Batch drying of potato slices: kinetic changes of colour and shrinkage in response of uniformly distributed drying temperature

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Abstract: Uniform quality drying throughout the drying chamber of a dryer is important for a quality oriented drying process. The final quality of dried products significantly depends upon the drying temperature. A batch type food dryer was developed for spatial drying uniformity. ANSYS-fluent was used to analyse the temperature distribution in the dryer. In order to assess the effect of drying temperature homogeneity on colour and shrinkage of potato slices, these parameters were measured for 6 mm thick slices dried at 60 ℃. The colour parameters were quantified in CIELAB colour space system. The shrinkage of 20 mm roundslices was measured by analysing their captured images using image analysis software (Image J). The rate of colour change was found uniform at all sections of the drying chamber with high value of R2 (0.99). The kinetics of colour change showed that changes in values of L*and b* fitted well to the first-order kinetic model while values of a* and ΔE followed zero order kinetic model for all sections of the drying chamber. The rate of shrinkage was found to be uniform with an average area reduction of 43% for all sections of the drying chamber. These results show that drying temperature is important for product quality, therefore uniform distribution of drying temperature is important to get spatial uniform quality of dried product. The study is of immense benefits to the researchers involved in control of quality attributes problems especially in medium scale batch food dryers.

Keywords: batch dryer, drying temperature, uniform quality drying, colour and shrinkage

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1 Introduction

Many factors are involved in maintaining the quality of dried product, such as medium of drying, food tray material, pre-treatment processes but among them the drying temperature is the most critical. It is very important to control the rate of moisture removal to get good quality of dried materials. In food drying process, the effect of drying temperature on the quality parameters has been reported by numerous researchers (Farris et al., 2008; Orikasa et al., 2008; Diamante, 2010; Elamin and Akoy, 2014). Krokida et al. (2003) studied the effect of air drying conditions on the drying behaviour of potato, carrot, pepper and garlic. They found out that drying temperature is the most important factor affecting the drying rate. Babalis et al. (2004) also found that drying air temperature significantly affects the drying kinetics during thin layer drying of figs. Therefore, it can be deduced that drying temperature is the main influencing factor to determine the quality of the final product (Farias and Ratti, 2008; Elamin, 2014).

In a convective dryer (especially large in volume), uniform temperature distribution is vital both from quality retention and energy consumption points of view. Major quality attributes, namely, nutritional, physical, and chemical mainly depend on drying temperature and

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rate of heat flow. Uniform distribution of heat in the drying chamber is needed to vaporize water equally from the product lying throughout the drying chamber. A product which dries faster will exhibit different quality parameters than that dries slower. The achievement of drying uniformity is always a challenging task and it becomes more difficult for large batch drying systems. It could be obtained through proper air distribution inside the drying chamber to get uniform heat distribution.

For the assessment of product quality, colour and shrinkage are the most important aspects as they play an important role in the acceptance of product. Consumers tend to associate colour and other visual properties with flavour, safety, storage time, nutrition and level of satisfaction (Pedresche et al., 2006). Therefore, these quality parameters were selected to assess the spatial uniform quality drying in the dryer.

The objectives of the current study are to conduct heat transfer simulation using ANSYS-fluent to visualize temperature distribution in the drying chamber in response of an appropriate airflow design and to measure the rate of change of food quality parameters to assess their uniformity throughout the drying chamber.

Spatial variations of these two quality parameters (colour and shrinkage) were selected as criteria to assess the uniform quality drying throughout the dryer's chamber.

2 Materials and methods

2.1 Description of the dryer

Figure 1 illustrates the dryer which was designed for uniform airflow in the drying chamber (11 m×1.20 m×1.25 m). It consisted of three major parts named as connector, lower half which is the heating chamber and upper half, the drying chamber. The heating chamber was positioned at the bottom of the drying chamber to reduce space requirement. In this chamber, there was a constant speed axial tube fan (Dia. 0.7 m, 453 m^3/h, 2.2 kW) and an electric water-air heat exchanger. A connector, made of galvanized iron, was used to connect the lower half to the upper half of the dryer. In the drying chamber, twenty-five food buckets were arranged diagonally, on a rolling track (for easy loading and unloading of food buckets). Each bucket covered a distance of 0.4 m in the drying chamber. These diagonally arranged buckets gave a shape of diagonal airflow channel at an angle of 1.42^0 with the wall of drying chamber in longitudinal direction (Figure 2). The incoming air inside the diagonal air flow channel converged towards the end of the drying chamber due to the diagonal design. This makes the possibility of similar inlet air conditions for all the food buckets. The walls of dryer were made of polyurethane foam sandwiched into galvanized iron sheets for easy machining and excellent insulation. Two opening doors (0.65 m × 0.36 m) were kept for the loading and unloading of buckets at both sides of the drying chamber. A rectangular passage (0.30 m × 0.15 m) was kept just before the outlet door (0.30 m × 0.15 m) for recirculation of air to increase energy utilisation efficiency. This passage was opened and closed with the flap of outlet door. The operation of the outlet door was controlled with a controller based on set temperature. A control panel was used to set temperature and time (three different temperatures can be set for three different intervals of drying time for a drying process).

