MODELING OF THIN BED DRYING KINETICS OF A HYGROSCOPIC MATERIAL (SOLANUM TUBEROSUM) IN TUNNEL DRYER

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Abstract

To study the characteristics of fresh potatoes, an experimental tunnel dryer is developed in the work room. The test of the potato slice for drying was made in a cubic shape of dimensions 10mm. For the study of samples characteristics, drying observation were made at temperatures of 45°C, 50°C, 55°C, 60°C, 65°C, 70°C, and 75°C, and the test was equipped to various drying models. The preferred models were fitted on basis of model energy efficiency (EF), reduced chi square, and r.m.e.s. to select the best fit for drying potato slices. The modified page model gave higher energy efficiency in a larger range of experimental constants (0.7 to 1.2) with lower r.m.e.s. and a reduced chi square was corelated to the page model. The data observed from the test was fitted to the various drying model. From the result which observed and experimental constants basis, Modified Page model was preferred that gives the maximum energy efficiency value of 0.9829, a reduced value of chi square of 0.0016, and the minimum r.m.e.s. value of 0.0331 at drying air temperatures range of 45°C–70°C.

Keywords: Air velocity, Drying, Humidity Ratio, Moisture Ratio, Tunnel dryer.

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1. Introduction

Potatoes are the 4^{th} largest food crop in the world after rice, wheat, and maize [1]. Potatoes are members of the Solanaceae category which one is much widely forming. In 2018 potato (Solanum tuberosum) production was more than 368.2 million tons worldwide [2]. It was consumed in food by peoples, animal feed and used as ingredients in the pharmaceutical industry. The forming of potato production in the world are in order to China, India, USA, Indonesia etc. In India the production of was predicted in 2022 at nearly 51 million tons which cannot satisfy the expected increase in food demand by 2050 [3].

In food industry, food drying machine has been mostly used for the refining of the potatoes food products. At the time of refining of the food products made by potatoes, the food undergoes inherent changes which have a negative effect over the potato's food products [4]. In the last few decades, many researchers have studied the characteristics of food drying, especially Solanum tuberosum.

The drying of food is among using the earliest processing and preservation for further use. Food may be dried in a food dehydrator with the proper air current, warm temperature, and low humidity conditions, as well as in the sun or oven, which are the traditional methods of drying [5]. Sun drying is a popular way of drying, although it has many drawbacks. Since the food is not shielded from wind, rain, dust, or even household animals, birds, insects, rodents, during drying, conventional sun drying techniques frequently generated for low quality [6]. The end result is soiling, contamination with bacteria, the production of mycotoxins, and infection with pathogenic microbes. The drying process involving solar energy has a medley of merits yielded by conventional and industrial methodologies, to name a few, like lower investment costs and high product quality.

Among the procedures required to maintain the freshness of fruits and vegetables is drying. This procedure extends the agriculture goods' shelf life, extends the duration of storage, and reduces loss of storage. Shipping and transportation expenses are decreased by the drying process [7]. The relationship between moisture ratios and drying instants as well as the thermal kinetics of drying were established [8]. Newton's Law of Cooling is based on Lewis's concept.

$$\frac{dM}{dt} = -k(M - M_0) \quad (1)$$

Therefore, the primary goals of this work are to create an experimental setup and conduct a theoretical analysis of potato samples with a cubical shape [9].

2. Materials And Methods:

2.1 Material

The experiment examined the impact of preserving or drying potatoes. The fresh potatoes were bought from a nearby market in May and June. The potatoes were chosen for the experiment because they had an average full-size of 45–55 mm in the length and 25–35 mm in breadth. The potatoes used in the investigation were thoroughly cleaned before being peeled and cut into 10*10*10 mm^3 slices using a sharp knife [10].

2.2 Methods

Fig. 1 depicts the experimental setup used to perform the thin layer drying. A humidification unit, an air heating unit, and a drying unit make up its three primary components. The humidification unit was made of two cylindrical pieces of galvanized iron sheet that were linked together by an airtight flange joint. The humidification unit's lower section has a 0.35 m diameter and a 1.1 m height. The lower part of the humidification unit uses a float valve to keep the water level at the correct level. The unit receives water from an above water tank. The humidification unit is connected to the 3.1 m long and 10.6 cm in diameter air suction pipe by an orifice-meter that is located immediately higher than water line. The humidification's lowest portion unit contains a 1.2 cm diameter perforated spray tube, a drain valve, two 2.1 kW electric immersion heaters, a water pump, and other components.

