorption expression by the change of sign.

$$\text{Water absorption (WA)} = \frac{(W_t X X_t) - (W_{0_\circ} X X_{0_\circ})}{W_\circ} \text{ (kg/kg)}$$

Where,
$W_\circ$ is initial mass of the sample (kg)
$W_t$ is mass of the sample at the given time (kg)
$X_\circ$ is the initial moisture content of the sample (% w b) (kg water/kg of fruit)
$X_t$ is the moisture content of the sample at the given time (% w b) (kg water/kg of sample)

### *J. Heat penetration studies*

The process time is the time needed to achieve a certain level of "lethality", or killing of a number of target pathogens or spoilage organisms for that food. The processing time needs to ensure that the minimum temperature and time combination, to destroy spores of C. botulinum, was reached, so that the safety of food was ensured, when stored on the shelf. The lethal rate at each degree raise in temperature was calculated using the following formula:

$$\text{Lethal rate} = 10^{\frac{(T-Tr)}{z}}$$

Where,
T is the temperature, in Celsius at which the lethal rate is calculated
$T_r$ is the reference temperature at which the equivalent lethal effect is compared
Z-value measured in °C is the reciprocal of the slope of the thermal death curve for the target microorganism or spore

Followed by the lethality rates, the total lethality was calculated by summing up all the lethal rates obtained respective to each temperature. Along with the determination of $F_\circ$ value, Heat penetration factor ($f_h$) and heating lag factor ($j_h$), which is derived from the Ball's formula were also calculated.

$$\text{Heating lag factor, } j_h = \frac{T_r - T_{pih}}{T_r - T_{ih}}$$

Where,
$T_r$ is the retort temperature
$T_{pih}$ is the pseudo initial heating temperature by extrapolating the linear portion of a heating curve to time, $t_B = 0$
$T_{ih}$ is the initial product temperature

The heat penetration factor ($f_h$) can be determined using the graphical method by plotting the time and temperature profile in the semi-log graph paper. It is the time required for the heat penetration curve to traverse one log cycle during the thermal processing.

### *K. Mathematical Modelling*

The samples were dried stage wise with the difference of 20% at each level. For this drying operation, the mathematical modeling and curve fitting were done. The model was selected according to the goodness of fit, which is obtained by the higher values of coefficient of determination and the lower values of root mean square error.

$$\text{RMSE} = \left(\frac{1}{N}\Sigma[MR_{pred} - MR_{obs}]^2\right)^{\frac{1}{2}}$$

Where,
$MR_{pred}$ = Predicted moisture ratio.

$MR_{obs}$ = Observed moisture ratio from experiment.

N = number of observations in the experiment.

Along with RMSE and coefficient of determination value, accuracy factor and Bias factor were also calculated. Bias factor ($B_f$) and accuracy factor ($A_f$) were used as quantitative method to measure the performance of models (Zhong et al., 2005). The Bias factor indicates how much a model overpredicts ($B_f$ >1) or underpredicts ($B_f$ <1) the observed data. $A_f$ indicates how much the prediction differs from observed data. They are given in the following equations:

$$A_f = 10^{\left\{\Sigma\left|\frac{\log\left[\frac{predicted}{observed}\right]}{n}\right|\right\}}$$

$$B_f = 10^{\left\{\Sigma\left(\frac{\log\left|\frac{predicted}{observed}\right|}{n}\right)\right\}}$$

Where,
n = number of observations
Predicted = Moisture ratio (predicted)
Observed = Moisture ratio (observed)

With the help of above parameters, best model for drying particular food can be concluded.

## III. Results and Discussions

### *A. Texture profile analysis*

The texture of carrot varied significantly with respect to its level of processing. The hardness of the raw sample was certainly high when compared to that of processed ones. However, during the course of drying, hardness increased with the decrease of moisture content. The hardness observed for raw and dried samples were has given in Table 1. The highest degree of hardness (32.244 ± 1.2584 N) was observed in carrot which was dried to 62% moisture content. After brining, the hardness of carrot with 42% moisture content was observed to be the highest (26.073 ± 5.3678 N) (Figure 1). In case of retorted samples, the level of hardness increased with the decrease of moisture content in carrot previous to brining.

