CFAES The Ohio State University / Department of Food, Agricultural and Biological Engineering

Kinetic Modeling of Volume and Lightness Retention of Shrimp During Drying

Ivanett Z. Barreto Concepción[1] , Dennis R. Heldman[1,2]

INTRODUCTION

- Research studies have shown that reducing the water activity from meat products inhibits microbial growth consequently preventing spoilage and undesirable quality losses.[1]
- The rate of drying is significantly affected by air temperature, humidity, airflow rate and distribution.[1]
- High-quality dried shrimp includes the final moisture content of not more than 20% (w.b) or 25% (d.b), red-orange natural color, low degree of shrinkage, high rehydration ability and be soft to slightly tough.[2]
- Kinetic studies and mathematical models on quality changes of foods are essential in the proper design of thermal treatments to ensure consumer satisfaction.[3]

AIM

The objectives of this study were:

1. To investigate the effect of drying temperatures and convective heat transfer coefficients on a shelf-life limiting attribute and quality attribute of shrimp during drying.
2. To develop mathematical models to control and predict shrimp quality during drying.
3. To optimize the process to achieve maximum quality retention.

To accomplish these objectives the data was obtained from Hosseinpour et al. (2013) and Niamnuy et al. (2007).

MATERIALS

Drying equipment and experiments

Hot-air and superheated steam dryer process parameters[4]

- Shelf-limiting attribute: lightness ratio retention
- Equipment: hot-air (HA) dryer and superheated steam (SS) dryer
- Drying temperatures: 90 ˚C (HA), 110 and 120 ˚C (SS)

Jet-spouted bed dryer process parameters[2]

- Quality attribute: volume retention
- Equipment: jet-spouted bed dryer
- Drying temperatures: 80, 100 and 120 ˚C

Extracted from pngwingle

METHODOLOGY

Part 1 - Kinetic modeling

Lightness ratio retention and volume retention

1. Calculate the rate constants using the first-order model.
2. Calculate the activation energy using the Arrhenius equation, $k = k_0 \exp\left(\frac{-E_a}{RT}\right)$.

Part 2 - Intermediate heat transfer

A. Initial Conditions: t_1= 0 min; T_1=20˚C; MC1=76% (w.b.); Δt=2.4 minutes

1. Calculate the thermophysical properties (Choi and Okos model 1986) at t_1 and T_1.
2. Calculate T_2 at t_2 using the approximate analytical solution for a one-dimensional sphere, $\theta(t^*, r^*) = \frac{T(t^*,r^*)-T_\infty}{T_o-T_\infty} = A_1 exp(-\lambda_1{}^2 t^*)\frac{\sin(\lambda_1 r^*)}{\lambda_1 r^*}$.

B. At T_2 and t_2

1. Calculate MC_2 using the Arrhenius relationship, $k = k_{ref}\, exp\left[\frac{-E_a}{R}\left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right]$, and the incremental analysis equation, $A = A_o\, exp(-k * \Delta t)$.
2. Calculate the thermophysical properties at MC_2.
3. Calculate T_3 at t_3 using the approximate analytical solution for a one-dimensional sphere.
4. Repeat until the shrimp reach a MC of 20% (w.b.).

Part 3 – Quality retention

A. Initial Conditions: t_1= 0 min; T_1=20˚C; Lightness ratio retention (L^*_1)=1.00 Volume retention (S_1) = 100%; Δt=2.4 minutes

1. From the temperature profile obtained in part 2, calculate L^*_2 and S_2 at t_2 using the Arrhenius relationship and incremental analysis equation.

B. At T_3 and t_3

1. Calculate L^*_3 and S_3.
2. Repeat to determine the quality retention of shrimp with a MC of 20% (w.b.).

RESULTS

Drying curves

- Moisture decreased faster at higher temperatures.
- JSB dryer required much less time compared to the HA and SS dryer (Figure 1b).
- JBS was the best alternative to study the effect of drying temperatures and to achieve maximum quality retention of attributes.

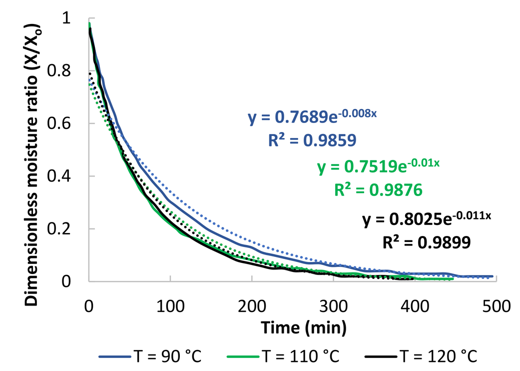

Figure 1a. Drying curves and Page's model equations of shrimp dried at an inlet air velocity of 2 m/s and under various inlet air temperatures in a hot-air and superheated steam dryer.