Fig. 1 Experimental set-up

Its purpose was to saturate the ambient air to the proper dew point with a thin spray of water created water pump and perforated tubing in the humidification chamber. Two pairs of louvers are installed at the top of the humidification unit to catch the water droplets in the humid air. On the blower's suction side, there is an insulated humidification unit, as shown in Fig. 2.

Fig. 2 Humidification Unit

Three different components made up the air heating system. The central section is a 1-meter-long cylindrical structure with two diffusers on either end. To raise the air temperature that exits the humidification unit to a predetermined level, three 1.1-kW heaters and two 2.1-kW heaters are installed in the cylindrical part. The component that is attached to the blower's delivery side as shown in Fig. 3.

Fig. 3 Air heating unit

Three pieces make up the thin-layer drying apparatus: an exposure chamber, a plenum chamber, and a base plate with five holes. A 30cm diffuser with a 0.5m height is placed in a chamber that resembles a cylinder. To connect the drying unit to the air heating unit, a 90 cm by 15 cm pipe is bent to the diffuser. A plate with 18.5cm-diameter holes that are evenly spaced is forced over a 0.3 cm-thick mild steel plenum chamber. When drying pans are fitted over the apertures, rubber gaskets are provided to prevent air leakage from the sides, and four bearings are tightened on the plate around each entrance according to size to ensure proper installation.

Temperature, relative humidity, and velocity readings are taken every 1.5hour while the experiment is running. The temperature and relative humidity sensors are situated at the fan's base (T, RH), the tray's (T1, RH1) upstream and (T2, RH2) downstream sides. An anemometer is set up near the tunnel's exit, and air passing over the potato cubes moves at a speed of 1.2 m/s. The potato was found to lose weight with time, and the humidity also dropped over time.

In the experiment, a hygrometer was an instrument used to measure the amount of humidity and water vapor in the atmosphere or in confined spaces [11]. The equipment for measuring humidity relies on a few other physical quantities. The calculation of the quantities is followed by the measured value for humidity [12]. But in the present scenario, because of the dominance of modern equipment, humidity is measured by evaluating changes in physical quantities like resistance or capacitance. The temperature of the air determines the amount of water vapor that can be accumulated in it. While experimenting, all other parameters are fixed, whereas variation in drying temperature is facilitated [13].

3. Result And Discussion:

The amount of wetness (%d.b.) were calculated from the weight loss that occurred after drying at various temperatures. By adjusting the temperatures, the ratio of moisture content to drying time may be calculated.

The equilibrium wetness content, a starting moisture level, and moisture ratio at various temperatures throughout an 18-hour period were employed to determine the moisture ratio. Because there was more free water available in the early stages of drying, it was found based on the graph of drying time and moisture ratio at different temperatures Fig. 4, that During the first 13 hours of drying, the moisture ratio dropped more quickly than it did later on [14]. The rate of moisture loss decreases as drying time increases and increases as drying temperature increases, according to the moisture ratio that was calculated for all drying durations and temperatures [15].

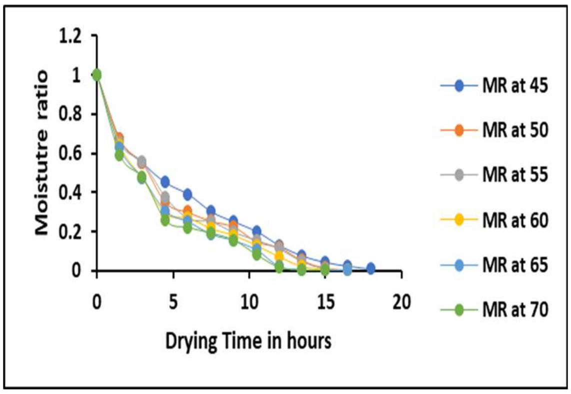

Fig. 4 Experimental moisture ratio at different temperatures

Further investigation into the moisture ratio Fig. 5 displays the examined and projected values for various drying times (in hours). Since the results were shown at more optimal drying rate.

