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Modelling of unsteady spatially distributed drying parameters assessed non-destructively in a small industrial food dryer

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ABSTRACT

Modelling of unsteady moisture diffusion in relation of product temperature become complex due to complexity involve in solving complex numerical equations. In this study, a simplified methodology (determination of drying parameters: lag factor and drying constant) used to model change in food quality with its temperature in an industrial dryer using potato slices (6mm thick, 60°C). A shiftable real time data acquisition box was developed. Linear and exponential models were developed to estimate product quality as a function of dimensionless moisture ratio, linked with change in product temperature. The experimental and models predicted color kinetics using variable values of lag factor and drying constant revealed good correlation coefficients (R2 = 0.88-0.99, P < 0.0001). The change in spatially distributed quality parameter with product weight loss was successfully assessed and modelled unsteadily, providing a better way to optimize the design process as a function of food physiognomies in an industrial dryer.

Keywords: Unsteady modelling, Real time data acquisition, image analysis

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Introduction

Drying parameters strongly depend on the structural characteristics of food. Optimization of a food drying process is very important to achieve quality standard and to make process energy efficient. In order to define the required/optimum drying conditions for minimum change in product quality, true process information is necessary for the dynamic control of a drying process. During the drying process, biological materials show varying characteristics even with the same operating conditions due to their heterogenic nature (Nazghelichi et al., 2011). Often product temperature is unknown or assumed to be constant or if it is measured it is not included in the process control system (Mujumdar and Law, 2009; Sturm, 2010; Sturm et al., 2014). However, several studies on fruit and vegetable (Sturm et al., 2012; Nunez Vega et al, 2016) show that product temperature changes throughout the drying process for product with high initial moisture contents like pineapple, potato and tomato. This change in product temperature affects the rate of moisture diffusion and ultimately the quality parameters due to unsteady mass diffusion which normally considered as steady state for thin layer drying modelling. It is done due to the complexity involved in the computation of complex numerical equations. Therefore, temperature dependent drying parameters must be precisely monitored and measured for the assessment of the drying process which would be helpful in the design of a food dryer.

Drying constant (ability of product to be dried per unit time) and lag factor (resistance in the transfer of moisture from internal to external) are considered main drying parameters (Dincer and Dost, 1996) for unsteady state diffusion analysis to determine heat and mass transfer coefficients. The correlation between drying constant and process variables for fruits and vegetables was reported by numerous researchers (Akpinar et al., 2003; Akpinar and Bincer, 2006; Simal et al., 2005) but using constant drying conditions (steady state) while food structure, process conditions and measuring techniques affect these parameters (Tripathy and Kumar, 2008). It means the values of these parameters continue to change during a drying process with variable drying condition. So it become significant to determine these parameters separately for each specified interval of drying process rather to use a single value for the entire drying curve which is a normal practice and it becomes more difficult in industrial drying unit where these drying parameters are spatially distributed. In case of industrial dryer especially batch type, the main hindrance for development of such mathematical model under variable drying conditions is the lack of accurate information for the drying kinetics of the respective product. This is due to the use of conventional and inappropriate methods for gaining such information which result in the inability to ensure the desired progress of a process. For example, it is evident from an analysis of published papers in an international journal Food and Bioprocess Technology (2008–2011) that more than half (58.62 %) reported the use of Minolta colorimeter, 24.14 % used a Hunter-Lab instrument, and 17.24 % used other types of instruments (mixed) for the measurement of colour attributes in the drying processes (Pathare et al., 2012). Therefore, non-destructive measurement of drying parameters is of much important to get data for precise thin layer modelling. There is lack of study on both these aspects (unsteady model and inline monitoring) in small industrial drying unit where data is spatially distributed.

Keeping in view the aforementioned facts, the current study is focusing on the development of unsteady drying model based on inline monitored spatially distributed drying parameters. A relationship has been established between quality parameter (colour change) and product temperature using variable values of drying parameters for accurate optimization.

2. Material and methods

2.1 Food dryer used

A small industrial dyer with a salient designing feature of diagonal airflow channel was used. The system consists of three major compartments, lower half, upper half and a connector to connect both halves. An axial tube fan and an electric water air heat exchanger installed in the lower half. Twenty five plastic buckets placed in diagonal form in the upper half i.e. drying chamber. That arrangement formed a diagonal airflow channel at the inlet side of the buckets, which helped to pass air across these buckets uniformly without addition of any baffle plate. Polyurethane sheets were used as construction material. The detailed numerical and experimental based functional description of this dryer has been reported by (Amjad et al., 2015).

2.2 Data acquisition system

In order to obtain real time data for change of quality attribute, moisture and sample temperature, a data acquisition box was made equal in size of a food bucket (length 0.6 m × width 0.4 m). For capturing food sample image, a color camera (Autofocus DFK 72AUC02-F Germany) with a USB CMOS MT9P031 sensor (Lens mount M12x0.5) were installed in the box. For measurement of real time change in moisture, a load cell (KD60±50N) and thermocouples were also installed. The data acquired was stored in a connected computer (Lenovo T500) as shown in Figure 1.