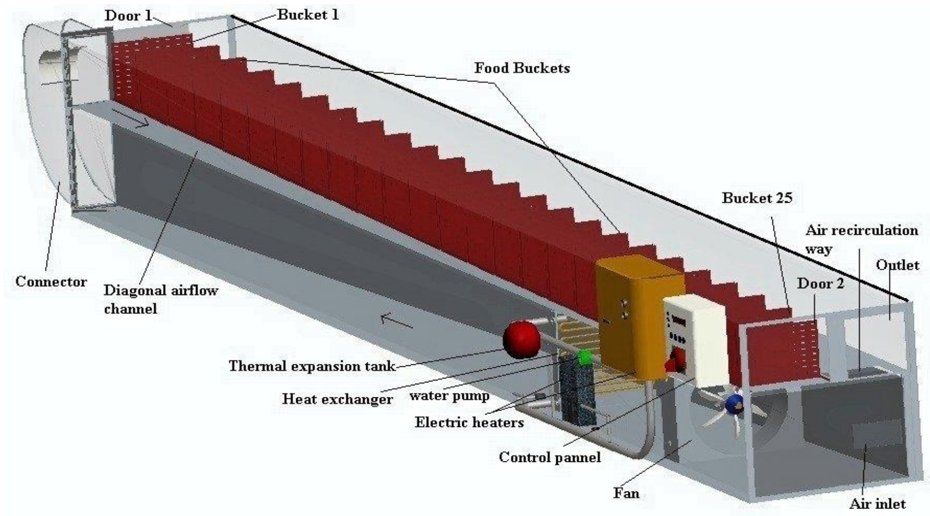

Figure 1 3D-model diagram of the dryer

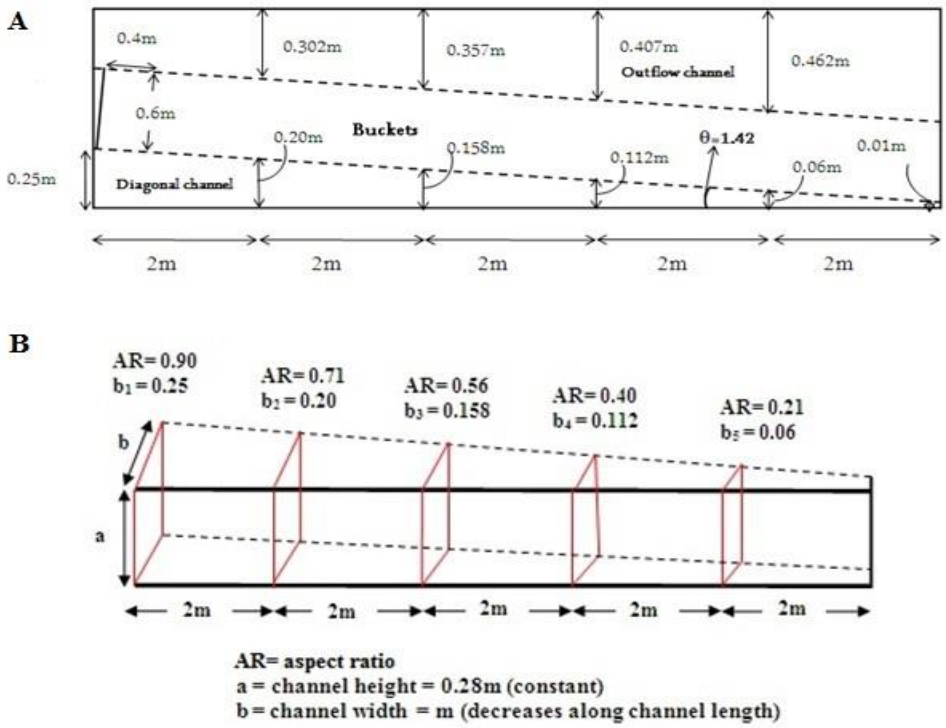

Figure 2 Line diagram of the drying chamber (a) and 3D view of diagonal channel (b)

The aspect ratio of an airflow channel is significant to control the pressure drop. The higher the aspect ratio, the higher-pressure loss in the rectangular airflow system (Hassan and Yue, 2002). Therefore, the aspect ratio of the diagonal channel was gradually decreased along with the length of the drying chamber to build uniform velocity pressure inside the channel, enforcing the air to pass equally across all the buckets.

2.2 Simulation

ANSYS Fluent was used for the simulation of air distribution in ANSYS workbench. The programme provides a comprehensive suite of computational fluid dynamics (CFD) software for modelling fluid flow and other related physical phenomena (Fluent user's guide, 2005). The geometry of the dryer was modelled and analysed for two configurations of airflow channels, namely, straight air flow channel and diagonal air flow channel (θ=1.42^0). The simulation with straight flow channel was done for the comparison of diagonal airflow design in the dryer compartment. The purpose of simulation was to check the temperature distribution in the drying chamber, so only the concerning part of the dryer (drying chamber) was designed and simulated. The characteristics and settings of simulations are tabulated in Table 1.

Table 1 Model properties and settings of the simulations

Properties	Values
Grid type	tetrahedral, unstructured
Turbulence model	k-ε standard
Discretization	Second-order upwind
Wall friction model	no slip
Inlet air velocity (normal to air inlet)	5.0 m/s
Mass flow inlet	1.31688 kg/s
Outlet pressure	0 Pa
Specific heat capacity Cp	3430 KJ/kg.K
Density (white potato)	796 kg/m^3
Thermal conductivity, k	0.545-0.957 $W/m.^0C$ (50^0C-100^0C)