**Table 1: Hardness of Carrot before and after retorting**

| Texture profile - Hardness of carrot before and after retorting | | | |
|---|---|---|---|
| S. No | Sample with its Percentage moisture content (%wb) | Hardness 1 (N) | Hardness 2 (N) |
| 1 | 82% before retorting | 22.648 ± 6.1998 | 12.3951 ± 5.4146 |
| 2 | 82% after retorting | 0.3765 ± 0.0657 | 0.2575 ± 0.0953 |
| 3 | 62% before retorting | 17.4552 ± 6.9998 | 8.9034 ± 4.1351 |
| 4 | 62% after retorting | 2.1718 ± 1.0281 | 1.0102 ± 0.3387 |
| 5 | 42% before retorting | 26.073 ± 5.3678 | 7.6795 ± 4.6949 |
| 6 | 42% after retorting | 0.9205 ± 0.7631 | 0.3681 ± 0.4336 |
| 7 | 22% before retorting | 13.5395 ± 1.6227 | 7.3831 ± 3.4532 |
| 8 | 22% after retorting | 1.35983 ± 0.9081 | 0.2547 ± 0.0937 |
| Texture profile - Hardness of raw samples | | | |
| 9 | Fresh Potato (82% MC) | 26.7035 ± 4.2158 | 12.375 ± 3.1248 |
| 10 | Dried Potato (62% MC) | 32.244 ± 1.2584 | 12.633 ± 0.01547 |
| 11 | Dried Potato (42% MC) | 24.2575 ± 2.6548 | 10.20995 ±1.2548 |
| 12 | Dried Potato (22% MC) | 22.8925 ± 2.0145 | 21.0075 ± 2.1487 |

All values are means ± standard deviation of data from five independent experiments

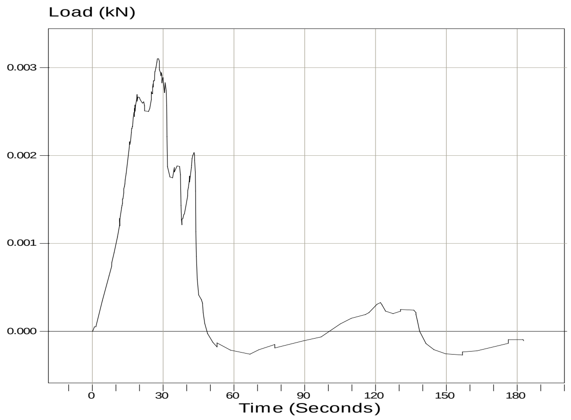


**Figure 1: Texture profile of retort processed 42% moist carrot**

### *B. Color values of Carrot*

While analyzing the physical properties of the samples, color values play an important role in determining the product quality. L*, a*, b* and dE* values of retorted and unprocessed samples were analyzed. The degree of lightness was stable before processing irrespective of the moisture content of the sample. The color value of brine was also observed and lightness was in equivalence with carrot. This denoted the carotene distribution in brine. The color values of Carrot before and after retorting are given in the Table 2. With a decrease in the moisture content, the degree of redness increased in all samples prior to processing. After processing, the redness was found to be decreased and brine redness was increased, so that the redness of carrot and brine after processing were almost equal. The yellowness of carrot was found to be increased after processing. The degree of deviation of colors of retorted samples, with respect to the unprocessed control samples were denoted by dE* value. The dE* value is 16.21 ± 3.3334, 12.91 ± 2.6493, 7.986 ± 0.9640 and 5.978 ± 2.0847 for retorted fresh carrot, 62% moisture carrot, 42% moisture carrot and 22% moisture carrot respectively.

**Table 2: L*, a*, b* and dE* values of carrot before and after retorting**

| S. No | Sample with its Percentage moisture content (%wb) | L* | a* | b* | dE* |
|---|---|---|---|---|---|
| 1 | 82% before retorting | 55.9 ± 1.2369 | 43.3 ± 0.9878 | 49.74 ± 1.2585 | 16.21±3.3334 |
| 2 | 82% after retorting | 51.42 ± 1.4804 | 30.08 ± 3.3247 | 57.42 ±3.0103 | |
| 3 | 62% before retorting | 58.46 ± 0.259 | 41.29 ± 1.8565 | 56.72 ±2.5687 | 12.91±2.6493 |
| 4 | 62% after retorting | 49.84 ± 2.3287 | 33.60 ± 1.7474 | 51.47±2.3936 | |
| 5 | 42% before retorting | 53.41 ± 1.2589 | 41.88 ± 0.6592 | 52.73 ± 0.9585 | 7.986±0.9640 |
| 6 | 42% after retorting | 48.21 ± 1.6546 | 36.36 ± 1.1889 | 52.27 ± 1.9304 | |
| 7 | 22% before retorting | 51.22 ± 0.5698 | 40.55 ± 1.9515 | 51.58 ± 0.5858 | 5.978±2.0847 |
| 8 | 22% after retorting | 48.77 ± 3.8113 | 36.01 ± 1.2586 | 52.42 ± 4.4194 | |

