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Research Article

Modelling of Rehydration of Freeze-dried Dumpling Wrapper

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Abstract: It was aimed to assess the impact of rehydration process of freeze-dried dumpling wrapper on their property and rate of rehydration, it is necessary to study the temperature effect; therefore the rehydration kinetic of freeze-dried dumpling wrapper was investigated at temperature of 308, 343 and 373 K, respectively. Fick Diffusion theory, Peleg model and Weibull model were used to describe rehydration process. The results show that: the predictions with Peleg model and Weibull model are in good agreement with experimental data. The study on rehydration process will help understand rehydration characteristics and rehydration mechanism of dry foodstuff and provide theoretical guidance for the freeze-dried food.

Keywords: Dumpling wrapper, Fick diffusion, mass transfer, peleg, rehydration, vacuum freeze-drying, Weibull

INTRODUCTION

Dried foodstuffs often need to be rehydrated before they are consumed. It is desirable for the dried foodstuffs to hydrate as fast as possible and show adequate structural and chemical characteristics. Information about water absorption as a function of temperature of those materials is critical importance to their shelf life and product usage. Rehydration of food materials also has an important impact on their rehydration rate, nutritional and sensorial properties.

A number of studies have been reported to model the hydration kinetics of food and different types of models have been used. Models used to describe the relation between moisture content and time during rehydration is commonly classified into two categories: theoretical ones and empirical ones. Fick Diffusion Model is a theoretical model, typically and frequently used. In spite that the model is complicated, trivial computation and many of assumptions were at variance with real system, yet, this model is based on Fick's First and Second Laws of Diffusion, which can accurately reflect the essence of mass transfer, so Fick Diffusion Model is widely applied in food and chemical engineering. Among empirical models, Peleg model and Weibull model are often used. Peleg model has been proved fit to model the rehydration of milk powder and whole graham flour (Hung *et al*., 1993). As it is a popular empirical non exponential model and easy to calculate, Peleg model is often used to describe rehydration of various foodstuffs. Another widely applied model is Weibull model, by which enzymatic or microbiological process degradation can be depicted exactly. Due to its simplicity and flexibility in the estimation of two parameters, Weibull model is also extensively applied in food industry.

The objective of this study is to assess the impact of rehydration process of freeze-dried dumpling wrapper on their property and rehydration rate. In particular, the effect of temperature is modeled. Rehydration behavior of dumpling wrapper at various temperatures is investigated. Three models are proposed to model the rehydration process and predictions of model were compared, it was found that Peleg model and Weibull model are in good agreement with experimental data.

EXPERIMENTS

Material and apparatus: Wheat flour is produced by Huaxue Grain and Oil Processing Co., Ltd. The vacuum freezing dryer LGJ-12S is produced by Huaxing Technology Development Co., Ltd. Songyuan Beijing corn. JY series function electronic balance is produced by Shanghai Medical Device Factory. Electric-heated thermostatic water bath is produced by Shanghai Balancer Factory.

Experimental processes: Weigh freeze-dried dumpling wrapper of about 10 g and immerse into 300 mL distilled water at a certain temperature with thermostat water bath. The temperatures are 35, 70 and 100°C, respectively. During rehydration, the dumpling wrapper

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need to weigh every now and then and water on the surface is removed by filter paper. When the deviation of mass for two times is less than 0.01 g, moisture content has reached equilibrium and rehydration process is finished.

Models:

Fick diffusion law: Fick's Second Law was applied to obtain diffusion coefficient in this study and the formula can be expressed by Eq. (1). The equation is under these assumptions (Crank, 1975; García *et al*., 2006): initial moisture content is same, there's no shrinkage, diffusion coefficient is a constant at a certain temperature:

$$M_t = M_e + (M_0 - M_e)\frac{8}{\pi^2}\exp(-\frac{D_{we}\pi^2 t}{4L^2}) \quad (1)$$

where, M_0, M_t and M_e is the initial moisture content, moisture content at time t and equilibrium moisture content (g H_2O/g dry material); D_{we} is diffusion coefficient; $2L$ is the thickness of sample.