2.3 Drying experiments

The drying experiments were carried out using locally available potatoes. Potatoes had a mean water content of 82% on wet basis. Prior to the start of each experiment, potatoes were washed, peeled, and sliced radially (in 6 mm thickness) with an adjustable cutting thickness cuter (Bosch MAS62 slicer, 110 watt, 120 rpm, Germany). After that, slices were blanched in boiled water for three minutes to inhibit enzymatic reactions. The free water on the surface of blanched potatoes was dried up with clean cloth before loading into the food buckets. Two perforated trays were put into each bucket at successive intervals of 0.097 m. Experiments were conducted by loading each bucket with one kilogram of potatoes slices; each of its trays was carrying a half kilogram of potato slices. The operating drying temperature was electronically set at 60℃. Potatoes were dried up to 12% of final moisture contents. The dryer was not fully loaded due to difficulty in handling of materials during experiments and to avoid material cost for repetitive trials. Therefore, the entire length of the drying chamber was divided into five sections, each two meters in length and comprised of five buckets. In this way five experiments were conducted, one for each section, under the same drying conditions. For this, the drying material was not loaded for each trial just after the start of dryer until the required air conditions were obtained within the drying chamber. Three replicates were carried out, thus values reported are the average of the replicates. Each replication was comprised of five numbers of experiments (one experiment for one section of the drying chamber). In this way fifteen experiments were carried out to complete three replicates.

Temperatures at every one meter distance of the drying chamber were measured by inserting thermocouples (K-type ±1.5 k) at the top of the drying chamber, connected to a data logger (Agilent 34970A, Malaysia) to assess temperature distribution throughout the drying chamber. Mini data logger (MSR-145 ±2%, Swiss) was used both at inlet and outlet positions of the drying chamber to measure relative humidity. Electric powered electronic weighing balance (BIZERBA, Germany) was used for weighing of fresh and dry material for drying rate measurements at different intervals of an experiment. Air flow through each bucket was measured by inserting TA5 hotwire anemometer (resolution of 0.01 m/s) at three points for each bucket by running empty dryer. These points were made by drilling holes at the roof of the drying chamber to insert the probe of anemometer at the place of each bucket. For a single bucket, five velocity readings were measured for each of its three points at various depths and then an average velocity was calculated for that bucket.

2.3.1 Colour measurement

The surface colour of samples was measured before the drying and after every one hour interval during the drying process using a colorimeter (Konica Minolta CR-410). Six samples were selected randomly (three from each tray) to measure colour change for a bucket, making the measurements more representative. As colorimeter had 50 mm diameter measurement area which provided average value of this small areas of a sample, so reading were taken from different locations of a sample to obtain a representative colour profile. The colours were expressed in *CIELAB* colours space system as $L*$ (lightness/darkness), $a*$ (redness/greenness) and $b*$ (yellowness/blueness). Total colour difference (ΔE) was calculated as in Equation 1 for the determination of food quality changes (Sturm et al., 2014).

$$\Delta E = [(L_0^* - L^*)^2 + (a_0^* - a^*)^2 + (b_0^* - b^*)^2]^{0.5} \quad (1)$$

Kinetic modelling is necessary to derive basic kinetic information of a particular food during processing. For the kinetics of colour changes of food materials, the use of zero-order or first-order kinetics models has been reported by many researchers (Mujumdar, 2000; Sturm et al., 2014).

$$C = C_o \pm k_o t \quad (2)$$

$$C = C_o exp(\pm k_1 t) \quad (3)$$

Where, C is the measured value of colour variables (L^*,a^*,b^*) at time t during drying, C_o is the initial value of colour variables at the start of drying, t is the drying time, k_0 is the zero-order kinetic constant and k_1 is the first-order kinetic constant. The positive and negative signs indicate formation and degradation of quality parameter respectively.

So, these equations were used for the mathematical modelling of colour changes of potato slices at different places of the drying chamber during the drying process.

2.3.2 Shrinkage measurement

The potato slices were of irregular shape in diameter, so a circular cutting mold was used to make round slices of 20 mm in diameter. At the start of each experiment, three samples were placed at different positions of each tray in a bucket. In this way six measurements (three for each tray) were taken and then average values were calculated. These were measured by taking top images of samples with a digital camera (Canon EOS 10D). The photos were acquired into a computer and analysed with a common domain software package, Image J1.29X (National Institutes of Health, USA, http://rsb.info.nih.gov/ij/, JAVA1.3.1_03). The wand-tracing and the straight-line selection tools were used to measure cross-section area of the front surface and diameter of the samples. The area of the sample was defined as the number of pixels contained within its boundary. The raw sample's diameter was the length of a straight-line segment passing through the centre of sample and terminating at the periphery. The use of this method has also been reported by Yan et al. (2008).

3 Results and discussion

3.1 Simulation results

Figure 3 shows the temperature distribution in the drying chamber for straight airflow channel (Figure 3a) and diagonal airflow channel (Figure 3b). The temperature of drying air decreases as it moves over the wet food materials due to sensible heat transfer to food and latent heat used in the transfer of moisture from the food material into the air. In straight airflow channel, air moved directly to the end of the drying chamber which caused higher air velocity at the end of drying chamber and resulted a high temperature zone comparative to the other part of drying chamber as temperature distribution is associated with airflow distribution. It is evident since temperature contours were not uniform across the buckets.

On the other hand, diagonal airflow channel showed a good temperature distribution through the buckets (Figure 3b). The air converged as it moved towards the end of drying chamber due to diagonal airflow design. It resulted in almost the same velocity pressure in the channel enforcing uniform airflow through all the food buckets. Due to this uniform airflow, uniform temperature distribution took place through all food buckets which can be observed from the contours of temperature distribution. This uniform temperature distribution caused uniform moisture removal from the food buckets. So simulated analysis for diagonal airflow pattern gave good uniformity of temperature distribution through the concerned region (food buckets).