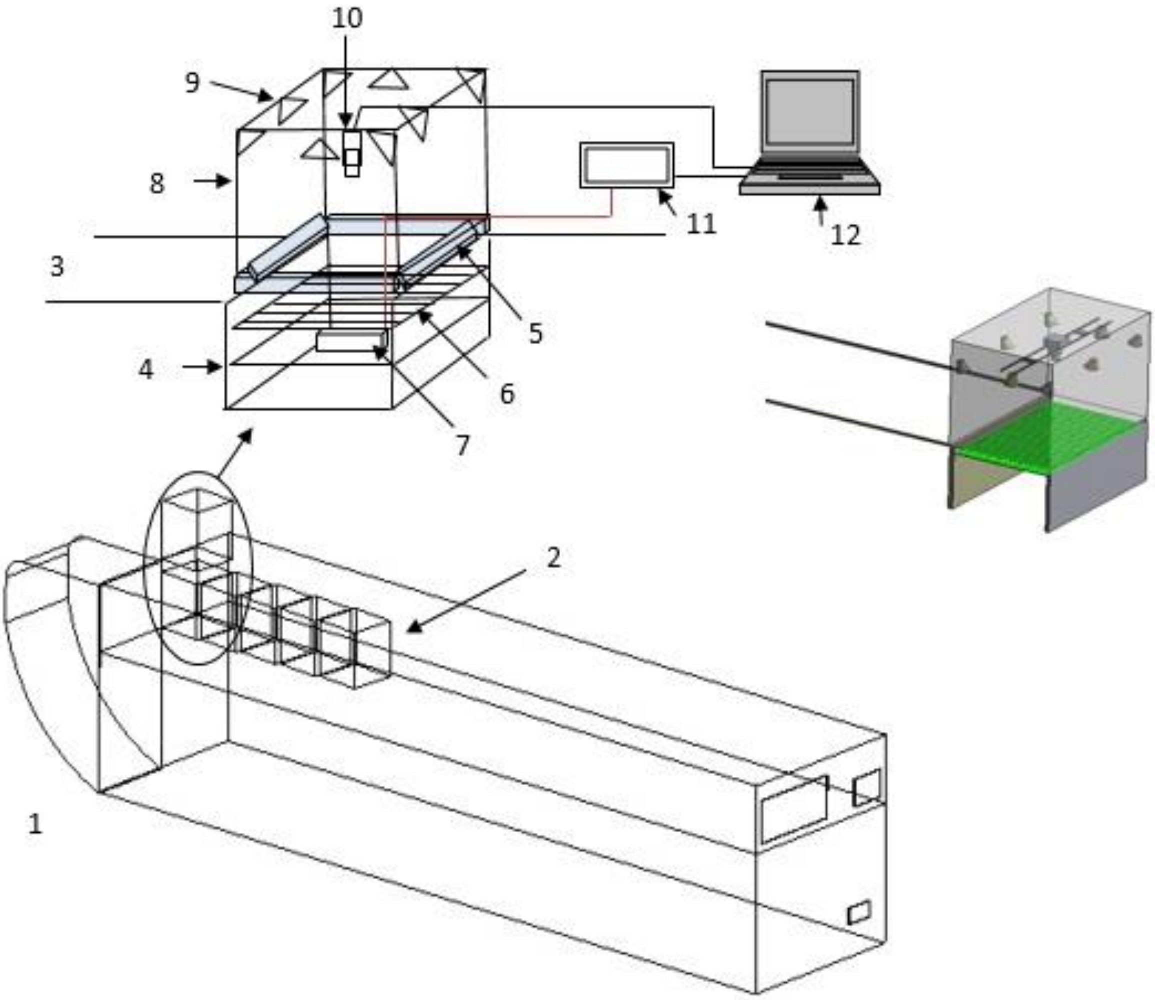


Fig. 1 Real time data acquisition system. (1) Diagonal-airflow dryer (2) Food buckets arranged in diagonal form (3) roof of the dryer (4) Plastic bucket for food samples (5) Acrylic sheet (6) Food tray (7) Load cell (8) Imaging box (9) Florescent lights (10) imager i.e. camera (11) Data logger (12) Computer.

For light, eight LED bulbs (each of equal to 60 watt) were fixed in the box to achieve sharp contrast at the edges of captured image, which is obtained by avoiding glitter. These lights were fixed in such a way that the angle between the axis of camera lens and lights was 45^{o}. This is important to capture the diffuse reflection, which generate the colour (Fernandez et al., 2005). The height of the bars, holding the camera within the imaging box above the food samples, was set based on the quality of image (high pixel and contrast) captured and it was 42cm. The inner of the box was painted black to counter the effect of reflection from the room. The upper side i.e. roof of the drying chamber was cut from the place of first food bucket for the placement of developed box. At the bottom of the box, a transparent acrylic sheet was placed to inhibit air to flow into the box and to allow transmission of the light to the target position (food tray) as shown in Figure 1. The characteristics of acrylic sheets are as follows: lightweight (less than half that of glass), strength (10-20 times resistant to strokes than glass), clarity (light transmission is 92% while glass has 90%) and easy machining, therefore they are the best to use. The shifting of box to next position continued until last bucket to get data along the entire length of the dryer. Once the imaging-box shifted to the next position (position of next bucket), the previous cut part was covered with a glass sheet with side insulation with kingspan air-cell insulation tape.

For real time measurement of moisture change (weight loss), a load cell (KD60±50N of accuracy 0.1%) was mechanically connected to the food tray (holding food samples) and positioned on the lower tray (just beneath the food tray). The load cell was linked to a data logger (Agilent 34970A) as shown in Figure 1. Temperatures of food samples at every section of drying chamber were assessed by thermocouples (K-type ± 1.5 k), linked with data logger (Agilent 34970A). Several thermocouples were fixed at different locations just beneath the sample surfaces. Drying temperature ($60^{0}C$) was set with controller. Potatoes were dried up to twelve percent final moisture contents. To monitor the change in humidity at inlet and outlet sides of the drying chamber, Mini data logger (MSR-145 ± 2%, Swiss) was employed.

