EFFECT OF TEMPERATURE AND LOADING DENSITY ON DRYING KINETICS OF WHEAT

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KEYWORDS

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ABSTRACT

The effect of temperature and loading density on drying kinetics of wheat were studied experimentally in a laboratory-scale cabinet dryer. The study was conducted at drying temperatures of 40, 45, and 50°C with loading density of 2.12 and 4.24 kg/m² at constant air velocity of 0.6 m/sec. The Henderson and Pabis model was applied to fit the drying conditions. Results of study revealed that drying rate constant gradually decreased with the increasing of loading density of wheat. The effective moisture diffusivity for wheat was increased with the increasing of drying temperature, and it was in the range of 3.27×10^{-11} cm²/sec to 7.95×10^{-11} cm²/sec while the activation energy of 17.64 kcal/ g-mole was found from the Arrhenius equation.

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1 Introduction

Wheat (*Triticum aestivum*) belongs to the family Graminae, is one of the important cereals to make flour for diet and livestock feed. Wheat can be easily processed to flour and semolina. Further, wheat is also used as rich source of carbohydrate, fiber, vitamin B complex and minerals (Sramkova et al., 2009). It is believed that wheat is originated in the Nile Valley by 5000 BC and the Mediterranean region is the center of domestication (Zohary & Hopf, 2000). In Bangladesh, wheat cultivation is started from the late 1980s. Firstly, it is consumed in rural areas but now, it is second highest consumed cereal crop (Banglapedia, 2006). According to BARI report 2010, about 1 million ton of wheat is produced against the annual demand of 3.0-3.5 million tons in Bangladesh. Consequently, 2.0-2.5 million tons of wheat is imported every year in Bangladesh to meet the national demand. On the other hand, postharvest loss of wheat is found almost 3.62% in Bangladesh, among this storage loss is 1.54%. However, improved drying system with proper drying management is important to minimize the storage loss of wheat (Bala et al., 2010).

Drying is one of the oldest but important techniques to preserve and improving the storage quality of agricultural produces. Drying technique involves the removal of moisture content to safe level by means of heat and mass transfer (Ertekin & Yaldiz, 2004), as a result of this, it prevents the enzymatic and microbial spoilage of food products. Furthermore, dried products need less space for storage and drying technique makes agricultural products easier to handle without losing remarkable amount of vitamins (Izadifar & Mowla, 2003; Sagar & Kumar, 2010). In Bangladesh, drying technique varies from natural sun drying to mechanical drying depending on product and affordability in cost. Sun drying is most common drying technique for wheat but it requires relatively long drying time and is associated with drying loss of wheat.

On the other hand, mechanical drying namely cabinet drying is alternative option with several advantages including high thermal conductivity, energy saving, better space utilization and precise controlling system (Maskan, 2000). Several researchers investigated drying characteristics of fruits and vegetables in various drying system. Thin layer drying characteristics of pomegranate arils with varying temperature (50, 55 and 60°C) in cabinet drying system are studied by Kingsly & Singh (2007). The effects of different drying temperatures and air velocity levels on drying behavior of carrot have been studied by Erenturk & Erenturk (2007). In addition, different drying models are used to design dryers for efficient moisture transfer analysis along with to describe the drying behavior of agricultural produces (Midilli et al., 2002; Da Silva et al., 2009; Kumar et al., 2011).

Hence, present study was aimed to investigate the drying behavior of wheat with varying drying temperature and loading

density (layer) in a cabinet dryer. Apart from this, effective diffusivities and activation energy were calculated in selected drying conditions.

2 Materials and Methods

2.1 Sample collection

The Prodig (BAW-1008) wheat was used in this study and collected from the central farm of Bangladesh Agricultural University during harvesting time. After collecting, wheat was winnowed to get fresh and quality sample material. On the same day, prepared sample was subjected to drying process.