For the comparison of airflow, in CFD solution, lines were drawn passing through buckets in longitudinal direction to measure average velocity. These results of average velocity were compared with the corresponding experimental results. The result of statistical analysis shows good correlation (coefficient of determination 87.09%) for airflow distribution between the average predicted and the average experimental measured velocity as is shown in Figure 4.

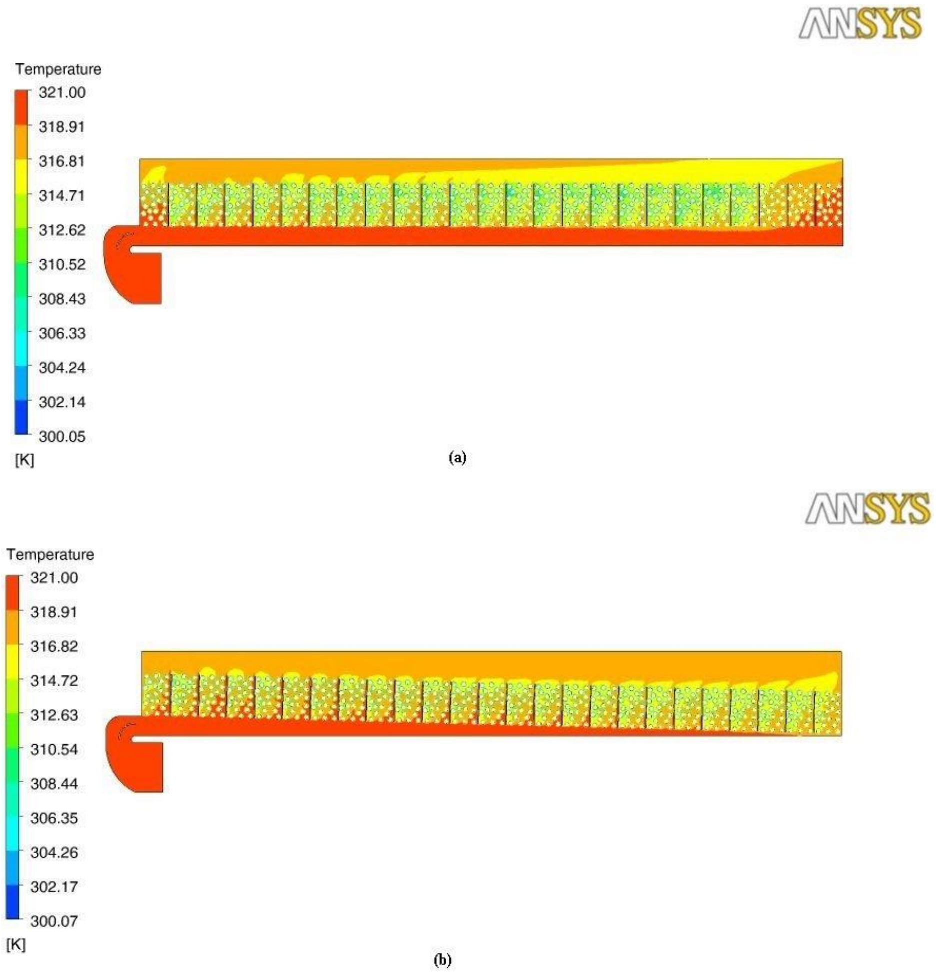

Figure 3 Temperature distribution in straight airflow (a) and diagonal airflow channel (b)

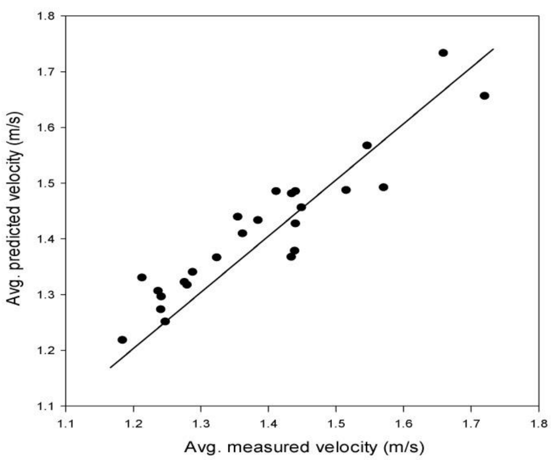

Figure 4 Comparison of mean predicted and measured velocity in the drying chamber

3.2 Colour parameters

Figure 5 shows the experimental data of colour parameters and overall colour change in potato slices with drying time at all five sections of the drying chamber. The figure shows that Luminosity (L^*) diminished with the drying time. This change in the brightness of dried potato slices can be taken as a measurement of browning (Lozano and Ibarz, 1997; Lee and Coates, 1999; Avila et al., 1999), which reduced from an average value of 64.23 to an average value of 52.62 along the entire length of the drying chamber. It means that potato slices tended to get a little darker as drying proceeded and resulted to increase colour difference (ΔE) about ten units. It can be observed by the progressive increasing of ΔE values with the drying time.