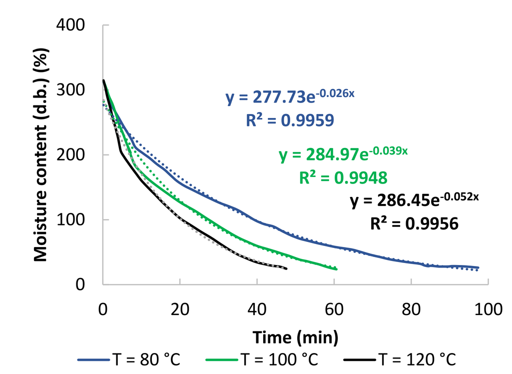

Figure 1b. Drying curves and Page's model equations of shrimp dried at an inlet air velocity of 2 m/s and under various inlet air temperatures in a jet-spouted bed dryer.

Lightness ratio retention

- Lightness ratio retention decreased over time as the shrimp was turning darker during the drying process.

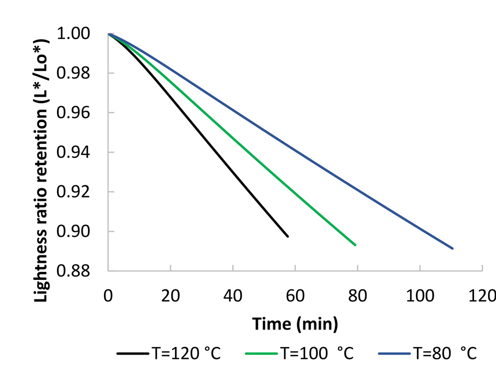

Figure 2. Lightness ratio retention of shrimp dried under various inlet air temperatures and a h=100 W/m²K in jet-spouted bed dryer.

Volume retention

- Volume retention decreased almost linearly with an increase in drying time.