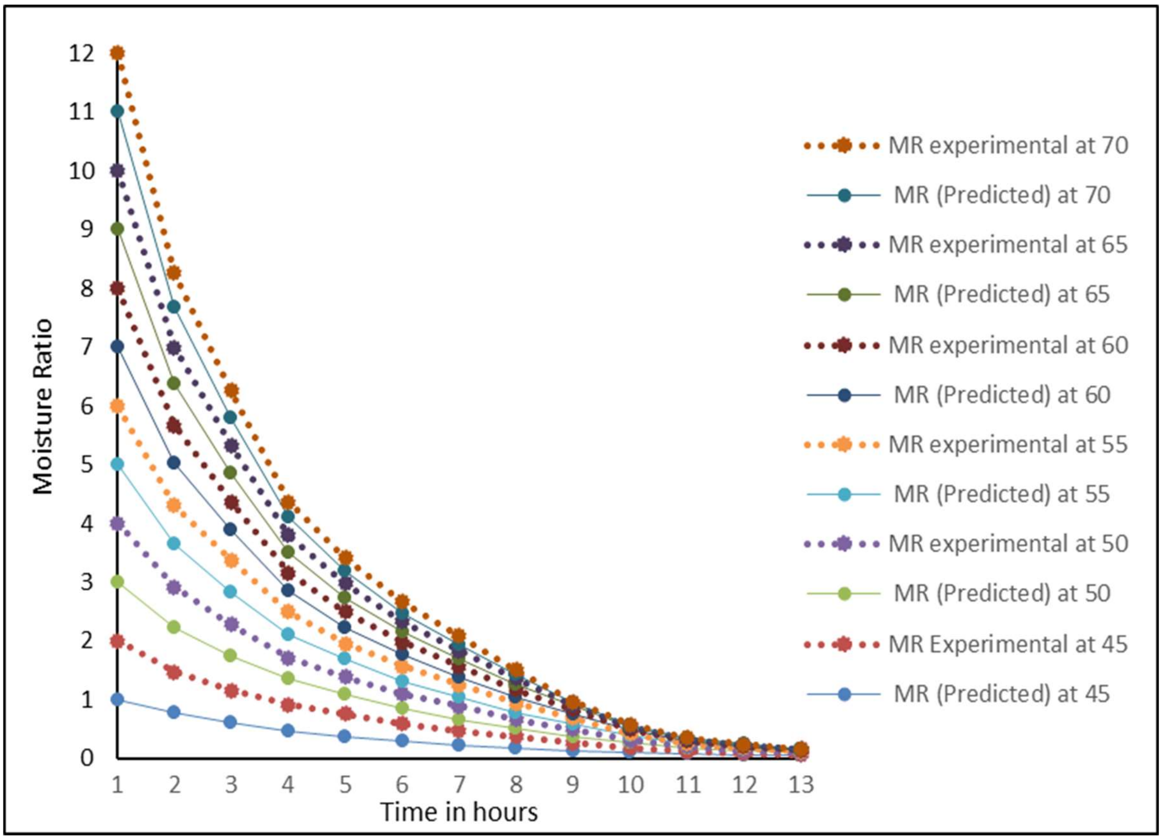

Fig. 5 Experimental moisture ratio Examined and Predicted at different drying times (hrs)

The link between drying time and moisture ratio that is semi-logarithmi was displayed at various temperatures as shown in fig. 6.

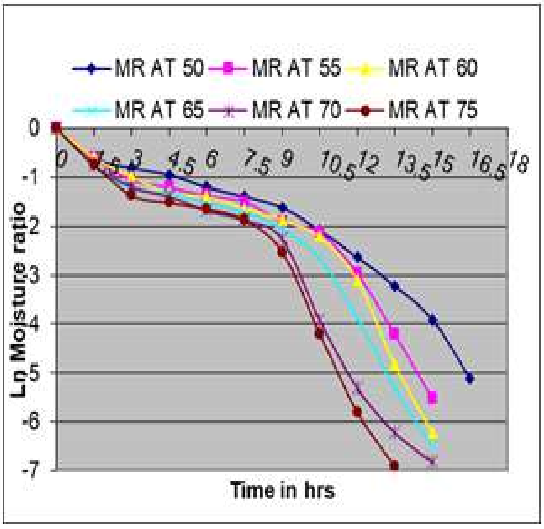

Fig. 6 Semi-log plot of moisture ratio vs. drying time

Straight lines were found, showing that the diffusion process-controlled moisture transfer. As shown in Table 1, the drying coefficient was calculated from the coefficient was calculated from the intercept of a straight line whose slope was converted into the natural logarithmic value for a range of temperatures. The drying coefficient K was calculated using the half-life approach [16] and plotted in Fig. 7.