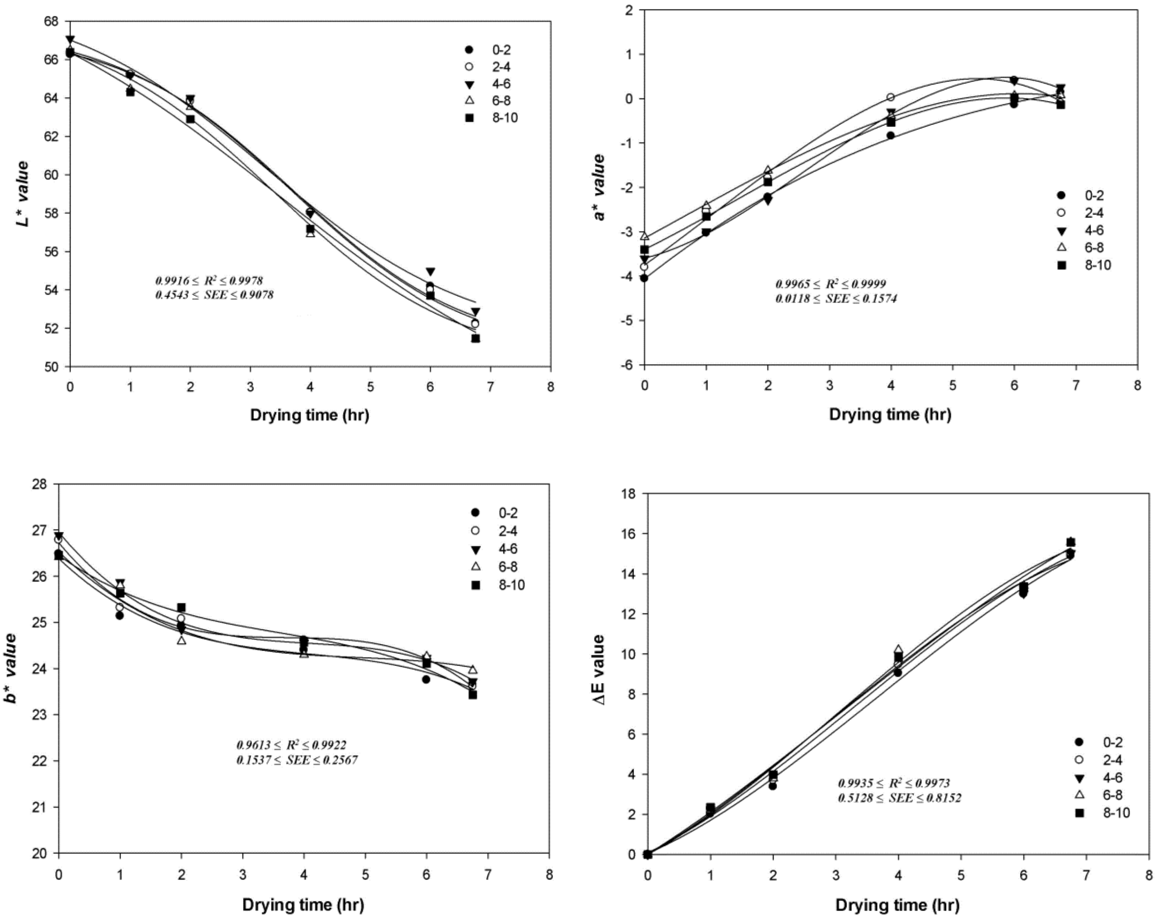

Figure 5 Kinetics of change in colour parameters (L*, a*, b*) and total colour difference (ΔE) as a function of drying time at all sections of drying chamber

The blanching treatment during sample preparation inactivated the most of enzymes, so decreasing of L* could be attributed to the non-enzymatic browning and brown pigment formation (Krokida et al., 1998). It might also be related to an increase in samples opacity resulting from structural shrinkage due to the moisture evaporation (Contreras et al., 2008). Pedreschi et al. (2007) reported that the luminosity of potato slices decreases more with the increase in temperature hence the observed reduction in lightness. The declining trend in lightness of potato slices at all sections of the drying chamber were found similar which ascertain the fact of uniform temperature availability throughout the drying chamber. It is because of uniform air distribution within the drying chamber as temperature distribution is associated with airflow in the drying chamber.

The chromatic parameter (a^*) of potato slices increased during drying due to non-enzymatic browning reactions. The initial value of samples showed a negative value (-3.59) indicating greenness, and increased to a positive value (0.048) at the end of drying. So, a^* resulted about three units in increasing ΔE values. As a consequence of uniformity in drying rate due to uniform temperature, potato slices at different positions of drying chamber showed almost similar change in values of a^*. The rate of change in colour component b^* was observed less as compared to L^*. The slow declining trend of b^* with drying time showed that the yellowness of potato slices were retained. The initial b^* values decreased from average 26.60 to average 23.67. It can be observed from Figure 5 that for all sections of the drying chamber, the rate of change of b^* is almost the same.

As a whole, the total colour difference (ΔE) was calculated for the determination of colour changes in the potato slices during drying. It can be seen from Figure 5 that the ΔE increased with the drying time (with decreasing moisture content). Dependence of ΔE was more on colour parameter L^* than a^* and b^* parameters.

Further to show the dependency of total colour difference (ΔE) more on L^* value, modelling of the ΔE had done as a function of colour parameters L^*, a^* and b^* (Table 2). High values of coefficient of determination (R^2) for the relations between ΔE and L^* showed that the change in ΔE was more sensitive to the change in L^*. This trend wass similar throughout the drying chamber showing the uniform change in this quality parameter.