Peleg model: The expression of Peleg model is as follow (Peleg, 1988):

$$M_t = M_0 + \frac{t}{k_1 + k_2 t} \quad (2)$$

where, M_0 and M_t refer to the initial moisture content and moisture content at time t (g H_2O/g dry material); k_1(s/%) and k_2 (% $^{-1}$) are two parameters for Peleg model.

As rehydration process is unlike dehydration process, equilibrium moisture content cannot be measured. Besides, the long soaking time will bring many changes in the structures and properties of foodstuffs, so it is very hard to establish equilibrium. Equilibrium moisture content M_e is expressed by Eq. (3):

$$M_e = M_0 + \frac{1}{k_2} \quad (3)$$

Weibull model: The expression of Weibull model is shown as follow (Machado *et al*., 1999):

$$M_t = M_e + (M_0 - M_e)\exp[-(\frac{t}{\beta})^{\alpha}] \quad (4)$$

where, M_0, M_t and M_e refers to the initial moisture content, moisture content at time t and equilibrium moisture content (g H_2O/g dry material); α β are two parameters for Weibull model which are called shape parameter and scale parameter, respectively.

Statistical analyses: The model was evaluated by Root Mean Square Deviation (RMSD), SSE (Sum of Square Error) and RAD (Relative Average Deviation), which are defined as (Sopade *et al*., 1992):

$$RMSD = \frac{1}{n}\sqrt{\sum_{i=1}^{n}(M_{ei} - M_{ci})^2} \quad (5)$$

$$SSE = \frac{1}{n}\sum_{i=1}^{n}(M_{ei} - M_{ci})^2 \quad (6)$$

$$RAD = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{M_{ei} - M_{ci}}{M_{ei}}\right| \quad (7)$$

RESULTS AND DISCUSSION

Fick diffusion: Take the logarithm treatment to both sides of Eq. (5), then Eq. (9) was obtained:

$$\ln(\frac{M_t - M_e}{M_0 - M_e}) = \ln\frac{8}{\pi^2} - \frac{D_{we}\pi^2}{4L^2}t \quad (8)$$

A plot of $\ln[(M_t\text{-}M_e)/(M_0\text{-}M_e)]$verse t yields a straight line with slope being $-D_{we}\pi^2/4L^2$ from which D_{we} can be calculated. The plot of $\ln[(M_t\text{-}M_e)/(M_0\text{-}M_e)]\sim t$ was shown in Fig. 1.

It can be found from Fig. 1 that there are two stages in each rehydration curve, indicating that rehydration process is mainly composed of two different stages, namely initial stage and final stage, each of which has an effective diffusion coefficient shown in Table 1.

From Table 1, effective diffusion coefficients D_1, D_2 increased as temperature increased at the initial stage and final stage. Moreover, D_1 is larger than D_2 obviously at constant temperature, implying the water absorption rate at the initial stage is quicker than that of last stage. According to diffusion theory, the diffusion of liquid and gas in porous materials depends on molecular transition. And diffusion coefficient can be expressed by Eq. (10) (Crank and Park, 1968):

$$D = \frac{1}{6}\Phi\delta^2 \quad (9)$$

where,

- δ : To transition distance from one cell to adjacent cell in the solid
- Φ : Means the number of molecules that diffuse in unit time within δ
- D : Diffusion coefficient

The frequency of molecule transition Φ depends on the diffusion energy, which is determined by its temperature. Nevertheless, as there is no equation to express the relationship between frequency of molecule