For experimentation, the dyer length was divided into five sections, each of is 2m comprised on five buckets. In this way five experiments were conducted, one for each section to cover the compete length of the dryer. Similar drying conditions were tried to obtain before the start of each experiment and after that food samples were placed over the tray. The experiments were carried out using locally available potatoes. Potatoes were washed, peeled, and sliced (6mm) with an adjustable cutting thickness cuter (Bosch MAS62). Then sample slices were dipped in boiled water to blanch for a period of three minutes to stop enzymatic reactions. Before putting blanched slices (half kilogram) over the tray that is connected to load cell, their free surface water was dried with a clean cloth. Throughout the drying process, images (2048×1536 pixels) of slices were taken continuously with an interval of five minutes as shown in Figure 2.

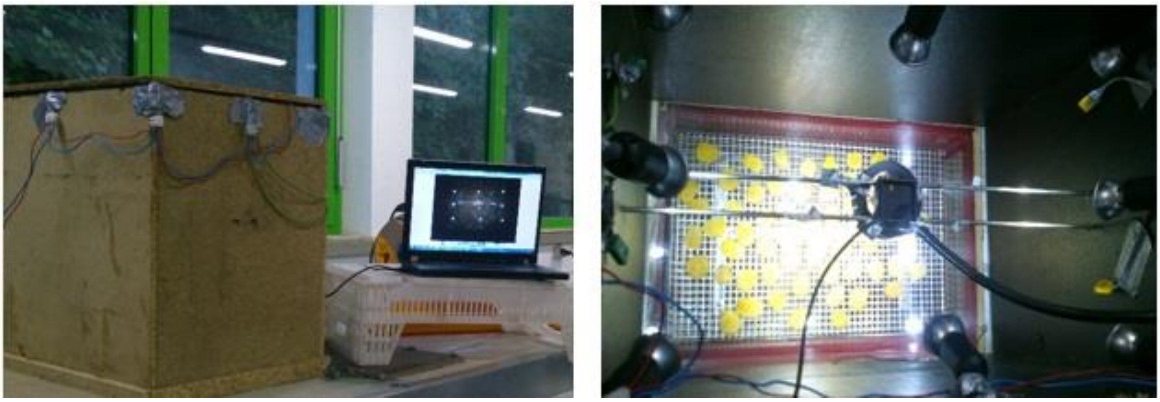
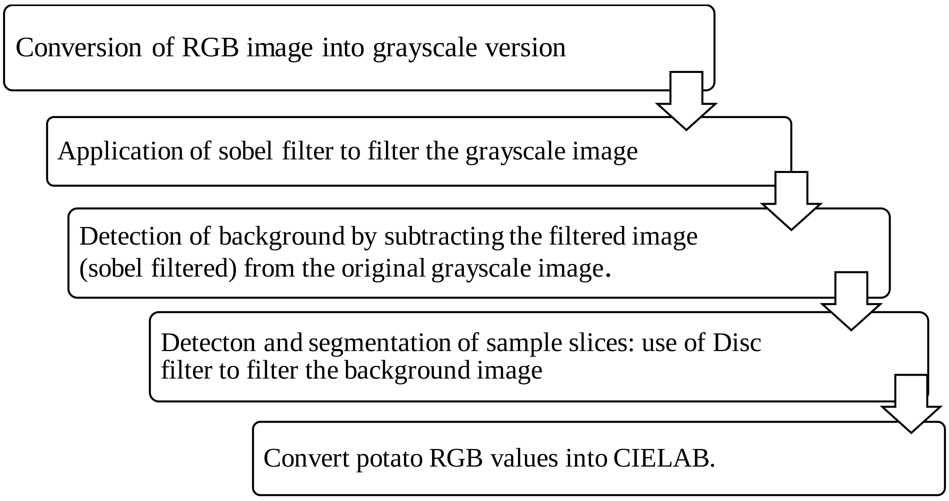