All values are means ± standard deviation of data from four independent experiments

### *C. Determination of Salt infusion in Carrot*

The amount of salt infused inside the matrix of the food samples is determined in order to analyze the effect of osmotic agent in the product, before and after retort processing. Generally, infusion of salt is much better after thermal processing when compared to just brining. The salt infused in carrot prior to processing was observed to be increasing, except in 42% moisture carrot which was due to cellular collapse. The percentage of salt infused, in the before and after retort processed samples, was given in Table 3. After processing, 2.217 ± 0.0005%, 2.049 ± 0.0015%, 1.55 ± 0.0099% and 2.657 ± 0.00158% was the salt infusion observed in fresh carrot, 62% moist carrot, 42% moist carrot and 22% moist carrot respectively. The salt infusion was increased around 16.9 times after retorting in case of fresh carrot in brine. Similarly, infusion was increased about 4.98, 6.00 and 3.24 times in case of 62% moist carrot, 42% moist carrot and 22% moist carrot respectively.

**Table 3: Salt infusion in Carrot before and after retorting**

| S.No | Sample | Percentage of salt infused (%) |
|---|---|---|
| 1 | 82% before retorting | 0.1316 ± 0.0001 |
| 2 | 82% after retorting | 2.217 ± 0.0005 |
| 3 | 62% before retorting | 0.419 ± 0.0012 |
| 4 | 62% after retorting | 2.049 ± 0.0015 |
| 5 | 42% before retorting | 0.2583 ± 0.0006 |
| 6 | 42% after retorting | 1.55 ± 0.0099 |
| 7 | 22% before retorting | 0.8186 ± 0.0004 |
| 8 | 22% after retorting | 2.657 ± 0.00158 |

All values are means ± standard deviation of data from three independent experiments

### *D. Determination of moisture content*

Moisture content of the product tends to vary after thermal processing. Therefore, moisture content of the samples was determined after retorting. Moisture content increase in carrot follows the same trend as that of potato. After retorting, the moisture content in the carrot has increased from its initial moisture content. It increased from 82% to 84.16%. Also, it was observed that the fresh carrot had very little increment in moisture content and 22% dried carrot had highest increment in moisture content, that is., it increased from 22% to 88.02%.

### *E. Determination of water absorption*

The amount of water absorbed before retorting and after retorting was analyzed in all samples at different moisture contents. Thermal processing had induced higher water absorption in all the treated samples. There was a significant increase of water absorption in carrot after retort processing. The amount of water absorbed was more after retorting, irrespective of its initial moisture content. The quantity of water absorbed was 0.0433 g, 0.0951 g, 0.345 g and 0.8026 g in 82%, 62%, 42% and 22% moist samples respectively, before retort processing. However, 0.1351 g, 0.5335 g, 1.2867 g and 2.5664 g of water were absorbed by one gram of sample after retorting (Table 4). This is evidently higher than water absorption before retort processing. It was observed that, lesser the initial moisture content, higher was the moisture absorption.

**Table 4: Water absorption in Carrot before and after retort processing**

| Water absorption of Carrot before processing | | |
|---|---|---|
| S. No. | Sample with its Moisture Content (% wb) | Water absorbed (gram of water/gram of sample) |
| 1 | 82% MC | 0.0433 |
| 2 | 62% MC | 0.0951 |
| 3 | 42% MC | 0.345 |
| 4 | 22% MC | 0.8026 |
| **Water absorption of Carrot after processing** | | |
| S. No. | Sample with its Moisture Content (% wb) | Water absorbed (gram of water/gram of sample) |
| 1 | 82% MC | 0.1351 |
| 2 | 62% MC | 0.5335 |
| 3 | 42% MC | 1.2867 |
| 4 | 22% MC | 2.5664 |