Table 1 shows the value of the drying coefficient at different temperatures.

Temperature, °C	Drying coefficient "K"
45	0.17179
50	0.19017
55	0.20302
60	0.22068
65	0.24249
70	0.27636

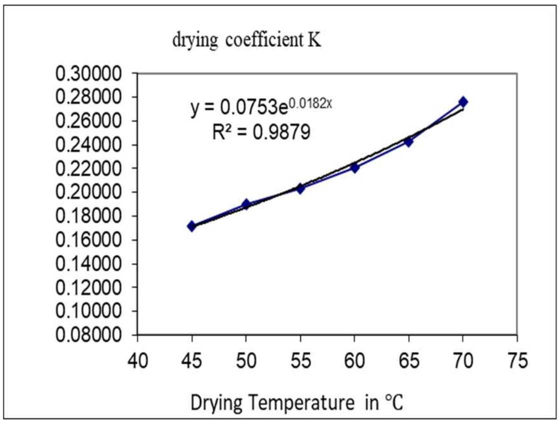

Fig. 7 shows an exponential graph of the drying coefficient "K"

Consequently, the following equation provided the greatest fit for the exponential model:

$$K = 0.0753\ e^{0.0182T} \quad (2)$$

T is the temperature in, and K is the exponent index.

The drying equation as a result of experimental data is

$$\frac{(M-M_e)}{(M_o-M_e)} = \exp^{-(0.0753e^{0.0182T})\,t} \quad (3)$$

t is the drying time expressed in hours [17]. The drying coefficient for the page model at 50°C is obtained using equation 3. These results show the astounding energy efficiency at n = 1 in Table 2.

Table 2 Page Model at a 50 value of n

N	0.8	0.9	1	1.1	1.2	1.3
χ^2	0.022148	0.006681	0.001569	0.003563	0.009402	0.016764
r.m.e.s.	0.135028	0.072796	0.032316	0.044292	0.072052	0.097145
EF	0.746563	0.924178	0.982345	0.960235	0.895935	0.816031

As a result, the Page model also yields the maximum energy efficiency depicted in Fig. 8 for n = 1.

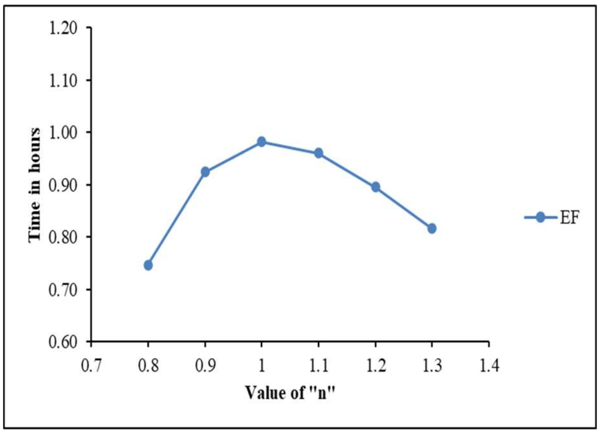

Fig. 8 EF (Efficiency) and the value of the experimental constant (n) at 50 °C for the Page model

The Modified Page model was tested once more at various values of n; As seen in Table 3, this model also demonstrates the best energy efficiency for a value of n = 1 at 50°C. and fig. 9.

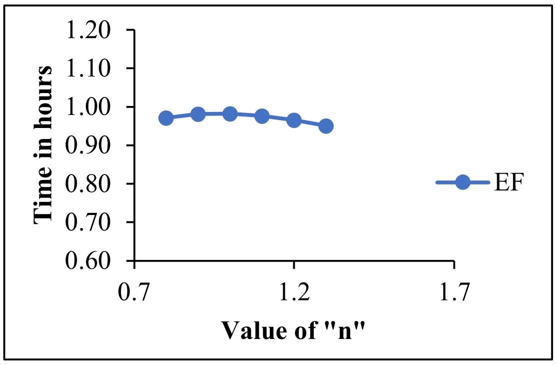

Fig. 9 EF (Efficiency) and the value of the experimental constant (n) at 50 °C for the modified Page model

Table 3 Modified Page Model with 50 n-values

Temp	0.8	0.9	1	1.1	1.2	1.3
χ^2	0.002499	0.001647	0.001569	0.002105	0.003114	0.004474
rmes	0.034099	0.032153	0.032316	0.034438	0.038677	0.045654
EF	0.971404	0.981305	0.982345	0.976507	0.965537	0.950904

All evaluated drying model energy efficiency, r.m.e.s., and chi square values are presented in Table 4.