Fig. 2 Imaging-box system made for data acquisition



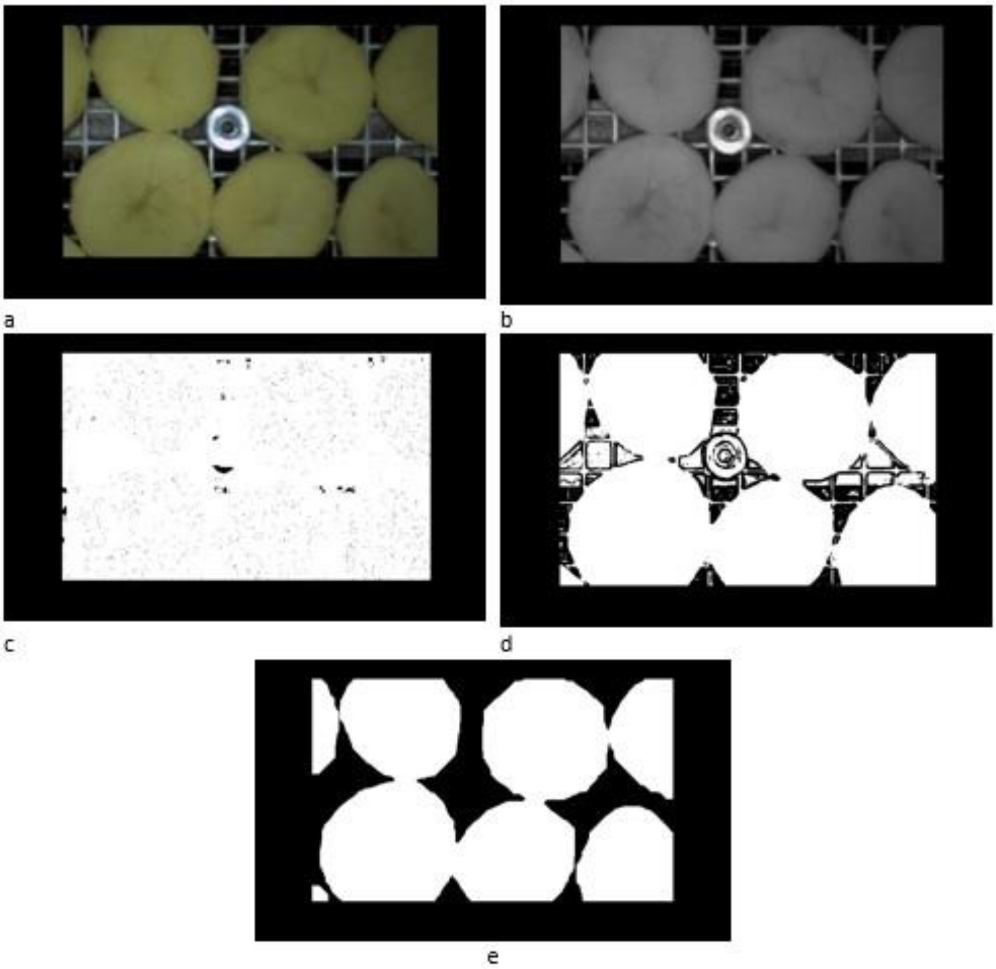


Fig. 3 Steps involved in image analysis process for color data: (a) RGB image (b) grayscale version of image (c) filtered grayscale image (d) detection of background (e) segmented sample slice

2.3 Calibration of the imaging system (color camera)

Color calibration of the RGB camera (The Imaging Source, Germany) was achieved through the polynomial colour correction (Finlayson *et al*, 2015). An X-Rite Color Checker Classic 24 patch chart (X-Rite Inc., Michigan, USA) was imaged using a set exposure. Polynomial colour correction rather than root polynomial colour correction (Finlayson *et al*, 2015) was utilized due to the use of a single exposure for imaging during the drying process. The reflectance and colorimetric data of each patch was then measured using a calibrated spectrometer (Q mini, RGB Photonics GmbH, Kelheim, Germany). The measured colorimetric XYZ values were then regressed alongside the measured average patch RGB values after subtraction of the average black patch RGB values. This produced a polynomial function, which allowed the calculation of XYZ co-ordinates from measured RGB values. These calculated XYZ values were then converted into CIELAB co-ordinates using illuminant D65 as the reference white point, with a luminance value equal to the luminance of the white patch under the test illumination.

2.4 Image analysis for colour extraction

The scheme of color measurement (RGB) is affected by the camera sensors and light source (Leon *et al*, 2006). Computational techniques and mathematical based algorithms for data extraction from the acquired images mainly effects the imaging process as it involve various sub-processes as shown below and graphically presented in Figure 3. For quick color estimation through these steps, a computer program was written in MATLAB code.

2.5 Drying process model equations

For the one dimensional transient mass transfer for slice shaped solid object (thin layer), the governing equation can be written as (Crank, 1975).

$$\frac{\partial M(x,t)}{\partial t} = D_{eff}\left(\frac{\partial^2 M(x,t)}{\partial x^2}\right) \qquad 1$$

It is considered that at start the moisture content is uniformly distributed within the product following a symmetric gradient around the center.

In order to get solution of equation 1 in the form of finite series of moisture distribution (dimensionless), whole volume needed to integrate to get average mass concentration. It is important to get this solution to make a comparison between moisture distributions (dimensionless) inside the sample product with respective experimental data. In case Fourier number, Fo > 0.2, the solution involving infinite series may be approached by the first term of the series. Turhan, and Erdogdu (Turhan and Erdogdu, 2003) reported the resultant solutions for dimensionless average moisture contents (∅) for infinite slice is given as

$$\overline{\emptyset} = \frac{M(t) - M_e}{M_o - M_e} = \frac{2\sin^2\mu_1}{\mu_1(\mu_1 + \sin\mu_1\cos\mu_1)}\exp\left(-\mu_1^2\frac{D_{eff}}{L^2}t\right) \qquad 2$$

Where M (t), M_0 and M_e are moisture contents (dry basis) of sample product for any given time interval t, at start (t = 0) and at the equilibrium, respectively. D_{eff} expresses the coefficient for moisture diffusion and L stands for the thickness (half) of slice.

As the values of M_e are normally less in comparison to values of M(t) or M_0, so the left-hand side of average dimensionless moisture content in equation 2 can be simplified to parameter $\overline{\emptyset} = \frac{M(t)}{M_o}.\mu_1$ .This parameter is given by characteristic equation,

$$Bi_m = \mu_1\tan\mu_1 \qquad 3$$

Where Bi_m is the Biot number (which is ratio of internal resistance to external resistance to mass transfer).