2.2 Drying process

Drying process of wheat was accomplished in cabinet dryer (model OV-165, Gallenkamp Company), consists of several chambers in which samples were placed in trays. Usually, a fan is used for blowing air over a heater and above the samples placed in trays of cabinet dryer. The air velocity was measured by Anemometer.

Fresh wheat with known loading density (2.12 kg/m² and 4.24 kg/m²) was subjected to cabinet drying process at three different dry bulb temperatures (40, 45 and 50°C) with constant air velocity (0.6 m/sec) to know the effect of loading density and temperature on drying kinetics of wheat.

2.3 Theoretical consideration

2.3.1 Mechanical modeling of drying curves

Different drying models are used to fit the drying curves to experimental data for determining most efficient drying model. An effective drying behavior model is very important to know the drying characteristics of wheat for a cabinet dryer. In this study, the experimental drying data of wheat at different conditions were fitted into Henderson and Pabis model given below (Figiel, 2010):

$$MR = a \exp(-kt) \dots\dots\dots (1)$$

The moisture ratio of fresh wheat was calculated by the following equation (Figiel, 2010):

$$MR = (M_t - M_e) / (M_o - M_e) \dots\dots(2)$$

Where, MR is moisture ratio, M₀, M_t and M_e are initial moisture content, moisture content at specific time and equilibrium moisture content (kg water/kg dm) respectively.

For low equilibrium moisture content and moisture ratio (MR < 0.6), equation reduces to

$$MR = M_t / M_o \dots\dots (3)$$

2.3.2 Effective moisture diffusivity

In drying process, moisture moves to surface by a physical mechanism known as diffusivity, which can be explained by Fick's diffusion equation (Abe & Afzal, 1997). On the other hand, effective moisture diffusivity depends on chemical composition, temperature, density and porosity of substance (Perry et al., 1984). Several researchers have been stated that effective moisture diffusivity (D_{eff}) of food substance can be calculated by 'methods of slope' technique (Karathanos et al., 1990; Zogzas et al., 1996; Sharma et al., 2005). It is assumed that food dehydration is occurred by diffusion process. Therefore, mass transfer during drying process can be described by Fick's second law of diffusion. The expression is:

$$\frac{\delta M}{\delta T} = \nabla^2 D_e M \quad \dots (4)$$

Where, M is moisture content (dry basis), D_e is effective diffusion co-efficient and T is time (hr)

The above diffusion equation is usually used for a sphere shaped body such as grain with radius ' r ' (Brooker et al., 1974; Crank, 1975; Islam, 1980) can be written as:

$$MR = \frac{6}{\pi^2} \sum_{n=1}^{\infty} \exp \left\{ \frac{-(2n+1)^2 \pi^2 D_{eff} t}{r^2} \right\} \quad \dots (5)$$

Where, D_{eff} is the effective diffusivity (m^2/s) and r is radius.

The equation (5) can be simplified by taking the first term of series (Tutuncu & Labuza, 1996) and written as

$$MR = \frac{6}{\pi^2} \exp \left(- \frac{\pi^2 D_{eff} t}{r^2} \right)$$

or

$$\ln MR = \ln \frac{6}{\pi^2} - \frac{\pi^2 D_{eff} t}{r^2} \quad \dots (6)$$

The slope and effective diffusivity can be calculated from the above equation and written as:

$$\text{Slope} = \frac{\pi^2 D_{eff}}{r^2} \quad \dots (7)$$

$$\text{Again, } D_{eff} = \frac{r^2}{\pi^2} (\text{slope})$$

$$2. \quad \text{Where, slope} = (\ln MR_2 - \ln MR_1) / (t_2 - t_1) \quad \dots (8)$$

The temperature dependence of the effective diffusivity may be described by an Arrhenius-type relationship (Madamba et al., 1996; Ozdemir & Devres, 1999; Sanjuan et al., 2003; Akgun & Doymaz, 2005; Wang et al., 2006) and written as:

$$D_{eff} = D_0 \exp \left(\frac{E_a}{RT} \right) \quad \dots (9)$$

$$\text{or}$$

$$\ln D_{eff} = \ln D_0 - \frac{E_a}{RT} \quad \dots (10)$$

Where, D_0 = frequency factor of Arrhenius equation (m^2/s), E_a = activation energy (J/mol), T = absolute temperature (K) and R = universal gas constant (J/mol K). The activation energy (E_a) could be calculated from the slope of straight line of $\ln D_{eff}$ versus reciprocal of T .