Table 2 The modelling of ΔE as a function of colour parameters L^*, a^* and b^*

Section of drying chamber	ΔE as function of L^*		ΔE as function of a^*		ΔE as function of b^*	
	Relation	R^2	Relation	R^2	Relation	R^2
0-2	$\Delta E = -0.76 L^* + 52.50$	0.98	$\Delta E = 3.08 a^* + 9.95$	0.86	$\Delta E = -6.64 b^* + 168.4$	0.98
2-4	$\Delta E = -0.41 L^* + 31.13$	0.86	$\Delta E = 1.73 a^* + 7.90$	0.73	$\Delta E = -3.73 b^* + 98.31$	0.84
4-6	$\Delta E = -0.81 L^* + 54.76$	0.94	$\Delta E = 3.19 a^* + 10.77$	0.90	$\Delta E = -3.55 b^* + 95.58$	0.85
6-8	$\Delta E = -0.99 L^* + 62.91$	0.99	$\Delta E = 3.87 a^* + 9.83$	0.90	$\Delta E = -6.38 b^* + 164.2$	0.85
8-10	$\Delta E = -0.79 L^* + 51.12$	0.98	$\Delta E = 3.26 a^* + 9.63$	0.91	$\Delta E = -4.75 b^* + 121.9$	0.86

Sigmoid model was found to be best fitted to data of lightness/darkness (L^*) while polynomial cubic model was found best fitted to all other parameters with high values of coefficient of determinant (R^2) and lower values of standard error of estimate (SEE) using Sigma-plot 12.3 as is shown in Figure 5. It is clear from the values of standard error of estimate for all the measured (L^*, a^* and b^*) and calculated (ΔE) colour parameters at all sections of drying chamber that these observations are very close to the model fitted line of correspondent colour parameter. So, the model with the smallest standard error of estimate was the best fit for the sample.

3.3 Modelling of colour change

It was observed that L^* and b^* values were best fitted to the first-order kinetic model with high R^2 value while the values of a^* and total colour change (ΔE) followed a zero-order kinetic model. The results are in agreement with the several studies which have reported that the first-order kinetic model was better for L^* and b^* values of double-concentrated tomato paste (Barreiro, 1997), kiwifruits (Maskan, 2001), pineapple (Chutintrasri and Noomhorn, 2007) and peach puree (Avila et al., 1999) and zero-order kinetic model was better for a^* and total colour change (ΔE) values of kiwifruits (Maskan, 2001), pineapple (Chutintrasri and Noomhorn, 2007).

The estimated kinetic parameters of these models and the statistical values of coefficients of determination R^2 are represented in Table 3 for all the sections of the drying chamber.

Table 3 The estimated kinetic parameters and the statistical values of zero-order and first-order kinetics models for *L*, a*, b and *total*-colour change (Δ*E*) at five sections along the length of the drying chamber**

Drying temperature, ^{0}C	Parameters	Section	Zero order model			First order model		
			k_o (1/hr)	C_o	R^2	k_1(1/hr)	C_o	R^2
60	*L** (Lightness-darkness)	0-2	-1.6407	66.6730	0.9910	-0.0240	66.6730	0.9922
		2-4	-1.7304	66.8010	0.9923	-0.0254	66.8064	0.9934
		4-6	-2.1063	67.3470	0.9896	-0.0314	67.3632	0.9899
		6-8	-2.1314	66.7640	0.9871	-0.0319	66.7797	0.9879
		8-10	-2.1145	66.5340	0.9944	-0.0315	66.5313	0.9945
	*a** (Redness-greenness)	0-2	1.0521	-4.0455	0.9993	-0.9206	0.2540	0.4126
		2-4	1.5093	-3.9286	0.9873	-1.5032	0.2673	0.2429
		4-6	1.064	-3.8312	0.9782	-1.1782	0.241	0.5406
		6-8	0.9603	-3.209	0.9967	-0.2525	0.1283	0.5834
		8-10	1.0138	-3.5036	0.9938	-0.3159	0.1297	0.9018
	*b** (Yellowness/ blueness)	0-2	-0.6707	26.1810	0.9297	-0.0259	26.1748	0.9335
		2-4	-0.7149	26.4340	0.9079	-0.0272	26.4247	0.9108
		4-6	-0.8826	26.7170	0.9445	-0.0339	26.7143	0.9450
		6-8	-0.8802	26.3990	0.9418	-0.0345	26.4035	0.9414
		8-10	-0.5074	26.3090	0.9732	-0.0192	26.3060	0.9728
	ΔE (Total color change)	0-2	2.3292	0.6383	0.9944	0.7513	1.0240	0.9970
		2-4	2.5561	0.6231	0.9943	0.7259	1.1683	0.9973
		4-6	2.9356	0.9268	0.9910	0.7730	1.0863	0.9961
		6-8	2.9515	1.0282	0.9893	0.7814	1.0537	0.9950
		8-10	2.5860	0.4746	0.9932	0.7192	1.1945	0.9960

The values of kinetic rate constants of both models (zero and first order) for all colour parameters were found to be almost similar for all the positions of the drying chamber. This implies that the colour formation or degradation was found to be uniform throughout the drying chamber due to uniform temperature distribution because kinetic rate constant depends mainly on drying temperature (Lozano et al; 2000). The colour degradation rate increases with high drying temperature due to high energy transferred to the inside of drying material and vice versa. So, uniform distribution of drying temperature is of much importance to get uniform quality dried products throughout the drying chamber.

The values of colour parameters presented in Figure 5, Tables 2 and 3 represent values for different sections of drying chamber. As was discussed earlier that each section (2 m distance) had five food buckets, so the values of colour parameters for a section were the average of those values measured for these five buckets. In order to check the variation of colour parameters among food buckets, standard deviation of colour data (for all 25 buckets) was calculated and tabulated in appendix 1. The values of medians and standard deviations of colour data also showed drying uniformity among the food buckets.