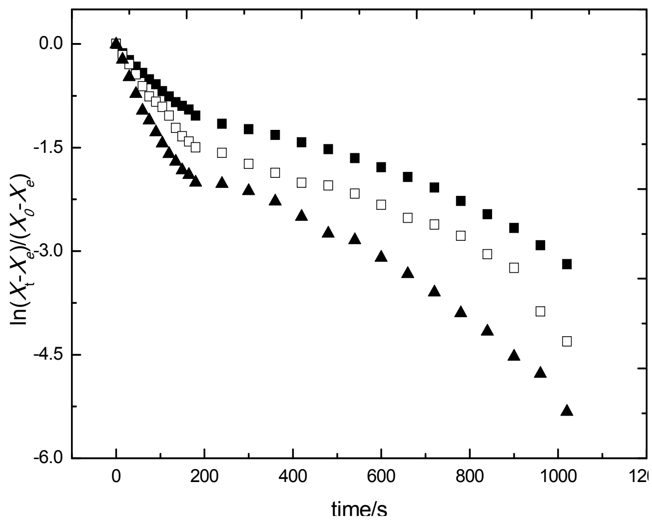

Fig. 1: Plot of ln[$(M_t$-$M_e)/(M_0$-$M_e)$] versa t at different temperatures ■, 308 K; □, 343 K; ▲, 373 K

Table 1: Effective diffusion coefficients of freeze-dried dumpling wrapper at different temperatures

Temperature/k	Time/s	D_1/m^2 s^{-1}	R^2	Time/s	D_2/m^2 s^{-1}	R^2
308	0~180	2.271×10^{-9}	0.991	180~840	0.818×10^{-9}	0.983
343	0~135	3.362×10^{-9}	0.992	135~960	0.971×10^{-9}	0.980
373	0~180	4.461×10^{-9}	0.971	180~900	1.542×10^{-9}	0.983

Table 2: Parameters of Peleg model for freeze-dried dumpling wrapper at different temperatures

Temperature/k	K_1/s	K_2	R^2	X_e/g water/g d m
308	161.556	1.123	0.997	0.890
343	91.630	1.098	0.999	0.911
373	49.756	1.093	0.996	0.915

Table 3: Parameters of Weibull model for freeze-dried dumpling wrapper at different temperatures

Temperature/k	A	B/s	X_e/g water / g d m	R^2
308	0.621	230.361	0.902	0.989
343	0.751	110.858	0.890	0.985
373	0.809	65.085	0.909	0.987

transition Φ and temperature, so only qualitative method is available for the description of relationship between them. From Eq. (10), as temperature increases, water molecules obtain more energy from surroundings and move much fiercely, leading to the increase of Φ and diffusion coefficient. The positive correlation between effective diffusion coefficient and temperature has been confirmed by many references (Sanjuán *et al*., 2001; Doymaz, 2004; Kaptso *et al*., 2008).

Peleg model: Peleg model parameters for freeze-dried dumpling wrapper at different temperatures were shown in Table 2.

Table 2, k_1 decreased with the increase of temperature. As k_1 is related with mass transfer rate, the smaller k_1 is, the higher water uptake rate is, which is in accordance with the fact that rehydration rate at higher temperature is higher too. At the same time, k_2 was found to be a function of temperature, decreasing as temperature increased. As k_2 is related with water holding capacity of material shown in Eq. (3), the minimum value of k_2 means the strongest water holding capacity and vice versa (Solomon, 2007). It also can be seen from Eq. (3) that the tendency of equilibrium moisture content with temperature is the same as k_2.

As k_1, k_2 both showed a certain relationship with temperature from Table 2, two equations were applied to illustrate the correlations, shown in Eq. (12, 13). k_1, k_2 were substituted into Eq. (2) and a new equation was proposed that can describe the relationship between moisture content, time and temperature, expressed by Eq. (11). Since k_1, k_2 are influenced by materials' intrinsic characteristic and external conditions, Eq. (11) is only suitable for the experiment system in this study. Any change in variety of dehydrated products or rehydration conditions will bring Eq. (11) moderate revision.

$$M_t = M_0 + \frac{t}{(-1.72766T + 690.68819) + (-0.00046T + 1.26458)t} \tag{10}$$

$$k_1 = -1.72766T + 690.68819 \tag{11}$$

$$k_2 = -0.00046T + 1.26458 \tag{12}$$

Weibull model: Weibull model parameters for freeze-dried dumpling wrapper at different temperatures were shown in Table 3.