3 Results and Discussion

3.1 Effect of temperature on drying kinetics

Wheat was dried at 40, 45 and 50°C in thin layer to know the effects of temperature on drying kinetics of wheat, whereas experimental data were analyzed using equation (6). Moisture ratio was plotted against drying time on semi-log graph paper (Figure 1) and the regression equations were developed as below:

$$MR = 0.9203e^{-0.226t} \text{ at } 40^\circ\text{C} \quad \dots (11)$$

$$MR = 0.9193e^{-0.285t} \text{ at } 45^\circ\text{C} \quad \dots (12)$$

$$MR = 0.9062e^{-0.353t} \text{ at } 50^\circ\text{C} \quad \dots (13)$$

From Figure (1) and above developed equations (11 to 13), it is clear that the moisture ratio (MR) decreased continuously with the drying progresses. Results of the study also revealed that drying time to a specific moisture ratio decreased with higher drying temperature of wheat. Figure (1) also suggests that drying rate constant gradually increased with the increasing of drying temperature. Higher temperature with low humidity may increase the drying rate at initial stage. But longer drying process would result in case hardening; therefore, it would reduce the drying rate significantly and deteriorate the product quality due to cooking instead of drying.

Similar findings have been stated by Sarker et al. (2012) for potato; Kumar et al. (2011) for carrot pomace; Khaliduzzaman et al. (2009) for garlic; Kamruzzaman & Islam (2006) for aroids. Thus optimum drying temperature is crucial parameter in mechanical drying process with counter current operation (Karel et al., 1975; Potter & Hotchkiss, 1978; Islam, 1980).

Figure 1 Effect of temperature on drying kinetics for wheat

Figure 2 Effect of loading density on drying kinetics of wheat at 40°C

Figure 3 Effect of loading density on drying kinetics of wheat at 45°C.

Figure 4: Effect of loading density on drying kinetics of wheat at 50°C.

3.2 Effect of loading density on drying kinetics

To measure the effects of loading density on drying kinetics of wheat, the experimental data were analyzed using equation (6). Moisture ratio was plotted against drying time on semi-log graph paper to draw regression lines (Figure 2, 3 and 4).

The following regression equations were developed for two loading densities and three dry bulb temperatures:

$$MR = 0.9371e^{-0.159t} \text{ at } 40^{\circ}\text{C} \text{-----} 2.12 \text{ kg/m}^2 \text{-----} (14)$$

$$MR = 1.0055e^{-0.105t} \text{ at } 40^{\circ}\text{C} \text{-----} 4.24 \text{ kg/m}^2 \text{-----} (15)$$

$$MR = 0.9386e^{-0.186t} \text{ at } 45^{\circ}\text{C} \text{-----} 2.12 \text{ kg/m}^2 \text{-----} (16)$$

$$MR = 1.0038e^{-0.147t} \text{ at } 45^{\circ}\text{C} \text{-----} 4.24 \text{ kg/m}^2 \text{-----} (17)$$

$$MR = 0.9621e^{-0.280t} \text{ at } 50^{\circ}\text{C} \text{-----} 2.12 \text{ kg/m}^2 \text{-----} (18)$$

$$MR = 0.9924e^{-0.192t} \text{ at } 50^{\circ}\text{C} \text{-----} 4.24 \text{ kg/m}^2 \text{-----} (19)$$

Figure 2, 3 and 4 show that drying rate of wheat decreased as loading density of wheat increases where drying rate constant was not decreased proportionally. Fig. 2 shows that rate constant 0.159 hr^{-1} was reported for loading density 2.12 kg/m^2 , whereas rate constant 0.105 hr^{-1} was resulted at 40°C for 4.24 kg/m^2 loading density.