The application of equation 2 is however difficult for any given drying time to measure dimensionless moisture content (∅), as it needs primary knowledge of variables namely $\mu_1$and D_{eff}. Tripathy and Kumar (2008) proposed a method to simplify this analysis by using thin-layer drying equation as:

$$\overline{\emptyset} = k_o exp(-kt) \qquad 4$$

Where

$$k_o = \frac{2\sin^2\mu_1}{\mu_1(\mu_1 + \sin\mu_1\cos\mu_1)} \qquad 5a$$

$$k = \mu_1^2 \frac{D_{eff}}{L^2} \quad 5b$$

Where k_0 stands for lag factor and k represents drying constant which are the drying parameters

The rate of change in moisture within product (moisture diffusion) is directly linked with product itself temperature and taken as base for the determination of temperature dependent drying parameters. In an industrial dryer, the uniform airflow distribution is very important to get drying homogeneity as it directly effects temperature distribution, which defines the quality of final dried food product based on change its moisture and quality attribute with respect to change in food temperature. As the design of a dryer is concerned with the distribution of temperature so this expression (equation 4) was used to find out the variation of drying parameters (k_0 and k) among different sections of drying chamber to model the unsteady spatially distributed temperature depending product parameters (moisture and quality). From equation 5a, lag factor (k_0) is the function of μ_1 which depends upon Biot number. A dryer section with high or low lag factor means, the food samples at this section has high or low internal resistance to mass transfer. The resistance to mass transfer mainly depends upon drying temperature. The uniformity in lag factor among different dryer sections would results the uniformity of drying temperature to these sections. The drying constant (k) represents the drying capability of food product and depends upon effective moisture diffusivity. The moisture diffusivity of food product at any dryer section also depends upon drying temperature in that section.

2.6 Statistical analysis

The drying parameters (lag factor and drying constant) which were derived from the division of drying characteristic curve at different time intervals for each section of the drying chamber were subjected to linear and exponential regressions in Sigma Plot 12.3. Using the following equations, statistical parameters were calculated to analyse model fitness (Pardsseshi, 2009).

$$RMSE \left(\frac{\sum_{i=1}^{N}\left(MR_{exp} - MR_{pre}\right)^2}{N}\right)^{1/2}$$

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{exp} - MR_{pre}\right)^2}{N-n}$$

$$P = \frac{100}{N}\sum_{i=1}^{N}\left|\frac{\left(MR_{exp} - MR_{pre}\right)}{MR_{exp}}\right|$$

MRexp: Measured moisture ratio, MRpre: Predicted moisture ratio N: number of observed values, n: constants in model

3. Results and discussion

3.1 Determination of drying constant (ko) and lag factor (k) from drying kinetics

Figure 4 shows the drying curves for potato slices based on the weight data measured non-destructively using load cell. The moisture content of the product was plotted as moisture ratio with drying time during the drying process. The rate of moisture removal was high during the first two and half hours of the drying time followed by a decreased rate of drying for the rest of the drying process. In order to get the dimensionless moisture in the form of equation 4 (using ko and k), the experimental obtained five kinetics curves for five sections of the drying chamber were regressed and values of lag factor (ko) and drying constant (k) for each curve were determined.

The obtained values of ko and k for each section represent the entire drying curve for that section and these values can be used to estimate the dimensionless moisture for that section using equation 4. The dimensionless moisture ratio data as a function of drying time for all five positions within the drying chamber were fitted well and a close agreement can be observed among experimental measured and regressed curves with correlation coefficient 0.99 for all the sections. Through regression, the obtained values of ko are 1.007, 0.9702, 0.945, 1.024, 1.147 and k are 0.009min^{-1}, 0.008min^{-1}, 0.008min^{-1}, 0.009min^{-1}, 0.009min^{-1} for sections 1,2,3,4,5 respectively. $y=1.0074e^{-0.009x}$

3.2 Relationship of drying constant (ko) and lag factor (k) with product temperature

The methodology adopted in this study is based on the hypothesis that food product temperature effect the rate of moisture diffusion in the product during the drying time. So it become important to consider sample temperature for the estimation of drying parameters (drying constant, ko and lag factor, k). For this, each of the drying curves shown in Figure 5 was divided into four parts i.e. four small drying time intervals. Following the same procedure used to find values of dying parameters in Figure 4, the values of drying constant and lag factor for each part were estimated through regression. In this way, four values of ko and k were obtained to complete a single drying curve for a section. Figure 5 shows the relationship between those drying parameters and correspondent sample temperature for each segment/part of the drying curve for all five sections of the drying chamber. It can be seen that both drying parameters increased with the rise of potato slices temperature at all the sections of the drying chamber. For a comparative analysis, the increase rate of lag factor (51%) and drying constants (47%) is almost similar under same sample temperatures. It shows that capability of potato slices to be dried (drying constant) increased as their temperature increased (Fig. 5b). Similarly, at the start of a drying process, the drying rate is fast due to evaporation of loosely bounded moisture but resistance to the removal of hygroscopic water increases in the falling drying rate time (Dincer and Hussain, 2004). So internal resistance to moisture removal increases in this time i.e. lag factor increased. So to remove water, product temperature starts to rise up which lead to the increase of internal resistance with temperature as shown in Figure 5a. Table I shows the values of constants for linear and exponential expressions (through regression analysis) used to express k and ko as function of sample temperature.