### *F. Heat penetration characteristics of Carrot*

While studying the heat penetration characteristics of carrot at different moisture content with 20% moisture variations, totally four cases were studied, that is, the heat penetration characteristics of carrots with various moisture content such as 82%, 62%, 42% and 22%, were studied. For each variation, lethality, heating lag factor and heat penetration factor were calculated. The total lethality of 82%, 62%, 42% and 22% moist sample was 5.94, 4.85, 4.557 and 5.25 (F0 value) respectively. For determining heat penetration factor, the product temperature was plotted using a semi log graph of 5 log cycle. The time taken for reduction of one log cycle was estimated as fh value. The fh value was estimated to be 7.1, 8.2, 5 and 5.2 respectively for 85% moist sample to 25% moist sample. With the help of the same plot, pseudo initial temperature (Tpih) was also measured. The pseudo initial temperature was found to be 99.7 °C, 90.7 °C, 82.1 °C and 100.1 °C respectively. Heating lag factor (jh) obtained was 0.227, 0.3212, 0.4136 and 0.2265, for each moist sample respectively. The heat penetration curves for the samples were given in Figure 2.

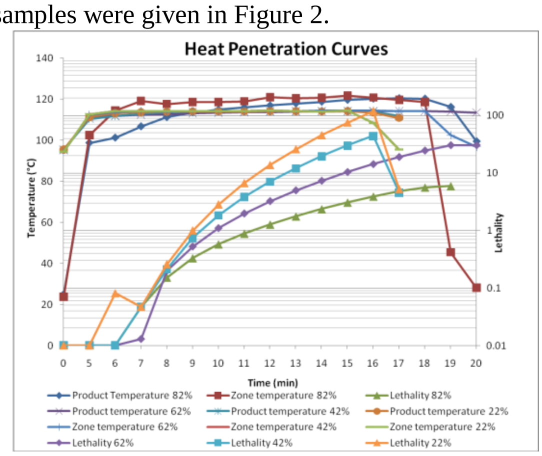


**Figure 2: Heat penetration curves of carrots with various moisture content- 82%, 62%, 42% and 22%**

### *G. Modeling of drying in carrot*

Mathematical modeling was performed in order to obtain the most suitable equation for drying behaviour. Goodness of fit was mainly considered for concluding the most suitable model. The obtained data was applied in Henderson and Pabis model, Page model and Newton model for concluding the best fit. The moisture ratio observed by drying the carrot to known moisture content was 1, 0.3277, 0.1444 and 0.0588 for obtaining 82% MC, 62% MC, 42% MC and 22% MC at time period of 0 min, 150 min, 285 min and 375 min respectively. With the above data, the equations were obtained for the three models. The equation of Henderson and Pabis model is Moisture ratio (MR) = a exp (-kt). With the known moisture content and time, the graph was plotted and the following equation was obtained in exponential form, y = 1.0161e-0.007x. The predicted moisture ratio was 1.0161, 0.3399, 0.1269 and 0.0658 for 82% MC, 62% MC, 42% MC and 22% MC samples. The equation of Page model is Moisture ratio (MR) = exp (-kt$^n$). With the known moisture content and time, the graph was plotted and the following equation was obtained in linear form, y = 0.989x - 4.8653. The predicted moisture ratio was 1, 0.3348, 0.1249 and 0.0667 for 82% MC, 62% MC, 42% MC and 22% MC samples. The equation of Newton model is Moisture ratio (MR) = exp (-kt). With the known moisture content and time, the graph was plotted and the following equation was obtained in linear form, y = 0.0073x. The predicted moisture ratio was 1, 0.3345, 0.1249 and 0.0647 for 82% MC, 62% MC, 42% MC and 22% MC samples. After predicting the moisture ratio from the equations of different models, the root mean square error (RMSE), co-efficient of determination (R2), Accuracy factor (Af) and Bias factor (Bf) were estimated to find out the best equation for the drying behaviour from the above models and is given in Table 4. The deviation of predicted moisture ratio values from observed moisture ratio value is shown in the Figure 3. The Table 4 clearly points out that the R2 value of both Henderson and Pabis model and Newton model are the highest. Ali et al., (2014) indicated that the Page model was the best mathematical model to describe the drying behavior of sauna dried seaweed. Similarly, as the R2 value is similar for both models, RMSE value is taken into consideration. Lowest RMSE value shows the best fit. So, Newton model with 0.0108 RMSE value was concluded as the best fit for drying Carrot.