In Weibull model, α is called shape parameter, which increased with the increase of temperature shown in Table 3. As a shape parameter, different shapes of foodstuff will lead to different values of α. In this study,

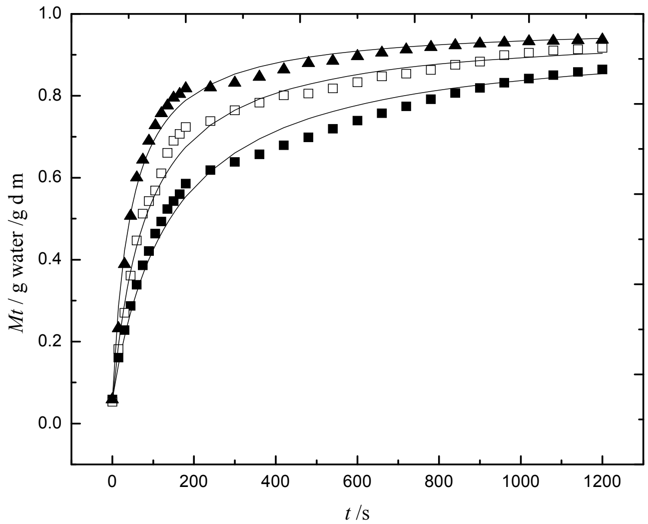

Fig. 2: Peleg constants k_1, k_2 versa t at different rehydration temperatures ■, *k1*; □, *k2*

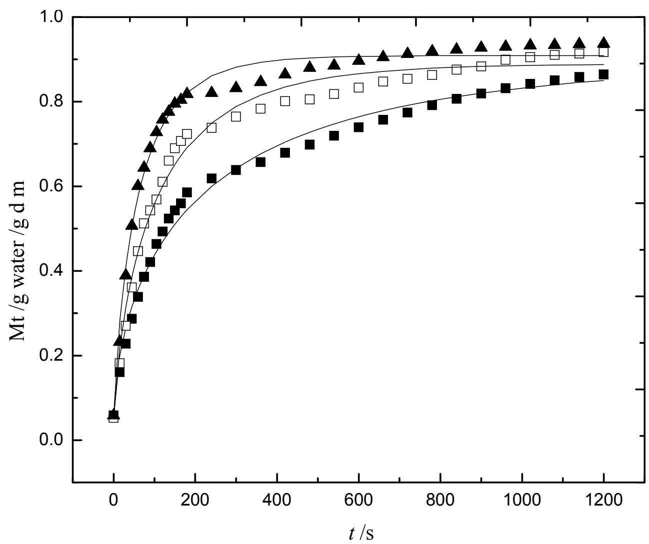

Fig. 3: Experimental and predicted moisture content by Fick Diffusion Law for rehydration of dumpling wrapper at different temperatures, ■, 308 K;□,343 K;▲,373 K; -predicted data

since the shape of dumpling wrapper is constant and different values of α at different rehydration temperatures indicate a co-relationship between α and temperature. Yet, it was considered there was no relationship between the parameter and temperature. Therefore, it is worth nothing even though the two parameters show a positive correlation and thus α can be regarded as a constant independent of temperature (Abu-Ghannam and McKenna, 1997). Therefore, it is believed that in this study apart from the factor of foodstuff shape, α might also be influenced by the experimental conditions like temperature. Besides, α not only reflects material shape, but also might be related with water uptake rate during rehydration.

Meanwhile β in Table 3 decreased with increasing temperature. Its reciprocal is similar to effective diffusion coefficient in Fick Diffusion Law, which represents kinetics parameter in Weibull model and measures the difficulty or facility degree of material to rehydrate. β is the time by which 63% of process has been carried out (Saguy *et al*., 2005). The smaller β is, the higher rehydration rate is. From Table 3, it can be seen that β decreased as temperature increased, indicating water uptake rate at higher temperature is larger than at lower temperature. Also from Fig. 5, it is very obvious that rehydration rate at 373 K is larger than 308 K and 343 K.

Statistical analyses: The mean values of RMSD RAD and SSE in Eq. (5, 7 and 6) for each model at different temperatures were listed in Table 4 and comparison between theoretical values and experimental values was shown in Fig. 2 to 5.