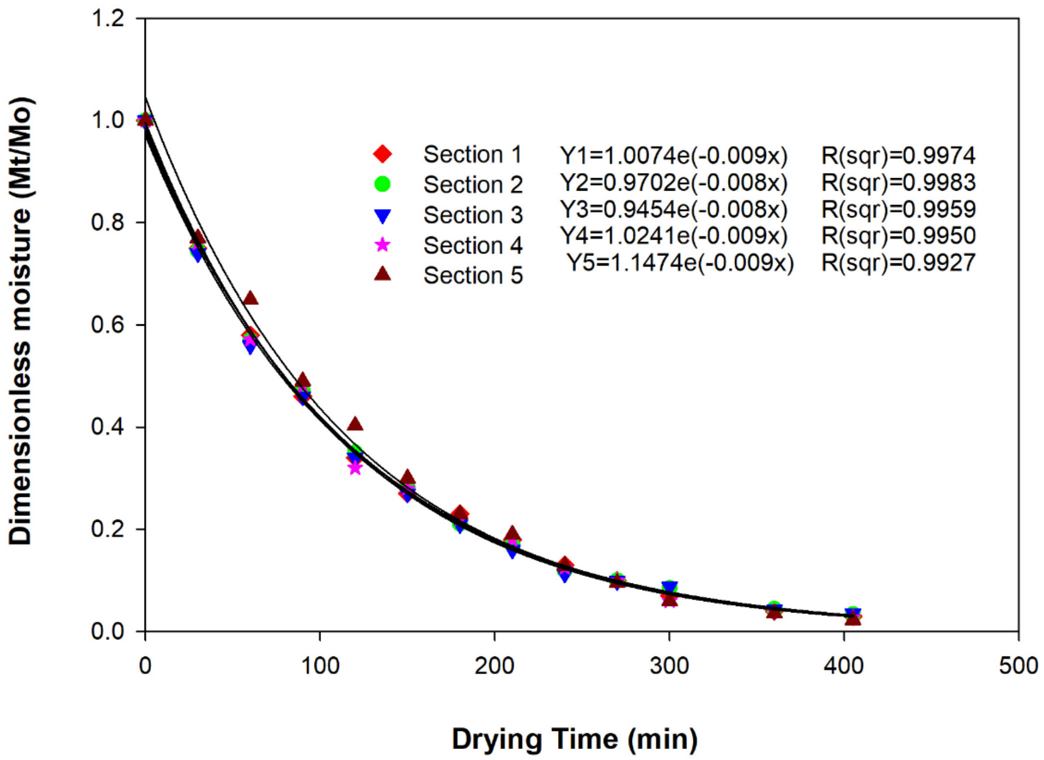


Fig. 4 Drying characteristics of potato slices at different sections of the drying chamber

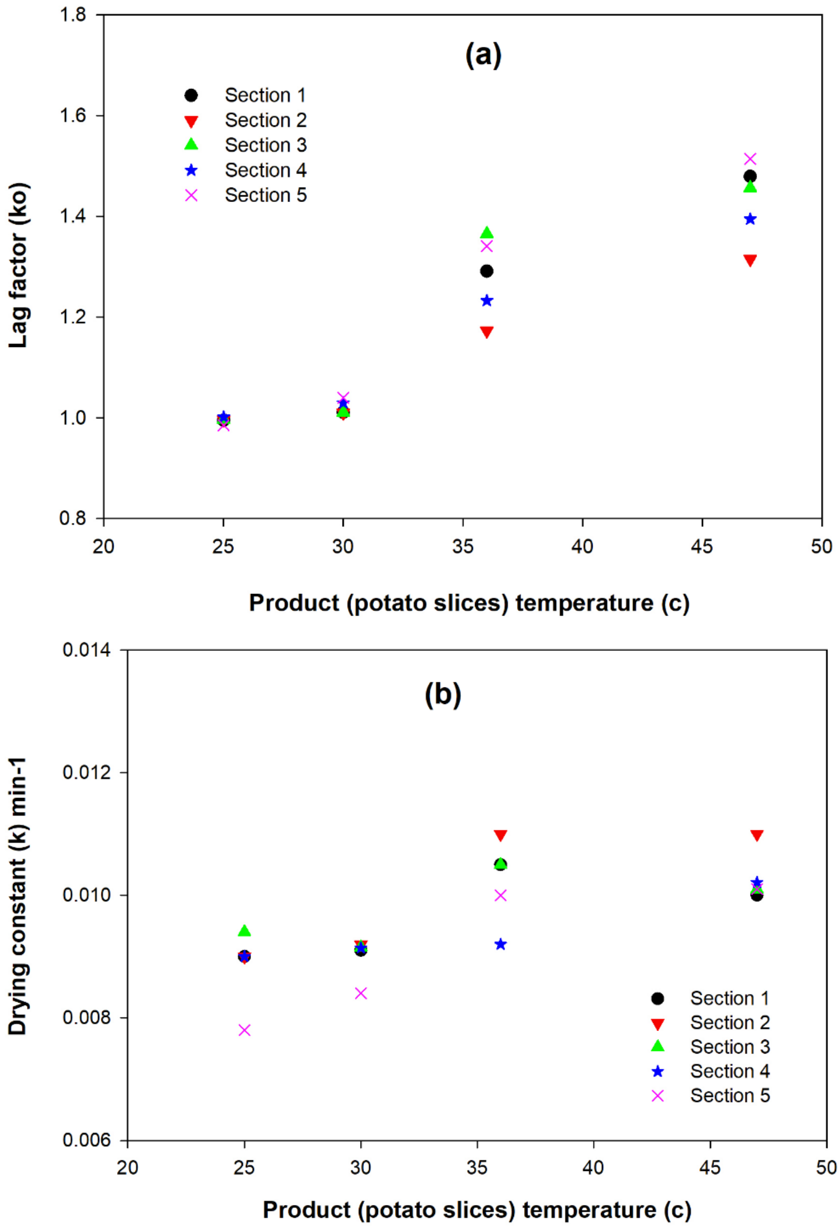


Fig. 5 Variation of lag factor (a) and drying constant (b) with sample temperature at different sections of dryer.