**Table 4: Factors for goodness of fit in Carrot**

| S.No | Model | $R^2$ | RMSE | $A_f$ |
|---|---|---|---|---|
| 1 | Henderson and Pabis | 0.9993 | 0.0113 | 1.0385 |
| 2 | Page | 0.9996 | 0.0020 | 1.0116 |
| 3 | Newton | 0.9992 | 0.0077 | 1.0256 |

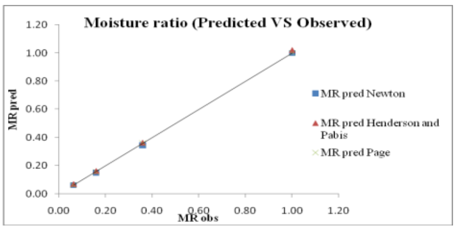


**Figure 3: Predicted Moisture ratio Vs Observed Moisture ratio (Carrot)**

## IV. Conclusions

The heat penetration factor and heating lag factor were calculated for carrots at different moisture contents namely 82%, 62%, 42% and 22%, and were found to be 6.2, 6.6, 5.7 and 5.2 respectively and 0.5803, 0.5440, 0.4741 and 0.3638 respectively. The mathematical modeling, observed to follow the Newton model with a 0.0108 RMSE value, R2 value of 0.9929, Af value of 1.0702 and Bf value of 0.9889, which was concluded as the best fit for drying Carrot.

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## References


[1] Larousse, J. and Bruce E. Bruce., (1997). Food Canning Technology. John Wiley and sons, Inc., New York: 377-476.

[2] Agarry, S.E., Ajani, A.O., and Aremu, M.O. (2013). Thin Layer Drying Kinetics of Pineapple: Effect of Blanching Temperature – Time Combination. Nigerian Journal of Basic and Applied Science, 21(1): 1-10.

[3] Ali, M.K.M., Fudholi, A., Sulaiman, J., Ruslan, M.H. and Yasir, S.M. (2014). Sauna Technique, Drying Kinetic Modeling and Effectiveness on Solar Drying Compared with Direct Drying in Drying Process of Kappaphycus striatum in Selakan Island Malaysia. Energy and Power Engineering, 6: 303-315.

[4] Jangam, S.V. and Mujumdar, A.S. (Eds), (2010). Basic concepts and definitions in Drying of Foods, Vegetables and Fruits-Volume1, 1, 3.

[5] PremAnandh, C., Ramasamy, D., Surendraraj, A. and Gnanalakkshmi, K.S. (2014) Process optimization and shelf life study of retort processed rose flavored milk. International Journal of Food, Agriculture and Veterinary Sciences. 4 (1): 36-46.

[6] Rajkumar, V., Dushyanthan, K. and Arun K. Das. (2010). Retort pouch processing of Chettinad style goat meat curry –a heritage meat product. Journal of Food science and Technology. 47(4):372-379.

[7] Ranganna, S. (2000). Handbook of analysis and quality control for fruit and vegetable products. 2nd Ed. Tata McGraw Hill Publishing Company Ltd., New Delhi: 205.

[8] Kabiru, A.A., Joshua, A.A. and Raji, A.O. (2013). Effect of slice thickness and temperature on the drying kinetics of mango (mangiferaindica). IJRRAS15 (1):41-50.

[9] Jhah, A., Patel, A.A., Srinivasa Gopal, T.K. and Ravishankar, C.N. (2014). Heat penetration characteristics and physico-chemical properties of in-pouch processed dairy dessert (Kheer). Journal of Food Science and Technology. 51 (10): 2560-2567.

[10] Garavanda, A.T., Rafieea, S. and Keyhania, A. (2011). Mathematical Modeling of Thin Layer Drying Kinetics of Tomato Influence of Air Dryer Conditions. International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies. 2(2): 147-160. ISSN 2228-9860.

[11] Goyaldle, N.A., Melo, E.C., Rocha, R.P., Goneli, A.L.D. and Araújo, F.L. (2009). Mathematical modeling of the drying kinetics of sugarcane slices. Revista Brasileira de Produtos Agroindustriais, 11(2): 117-121.

[12] Jan, K., Riar, C.S. and Saxena, D.C. (2014).Mathematical Modeling of Thin Layer Drying Kinetics of Biodegradable Pellets. Journal of Food Process Technology. 5(9). ISSN: 2157-7110.

[13] Jokić, S., Velić, D., Bilić, M., Lukinac, J., Planinić, M. and Bucić-Kojić, A. (2009). Influence of Process Parameters and Pre-treatments on Quality and Drying Kinetics of Apple Samples. Journal of Food Science.27 (2): 88–94.

[14] Silva, W.P., Silva, C.M.D.P.S., Gama, F.J.A. and Gomes, J.P.(2014). Mathematical models to describe thin-layer drying and to determine drying rate of whole bananas. Journal of the Saudi Society of Agricultural Sciences13: 67–74.