3.4 Shrinkage

Figure 6 shows the decline in area of potato slices with drying time at various places of the drying chamber. The rate of area change was high in the first 180 min (three hours) of drying time due to rapid removal of loosely bounded surface moisture, then it became slow and remained constant afterward. A similar trend was found in grape tissues and apple slices by Ramos et al. (2004) and Fernandez et al. (2005) respectively. The visual changes in the size of the slices, indicating shrinkage and shape were gradually led towards an irregular form, can also be observed in Figure 7.

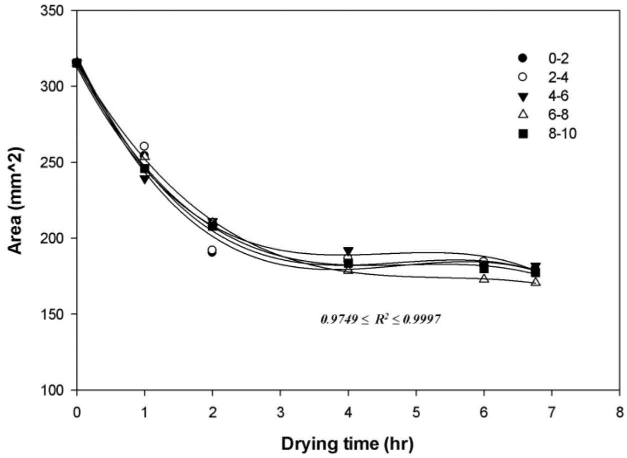

Figure 6 Change in of area of potato slices with drying time along the length of drying chamber

Figure 7 Change in size of potato slices as drying proceeded (at section two-four)

As shrinkage directly relates to the rate of moisture removal from the product (Mayor and Sereno, 2004; Alireza Y. et al., 2009), a uniform change in area was found throughout the length of the dryer due to uniform moisture removal caused by uniform temperature availability at all the places of the dryer. It can be observed in Figure 8 which presents the area change as a function of dimensionless moisture content for different places of the drying chamber. As was discussed above, area decreased rapidly at early stages of the drying process due to the removal of water at high rate up to $X/Xo \geq 0.7$. It can be presumed that the changes in the slices area at early stages of drying were due to the elasticity of cellular potato tissues which caused shrinkage into the space left by the evaporated moisture (Alireza et al., 2009). Subsequently, the rate of area shrinkage decreased because of slices being of rigid structure. Towards the end of drying process, at low drying rate, the amount of shrinkage bears a simple relationship to the amount of moisture removed. The amount of moisture at the centre of a sample (potato slices) is never very much higher than at the surface, so the internal stresses are minimized and the material shrinks down fully onto a solid core (Wang and Brennan, 1995).

Regression analysis gave high values of coefficient of determinant (R^2) for each position of the drying chamber. Its shows the occurrence of uniform change in area of potato slices throughout the drying chamber. The observed rate of shrinkage change for all sections followed similar trend as tabulated in Table 4.

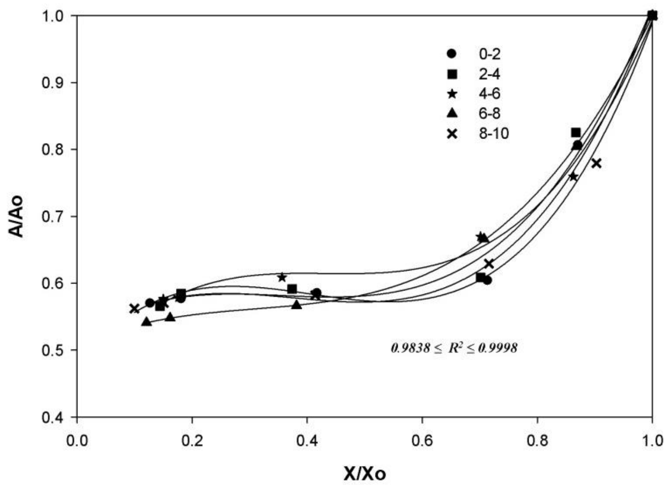

Figure 8 Dimensionless area changes (A/A0) as a function of the dimensionless moisture content (X/X0) at all sections of drying chamber

Table 4 Percentage of area changed along the dryer's length

Section	Initial area, mm^2	Final area, mm^2	Area decreased, mm^2	Area decreased, %
0-2	315.25	179.52	135.73	43.05
2-4	315.25	178.38	136.86	43.41
4-6	315.25	181.68	133.57	42.37
6-8	315.25	170.54	144.71	45.90
8-10	315.25	177.24	138.01	43.78

4 Conclusion

A batch type food dryer was developed for uniform distribution of drying temperature throughout the drying chamber. The numerical and experimental profiles of airflow distribution were found uniform. During drying experiments, kinetic changes in colour and shrinkage of potato slices were measured at 60℃. Results showed that the rate of change of these quality parameters at all sections of the drying chamber were found similar. Drying temperature mainly influence the quality parameter so the change in these quality parameters is directly linked with the uniformity of drying temperature.

Therefore, the spatial uniform distribution of drying temperature is of much importance to reduce the factor of over and under drying and consequently to get product of uniform quality throughout the drying chamber. For this, design of airflow in the drying chamber is the main factor to be considered. Diagonal airflow design gave good temperature distribution which is important in reducing the heterogeneity of quality parameters in the drying chamber. Further work is under way to optimize the drying process to save the energy with respect to the minimum change in quality parameters. This control of drying temperature during a process will not only save energy consumption, but also give dried food product with maximum retention of quality attributes.