Table 1: Estimated values of constants (a & b) to represent drying parameters as a function of sample temperature

Correlation	Section	**Drying parameter**											
		Lag factor k_0						**Drying constant k (min^{-1})**					
		a	**b**	**R^2**	**RMSE**	**χ^2**	**P (%)**	**a**	**b**	**R^2**	**RMSE**	**χ^2**	**P (%)**
Linear (k or $k_0 = a + bT_s$)	1	0.3701	0.0239	0.9364	0.02347	0.00070	3.321	0.0078	0.00005	0.7822	0.04613	0.00210	5.171
	2	0.5861	0.0156	0.9563	0.01376	0.00032	2.741	0.0066	0.0001	0.7912	0.01376	0.00062	4.289
	3	0.4071	0.0232	0.8509	0.01632	0.00039	4.144	0.0083	0.00004	0.825	0.01632	0.00109	3.344
	4	0.5067	0.0191	0.9572	0.03976	0.00081	3.041	0.0075	0.00006	0.8815	0.03976	0.00076	3.377
	5	0.3357	0.0256	0.9374	0.02632	0.00024	4.654	0.0053	0.0001	0.8031	0.02632	0.00034	4.819
Exponential (k or $k_0 = a\ exp\ (bT_s)$)	1	0.5984	0.0195	0.9227	0.03401	0.00086	4.031	0.0079	0.0056	0.8003	0.00987	0.00334	3.971
	2	0.6984	0.0136	0.9501	0.04412	0.00051	3.041	0.0071	0.0101	0.7954	0.02376	0.00082	4.289
	3	0.6143	0.0192	0.8377	0.03981	0.00089	4.554	0.0084	0.0044	0.8321	0.01544	0.00066	3.365
	4	0.6629	0.0161	0.9488	0.01676	0.00054	3.341	0.0077	0.0057	0.8815	0.02501	0.00056	3.077
	5	0.5864	0.0208	0.9236	0.05401	0.00076	3.131	0.0059	0.0122	0.8008	0.03655	0.00044	3.832

Using the linear and exponential model equations (Table 1) for drying parameters (ko and k) in the thin-layer equation (4), the dimensionless moisture content can be found directly from the values of sample temperature and the expression for mean dimensionless moisture content for each section of the drying chamber can be written as,

Linear model:

Section 1

$$\bar{\emptyset} = (0.37 + 0.0239T_s)exp[-(0.0078 + 0.00005T_s)t] \quad (6a)$$

Section 2

$$\bar{\emptyset} = (0.5861 + 0.0156T_s)\exp[-(0.0066 + 0.0001T_s)t] \quad (6b)$$

Section 3

$$\bar{\emptyset} = (0.4071 + 0.0232T_s)\exp[-(0.0083 + 0.00004T_s)t] \quad (6c)$$

Section 4

$$\bar{\emptyset} = (0.5067 + 0.0191T_s)\exp[-(0.0075 + 0.00006T_s)t] \quad (6d)$$

Section 5

$$\bar{\emptyset} = (0.3357 + 0.0256T_s)\exp[-(0.0053 + 0.0001T_s)t] \quad (6e)$$

Exponential model:

Section 1

$$\bar{\emptyset} = 0.5984\exp(0.0195T_s)\exp[-(0.0079\exp(0.0056T_s)t] \quad (7a)$$

Section 2

$$\bar{\emptyset} = 0.6984\exp(0.0136T_s)exp[-(0.0071\exp(0.0101T_s)t] \quad (7b)$$

Section 3

$$\bar{\emptyset} = 0.6143\exp(0.0192T_s)exp[-(0.0084\exp(0.0044T_s)t] \quad (7c)$$

Section 4

$$\bar{\emptyset} = 0.6629\exp(0.0161T_s)exp[-(0.0077\exp(0.0057T_s)t] \quad (7d)$$

Section 5

$$\bar{\emptyset} = 0.5864\exp(0.0208T_s)exp[-(0.0059\exp(0.0122T_s)t] \quad (7e)$$

The overall model for the dryer can be developed through the relationship between the average values of drying parameters (k and ko) measured for all sections of the dryer separately and respective sample temperatures as explained in Figure 6. Estimated values of constants for the avg. drying parameters (k and Ko) are listed below,

Correlation	Dying parameter					
	Lag factor k_0			Drying constant k (min^{-1})		
	a	**b**	**R^2**	**a**	**b**	**R^2**
Linear	0.4411	0.0215	0.9305	0.0071	7.00E-05	0.8723
Exponential	0.6298	0.0179	0.9178	0.0074	0.0075	0.8826

Dryer model:

Linear model of the dryer for moisture ratio using k_o and k values:

$$\bar{\emptyset} = (0.4411 + 0.0215T_s)exp[-(0.0071 + 0.00007T_s)t] \quad (8a)$$

Exponential model of the dryer:

$$\bar{\emptyset} = 0.6298\exp(0.0179T_s)exp[-(0.0074\exp(0.0075T_s)t] \quad (8b)$$

3.3 Relationship of drying quality attribute (color) with product temperature

The ultimate objective of a drying process is to produce quality-dried product. Figure 6 shows the relationship between experimental measured values of total color change extracted from the captured images and experimentally determined moisture ratio (average of all the moisture at five sections as shown in Fig. 4). As the moisture of the product reduced with the drying time, color change in product increased. Regression analysis generated an expression to show relationship between moisture and color change.