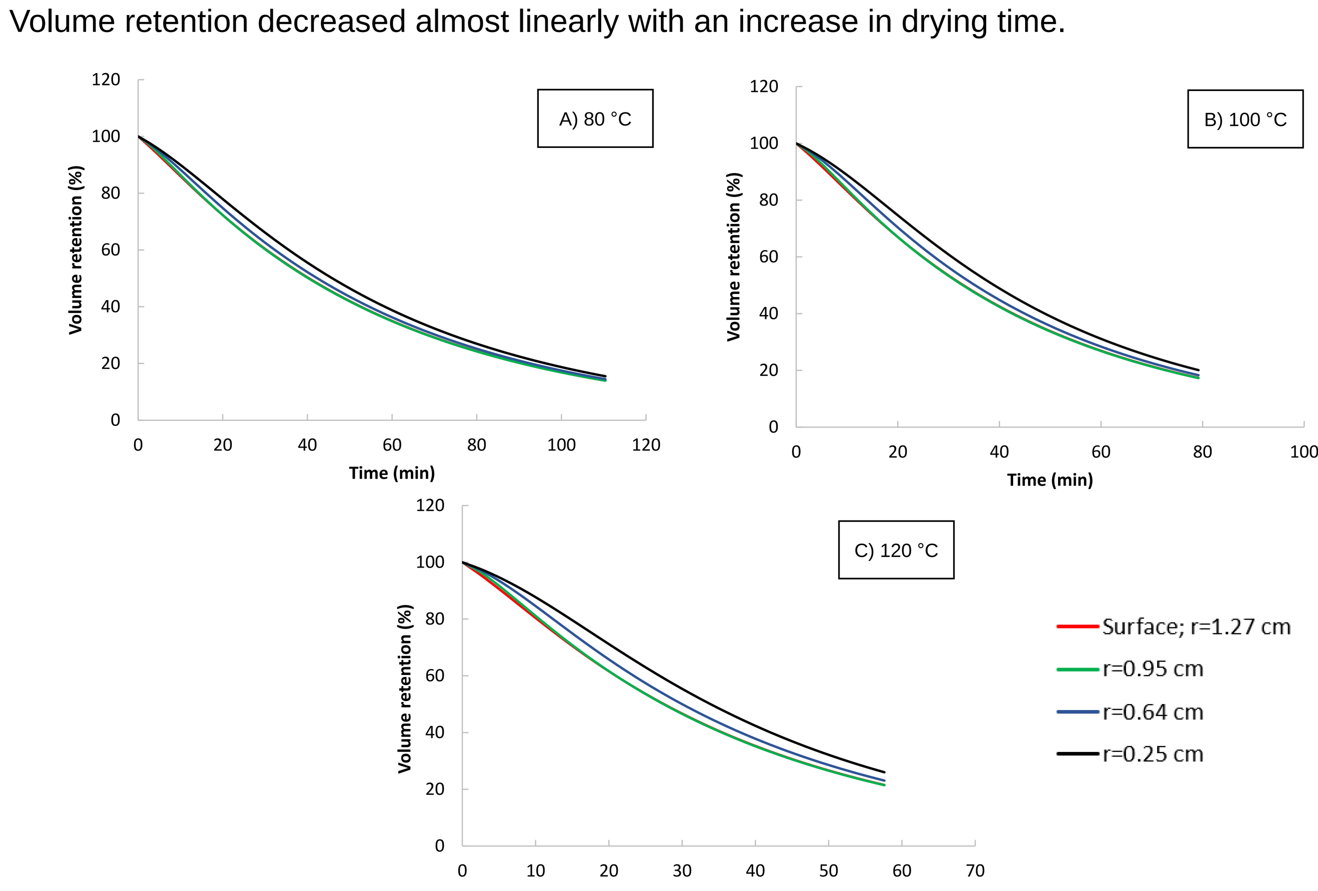

Figure 3a-c. Volume retention of shrimp at different locations dried under various inlet air temperatures and a h=100 W/m²K in jet-spouted bed dryer.

Kinetic modeling

Table 1. First order kinetic modeling results for lightness and volume retention

Temperature (°C)	First Order Model – Lightness retention					Temperature (°C)	First Order Model – Volume retention				
	k (min⁻¹)	R^2	E_a [J/mol]	k_0	R^2		k (min⁻¹)	R^2	E_a [J/mol]	k_0	R^2
90	0.00124	0.97	18,257	1.96	0.93	80	0.0432	0.99	15,373	8.31	0.98
110	0.00154	0.98				100	0.0615	0.99			
120	0.00202	0.98				120	0.0734	0.97			

Effects of the convective heat transfer coefficient on the temperature distribution

- At a higher convective heat transfer coefficient, the shrimp dry and reach a moisture content of 20% (w.b.) faster.

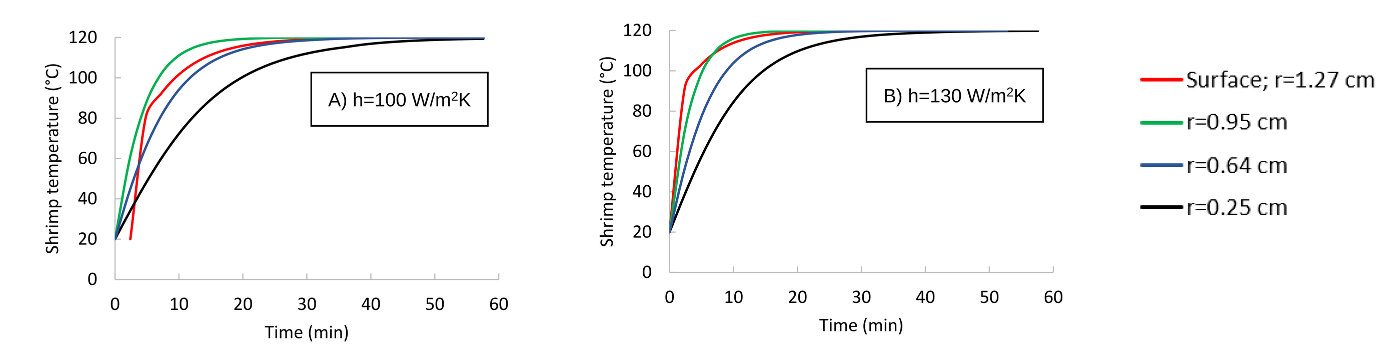

Figure 4a-b. Shrimp temperature at different locations dried at 120 °C in a jet-spouted bed dryer.

Effects of the convective heat transfer coefficient on the quality retention

- As the drying temperature and convective heat transfer coefficient increase, drying time decrease and volume retention increase.
- The lightness ratio retention was not significantly affected when varying the dying temperature and convective heat transfer coefficient.

Table 2. Process time, mass average volume retention and lightness ratio retention of shrimp at various drying temperatures and h-values.

Convective heat transfer coefficient (W/m²K)	Drying temperature (°C)	Drying time (min)	Mass average volume retention (%)	Lightness ratio retention
100	120	57.6	28	0.90
100	100	79.2	22	0.89
100	80	110.4	18	0.89
130	120	57.6	27	0.89
130	100	76.8	23	0.89
130	130	50.4	29	0.89

CONCLUSION

- Drying temperature and convective heat transfer coefficient had a significant effect on the heat transfer and rate of moisture reduction of the sample.
- The highest quality of dried shrimp was obtained with a JSB dryer, drying temperature of 130 °C, convective heat transfer coefficient of 130 W/m²K and drying time of 50 minutes.

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