Table 4 Value of r.m.e.s. for all models

Model	temp	χ^2	**rmes**	**EF**
Newton Model $MR = Exp(-kt)$	45	0.0015	0.0327	0.9815
	50	0.0015	0.0331	**0.9816**
	55	0.0027	0.0399	0.9673
	60	0.0048	0.0523	0.9418
	65	0.0076	0.0658	0.9067
	70	0.0112	0.0823	0.8638
Page Model $MR = exp\ (-kt^n)$	45	0.00227	0.03572	0.97440
	50	0.00167	0.03338	**0.98118**
	55	0.00299	0.04042	0.96639
	60	0.00529	0.05294	0.94044
	65	0.00844	0.06655	0.90499
	70	0.01229	0.08297	0.86169
Modified Page $MR = exp\ [-(kt)^n$	45	0.0015	0.0320	0.9816
	50	0.0016	0.0331	**0.9829**
	55	0.0029	0.0399	0.9673
	60	0.0052	0.0523	0.9418
	65	0.0083	0.0658	0.9067
	70	0.0121	0.0823	0.8638

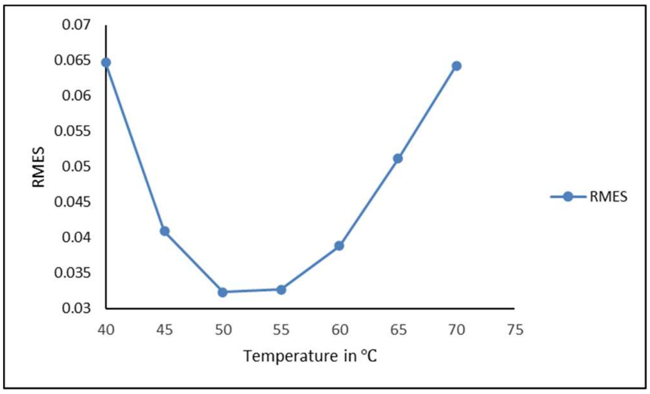

Fig. 10 shows the value of r.m.e.s. as a function of temperature using the modified page model at 50°C, n=1.

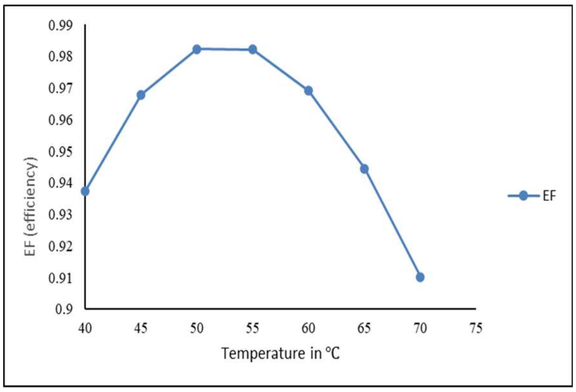

Fig. 11 shows the value of EF vs. temperature using the modified Page model at 50°C, n=1 for the experiment.

According to the aforementioned Figure 10, the lowest value of r.m.e.s. is at 45°C to 55°C and based on fig.11, Energy efficiency is highest between 45 degrees Celsius and 55 degrees Celsius.
Potatoes are dried, and the experimental moisture ratio is compared to the anticipated moisture value. MR = exp (Kt) n at Experimental temperature 50°C, according to the modified page model [18]. the drying factor as well as the experimental constant at n = 1.0 is $K = 0.0753\ e^{0.0182T}$ shown in Fig. 12