$$\Delta E = -4.397 \ln \emptyset - 0.0797 \qquad (9)$$

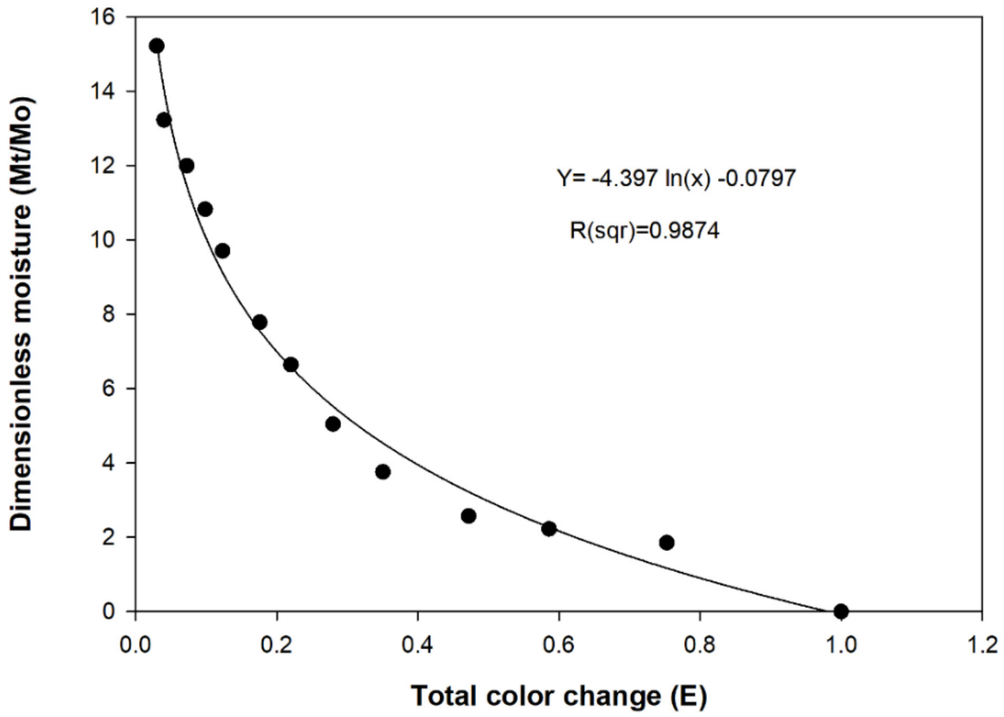


Fig. 6 Relationship between experimentally measured moisture ratio and total color change

In order to link this quality parameter i.e. color change with product temperature, the values of moisture content obtained at different product temperature using equations 8a and 8b were used in equation 9 to find values of color change and compared with experimental measured values of total color change at respective product temperature as tabulated in Table 2. A comparative view of these values shows that a close agreement can be observed among the modelled based and experimentally measured values of color change. It shows the validation of developed model equations (8a and 8b) which are based on sample temperature, capable to estimate product quality accurately. So once the moisture of samples will be measured at different product temperatures (using equation 8a or 8b), color change will also be calculated easily using this relationship (equation 9). This shows that change in product color ultimately depends on sample temperature.

The model predicted values of color difference w.r.t linear and exponential change in moisture ratio are similar to the experimental measured colour values, strengthen the developed models. The results reveal that by the increase of sample temperature 126 times the change in color is by more than 700 times the original value of color during the entire drying process. In this way, the change in color or any quality attribute at any interval of drying period can be assessed to monitor and optimize the dying conditions in the industrial dryers.

Table 2: Comparison among model predicted (both linear and exponential) and experimentally measured values of total color change, showing relation of color change with sample temperature during drying time.

Time (min)	Sample temp. (°C)	∅ = Mt/Mo		Change in total color, ΔE (using eq.9)		Experimentally measured ΔE
		a. Linear (eq.8a)	b. Expo (eq.8b)	Linear ΔE: using linear value of moisture ratio (eq.8a)	Exponential ΔE: using exponential value of moisture ratio (eq.8b)	
0	21.00	0.98	0.99			0.00
30	23.20	0.78	0.78	1.01	1.02	1.85
60	25.00	0.61	0.61	2.09	2.13	2.22
90	27.00	0.47	0.47	3.20	3.26	2.57
120	28.50	0.37	0.36	4.29	4.38	3.76
150	30.00	0.28	0.28	5.45	5.55	5.04
180	32.50	0.22	0.21	6.68	6.79	6.63
210	34.80	0.16	0.16	7.92	8.05	7.78
240	36.00	0.12	0.12	9.22	9.35	9.70
270	38.00	0.09	0.09	10.58	10.72	10.82
300	42.00	0.06	0.06	12.00	12.15	11.99
360	45.00	0.03	0.04	14.76	13.67	13.22
405	47.50	0.02	0.03	16.16	15.13	15.22

So present study shows the use of variable values of drying parameters (unsteady state) instead of their constant values to develop relationship between quality attribute and product temperature in a small industrial diagonal airflow dryer. Generally quality parameters are modelled or linked with drying time due to complexity involved in the analytical solution of Fick's model for mass diffusion which significantly deviate from the experimentally data. The variation in the drying conditions does not directly linked with the physiology of the product to be dried i.e. drying temperature and product temperature varies, so optimization of a dryer should be done based on the changes taken place in the product. Therefore, variation in product temperature can be linked directly with change of quality parameter in controller to control the dryer operation. The study would help to stakeholders especially designers working in the drying sectors that how to model quality parameter with mass diffusion to simulate accurate drying behaviour.

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