On the other hand, rate constant 0.186 hr^{-1} and 0.147 hr^{-1} were observed at 45°C for loading density 2.12 kg/m^2 and 4.24 kg/m^2 respectively (Fig. 3). Again, at 50°C , loading density of 2.12 kg/m^2 resulted in rate constant (0.315 hr^{-1}), whereas rate constant (0.158 hr^{-1}) was revealed for loading density of 4.24 kg/m^2 at same condition (Fig. 4). These results were supported by the findings of Kamruzzaman & Islam (2006) who noted that drying rate constant decreased with the increased loading density of aroids. Similar behavior regarding the influence of loading density on drying rate constant was observed by Kamrul (2006) for raw paddy.

3.3 Effect of temperature on diffusion co-efficient of wheat

Diffusion coefficient (D_e) and inverse absolute temperature (T_{abs}^{-1}) were plotted on semi-log paper and regression lines were drawn (Figure 5). The Arrhenius equation was found as below:

$$D_e = 72.126 e^{-8881.89/T_{\text{abs}}-1} \quad \dots(20)$$

Where, D_e is Diffusion coefficient (cm^2/s) and T_{abs} is Absolute temperature ($^{\circ}\text{K}$).

It was observed that the effective moisture diffusivity increased with the increasing of drying temperature. The highest diffusivity ($7.95 \times 10^{-11} \text{ cm}^2/\text{sec}$) was noted at 50°C , whereas the lowest values ($3.27 \times 10^{-11} \text{ cm}^2/\text{sec}$) was noted at 40°C . Similar trend in effective moisture diffusivity with increasing drying temperature was reported by Roberts et al. (2008).

In this reaesrch, calculated activation energy (E_a) for wheat was $17.64 \text{ kcal/g-mole}$. The activation energy for wheat was higher than those reported by Kamruzzaman & Islam (2006) for aroids (5.12 kcal/g-mole); Islam et al. (1997) for mango (4.4 Kcal/g-mole); Alam et al. (2014b) for blanched slices of onion (2.46 Kcal/g-mole); Alam et al. (2014a) for ginger ($15.868 \text{ Kcal/g-mole}$); Sarker et al. (2012) for potato (5.06 Kcal/g-mole); Khaliduzzaman et al. (2009) for garlic (7.48 Kcal/g-mole) and lower than those noted by Ginger & Mascheroni (2001) for whole wheat ($27.00 \text{ Kcal/g-mole}$); Afzal Babu et al. (1997) for onion ($26.83 \text{ Kcal/g-mole}$) and Iqbal (2003) for cucumber (8.50 Kcal/g-mole) and for cauliflower (7.76 Kcal/g-mole).

Figure 5 Effect of temperature on diffusion coefficient

Conclusion

The Henderson and Pabis model was used to fit different drying conditions for wheat in cabinet drying system. The model revealed that drying of wheat could be accomplished commercially by cabinet dryer. It was observed that drying time to a specific moisture ratio decreased with higher drying temperature. On the other hand, loading density of wheat showed negative effect on drying rate constant. The effective moisture diffusivity varied from $3.27 \times 10^{-11} \text{ cm}^2/\text{sec}$ to $7.95 \times 10^{-11} \text{ cm}^2/\text{sec}$ with a temperature range of 40 to 50°C and was found to be increased with the increasing of temperature. Furthermore, activation energy (E_a) was found 17.64 kcal/ g-mole. Drying temperature of 50°C with loading density of 2.12 kg/m² could be suggested for drying of wheat in cabinet drying process.

Conflict of interest

Authors would hereby like to declare that there is no conflict of interests that could possibly arise.

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