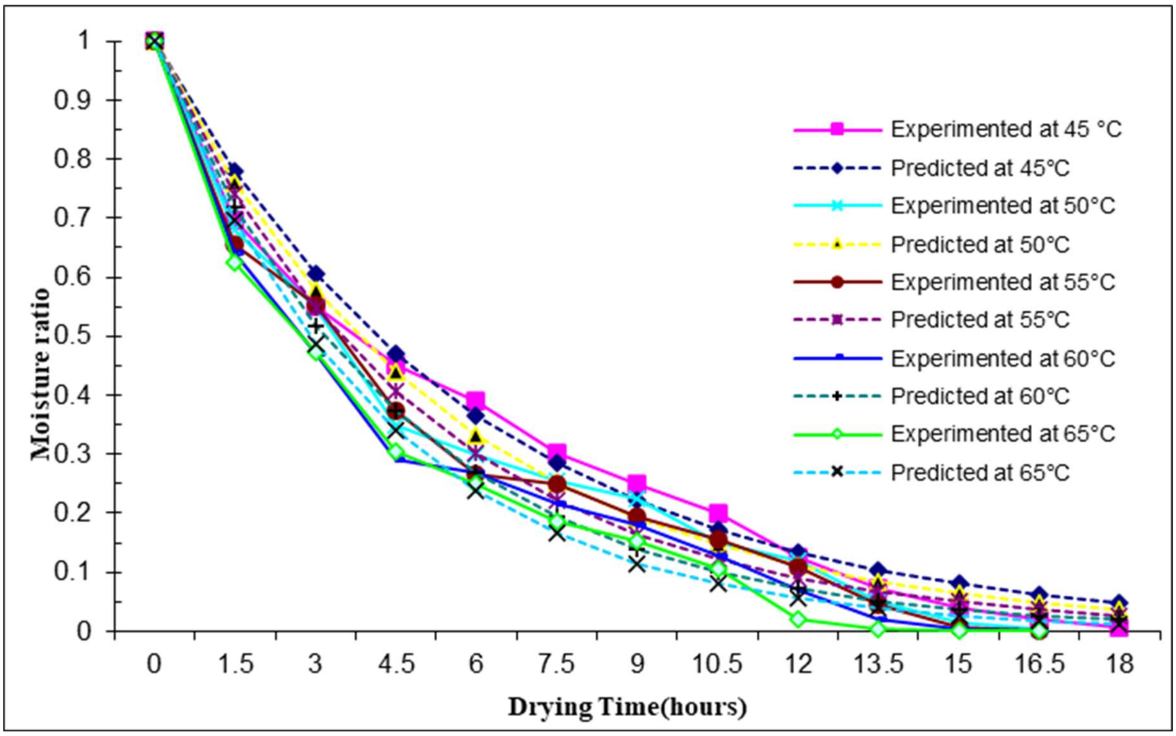

Fig. 12 Moisture ratio predicted and measured experimentally vs. time using the modified page model

4. Conclusion:

In a thin layer drying model and two-dimensional drying method for hygroscopic materials like potato cubes, the moisture ratio is calculated using the half-life time approach during the drying process. Although it is presumable that it is possible to keep a steady drying air (humidity and temperature) throughout the material if the material is sufficiently thin and the air speed is high enough at an average velocity of 1.1 m/s and the drying air temperature in the range between 45°C and 70°C.On the basis of dry weight, data obtained by experiment on moisture content is of utmost importance for developing a model for drying purposes. These moisture content measurements, which were recognized by MR at any step of the drying process, made non-dimensional by dividing them by the initial moisture content, were taken at varied temperatures of the drying air and under the condition of constant velocity. The moisture ratio and drying time were related.

While there is a plethora of models for drying purposes, such as the Page model, Modified Page model, and Newton's model, these are compared on the grounds of statistical coefficients in order to witness the closeness between predicted and experimental values. The results showed that the modified page model had the lowest values of r.m.s.e. and chi-square and the greatest values of EF across all models at a certain temperature and across a wider range of constants n. In the chosen model, the definition of MR is altered from (M-Me)/(Mo-Me) to M/Mo. Since determining the EMC was beyond the scope of the investigation. The initial and equilibrium moisture contents are represented by Mo and Me, respectively. Even with the modified definition of MR, the equation's form was preserved, and the constant k was calculated for a specified drying air temperature at various time instants using the Half Life Method. The constant k was discovered when curve fitting was performed for a range of drying air temperatures (45°C-70°C). Below is the resulting equation:

$$MR = \left(\frac{M}{M_o}\right) = e^{-0.0753e^{0.0182T}}$$

Modified For all of the drying settings included in the current study of potato, page models were shown to be closely aligned with the findings of the experiment ($\chi 2$=0.0016, r.m.e.s. = 0.0331, and EF = 0.9829).

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