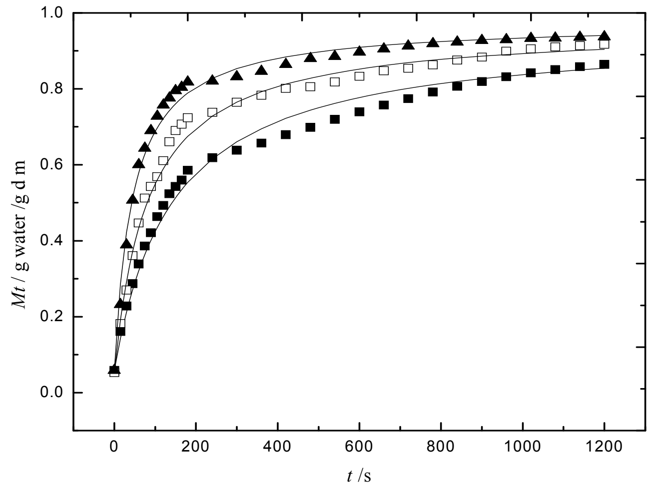

Fig. 4: Experimental and predicted moisture content by Peleg model for rehydration of dumpling wrapper at different temperatures ■, 308 K; □, 343 K; ▲,373 K; -predicted data

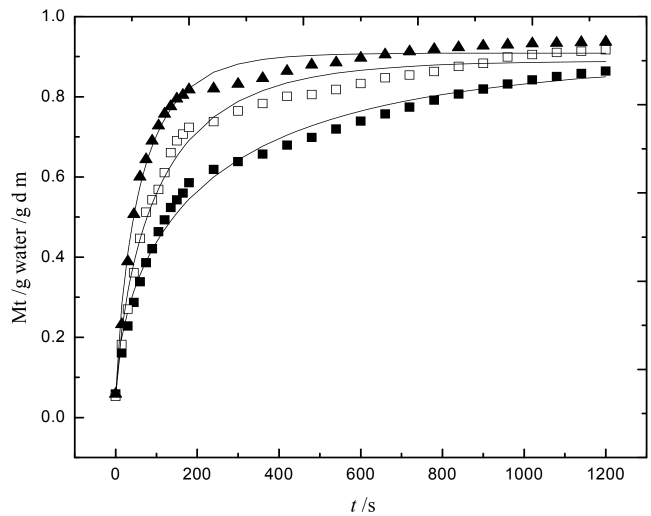

Fig. 5: Experimental and predicted moisture content by Weibull model for rehydration of dumpling wrapper at different temperatures ■, 308 K; □,343 K; ▲,373 K; -predicted data

Table 4: Statistical analysis for each model

Means of statistical tests	Fick diffusion model	Peleg model	Weibull model
RMSD	0.02527	0.00587	0.00649
RAD	0.43676	0.03676	0.04957
SSE	0.00830	0.00069	0.00084

In general, each model can fit the rehydration data appropriately, among which Peleg model and Weibull model show better fitting accuracy than Fick Diffusion Law, indicating that the mass transfer mechanism during rehydration of freeze-dried dumpling wrapper is not Fick Diffusion Law. This might be because freeze-dried foodstuffs have plentiful micro pores brought by the particular drying method and the mass transfer mechanism of rehydration is capillary imbibition instead of Fick Diffusion Law while the mechanism for air-dried products is Fick Diffusion Law (Marabi *et al*., 2003).

The rehydration kinetics at different temperatures with different models was showed in Fig. 3 to 5 and the difference between experimental and predicted data can be seen from these figures, too. Though Fick Diffusion Law in Fig. 3 can predict the equilibrium moisture content, yet the difference between experimental and predicted data is much larger, which suggests the mass transfer mechanism is not governed by Fick Diffusion Law from another point of view.

CONCLUSION

Rehydration behavior of dumpling wrapper at various temperatures is investigated; rehydration of food is greatly influenced by temperature. Fick Diffusion Law, Peleg model and Weibull model were applied to model rehydration process and predicted equilibrium water content. Comparing with model predictions, it is found that Peleg model and Weibull model are in good agreement with experimental data, which is helpful to understand the transfer mechanism during rehydration process.

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