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References

Avila, I. M. L. B, and C. L. M. Silva. 1999. Modelling kinetics of thermal degradation of colour of peach puree. *Journal of Food Engineering*, 39(2): 161-166.

Alireza, Y., L. Acefeh, and M. Reza. 2009. New method for determination of potato slice shrinkage during drying. *Computer and Electronics in Agriculture*, 65(2009): 268-274.

Babalis, S. J., and V.G. Belessiotis. 2004. Influence of the drying conditions on the drying constants and moisture diffusivity during the thin-layer drying of figs. *Journal of Food Engineering*, 2004(65): 449-58.

Chutintrasri, B., and A. Noomhorm. 2007. Colour degradation kinetics of pineapple puree during thermal processing. *LWT*, 40: 300-306.

Contreras, C., M. E. Martin-Esparza, A. Chiralt, and N. Martinez-Navarrete. 2008. Influence of microwave application on convective drying: effects on drying kinetics and optical and mechanical properties of apple and strawberry. *Journal of Food Engineering*, 88 (1): 55-64.

Diamante, L., M. Durand, G. Savage, and L. Vanhanen. 2010. Effect of temperature on the drying characteristics, colour and ascorbic acid content of green and gold kiwifruits. *International Food Research Journal*, 17: 441-451.

Elamin, O. M., and Akoy. 2014. Effect of drying temperature on some quality attributes of mango slices. *International Journal of Innovation and Scientific Research*, 4(2): 91-99.

Fernandez, L., C. Castillero, and J. M. Aguilera. 2005. An application of image analysis to dehydration of apple discs. *Journal of Food Engineering* 67(1-2): 185-193.

Fernando R. L., and L. Cisneros-Zevallos. 2007. Degradation kinetics and colour of anthocyanins in aqueous extracts of purple-red-flesh potatoes (Solanum tuberosum L.). *Journal of Food Chemistry*, 100(3): 885-894.

Farris, S., S. Gobbi, D. Torreggiani, and L. Piergiovanni. 2008. Assessment of two different rapid compression tests for the evaluation of texture differences in osmo-air-dried apple rings. *Journal of Food Engineering*, 88(4): 484-491.

Farias, A.M., and C. Ratti. 2008. Dehydration of foods. In: Ratti C (ed) Advances in food dehydration. Contemporary food engineering. CRC Press, Boca Raton, pp 1-36 Fluent 6.3 user's Guide 2005. Fluent documentation. Fluent Inc, Lebanon

Hassan, O. A. B., and Z. Yue. 2002. Pressure drop in and noise radiation from rectangular and round ducts-literature survey. The third European conference on energy performance & indoor Climate in Buildings, France, pp. 387-392.

Krokida, M. K., E. Tsami, and Z. B. Maroulis. 1998. Kinetics on color changes during drying of some fruits and vegetables. *Drying Technology*, 16(3-5): 667-685.

Krokida, M. K., V. T. Karathanos, Z. B. Maroulis, and D. K. Marinos. 2003. Drying kinetics of some vegetables. *Journal of Food Engineering*, 2003(59): 391-403.

Lozano, J.E., and A. Ibarz. 1997. Colour changes in concentrated fruit pulp during heating at high temperatures. Journal of Food Engineering, 31: 365-373.

Lozano, J. E., Cristina Anon, and G. V. Barbosa-Canovas. 2000. Trends in food engineering. Technomic Publisher 2007 USA ISBN: 1-56676-991-4

Lee, H.S., and G.A. Coates. 1999. Thermal pasteurization effects on colour of red grapefruit juices. *Journal of Food Science*, 64(4): 663-666.

Mayor, L., and A. M. Sereno. 2004. Modeling shrinkage during convective drying of food materials: a review. *Journal of Food Engineering*, 61(3): 373-386.

Mujumdar, A. S. 2000. Drying technology in agricultural and food science. Science publishers, Inc. Plymoth, UK., pp: 61-98 and pp: 253-286.

Muskan, M. 2001. Kinetics of colour change of kiwifruits during hot air and microwave drying. *Journal of Food Engineering*, 48(2):169-175.

Orikasa, T., L. Wu, T. Shiina, and A. Tagawa. 2008. Drying characteristics of kiwifruit during hot air drying. *Journal of Food Engineering*, 85(2): 303-308.

Pedreschi, F., J. Leoń, D. Mery, and P. Moyano. 2006. Development of a computer vision system to measure the color of potato chips. *Food Research International*, 39(2006): 1092-1098.

Pedreschi, F., J. Leoń, D. Mery, P. Moyano, R. Pedreschi, K. Kaack, and K. Granby. 2007. Color development and acrylamide content of pre-dried potato chips. *Journal of Food Engineering*,79(2007):786-793.

Ramos, I. N., C. L. M. Silva, A. M. Sereno, and B. J. M. Aguilera. 2004. Quantification of microstructural changes during first stage air drying of grape tissue. *Journal of Food Engineering*, 62(2): 159-164.

Sturm, B., N. V. Anna-Maria, and W. C. Hofacker. 2014. Influence of process control strategies on drying kinetics, colour and shrinkage of air dried apples. *Applied Thermal Engineering*, 62(2014): 455-460.

Wang, N., and J. G. Brennan. 1995. Changes in structure, density and porosity of potato during dehydration. *Journal of Food Engineering*, 24(1): 6l-76.

Zhengyong, Y., J. Maria, G. Sousa, and A. R. Fernanda Oliveira. 2008. Shrinkage and porosity of banana, pineapple and mango slices during air-drying. *Journal of Food Engineering*, 84(3): 430-440.